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MINUTES
OF THE TWENTY-FOURTH
EXPLOSIVES SAFETY SEMINAR

Volume I

Adam's Mark Hotel
St. Louis, Missouri
28-30 August 1990

Sponsored By
Department of Defense Explosives Safety Board
Alexandria, Virginia

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Alexandria, Virginia 22331-0600

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PREFACE

This Seminar is held as a medium by which there may be a free exchange of information regarding explosives safety. With this idea in mind, these minutes are being provided for your information. The presentations made at this Seminar do not imply indorsement of the ideas, accuracy of facts presented, or any product, by either the Department of Defense Explosives Safety Board or the Department of Defense.

JACK MATHEWS
Colonel, USAF
Chairman

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WELCOMING ADDRESS AND INTRODUCTIONS

By

Colonel Jack Mathews, USAF
Chairman, Department of Defense
Explosives Safety Board

At

Twenty-Fourth Department of Defense
Explosives Safety Seminar

St. Louis, Missouri
28 August 1990

THE 24TH DOD EXPLOSIVES SAFETY SEMINAR IS NOW IN SESSION.

MR. JEHN, MILLICENT WOODS, LTG BRAILSFORD, MG GREENBERG, MG BENDER, BRIGADIER ARMSTRONG, DISTINGUISHED PARTICIPANTS, AND GUESTS...

WELCOME TO THE 24TH EXPLOSIVES SAFETY SEMINAR SPONSORED BY THE US DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD. WE ARE PLEASED TO JOIN WITH THE MILITARY SERVICES, INDUSTRY AND THE INTERNATIONAL COMMUNITY IN SPONSORING THIS SYMPOSIUM OF EXPERTS DEDICATED TO THE ENHANCEMENT OF EXPLOSIVES SAFETY. I WISH TO EXTEND OUR APPRECIATION TO ALL OF YOU FOR TAKING THE TIME AND EFFORT TO MAKE THIS SEMINAR THE VALUABLE AND UNIQUE EVENT IT HAS BECOME.

OUR SPECIAL THANKS GO TO THOSE OF YOU WHO PREPARE AND PRESENT THE PAPERS AND DISCUSSIONS UPON WHICH THE SEMINAR IS BASED, AND THOSE WHO DESIGN AND CONDUCT THE MANY TESTS AND EXPERIMENTS, GATHER AND ANALYZE THE DATA SO WELL, AND PRODUCE THE INVALUABLE REPORTS WHICH SPARK THE PROGRESS OF THIS IMPORTANT UNDERTAKING --- TO MAKE THE WORLD SAFER FROM EXPLOSIVES ACCIDENTS. WITHOUT YOUR FINE WORK, WE WOULD NOT BE HERE TODAY.

AT THIS TIME I HAVE THE DISTINCT HONOR AND PLEASURE TO

INTRODUCE MY BOSS, THE DEPUTY ASSISTANT SECRETARY OF DEFENSE FOR FAMILY SUPPORT, EDUCATION, AND SAFETY, WHO WILL DELIVER OUR WELCOMING ADDRESS.

MILLICENT WOODS TOOK HER PRESENT OFFICE IN JANUARY 1990. A GRADUATE OF MARY BALDWIN COLLEGE, SHE STILL SERVES ON THE ADVISORY BOARD OF THAT INSTITUTION AND HAS BEEN LISTED IN WHO'S WHO IN AMERICAN WOMEN AND OUTSTANDING YOUNG WOMEN OF AMERICA.

SHE BEGAN HER PUBLIC SERVICE AS SPECIAL ASSISTANT TO THE UNDERSECRETARY OF THE DEPARTMENT OF LABOR IN THE MID-1970S. THERE SHE WAS INVOLVED WITH OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION ISSUES.

FROM 1980-83 SHE SERVED AS SENIOR VICE PRESIDENT OF POLICY AND EVALUATION AT THE NATIONAL ALLIANCE OF BUSINESS. THEN FOR OVER 6 YEARS SHE WAS VICE PRESIDENT FOR CORPORATE PLANNING AND EVALUATION WITH THE NATIONAL RED CROSS. THERE SHE DIRECTED STRATEGIC AND FINANCIAL PLANNING ACTIVITIES FOR THE RED CROSS.

IN HER PRESENT POSITION AS DEPUTY ASSISTANT SECRETARY OF DEFENSE FOR FAMILY SUPPORT EDUCATION AND SAFETY SHE MANAGES AND OVERSEES:

- THE DOD DEPENDENT EDUCATION PROGRAMS
- DOD FAMILY SUPPORT, INCLUDING SPOUSE EMPLOYMENT, FAMILY ADVOCACY, AND CHILD CARE
- THE IMPORTANT NEW AREA OF TRANSITION SUPPORT, AS WE

PREPARE TO RESIZE AND RESCOPE OUR MILITARY IN THE COMING PERIOD

- DOD SAFETY AND OCCUPATIONAL HEALTH PROGRAMS
- AND HER PRIMARY ROLE HERE THIS MORNING, AS MY BOSS SHE IS ALSO DIRECTLY RESPONSIBLE FOR DOD EXPLOSIVES SAFETY.

LADIES AND GENTLEMEN, IT IS WITH GREAT PLEASURE THAT I GIVE YOU A VERY GOOD FRIEND OF EXPLOSIVES SAFETY, AND AN ABLE SPOKESPERSON FOR THE IMPORTANCE OF OUR PROGRAMS ---

MY BOSS ---- MILLICENT WOODS

THANK YOU, MILLICENT, FOR THE FINE WORDS ON THE BACKGROUND AND IMPORTANCE OF OUR VITAL UNDERTAKING. IT DOES MUCH TO PUT OUR EFFORTS HERE TODAY INTO PERSPECTIVE.

IT IS NOW MY PRIVILEGE TO INTRODUCE THE KEYNOTE SPEAKER FOR THE 24TH DOD EXPLOSIVES SAFETY SEMINAR, THE HONORABLE CHRISTOPHER JEHN, ASSISTANT SECRETARY OF DEFENSE FOR FORCE MANAGEMENT AND PERSONNEL.

BORN AND RAISED IN CHICAGO, ILLINOIS, MR. CHRISTOHER JEHN SERVED ON THE FACULTIES OF THE GEORGE WASHINGTON UNIVERSITY AND THE UNIVERSITY OF ILLINOIS. HE JOINED THE RESEARCH STAFF OF THE CENTER FOR NAVAL ANALYSIS IN 1972, SERVING IN VARIOUS CAPACITIES IN THIS ORGANIZATION BEFORE BECOMING VICE PRESIDENT, NAVY-MARINE CORPS PLANNING AND MANPOWER DIVISION. HE ASSUMED HIS PRESENT JOB ON NOVEMBER 20, 1989. NOT ONLY DOES HIS POSITION INCLUDE RESPONSIBILITY FOR MILLICENT

WOODS' FAMILY SUPPORT, EDUCATION, AND SAFETY --- AND OUR DOD EXPLOSIVES SAFETY BOARD --- IT ALSO INCLUDES THE RATHER AWESOME RESPONSIBILITY OF CHAIRMAN OF TOTAL FORCE POLICY. IN THIS CAPACITY, HE DIRECTS STUDIES OF THE FORCE STRUCTURE OF THE ENTIRE DEPARTMENT OF DEFENSE, INCLUDING MILITARY, CIVILIAN, AND RESERVE STRENGTHS. IN A REAL SENSE, HIS POLICIES WILL AFFECT THE FORCE STRUCTURE OF THE DEPARTMENT OF DEFENSE FOR YEARS TO COME.

HE BRINGS TO US AN IMPORTANT VIEWPOINT IN A DYNAMIC AND CHANGING WORLD. LADIES AND GENTLEMEN, IT IS WITH A GREAT DEAL OF PLEASURE AND ANTICIPATION THAT I PRESENT TO YOU ----

MR. CHRISTOPHER JEHN

THANK YOU, MR. JEHN FOR THE INSIGHT AND THE CHALLENGE. WE WISH YOU EVERY SUCCESS AS YOU WORK TOWARD A NEW DOD FORCE STRUCTURE.

AT THIS TIME I HAVE THE PLEASURE OF INTRODUCING LIEUTENANT GENERAL MARVIN D. BRAILSFORD, DEPUTY COMMANDING GENERAL FOR MATERIEL READINESS, UNITED STATES ARMY MATERIEL COMMAND, WHO WILL PROVIDE US INSIGHTS INTO NEW DIRECTIONS IN THE ARMY EXPLOSIVES SAFETY PROGRAM.

GENERAL BRAILSFORD COMPLETED CURRICULA FOR BOTH THE RESERVE OFFICERS TRAINING CORPS, AND A BACHELOR OF SCIENCE DEGREE AT PRAIRIE VIEW A&M UNIVERSITY BEFORE RECEIVING HIS COMMISSION

AS SECOND LIEUTENANT IN JUNE 1959. HE ALSO HOLDS A MASTER OF SCIENCE DEGREE IN BACTERIOLOGY FROM IOWA STATE UNIVERSITY.

HIS MILITARY EDUCATION INCLUDES SUCCESSFUL COMPLETION OF ARMOR SCHOOL, THE CHEMICAL SCHOOL, THE UNITED STATES ARMY COMMAND AND GENERAL STAFF COLLEGE, AND THE UNITED STATES ARMY WAR COLLEGE.

BEFORE HIS CURRENT ASSIGNMENT, GENERAL BRAILSFORD SERVED IN A WIDE VARIETY OF SIGNIFICANT COMMAND AND STAFF POSITIONS. TO MENTION A FEW OF THOSE:

- COMMANDING GENERAL, U.S. ARMY ARMAMENT, MUNITIONS AND CHEMICAL COMMAND.
- DEPUTY COMMANDING GENERAL OF AMC COM.
- COMMANDING GENERAL, 59TH ORDNANCE BRIGADE, U.S. ARMY, EUROPE
- COMMANDER, 60TH ORDNANCE GROUP, 21ST SUPPORT COMMAND, U.S. ARMY, EUROPE
- CHIEF, PROGRAM MANAGEMENT OFFICE, U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER, DOVER, NEW JERSEY.

OF COURSE, IT IS GENERAL BRAILSFORD'S CURRENT POSITION, HIS SAFETY HAT, THAT WE PARTICULARLY VALUE THIS MORNING: HE IS THE U.S. ARMY EXECUTIVE FOR EXPLOSIVES SAFETY.

LADIES AND GENTLEMEN,

LIEUTENANT GENERAL MARVIN D. BRAILSFORD.

THANK YOU, GENERAL BRAILSFORD, FOR THE INFORMATIVE

PRESENTATION ON THE CURRENT AND FUTURE POSITION OF THE ARMY'S EXPLOSIVE SAFETY PROGRAM.

(PRESENTATION OF PLAQUES TO THE SPEAKERS)

LADIES AND GENTLEMEN OF THE SEMINAR, OUR GENERAL SESSION IS NOW COMPLETED. FOLLOWING THESE WORDS OF INSPIRATION, WE ARE READY TO APPROACH OUR WORK AT THIS SEMINAR WITH A BRIGHT AND POSITIVE PERSPECTIVE. I WILL BE WATCHING THE SESSIONS WITH GREAT EAGERNESS DURING THE NEXT FEW DAYS. I WISH YOU GREAT SUCCESS IN YOUR WORK. THANK YOU FOR TAKING PART IN THE 24TH EXPLOSIVES SAFETY SEMINAR.

AN ADDRESS TO THE 24TH EXPLOSIVES SAFETY SEMINAR

BY MILLICENT WOODS, DASD(FSE&S)

A BRIEF HISTORY OF THE DDESB

(Colonel Jack Mathews, USAF, Chairman DDESB, Will Introduce Ms. Millicent Woods, DASD(FSE&S)

THANK YOU, JACK FOR THAT YOUR GRACIOUS INTRODUCTION: MR. JEHN (ASSISTANT SECRETARY OF DEFENSE FOR FORCE, MANPOWER AND PERSONNEL) -- GENERAL BRAILSFORD (DEPUTY COMMANDING GENERAL, US ARMY MATERIEL COMMAND) -- GENERAL GREENBERG (COMMANDING GENERAL, US ARMY ARMAMENT MUNITIONS AND CHEMICAL COMMAND), REPRESENTATIVES OF THE NATO ALLIANCE, OUR ASSOCIATES AROUND THE WORLD, DISTINGUISHED GUESTS... I AM HONORED TO BE PART OF THE 24TH DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY SEMINAR.

AS COLONEL MATHEWS NOTED, IN MY ROLE AS DEPUTY ASSISTANT SECRETARY OF DEFENSE FSE&S I HAVE OVERSIGHT OF BOTH -- DOD SAFETY AND OCCUPATIONAL HEALTH POLICY -- AND THE EXPLOSIVES SAFETY BOARD. THE LAST LETTER IN MY TITLE -- FSE&S -- STANDS FOR SAFETY. IN MY RELATIVELY SHORT TIME AT THIS BUSINESS OF

SAFETY, I HAVE COME TO UNDERSTAND 2 THINGS. FIRST, I HANDLE NO TRIVIAL ACTIONS -- AND SECOND, THERE ARE NO ROUTINE SOLUTIONS. EVERYTHING IS CRITICAL.

FORTUNATELY, I AM SUPPORTED BY THE GOOD OFFICES OF THE FIRST RATE PROFESSIONALS WHO ARE DEEPLY ROOTED IN THE TRADITIONS AND THE DISCIPLINES OF BOTH THE TECHNICAL AND THE ADMINSTRATIVE ASPECTS OF DOD SAFETY. AT THIS PARTICULAR MOMENT, I AM SURROUNDED BY PERHAPS THE LARGEST ASSEMBLAGE OF TECHNICAL EXPLOSIVES SAFETY EXPERTS WHO EVER GATHERED IN ONE SYMPOSIUM. ONE CAN SENSE THE POWER IN THIS ROOM.

LET'S REFLECT A MOMENT ON THE REASON WE ARE HERE TODAY -- AND HOW WE GOT HERE -- THE HISTORY OF THE EXPLOSIVES SAFETY BOARD ITSELF. TO DO THIS, I ASK YOU TO FORGET MOMENTARILY, THIS SPLENDID MISSOURI SETTING AND THIS SPARKLING ROOM, AND TO TRAVEL BACK WITH ME TO A SULTRY, STORMY NEW JERSEY AFTERNOON ON JULY 10, 1926.

STORM CLOUDS HAD GATHERED, SHADING THE AFTERNOON SKY WHICH GRADUALLY DARKENED AND RUMBLED WITH THUNDER. AT 5:15 INTENSE LIGHTNING FLASHED OVER THE LAKE DENMARK AMMUNITION DEPOT A FEW MILES FROM DOVER, NEW JERSEY. WITHIN MINUTES, SMOKE BILLOWED FROM TEMPORARY MAGAZINE NUMBER 8.... A LARGE ABOVE GROUND STRUCTURE, AT THE SOUTHWEST CORNER OF THE INSTALLATION. THE DEPOT FIRE BRIGADE RESPONDED IMMEDIATELY.

WE ARE TOLD THAT AT LEAST ONE FIRE HOSE WAS MANNED, POURING A STREAM OF WATER ON THE FIRE AT 5:20 WHEN AN ESTIMATED 789,000 POUNDS OF HIGH EXPLOSIVES IN THE STOREHOUSE, DETONATED. SIXTEEN BRAVE MEN DIED THERE, MOST OF THEM AS PART OF THAT FIRST RESPONSE TEAM OF THE FIRE BRIGADE.

AN ETERNAL FIVE MINUTES LATER TEMPORARY MAGAZINE NUMBER 9, WITH 1.6 MILLION POUNDS OF HIGH EXPLOSIVES,-- MOST OF IT BULK TNT -- ALSO DETONATED. THE SECOND FIRE FIGHTING TEAM --ALMOST A THOUSAND FEET AWAY AT THE TIME -- SUFFERED 25 SERIOUS INJURIES IN A FORCE OF 38. ACCORDING TO HOUSE DOCUMENT 199, THREE EXPLOSIONS OCCURRED AT SHORT INTERVALS, THE THIRD INVOLVING 800,000 POUNDS OF EXPLOSIVES. SUBSEQUENT DETONATIONS, ONE INVOLVING 180,000 POUNDS OF HIGH EXPLOSIVES, WOULD HAVE QUALIFIED AS MAJOR EVENTS ON ANOTHER DAY. BUT ON JULY 10, 1926 THEY WERE ANTI-CLIMATIC. DURING THE DAY AND THROUGH THE FOLLOWING NIGHT, THREE MILLION POUNDS OF HIGH EXPLOSIVES, MERCIFULLY BURNED.

SUNDAY MORNING BROKE OVER A SHATTERED LAKE DENMARK. ROCK AND DEBRIS LITTERED THE GROUND AT THE STOREHOUSES TO A POINT BEYOND THE MAIN OFFICE AT PICATINNY ARSENAL -- 2000 FEET AWAY. HOMES REGISTERED SERIOUS STRUCTURAL DAMAGE AT DISTANCES BEYOND 4000 FEET. A SHELL DETONATED ON THE PARADE GROUND AT NEARBY PICATINNY ARSENAL -- ALMOST A MILE FROM ITS SUSPECTED POINT OF

ORIGIN (SHELL HOUSE 22). NINETEEN PEOPLE WERE KILLED.

THE TOTAL COST WAS 20 MILLION 1926 DOLLARS.

PUBLIC OUTRAGE REACHED THE HALLS OF CONGRESS, AND INTO THE WHITE HOUSE ITSELF. MAYORS, GOVERNORS, AND STATE REPRESENTATIVES TESTIFIED ON THE HILL. THE PUBLIC PROTESTED THE STORAGE OF MASSIVE AMOUNTS OF HIGH EXPLOSIVES ALONG THE CROWDED EASTERN SEABOARD DUE TO ITS INHERENT THREAT TO POPULATION CENTERS.

WHY WAS THE PUBLIC OUTRAGE SO INTENSE? WHY WAS FEAR OF HIGH EXPLOSIVES SO ACUTE IN THOSE DAYS? THERE WAS GOOD REASON...

THE EXPLOSION AT LAKE DENMARK WAS NOT THE FIRST OF ITS KIND IN NEW JERSEY. THE GENERAL AREA WAS WIDELY RECOGNIZED AS THE CENTER OF EXPLOSIVES MANUFACTURING AND AMMUNITION LOADING DURING WORLD WAR I.

IN 1916 A BARGE EXPLOSION IN NEW YORK HARBOR EXTENDED TO A RAIL YARD ON BLACK TOM ISLAND WHICH KILLED PEOPLE ON BOTH SHORELINES -- IN NEW YORK AND IN JERSEY CITY. IT EVEN DAMAGED THE TORCH ON THE OLD STATUE OF LIBERTY.

IN JANUARY OF THE FOLLOWING YEAR, A GLAZING PROCESS CONTAINING 461,000 POUNDS OF PROPELLANT DESTROYED TWENTY

MANUFACTURING BUILDINGS IN A PLANT AT HASKELL, NEW JERSEY, KILLING TWO AND CAUSING STRUCTURAL DAMAGE OUT TO 6300 FEET.

IN 1918, THE MORGAN PLANT NEAR PERTH AMBOY, NEW JERSEY -- THE LARGEST AMMUNITION LOADING PLANT IN THE WORLD AT THAT TIME -- LOST 325 PLANT BUILDINGS IN A SERIES OF EXPLOSIONS INVOLVING 12 MILLION POUNDS OF HIGH EXPLOSIVES. 64 DIED THERE.

IN 1924 THE NIXON PLANT IN NEW BRUNSWICK, NEW JERSEY SUFFERED A MASSIVE EXPLOSIVE EVENT COSTING 17 LIVES.

THIS TRAGIC BACKGROUND GIVES YOU A REFERENCE POINT FOR THE PEOPLE IN NEW JERSEY WHO FEARED THE STORAGE AND HANDLING OF HIGH EXPLOSIVES IN 1926. INCREDIBLE AS IT MAY SEEM, THIS WAS NOT THE WHOLE PICTURE OF EXPLOSIVES ACCIDENTS IN THAT ERA...

THERE WERE ELEVEN CATASTROPHIC EXPLOSIONS IN THE TEN YEARS BETWEEN 1916 AND THE LAKE DENMARK EVENT IN 1926. THESE EVENTS HAD NO RESPECT FOR NATIONAL BOUNDARIES.

HALIFAX, NOVA SCOTIA WAS PERHAPS THE MOST DEVASTATING -- WITH 5.5 MILLION POUNDS OF "EXPLOSIVES D" AND TNT -- IN A SINGLE HIGH ORDER DETONATION NEAR THE HEART OF THE CITY. EIGHTEEN HUNDRED DIED THERE.

OPPAU, GERMANY WITH ITS MASSIVE DETONATION OF 9 MILLION POUNDS OF NITRATES, KILLED 1100.

ONE HUNDRED FIFTY DIED IN AN EXPLOSION IN FALCONARA, ITALY AND MANY OTHERS AT STEINFELD, GERMANY.

IN A TEN YEAR PERIOD THESE ELEVEN EVENTS, UNPRECEDENTED BEFORE OR SINCE, RESULTED IN DETONATIONS OF 26 MILLION POUNDS OF EXPLOSIVES, THE DEATHS OF MORE THAN 3000 PEOPLE, AND INJURIES TO MORE THAN 10,000.

THESE HORRORS WERE IN THE NEWSPAPERS AND IN THE MEMORIES OF THOSE WHO HEARD AND FELT THE DEVASTATION AT LAKE DENMARK IN JULY 1926. THEY DEMANDED ACTION FROM THE WAR DEPARTMENT.

BRIGADIER GENERAL SAMUEL HOFF WAS APPOINTED SENIOR MEMBER OF A JOINT ARMY-NAVY BOARD-- ESTABLISHED BY THE 70TH CONGRESS TO REVIEW SAFETY CONDITIONS AT THE STORAGE DEPOTS -- AND TO PROVIDE RECOMMENDATIONS FOR REBUILDING PICATINNY ARSENAL. DURING THEIR DELIBERATIONS, THIS BOARD SELECTED THE NEW JERSEY LAWS GOVERNING EXPLOSIVES SAFETY AS THEIR STANDARD.

USING THIS CODE WHICH CONTAINED THE AMERICAN TABLE OF DISTANCES, THE ARMY-NAVY BOARD FULLY EVALUATED THE SAFETY OF AMMUNITION STORAGE IN THE CONTINENTAL UNITED STATES AND IN SEVERAL AREAS OVERSEAS.

THE NAVY SOLUTION REQUIRED TWO NEW DEPOTS: -- HAWTHORNE, NEVADA IN THE WEST -- AND YORKTOWN, VIRGINIA IN THE EAST.

THE ARMY FOUND SAVANNA DEPOT ADEQUATE IN SIZE BUT IN NEED OF NEW MAGAZINES -- THE SAME FOR ABERDEEN PROVING GROUND, FORT BRAGG AND FORT SILL.

OGDEN ARSENAL NEEDED LAND ACQUISITION.

THE DEPOTS IN DELAWARE, CHARLESTON, SC -- PIG POINT, VA

CURTIS BAY, MD -- AND BENECIA, CA -- WERE FOUND UNSUITABLE FOR BULK STORAGE OF HIGH EXPLOSIVES.

THE ARSENALS AT PICATINNY, RARITAN, AND CURTIS BAY WERE ALSO UNSUITABLE FOR AMMUNITION STORAGE WITHOUT ADDITIONAL INFRASTRUCTURE.

AMMUNITION STORAGE IN PANAMA, HAWAII AND THE PHILLIPINES REQUIRED SIGNIFICANT CORRECTIVE MEASURES TO MEET THE NEW JERSEY STANDARD.

THE APPOINTED BOARD COMPLETED ITS ASSIGNMENT BY ADVISING CONGRESS OF THE COSTS AND OPTIONS FOR BUILDING NEW FACILITIES AND REDISTRIBUTING EXPLOSIVES STORAGE AT EXISTING INSTALLATIONS.

FOLLOWING THESE DELIBERATIONS, A PERMANENT ARMY NAVY STORAGE BOARD WAS APPOINTED. ITS CHARTER WAS TO ADVISE THE SERVICE SECRETARIES OF CONDITIONS AFFECTING AMMUNITION SAFETY AT THEIR INSTALLATIONS. THAT BOARD, WITH VARIOUS REVISIONS OF

CHARTER AND AUTHORITY OVER THE YEARS, IS WHAT WE NOW KNOW AS THE DOD EXPLOSIVES SAFETY BOARD.

THE FORMAL BOARD CONSISTS OF ONE MILITARY OFFICER FROM EACH OF THE THREE SERVICES, AND A CHAIRMAN. EACH MILITARY BOARD MEMBER HAS A CIVILIAN ALTERNATE. EACH BOARD MEMBER -- OR ALTERNATE -- HAS A VOTE IN ESTABLISHING DOD EXPLOSIVES SAFETY STANDARDS. THE CHAIRMAN VOTES ONLY WHEN THE THREE BOARD MEMBERS ARE NOT UNANIMOUS, AND THE CHAIRMAN'S VOTE CARRIES.

THE DDESB SECRETARIAT CONSISTS OF MILITARY LIAISON OFFICERS, REPRESENTING EACH SERVICE, A CHAIRMAN WHO ROTATES

BETWEEN THE SERVICES ON A THREE YEAR TERM, AND A CIVILIAN SECRETARIAT OF ENGINEERS AND ADMINISTRATIVE PERSONNEL. IN SUPPORT OF THE CHARTER, EACH DOD COMPONENT SUCH AS -- THE DEFENSE LOGISTICS AGENCY -- THE DEFENSE NUCLEAR AGENCY -- THE US ARMY SURGEON GENERAL AND MAJOR AMMUNITION COMMANDS, PROVIDE EXPERT CONSULTANTS.

THIS GROUP ACTING AS TECHNICAL CONSULTANTS, ADVISE THE SAFETY BOARD ON THE DEVELOPMENT OF STANDARDS AFFECTING THE HANDLING AND STORAGE OF AMMUNITION AT DOD INSTALLATIONS AROUND THE WORLD. THESE STANDARDS ARE FOUNDED UPON THE RESULTS OF TESTS -- CONDUCTED BY SOME OF YOU HERE TODAY -- TO ASSURE THE PUBLIC IS PROTECTED FROM THE REAL HAZARDS OF EXPLOSIVES AND AMMUNITION.

THIS BOARD ENACTED THE FIRST MILITARY QUANTITY-DISTANCE TABLES BASED ON DATA OBTAINED FROM ACCIDENTS OCCURRING AFTER LAKE DENMARK, AND DATA FROM THE TESTS AT ARCO IDAHO IN THE 1940'S. ONE OF THE MAJOR SOURCES FOR QUANTITY-DISTANCE TABLES, AS THEY ARE KNOWN TODAY, WAS THE DEVASTATING EXPLOSION AT PORT CHICAGO, CALIFORNIA IN 1943 WHICH WAS MORE PAINSTAKINGLY RESEARCHED THAN ANY OTHER EVENT. THE DDESB HAS UPDATED THESE TABLES A NUMBER OF TIMES SINCE THE 1940'S BASED ON MORE RECENT TESTS AND CURRENT DATA.

HAVING REFLECTED ON THE HISTORY OF THE DDESB, LET'S TURN NOW TO OUR SEMINAR. THE FIRST DOD EXPLOSIVES SAFETY SEMINAR WAS ACTUALLY A MEETING OF ONE HUNDRED EXPERTS IN THE ROCKET PROPELLANT BUSINESS. THEY MET AT INDIAN HEAD MARYLAND IN 1959 AND PRODUCED 180 PAGES OF REPORTS.

IT WAS SO WELL RECEIVED THAT IT BECAME AN ANNUAL EVENT UNTIL ITS SIZE AND EXPENSE WARRANTED AN ADDITIONAL YEAR BETWEEN MEETINGS.

AT THE LAST SEMINAR IN ATLANTA -- WE REGISTERED OVER 700 MEMBERS WHO REPRESENTED 18 NATIONS. THE MINUTES EXCEEDED TWO THOUSAND PAGES. TODAY WE SEE AN EVEN LARGER ATTENDANCE. I'M TOLD REGISTRATION AT THIS CONFERENCE MAY EXCEED 800.... A CONFIRMATION THAT THERE IS WIDESPREAD COMMITMENT AND PROFESSIONALISM INVOLVED IN ASSURING SAFETY TO THE PUBLIC AT THE SAME TIME THAT WE DEFEND THE NATION WITH APPROPRIATE AMMUNITION.

THE DDESB WAS FORGED IN A LIGHTNING STORM WHICH BROKE OVER LAKE DENMARK ON A SWELTERING DAY IN JULY 1926. THE ENSUING BLAST -- WHICH SENT A SHOCKFRONT ACROSS THE NEW JERSEY COUNTRYSIDE AT A DESPERATE COST IN LIVES -- SWEPT ALL OF US INTO THIS CONFERENCE TODAY. THE STAKES ARE EVEN HIGHER NOW. WE SEEK MORE INFORMATION, BETTER METHODOLOGY -- AN END TO THE CATASTROPHIC WASTE OF HUMAN RESOURCES.

THIS SEMINAR INVOLVES THE SCIENTIST, THE ENGINEER, THE SAFETY MANAGER AND PUBLIC POLICYMAKERS FROM MANY POINTS OF THE GLOBE. IN MEMORY OF THAT LONG AGO DAY FILLED WITH FIRE AND ANGUISH -- OUR TASK OF PROTECTING OUR PEOPLE, OUR RESOURCES, OUR MISSION -- IS STILL CRITICAL.

I URGE YOU NOT TO FORGET THE PAST, OR YOUR CRITICAL MISSION -- TO PUT FORTH YOUR FINEST EFFORTS TO INFORM AND TO LEARN SO THAT OUR PAST BECOMES A LESSON, RATHER THAN A CYCLE TO BE REVISITED.

PLEASE ACCEPT MY CONGRATULATIONS, COLONEL MATHEWS, FOR EXTENDING THE FINE TRADITION OF THE DDESB THROUGH THE WORK OF THIS SEMINAR.

MY OFFICE AND MY STAFF STAND IN FULL SUPPORT OF YOUR EFFORTS.

I WISH ALL OF YOU MY BEST.

KEYNOTE ADDRESS

by

MR. CHRISTOPHER JEHN

ASSISTANT SECRETARY OF DEFENSE (FM&P)

SAFETY IN CRITICAL TIMES

IT'S A PLEASURE TO TALK TO YOU TODAY. YOUR PROFESSIONALISM AND ENORMOUS RESPONSIBILITY MAKE IT A PRIVILEGE AS WELL.

SINCE YOUR LAST CONFERENCE, THE WORLD HAS UNDERGONE MOMENTOUS CHANGE. THE BERLIN WALL HAS COME DOWN, CHECKPOINT CHARLIE IS GONE, AND GERMANY RACES TOWARD A UNIFIED FUTURE. THE SOVIET UNION LOOKS INWARD, FACED WITH SERIOUS INTERNAL PROBLEMS. CITIZENS OF EAST BLOC NATIONS LOOK TO NEW FRIENDS IN THE WEST AS THEY TASTE FREEDOM FOR THE FIRST TIME IN MORE THAN 40 YEARS.

THE MEN AND WOMAN OF OUR ARMED FORCES AND THEIR CIVILIAN COLLEAGUES MUST TAKE ENORMOUS SATISFACTION IN KNOWING THAT THEIR EFFORTS THESE PAST 40 YEARS HAVE BEEN REWARDED. BUT NOW THEY FACE SIGNIFICANT CHANGE AND NEW CHALLENGES. ONE OF THESE NEW CHALLENGES EVOLVES IN THE

MIDDLE EAST AS WE MEET HERE TODAY.

BUT THE PRESIDENT'S DEFENSE BUDGET FOR FY 1991 PROPOSES TO REDUCE REAL SPENDING TWO PERCENT PER YEAR OVER THE NEXT FIVE YEARS. MANY IN CONGRESS HAVE PROPOSED MUCH BIGGER REDUCTIONS, THOUGH CURRENT EVENTS MAY MODIFY THEIR VIEWS. IN ANY CASE, WE KNOW WE WILL SIMPLY HAVE LESS MONEY FOR DEFENSE, AND THAT WILL HAVE NUMEROUS CONSEQUENCES.

IT WILL AFFECT THE DEVELOPMENT AND FIELDING OF NEW WEAPONS SYSTEMS AND THE MODERNIZATION OF SYSTEMS ALREADY FIELDED. THE PACE WILL BE SLOWER, MORE SELECTIVE, AND REFLECT NEW THINKING ABOUT THE THREATS WE FACE.

OUR FORCES OVERSEAS WILL BE SCALED BACK, CONSOLIDATED, AND MANY OVERSEAS FACILITIES MAY BE CLOSED. AND THE SAME IS TRUE FOR STATESIDE FORCES. THERE WILL BE FEWER PEOPLE IN UNIFORM, FEWER CIVILIANS WORKING IN THE DEFENSE DEPARTMENT.

WE ARE HERE TO EXPLORE AN IMPORTANT AND CONSTANT ELEMENT IN THE DEPARTMENT OF DEFENSE -- THE EXPLOSIVES SAFETY

PROGRAM. WHAT DO THE CHANGES I'VE BREIFLY MENTIONED MEAN TO YOU IN EXPLOSIVES SAFETY -- TO ALL OF US IN THIS ROOM? SAFETY PROVIDES AN ORGANIZED DEFENSE AGAINST AN ENEMY OTHER THAN THE CLASSIC BATTLEFIELD FOE. THAT ENEMY IS THE THREAT OF ACCIDENT, AND ITS COST -- VITAL MANPOWER, TIME AND EQUIPMENT. THE COMMITMENT TO SAFETY CANNOT BE DIMINISHED ANY MORE THAN CAN OUR OVERALL COMMITMENT TO THE NATION. THE WAR AGAINST THE SORT OF EXPLOSIONS MILLICENT WOODS DESCRIBED -- DISASTERS TO BOTH RESOURCES AND HUMAN SPIRIT -- MUST CONTINUE TO BE WAGED.

AND AS THE DEPARTMENT OF DEFENSE CHANGES AND BECOMES SMALLER, THE PROBLEMS OF SAFETY WILL GROW, NOT SHRINK -- AT LEAST FOR AWHILE.

IT IS CERTAIN THAT A LOT OF AMMUNITION IS GOING TO BE RETURNED FROM FORWARD AREAS. VAST AMOUNTS OF AMMUNITION WILL HAVE TO BE REWAREHOUSED, MOVED, AND STORED IN NEW LOCATIONS, OR DESTROYED. THIS WILL REQUIRE SOLID PLANNING, THE AVAILABILITY OF SUFFICIENT SAFE STORAGE, AND CAREFUL MONITORING. WE MUST CONDUCT THESE AMMUNITION OPERATIONS IN

FULL VIEW OF CONGRESS, THE PUBLIC AND THE WORLD -- AND THEY MUST BE DONE AS SAFELY AS POSSIBLE.

RECALL, IT WAS AMMUNITION RETURNED FROM THE BATTLEFIELDS OF WORLD WAR I, OVERLOADING THE MAGAZINES AT LAKE DENMARK ON THAT STORMY DAY IN 1926, THAT BRINGS US HERE TODAY.

ANOTHER PROBLEM WILL ARISE AS WE CLOSE DOWN EXPLOSIVES MANUFACTURING AND STORAGE FACILITIES THAT HAVE SERVED THIS NATION FOR GENERATIONS. THAT PROBLEM IS CONTAMINATION. EQUIPMENT, BUILDINGS, THE EARTH ITSELF, MUST BE DECONTAMINATED TO MEET NEW ENVIRONMENTAL RULES -- SO THAT FUTURE GENERATIONS WILL INHERIT A CLEANER, SAFER WORLD. DECONTAMINATION OPERATIONS WILL REQUIRE STRINGENT MEASURES TO ASSURE THE PERSONAL SAFETY OF THOSE INVOLVED IN THESE METICULOUS AND POTENTIALLY LETHAL ACTIVITIES.

OLD, FAMILIAR, CHALLENGES WILL ACCOMPANY THESE NEW ONES. AGING STOCKS MUST BE DEMILITARIZED. THE PROCEDURES, THE OPERATIONS, THE STORAGE, TRANSPORTATION AND HANDLING OF ALL

THESE HAZARDOUS ITEMS REQUIRE THE ULTIMATE IN OPERATIONAL SAFETY.

FUTURE WEAPON SYSTEMS WILL BE DEPLOYED IN CRITICAL FORWARD AREAS. THESE WEAPONS MUST BE MAINTAINED AND STORED TO DEFEND US, NOT ENDANGER US. AND THERE WILL BE A CONTINUING NEED FOR EXPLOSIVES SAFETY IN MANUFACTURING AND LOADING OPERATIONS, AT PLANTS AND DEPOTS, AT CAMPS AND FORTS, ON AIR BASES, ON BOARD SHIPS AT SEA.

SO YOUR JOBS WILL REMAIN AS IMPORTANT AND CHALLENGING AS THEY HAVE EVER BEEN -- AT A TIME WHEN CONGRESS AND THE AMERICAN PEOPLE WILL GIVE YOU FEWER RESOURCES WITH WHICH TO DO THOSE JOBS.

THE CHALLENGE BEFORE THIS GROUP TODAY IS HOW TO MAINTAIN EFFECTIVENESS -- SAFETY IN THE DEFENSE DEPARTMENT -- WITH A SHRINKING BUDGET. I THINK THE ANSWERS ARE RIGHT HERE IN THIS ROOM. YOUR PROFESSIONALISM AND DEDICATION WILL SERVE THE DEPARTMENT WELL IN THE FUTURE -- AS IT HAS IN THE PAST.

THE PROFESSIONALISM AND DEDICATION OF THIS GROUP IS NO TRIFLE. YOU ARE SCIENTISTS, ENGINEERS, SAFETY PROFESSIONALS, AND ORDNANCE PERSONNEL FROM THE DEFENSE DEPARTMENT AND THE EXPLOSIVES INDUSTRY, BOTH HERE AND OVERSEAS -- ALL FOCUSED ON THE STATE OF THE ART IN EXPLOSIVES SAFETY. THE PAPERS YOU PRESENT HERE, THE IDEAS YOU TAKE HOME WITH YOU, THE INTERACTION BETWEEN PROFESSIONALS, BETWEEN NATIONAL PARTNERS -- ALL CONTRIBUTE TO THE OVERALL EFFECTIVENESS OF THE EXPLOSIVES SAFETY PROGRAM.

YOU WILL HEAR PRESENTATIONS ABOUT THE CONSTRUCTION OF SPECIALIZED STRUCTURES TO RESIST EXPLOSIVES EFFECTS. YOU WILL DISCUSS COMPUTER PROGRAMS WRITTEN TO PREDICT BLAST DAMAGE TO IMPROVE BUILDING DESIGNS. YOU WILL DISCUSS INSENSITIVE MUNITIONS, FROM BOTH THE U.S. AND FRENCH VIEWPOINTS. YOU'LL DISCUSS QUANTITY-DISTANCE RULES ALONG WITH THE EVER-PRESENT PROBLEMS POSED BY LIGHTNING, FRAGMENTATION AND DEBRIS THROW. EXPLOSIVES WASTE MANAGEMENT AND EXPLOSIVES DISPOSAL WILL HAVE YOUR ATTENTION FOR A TIME. THE "KLOTZ CLUB" WILL MEET TO DISCUSS UNDERGROUND AMMUNITION STORAGE AND TESTING. UNEXPLODED ORDNANCE CLEARANCE AND EXPLOSIVES

MANUFACTURING CONCERNS WILL BE ADDRESSED, AS WELL AS THE LATEST REPORTS ON EXPLOSIVES ACCIDENTS. THESE SUBJECTS OF THE SEMINAR WILL BE DISCUSSED BOTH PUBLICLY AND IN PRIVATE; BETWEEN INDIVIDUALS, ASSOCIATIONS, AND NATIONS.

THAT IS IN THE TRADITION OF THE SEMINAR, THE SPIRIT OF FREE EXCHANGE OF INFORMATION AND TECHNOLOGY, THE FINE WORK OF PROFESSIONALS DEDICATING THEIR TIME AND TALENT TO MAKE A SAFER WORLD FOR THOSE WHO DEAL WITH THE DANGEROUS TOOLS OF OUR TRADE.

THESE DISCUSSION SHOULD TAKE YOU FROM THE HISTORICAL PERSPECTIVE PRESENTED BY MILLICENT WOODS TO THE CHALLENGE OF CURRENT REALITIES. WE ARE HERE IN THE ECHO OF A FATAL EXPLOSION 64 YEARS AGO. ITS SERIOUS IMPLICATIONS SHOULD SUSTAIN US NOW EVEN IN THE FACE OF GREAT CHANGES.

AS I LOOK ABOUT THIS AUDIENCE, I SEE THE GRAY HAIR OF EXPERIENCE OUT THERE, AS WELL AS THE BRIGHT PROMISE OF YOUNG PROFESSIONALS. MANY OF YOU HAVE BEEN TO PAST SEMINARS, AND KNOW THE FUTURE HOLDS GREAT CHANGES AND CHALLENGES. I AM

CONFIDENT IN ALL OF YOU -- IN YOUR ABILITY TO MEET THOSE CHALLENGES. I APPRECIATE YOUR CONTRIBUTIONS TO EXPLOSIVES TECHNOLOGY, TO EXPLOSIVES SAFETY, AND TO THE DEPARTMENT OF DEFENSE. I WISH YOU WELL IN THE FUTURE OF THIS TRADITION YOU'VE WORKED SO HARD TO ESTABLISH.

COLONEL MATHEWS, THANK YOU FOR INVITING ME TO THIS FINE SEMINAR. I WISH YOU ALL SUCCESS IN YOUR WORK. GOOD LUCK AND A PRODUCTIVE SEMINAR TO YOU ALL!

NEW DIRECTIONS IN THE ARMY EXPLOSIVES SAFETY PROGRAM

by

LIEUTENANT GENERAL MARVIN BRAILSFORD, USA

EXECUTIVE DIRECTOR FOR EXPLOSIVES SAFETY

CHAIRMAN, DDESB, TO ADDRESS THIS 24TH DEPARTMENT OF DEFENSE-SPONSORED EXPLOSIVES SAFETY SEMINAR. MY INTERESTS AND PERSPECTIVES ON AMMUNITION AND EXPLOSIVES SAFETY RUN DEEP AND PROBABLY PARALLEL THE CONCERNS OF MOST OF YOU EXPERTS GATHERED HERE TODAY. OUR OPERATIONAL READINESS AND WARFIGHTING CAPABILITIES RELATE DIRECTLY TO SOUND EXPLOSIVES SAFETY APPLICATIONS. WE MUST HAVE POLICIES AND PROCEDURES THAT SUPPORT THE MISSION WHILE PROTECTING FROM LOSSES OF PERSONNEL AND EQUIPMENT THROUGH EXPLOSIVES ACCIDENTS.

IN MY NEW POSITION AS THE ARMY'S EXECUTIVE DIRECTOR FOR EXPLOSIVES SAFETY AND ALSO AS THE EXECUTIVE DIRECTOR FOR CONVENTIONAL AMMUNITION, I INTEND TO AGGRESSIVELY PURSUE EXPLOSIVES SAFETY IMPROVEMENTS AND CONTINUE MANY OF THE ONGOING EFFORTS TO RESOLVE SEVERAL HARD-TO-FIX EXPLOSIVES SAFETY ISSUES. OUR ABILITY TO PRODUCE AND MANAGE SAFE AND RELIABLE MUNITIONS THROUGHOUT THE LIFE CYCLE MUST CONTINUALLY BE ASSESSED. THE STATE OF THE ART APPLICATIONS AND EXPLOSIVES RESEARCH, DEVELOPMENT, AND TESTING CAPABILITIES OF ALL THE SERVICES WHICH YOU WILL BE DISCUSSING AT THIS SEMINAR ARE KEY TO OUR UNDERSTANDING THE EXPOSURES AND RISKS THAT ARMY COMMANDERS OFTENTIMES MUST ACCEPT TO ACCOMPLISH THEIR MULTI-SERVICE SUPPORT MISSION. THIS POTENTIAL FOR LOSS OF LIFE AND PROPERTY CAN BE OUR MAJOR ENEMY.

THE ARMY, THROUGH ITS NEW EXPLOSIVES SAFETY MANAGEMENT PLAN, IS COMMITTED TO IMPROVING EXPLOSIVES SAFETY AND ADDRESSING THE ISSUES. THE U.S. ARMY TECHNICAL CENTER FOR EXPLOSIVES SAFETY, IN COORDINATION AND CONJUNCTION WITH THE ARMY STAFF, THE DIRECTOR OF ARMY SAFETY, THE MAJOR ARMY COMMANDS, AND THE NAVY AND AIR FORCE HAS TAKEN INITIATIVES IN SEVERAL AREAS OF EXPLOSIVES SAFETY MANAGEMENT.

THE EXPOSURES TO OUR SOLDIERS AND HOST NATION CIVILIANS RELATIVE TO UPLOADED AMMUNITION IN KOREA ARE OF CONCERN. THERE HAVE BEEN, AND CONTINUE TO BE, NUMEROUS CONCERTED ARMY ACTIVITIES IN SUPPORT OF EIGHTH U.S. ARMY TO IMPROVE THIS SITUATION AND PROVIDE FOR THE READINESS AND WARFIGHTING CAPABILITY OF THE 2D INFANTRY DIVISION. THE STORAGE OF LARGE QUANTITIES OF U.S.-TITLED AMMUNITION WITHIN THE REPUBLIC OF KOREA INSTALLATIONS CREATES UNIQUE EXPLOSIVES SAFETY MANAGEMENT CHALLENGES FOR THE U.S. FORCES IN KOREA.

THE JOINT U.S./REPUBLIC OF KOREA MILITARY ASSISTANCE GROUP RESOLVED TO PROVIDE TECHNICAL ASSISTANCE IN JOINTLY DEVELOPING SOLUTIONS TO THE AMMUNITION STORAGE PROBLEMS IN KOREA. THE PRIMARY OBJECTIVE IS A RESEARCH AND DEVELOPMENT EFFORT TO PROVIDE THE GREATEST EXPLOSIVES SAFETY WITH THE MOST EFFICIENT USE OF SCARCE LAND, IMPROVED SECURITY, AND SURVIVABILITY WHILE INCREASING THE COMBAT READINESS.

IN JANUARY 1990, THIS U.S./REPUBLIC OF KOREA GROUP SELECTED THE UNDERGROUND STORAGE TECHNOLOGY AS THE CANDIDATE FOR A JOINT RESEARCH AND DEVELOPMENT PROJECT. SIX RESEARCH AND DEVELOPMENT PROJECT CANDIDATES WERE SUBMITTED BY THE ARMY, NAVY, AND AIR FORCE.

A DRAFT MEMORANDUM OF UNDERSTANDING AND A MILESTONE SCHEDULE WERE ADOPTED FOR APPROVAL BY THE RESPECTIVE GOVERNMENTS. THE MEMORANDUM OF UNDERSTANDING IS EXPECTED TO BE RATIFIED BY EACH GOVERNMENT BY THIS FALL. THE ARMY IS EXPECTED TO PROVIDE A PROGRAM MANAGER IN THIS JOINT EFFORT.

THE STORAGE OF AMMUNITION IN JAPAN HAS REQUIRED STRONG SUPPORT BY HEADQUARTERS, DEPARTMENT OF THE ARMY, FOR THE COMMANDING GENERAL, U.S. ARMY, JAPAN, TO ASSURE FUNDING FOR CONSTRUCTION OF 61 EARTH-COVERED MAGAZINES NEEDED TO ELIMINATE EXPLOSIVES SAFETY VIOLATIONS.

ANOTHER MAJOR AREA OF REVIEW IS THE MOVEMENT OF AMMUNITION THROUGH COMMERCIAL SEAPORTS WORLDWIDE IN SUPPORT OF THE DEPARTMENT OF DEFENSE MISSION.

THE ARMY'S PLANNING AND IMPLEMENTATION OF A WORLDWIDE AMMUNITION PORT SURVEY, WHICH YOU WILL HEAR MORE ABOUT IN AN UPCOMING PRESENTATION, HAS A LONG IMPROVEMENT POTENTIAL IN THIS VITAL AREA.

EXPLOSIVES SAFETY ASSISTANCE HAS BEEN PROVIDED BY A HEADQUARTERS, DEPARTMENT OF THE ARMY, TASK FORCE IN AN EFFORT TO ADDRESS PREPOSITIONED SHIPS AFLOAT IN THE PACIFIC. OPTIONS HAVE BEEN UNDER REVIEW TO DETERMINE WHERE THE DOWNLOAD OF LARGE QUANTITIES OF AMMUNITION CAN BE ACCOMPLISHED SAFELY. THIS EFFORT WAS IN SUPPORT OF THE COMMANDING GENERALS, U.S. ARMY WESTERN COMMAND, AND U.S. ARMY JAPAN. THE POLITICAL REALITIES OF THAT PART OF THE WORLD HAVE REQUIRED PURSUIT OF ALTERNATIVES TO THE USE OF SUBIC BAY,

PHILIPPINES. THE U.S. NAVY AND U.S. AIR FORCE HAVE PROVIDED MUCH NEEDED ASSISTANCE IN THIS EFFORT.

THE WORK IN DEVELOPING A COMPREHENSIVE ARMY EXPLOSIVES SAFETY REGULATION IS KEY TO ESTABLISHING A SOLID ARMY PROGRAM. THE LAST MEETING OF THE DEPARTMENT OF THE ARMY EXPLOSIVES SAFETY COUNCIL RESULTED IN A GOAL OF PUBLICATION BEFORE THE END OF THE CALENDAR YEAR 1990. EFFORTS ARE ONGOING TO ACCOMPLISH IT.

WE ARE PROGRESSING TOWARD THE IMPLEMENTATION OF AN ARMY EXPLOSIVES TESTING PROGRAM. THE NEED TO EXPAND RESEARCH AND DEVELOPMENT AND TEST EFFORTS IN SUPPORT OF OUR MAJOR ARMY COMMANDS, AS WELL AS THE OTHER SERVICES, REQUIREMENTS IS UNDERSTOOD. THE INTERSERVICE RELATIONSHIPS ARE BEING WORKED TO ELIMINATE REDUNDANT TESTING AND TO SHARE AND ADDRESS THE AREAS OF COMMON INTEREST, LIKE INSENSITIVE MUNITIONS. THE TRI-SERVICE SYMPOSIUM ON EXPLOSIVES TESTING, WHICH THE ARMY HOSTED IN MARCH OF THIS YEAR AT WATERWAYS EXPERIMENT STATION, IS A PRIME EXAMPLE OF THE NECESSARY COORDINATION AND COOPERATION TO DEVELOP WAYS AND MEANS OF BETTER DEFINING OUR EXPLOSIVES SAFETY REQUIREMENTS. ALSO WE CAN GAIN THE MAXIMUM BENEFIT FROM THE DECLINING FUNDING AND FACILITIES AVAILABLE FOR TESTING. THIS IS KEY TO THIS EFFORT. I AM SURE MANY HERE WERE IN ATTENDANCE AT THAT SYMPOSIUM. WE NEED TO CONTINUE THIS FORUM OF INFORMATION EXCHANGE.

THE IMPORTANCE OF HAVING KNOWLEDGEABLE, TRAINED OPERATORS AND SOLDIERS GOES WITHOUT SAYING. ACCIDENTS HAVE VERIFIED WHAT HAPPENS WHEN THIS IS LACKING. WHETHER ON A LOAD, ASSEMBLY, AND PACK LINE OR IN AN M1 TANK IN GERMANY, UNDERSTANDING THE HAZARDS WHILE KNOWING AND FOLLOWING PROCEDURES IS A MUST. COOPERATIVE EFFORTS IN DEFINING ACCIDENT CAUSES AND LESSONS-LEARNED HAVE BEEN AT THE FOREFRONT.

THE NEED FOR OUR AMMUNITION MALFUNCTION INVESTIGATION EFFORTS TO TIE IN CLOSELY WITH EXPLOSIVES ACCIDENT INVESTIGATION PROCEDURES HAS BEEN RECOGNIZED IN THE ARMY AND IS BEING WORKED BY THE OFFICE OF THE DEPUTY CHIEF OF STAFF FOR LOGISTICS AND THE U.S. ARMY SAFETY CENTER.

THE ARMY'S TECHNICAL LIBRARY AT THE U.S. ARMY TECHNICAL CENTER FOR EXPLOSIVES SAFETY IS BECOMING AN ESTABLISHED SOURCE OF INFORMATION FOR AMMUNITION PEOPLE THROUGHOUT THE DEPARTMENT OF DEFENSE. NOT ONLY DOES THE LIBRARY PROVIDE ACCESS TO OTHER DATA BASES UPON REQUEST, IT MAINTAINS UNIQUE HOLDINGS OF ITS OWN. AN INITIATIVE UNDERWAY RIGHT NOW IS TO AUTOMATE THE LIBRARY CATALOG AS PART OF A BULLETIN BOARD SYSTEM WHICH WILL ALLOW AUTHORIZED USERS WORLDWIDE TO BROWSE THE LIBRARY CATALOG 24 HOURS A DAY. A MESSAGE LEFT ON THE BULLETIN BOARD OR CALL TO THE EXISTING HOT LINE, WILL TRIGGER AN IMMEDIATE RESPONSE.

WE HAVE BROUGHT ONLINE AN EXPLOSIVES SAFETY INFORMATION DATA BASE USING THE PRIME COMPUTER AT U.S. ARMY ARMAMENT, MUNITIONS AND CHEMICAL COMMAND. USERS WORLDWIDE WILL BE ABLE TO ACCESS ONE LOCATION AND REACH NUMEROUS SOURCES OF INFORMATION PREVIOUSLY KNOWN

ONLY TO SPECIALISTS FAR REMOVED FROM THE SOLDIER, SAILOR, OR AIRMAN IN THE FIELD.

IN OUR CONTINUING EFFORTS TO GET EXPLOSIVES SAFETY INFORMATION TO THE USERS, WE HAVE PREPARED AN EXPLOSIVES SAFETY BULLETIN. MILITARY PERSONNEL AND DEPARTMENT OF DEFENSE CIVILIANS WORLDWIDE ARE NOW RECEIVING COPIES. THE FIRST ISSUE OF THIS USER-FRIENDLY PUBLICATION WAS MAILED TO OVER 2,000 ADDRESSEES IN MAY 1990 AND THE FEEDBACK HAS BEEN TREMENDOUS. I BELIEVE IN THIS KIND OF AWARENESS EFFORT. IN THAT LIGHT, I INCLUDED A PERSONAL MESSAGE IN THE AUGUST BULLETIN. AS I SAID EARLIER, LIKE ALL OF YOU, I AM DEEPLY CONCERNED ABOUT MAINTAINING A SAFE WORKING ENVIRONMENT, ESPECIALLY IN THIS ERA OF UNCERTAIN EMPLOYMENT LEVELS AND SHRINKING RESOURCES.

IN AN EFFORT TO ELIMINATE AMMUNITION AND EXPLOSIVES ACCIDENTS AT OUR AMMUNITION PRODUCTION FACILITIES AND TO BETTER EDUCATE EXPLOSIVES WORKERS AT BOTH GOVERNMENT-OWNED/CONTRACTOR-OPERATED AND GOVERNMENT-OWNED/GOVERNMENT-OPERATED DEPOTS AND AMMUNITION PRODUCTION FACILITIES, WE ARE REVIEWING WAYS TO CERTIFY THOSE PERSONNEL WORKING IN AMMUNITION AND EXPLOSIVES OPERATIONS TO HIGHER EDUCATION AND AWARENESS LEVELS. A DRAFT MODEL CERTIFICATION PROGRAM HAS BEEN PREPARED FOR THE MAJOR COMMANDS WHICH WILL ALLOW THEM TO:

1. ESTABLISH CERTIFICATION PROGRAMS FOR PERSONNEL WORKING WITH AMMUNITION OR EXPLOSIVES OR,

2. IMPROVE LOCAL EXISTING CERTIFICATION PROGRAMS.

IN CONJUNCTION WITH THE PERSONNEL CERTIFICATION INITIATIVE, AN AMMUNITION PRODUCTION LINE VALIDATION PROGRAM IS ALSO BEING DEVELOPED TO PRESCRIBE THE RESPONSIBILITIES, POLICIES, AND PROCEDURES NECESSARY TO CONDUCT A PRODUCTION LINE VALIDATION OF BUILDINGS, EQUIPMENT, AND SYSTEMS. THE GOAL OF A PRODUCTION LINE VALIDATION PROGRAM IS TO MINIMIZE THE RISK BY ASSURING STATE-OF-THE-ART APPLICATIONS AND THE SAFEST PROCESS POSSIBLE PRIOR TO THE INTRODUCTION OF HAZARDOUS MATERIALS INTO A LINE.

WE WILL CONTINUE TO EXPAND THIS EXPLOSIVES SAFETY EFFORT. I AM PLEASED TO BE INVOLVED WITH THE PROGRAM. OUR CHALLENGE THROUGHOUT THE DEPARTMENT OF DEFENSE IN THE FUTURE WILL BE TO CONTINUE WITH REDUCED MANPOWER AND DOLLARS. THE IMPORTANCE OF EXPLOSIVES SAFETY WILL BE COMPOUNDED BY THE EXPANDING NEED TO RETROGRADE, STORE, AND MAINTAIN AS WELL AS DISPOSE OF THE DEMILITARIZED AMMUNITION. THE LARGE ROCKET MOTOR DEMILITARIZATION PROGRAM IS A PRIME EXAMPLE HERE.

DISPOSAL REQUIREMENTS OF LARGE ROCKET MOTORS ARE CURRENTLY GENERATED BY STRATEGIC ARMS REDUCTION TREATIES AND NORMAL LIFE CYCLE MANAGEMENT FUNCTIONS. OVER 84 MILLION POUNDS OF HAZARD CLASSIFICATION 1.1 AND HAZARD CLASSIFICATION 1.3 PROPELLANTS CONTAINED IN SYSTEMS SUCH AS THE MINUTEMAN II AND POLARIS WILL BE DESIGNATED FOR DISPOSAL BY 1996.

AS A RESULT OF INCREASINGLY STRINGENT ENVIRONMENTAL REGULATIONS AND PUBLIC PRESSURES, THE CURRENT METHOD OF DISPOSAL, OPEN BURNING/OPEN DETONATION, MAY BE DISCONTINUED IN THE FUTURE. STORAGE AND MAINTENANCE OF THE MOTORS WILL EXCEED THE CAPACITY OF THE DEPARTMENT OF DEFENSE LOGISTICS BASES BY 1993, UNLESS NEW FACILITIES ARE BUILT.

THE JOINT ORDNANCE COMMANDERS GROUP HAS STUDIED THIS ISSUE AND DETERMINED FOUR PROMISING DISPOSAL TECHNOLOGIES:

1. BIODEGRADATION.
2. SUPERCRITICAL WATER OXIDATION.
3. PROPELLANT REMOVAL TECHNOLOGY.
4. CONTAINED FIRING WITH SCRUBBER.

DOING ALL OF THE ABOVE WITHIN ENVIRONMENTAL CONSTRAINTS MAKE THE CHALLENGES ALL THE GREATER.

IT'S AN INTERESTING TIME IN OUR HISTORY AND MANY EXTERNAL INFLUENCES ARE GOING TO DICTATE OUR PRIORITIES. HOWEVER, NONE RATE HIGHER THAN PROTECTING OUR MILITARY AND CIVILIAN PERSONNEL FROM UNNECESSARY LOSSES DUE TO EXPLOSIVES AND AMMUNITION ACCIDENTS IN THIS PROCESS OF DRAWDOWN AND MAINTENANCE OF OUR DEPARTMENT OF DEFENSE MISSION.

I CHALLENGE YOU TO CONTINUE AND TO EXPAND YOUR EXTRAORDINARY EFFORTS. IMPROVEMENTS CAN BE REALIZED BY OUR CONCERTED EFFORTS AND AWARENESS GAINED AT SEMINARS SUCH AS THIS. I AND MY STAFF ARE AVAILABLE FOR ASSISTANCE IN OUR COMMON DEPARTMENT OF DEFENSE GOAL OF IMPROVED EXPLOSIVES SAFETY. GOOD LUCK TO ALL OF YOU AND HAVE A SUCCESSFUL SEMINAR.

CHANGES TO TECHNICAL MANUAL 5-1300 GOVERNING SHEAR REINFORCING REQUIREMENTS FOR BLAST RESISTANT CONCRETE REINFORCED STRUCTURES

BY
BY BOYCE L. ROSS, P.E.[1]
AND
WILLIAM H. ZEHRT, JR.[1]

ABSTRACT

The new version of TM5-1300 has made significant revisions to the design provisions for shear reinforcing in blast resistant concrete structures. These changes allow more flexibility in the use of stirrups in lieu of lacing for limited deflection applications. This paper discusses these new provisions and compares them with previous requirements. A commentary on the significance of these changes is also included.

BACKGROUND OF TM5-1300

The first edition of TM5-1300, "Structures to Resist the Effects of Accidental Explosions (Reference 1), was officially published in June, 1969. The Technical Manual (TM) presented quantitative procedures for design of structures to resist explosive effects. The original version of TM5-1300 focused heavily on reinforced concrete as the principal material of construction. Even with advances in technology and many unique types of materials of construction, reinforced concrete is still the most commonly used material in blast resistant structures. Material and labor costs associated with blast resistant concrete structures are greatly influenced by the type and complexity of shear reinforcement in the element. The old version of TM5-1300 took a very conservative approach to shear reinforcing in blast resistant structures designed for support rotations exceeding 2 degrees. Because of advances in technology and additional testing performed over the last two decades, the new revision of TM5-1300 (Reference 2) contains significant departures from the old TM in the area of shear reinforcement for structures exceeding 2 degrees in support rotation. The new TM also contains subtle changes which greatly enhance an engineer's ability to design a more cost effective structure.

HISTORY OF THE REVISION TO TM5-1300

In 1981 a decision was made to initiate a revision effort to TM5-1300. A significant amount of new test data had been developed since the original publication of the manual. In addition, deficiencies in the existing manual needed to be corrected and new guidance provided for structures other than those constructed of reinforced concrete. Development of the new TM was funded and managed by the U.S. Army Armament Research, Development and Engineering Center (ARDEC). The Project Engineer was Mr. Joe Caltagirone. Revision to the manual was managed by a steering committee with a subcommittee for blast effects technology and one for design applications. Tri-services representation was provided on the various committees. Significant

[1] U.S. Army Corps of Engineers, Huntsville Division

contributions were provided by the Naval Civil Engineering Laboratory (NCEL), the U.S. Army Corps of Engineers, Huntsville Division (CEHND), the Ballistic Research Labs (BRL), and the Naval Surface Warfare Center (NSWC). In addition, recognized experts supported the effort through contract efforts. These included Mr. Norvall Dobbs of Ammann and Whitney and Mr. Bill Baker, at that time, from Southwest Research Institute. Because of contracting and funding constraints, serious work on the manual did not begin until late 1982. In June, 1984, a draft version of the manual was released in limited distribution as ARDEC Special Publication ARLCD-SP-84001. Based on significant feedback on the use of this draft version, the expected formal DOD approval of the manual is expected to occur in late 1990.

PURPOSE OF SHEAR REINFORCEMENT

As a general rule, both the new and the old versions of TM5-1300 follow the same basic philosophy for shear reinforcement of blast resistant concrete structures. Both editions of the TM still break down concrete elements into three types of cross sections. Shear reinforcement in these cross sections has varying purposes depending on the design range and type of cross section being considered. The three different types of cross sections are shown in Figure 1 and are discussed in the paragraphs below.

The first cross sections (Type I) are elements which are limited to a maximum support rotation of 2 degrees. Basically, these elements are designed to remain in the elastic/elasto-plastic stress range and are allowed to crack on the tension side, but no crushing or spalling of the concrete is permitted. For these elements, the purpose of shear reinforcement is to simply resist shear stresses in excess of the allowable shear stress value. Single leg stirrups are the most popular form of shear reinforcing in this type cross-section.

The second cross sections (Type II) are elements which are allowed to achieve maximum support rotations ranging from 2 to 8 degrees. These elements are designed to remain intact; however, plastic deformation in the form of crushing of the concrete and permanent deflection is allowed. The purpose of shear reinforcement in these elements is not only to resist excess shear stresses, but also to restrain compression reinforcement. The new TM permits the use of single leg stirrups in this design region, provided support rotations are less than 4 degrees. It also permits the use of stirrups if tension membrane action is present for rotations up to 8 degrees. Lacing can also be used in this region. Lacing is mandatory for scaled distances less than one for all types of cross sections.

The third cross sections (Type III) are elements which are limited to a maximum support rotation of 12 degrees or incipient failure. These elements usually are used as dividing walls. Both complete crushing and spalling of the concrete is permitted in these elements. The purpose of shear reinforcing in this design range is to distribute very high and localized shear loads and to ensure confinement of concrete between the flexure and compression reinforcement. Lacing is the most common method of shear reinforcement in this design range except for walls subject to high intensity blast pressures at a scaled distance greater than 1 that do not attain large deflections. In the latter case, the new TM permits the use of shear reinforcement in the form of stirrups.

COMPARISON OF SHEAR REINFORCEMENT REQUIREMENTS

General:

Shear reinforcement requirements contained in the new version of TM5-1300 differ from the old TM for every type of structural element. The scope of the revision is major for elements with Type II cross sections which are designed for support rotations between 4 and 8 degrees. Revisions are less outstanding for other cross sections, but nevertheless have a very significant impact on the outcome of designs and the cost of the structure. A detailed discussion of each change in the TM involving shear reinforcement requirements for blast resistant structures is provided in the following paragraphs. A commentary on each change is provided in the following section.

Dynamic Increase Factors:

The only changes in dynamic increase factors for shear reinforcement are in the increase factors for direct shear and diagonal tension. The old TM5-1300 recommended that no dynamic increase factor be permitted when determining shear capacities. The new TM allows a 1.10 dynamic increase factor to be applied to the minimum yield strength for direct shear (diagonal bar) and diagonal tension (stirrup/lacing) applications in the "close-in" design range. It should be noted that a dynamic increase factor of 1.0 is still applicable to "far-range" design situation for stirrups. Dynamic increase factors for elements in flexure have also changed. These changes in allowable bending stresses indirectly influence shear reinforcement requirements by increasing ultimate resistance. A comparison of dynamic increase factors concerning shear reinforcement is shown below:

	New Technical Manual		Old Technical Manual
	Far Range	Close Range	
Diagonal Tension	1.00	1.10	1.00
Direct Shear	1.10	1.10	1.00

Static Strength Changes:

The old version of TM5-1300 used 60,000 psi as the minimum static yield strength for ASTM A 615, grade 60 reinforcement bars. The new version of the TM allows a minimum strength of 66,000 psi. This change was made because the minimum ASTM yield strength is exceeded by at least 10 percent by almost all reinforcement bar production mills. Because this value is used to determine the required area of stirrups, lacing, and diagonal bars, it results in less shear reinforcement in all types of cross sections.

Design Range For Stirrups:

In the old version of the TM, it was mandatory that lacing be used in all Types II and III cross sections. This meant that lacing had to be provided in all elements which exceeded 2 degrees in support rotation. The new version of TM5-1300 permits the use of stirrups in elements which have support rotations up to 4 degrees, and in elements which have support rotations up to 8 degrees if tension membrane action is present. Stirrups are only permitted in these cases if the scaled distance is greater than 1. This represents a significant departure from the old TM because it permits the use of stirrups in all types of cross sectional elements. Both versions of the TM still recommend stirrups, when necessary, in Type I cross sections but still retain the option of lacing.

<u>**Shear Capacity of Unreinforced Concrete:**</u>

The old version of the TM used one formula to calculate the shear stress permitted on an unreinforced element. This formula appeared as follows:

$$v_c = \phi[1.9\ (f'_c)^{1/2} + 2500p] \leq 2.28\ \phi(f'_c)^{1/2}$$ where ϕ is equal to 0.85 for all type cross sections

The new version of the TM contains three formulas for calculating shear in an unreinforced element. The shear capacity of an unreinforced element in flexure is limited to:

$$v_c = [1.9\ (f'_{dc})^{1/2} + 2500p] \leq 3.5\ (f'_{dc})^{1/2}$$

Significant changes between the above two formulas are that the ϕ factor has been dropped from the new TM formula and that the use of the dynamic strength of concrete versus the static strength is now permitted in calculating shear capacity. The latter change has no real bearing on the outcome of the value since the dynamic increase factor for concrete in the diagonal tension range is 1.0. It should also be noted that the 2.28 factor has been changed to 3.5 and is now consistent with the American Concrete Institutes (ACI) Building Code (Reference 3).

The second formula for calculating shear in the new TM is for members subject to axial tension. This condition was not addressed in the old TM. This formula appears as:

$$v_c = 2(1 + N_u/500A_g)(f'_{dc})^{1/2} \geq 0$$ N_u taken as negative

The third formula for calculating shear in the new TM is for members subject to axial compression. This condition was not addressed in the old TM. This formula appears as:

$$v_c = 2(1 + N_u/2000A_g)(f'_{dc})^{1/2}$$ N_u taken as positive

<u>**Shear Reinforcement Design Ranges:**</u>

The ranges where shear reinforcement is required have been completely revised in the new TM. These revisions were made to account for the design range (e.g. close-in or far-range) and the type of structural action present. Minimum design stresses which require shear reinforcement in the old TM appeared as:

Limits	Stirrups	Lacing
$v_u \leq v_c$	0	v_c
$v_c < v_u \leq 2v_c$	$v_u - v_c$	v_c
$v_u > 2v_c$	$v_u - v_c$	$v_u - v_c$

Minimum design stresses in the new TM appeared as:

Cross Section	Structural Action	$v_u \leq v_c$	$v_c < v_u \leq 1.85v_c$	$v_u > 1.85v_c$
Far Range				
Type I	Flexure	0	$v_u - v_c$	$v_u - v_c$
Type II	Flexure	$0.85v_c$	$0.85v_c$	$v_u - v_c$
Type II & III	Tension Memb.	0	$v_u - v_c$	$v_u - v_c$
Close-in				
Type II & III	Flexure or Tension Membrane	$0.85v_c$	$0.85v_c$	$v_u - v_c$

Shear Reinforcement Area Requirements:

The old TM required that stirrups, when necessary, extend a distance of the depth of concrete beyond the point where theoretically required. It also required that stirrups be provided between the face of the support and a section at a distance "d" from the support. The shear reinforcement in this region must be the same as that required at the critical section.

The new TM requires that shear reinforcement requirements be determined at the critical section of the element and that this amount of reinforcement be uniformly distributed throughout the element.

Equations for calculating the area of shear reinforcement required have also been changed. In the old TM, the formula for calculating the required area of stirrups appeared as:

$$A_v = \frac{(v_u - v_c) b_s s_s}{\phi f_s (\sin\alpha + \cos\alpha)}$$

The equation in the new TM now appears as:

$$A_v = \frac{(v_u - v_c) b_s s_s}{\phi f_{ds}}$$

Of particular importance in the above formulas is that the dynamic strength of the reinforcement steel is now permitted to be used. The $(\sin\alpha + \cos\alpha)$ term has also been deleted; however, this value turns out to be 1.0 in most designs and has a very infrequent effect on the outcome of the shear area value.

The formula for calculating the area of lacing required now appears in the revised TM as:

$$A_v = \frac{(v_u - v_c) b_s s_s}{\phi f_{ds} (\sin\alpha + \cos\alpha)}$$

The only change in this formula is that the use of the dynamic strength of the reinforcing steel is now permitted.

Shear Reinforcement Spacing Requirements:

The old TM required that stirrups be spaced so that every 45 degree line representing a potential crack through half of the member depth be intersected by at least one line of stirrups. It further required that when the ultimate shear stress exceeds $b\phi(f'c)^{1/2}$, every such line be crossed by at least two lines of reinforcement. The new TM requires that stirrups be spaced at half the member depth in Type I cross sections and half the depth minus the cover in Types II and III cross sections. In slabs, the new TM requires that stirrups be placed at each bar intersection as a minimum.

Design For Direct Shear:

After publication of ARDEC Special Publication ARLCD-SP-84001, several major changes were incorporated into the final manuscript which will serve as the final version of the new TM. Among these changes were revisions to almost every paragraph involving direct shear requirements. The discussion below is based on the amended version of the Special Report (i.e. the final version of the new TM).

In the old TM for Type I cross section (support rotation less than 2 degrees), diagonal bars were not required if the actual shear at the support (V_s) was less than the direct shear which could be resisted by the concrete (V_d). However, if the reverse case were true, diagonal bars capable of reacting the full amount of actual support shear (V_s) were required. The amount of direct shear that could be resisted by the concrete was determined by the formula:

$$V_d=0.18f'_c bd.$$

The new TM makes substantial revisions in diagonal bar requirements for Type I cross sections and simply supported slabs with moderate amounts of deflection. The new TM (amended) accounts for the shear capacity of the concrete due to the fact that cracking should not occur in these design regions. The new TM assumes that the concrete resists a shear force equivalent to that given by the formula:

$$V_d=0.18f'_{dc} bd$$

Therefore, for Type I cross sections and simply supported slabs with moderate amounts of deflection at their supports, the amount of direct shear that must be resisted by the diagonal bars is the difference in the actual and the allowable. The required area of diagonal bars is determined in the new TM from the equation:

$$A_d=\frac{(V_s b-V_d)}{f_{ds} \sin}$$ where $V_d=0.18f'_{dc} bd$ for < 2 degrees rotation or simply supported slabs with moderate deflections.

For Types II and III cross sections (support rotations exceeding 2 degrees) the old TM required that diagonals be provided to resist the applied support shear. The area of these diagonals was determined by the formula:

$$A_d = \frac{V_s b}{f_s \sin}$$

The new TM requires that for support rotations in excess of 2 degrees, simply supported slabs with excessive rotations, or for sections in net tension, V_d be taken as zero. This requires that all direct shear be reacted by diagonal bars. Therefore, the new TM equation for calculating diagonal bar areas in Types II and III cross sections, where large deflections or net tension is present is given by the formula:

$$A_d = \frac{(V_s b - V_d)}{f_{ds} \sin}$$ where $V_d = 0$ for the cases stated above.

COMMENTARY

Dynamic Increase Factors and Material Strength Changes:

The change in the new TM which permits the use of 66,000 psi as the minimum static yield strength for reinforcement bars has significant impacts on shear reinforcement design for all types of cross sections. This change, combined with the use of dynamic properties of reinforcement in all of the shear formulas, may allow for significant reduction in the amount of shear reinforcement in some blast resistant elements. This change alone may result in a reduction of 9.1 percent to 17.4 percent depending on the design range (close-in or far-range) and the ultimate resistance value of the element. This change may also reduce construction cost in laced concrete elements because laced elements utilizing large reinforcement bars are very difficult to construct. However, this change may be detrimental in some cases where minimum shear reinforcement is required based on the higher ultimate resistance values.

Design Range for Stirrups Versus Lacing:

This change, as described in the previous section, is one of the most significant departures from the philosophy in the old TM. The use of single leg stirrups, in elements which can attain support rotations up to 4 degrees and in elements which obtain support rotations up to 8 degrees when tension membrane action is present, presents significant material, construction, and labor savings over the use of lacing. It should be noted, however, that the use of single leg stirrups is only permitted when the scaled distance is greater than 1. The engineer should also note that single leg stirrup spacing and the size of the bars may become so congested and large, respectively, for support rotations over 4 degrees that the use of stirrups for constructibility reasons may become prohibitive.

Shear Capacity and Spacing Requirements:

The formula for calculating the shear capacity of concrete now permits the use of the dynamic strength of concrete, however this change has no significant impact on the outcome of the value since the dynamic increase factor for concrete is 1.0 for diagonal tension applications. In most cases, the capacity determined by the formulas in the new TM will yield a larger capacity than the old TM. The spacing requirements for stirrups in the new TM tend to negate the benefits gained by increased shear capacities and material properties, particularly if the engineer is not careful in laying out the spacing of the main flexure reinforcement. The new TM requires that stirrups in Type I cross sections be spaced at "d/2" and for Type II cross sections be spaced at "dc/2". It also requires that shear reinforcement be determined for the critical section in the element and be distributed uniformly throughout the element. For slabs, stirrups are required at each reinforcement bar intersection. A design engineer should keep in mind the spacing requirements for shear reinforcement when designing slabs or any other element which may require shear reinforcement. The spacing of the main flexure reinforcement may be effected by shear steel spacing requirements.

Equations for calculating the shear capacity of sections in net tension and compression were added to the new technical manual. These equations are particularly valuable when calculating the reduced capacities of elements in structures such as containment cells.

Direct Shear Requirements:

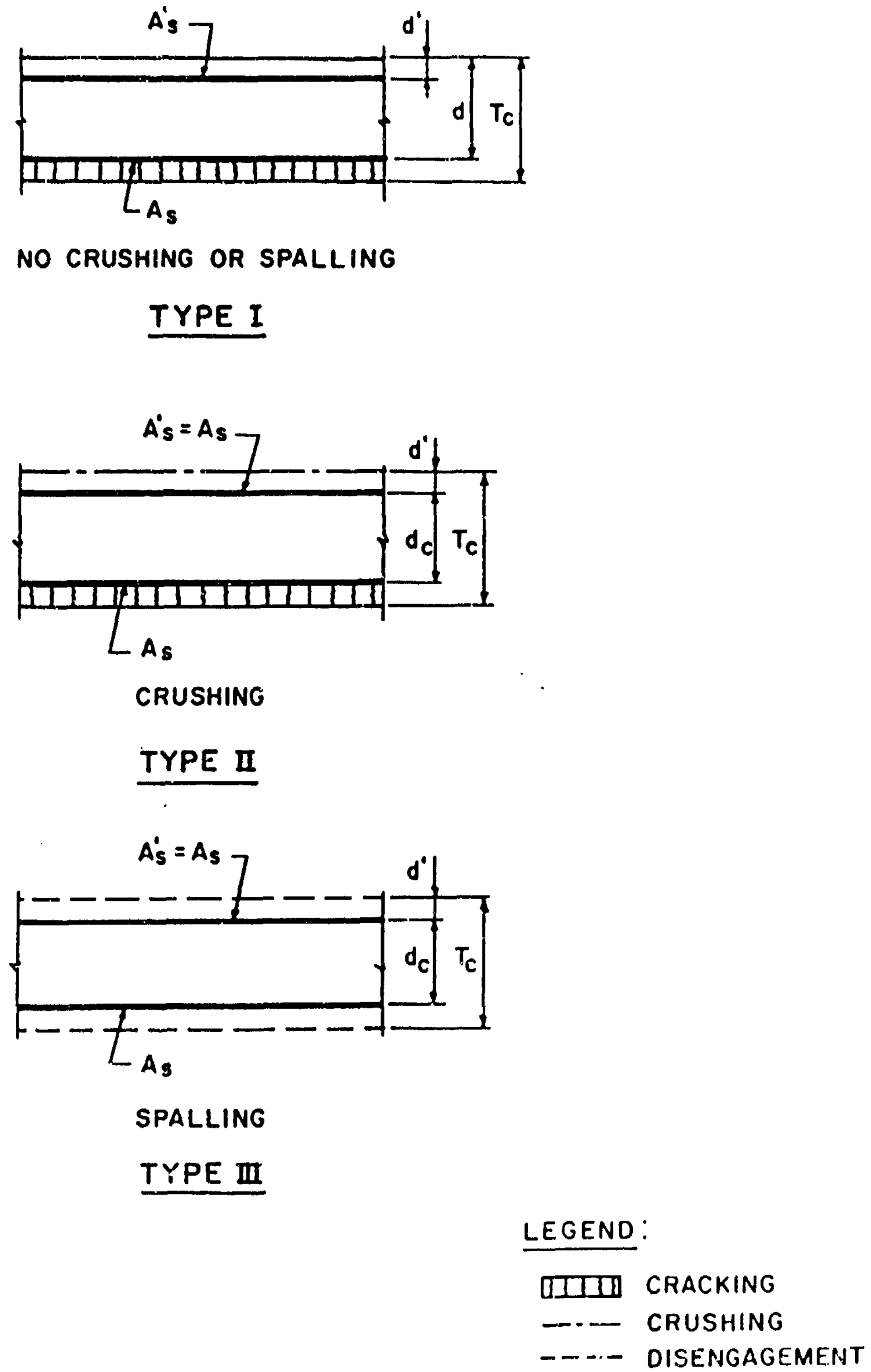
There is no question that the new TM provides a more realistic approach to diagonal bar design. The new TM accounts for the strength of the concrete when sizing diagonal bars for Type I cross sections and simply supported slabs with moderate support rotations. For Types II and III cross sections and sections in net tension, diagonal bars capable of resisting the actual support shear are still required.

REFERENCES

1. "Structures to Resist The Effects Of Accidental Explosions", TM 5-1300 dtd. June 1969.

2. "Structures to Resist The Effects Of Accidental Explosions Vol. IV, Reinforced Concrete Design", Special Publication ARLCD-SP-84001, dtd. April 1987.

3. "Building Code Requirements for Reinforced Concrete, ACI 318-83 Rev. 1986", American Concrete Institute, Detroit Michigan.



CROSS SECTION TYPES
FIGURE 1

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1.

ALTERNATIVE SHEAR REINFORCEMENT GUIDELINES FOR BLAST-RESISTANT DESIGN

by:
Stanley C. Woodson
U.S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

William H. Gaube and Timothy C. Knight
U.S. Army Engineer District, Omaha
Omaha, Nebraska

INTRODUCTION

The use of some type of shear reinforcement is required by current manuals for the blast-resistant design of reinforced concrete slabs. The primary purpose of this type of reinforcement, normally referred to as shear reinforcement, is not to resist shear forces, but rather to improve performance in the large-deflection region by tying the two principal reinforcement mats of the slab together. Shear reinforcement used in blast-resistant design usually consists of either lacing bars or stirrups (Figure 1). Lacing bars are reinforcing bars that extend in the direction parallel to the principal reinforcement and are bent into a diagonal pattern between mats of principal reinforcement. The lacing bars enclose the transverse reinforcing bars, which are placed outside the principal reinforcement. The cost of using lacing reinforcement is considerably greater than that of using single-leg stirrups due to the more complicated fabrication and installation procedures.

Two of the most commonly used manuals are the Army Technical Manuals (TM) 5-1300 (Reference 1) and 5-855-1 (Reference 2). Reference 1 is volume IV of the draft of the new TM 5-1300. A limited bank of relatively recent test data that indicate excessive conservatism in the shear reinforcement design criteria of these manuals was presented at the 23d Department of Defense Explosives Safety Seminar (Reference 3). The shear reinforcement design criteria are directly related to the allowable response limits (support rotations) of the slab. More recently, an extensive review of related test data has been conducted. Data for 278 tests were collected. The tests consisted of static and dynamic loadings of reinforced concrete slabs and box-type structures having lacing bars, stirrups, or no shear reinforcement. Although this is a large number of tests, there remain significant gaps in the data base. A thorough study of the role of shear reinforcement (stirrups and lacing) in structures designed to resist blast loadings or undergo large deflections has never been conducted; however, as discussed in this paper the available data base is sufficient to allow a relaxation of the shear reinforcement requirements for the roof, floor, and wall slabs of some types of protective structures. Such a relaxation is evident in a recently prepared Engineer Technical Letter (Reference 4) applicable to protective structures designed to resist the effects of conventional weapons.

DISCUSSION OF DATA REVIEW

The data base is presented in a draft technical report (Reference 5) currently being prepared for publication at the U.S. Army Engineer Waterways Experiment Station (WES). Parameters describing construction details, testing conditions, structural response, and failure modes were tabulated and discussed. In addition to recent tests, the data base includes the tests that were conducted in the 1960's and were instrumental in the formulation of the design criteria given in the original 1969 version of TM 5-1300. As discussed in Reference 3, the shear reinforcement design criteria have been only slightly relaxed in the new version of TM 5-1300 as compared to the 1969 version. The data developed in the 1960's primarily pertained to either laced slabs or slabs with no shear reinforcement; therefore, it is not surprising that TM 5-1300 is more restrictive for slabs containing stirrups rather than lacing bars. The data base in Reference 5 is the most comprehensive collection of data available concerning shear reinforcement details in blast-resistant structures. Portions of the data base are presented in Tables 1 through 5. The reader is directed to Reference 5 for a more extensive list of tests and parameters.

A study of the data base indicates that there are several parameters in addition to shear reinforcement details that affect the large-deflection behavior of reinforced concrete slabs. These primarily include: support conditions, amount and spacing

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of principal reinforcement, scaled range, and span-to-effective-depth (L/d) ratio. The support conditions will be generalized in this discussion as either laterally restrained or laterally unrestrained. The amount of principal reinforcement will be given as the tension reinforcement ratio (p) expressed as a percentage of the width and effective depth of the slab. The scaled range (z) refers to the size and standoff of the explosive charge weight and is expressed as $ft/lb^{1/3}$. The effects of these parameters on slab response must be considered in the study of the role of shear reinforcement, particularly since the available data are from many separate test programs with different combinations of these parameters. An understanding of how these parameters interact to enhance the ductility of a slab will lead to the design of more economical structures.

Laterally Restrained Slabs

The roof, floor, and wall slabs of protective structures, particularly those in the data base, are generally laterally restrained. This is partly due to the extension of the principal reinforcement of a slab into the adjoining slab. Also, the adjacent slabs usually exhibit similar degrees of stiffness (based on thickness, span, and p). Lateral restraint is necessary for the formation of tension membrane forces that enhance the large-deflection behavior of slabs. The laterally-restrained boxes tested at $z < 2.0$ $ft/lb^{1/3}$ were all buried and had a p of 2.0 percent. For low values of L/d in the range of approximately 6 or 7 with $z = 1.0$ $ft/lb^{1/3}$, damage was slight, but support rotations (Θ) were low (5 to 7 degrees) even when no shear reinforcement was used. Generally, wall slabs of boxes having L/d values of approximately 10 to 15 experienced large support rotations (15 to 29 degrees) and were damaged to near incipient collapse. However, a wall slab that had L/d = 7 and was tested at $z = 0.75$ $ft/lb^{1/3}$ sustained a support rotation of 26 degrees without breaching, although there was no shear reinforcement. Breaching did not occur in this group of slabs until support rotations reached 15 degrees, and some slabs achieved support rotations significantly greater than 15 degrees without breaching occurring. In general, no shear reinforcement was used in this group of slabs.

In addition to components of the box-type structures, the data base includes slabs that were laterally restrained in test devices or reaction structures. Many of the nonlaced slabs were

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tested in reaction devices of which the degree of lateral restraint cannot be determined with great confidence based on the information provided in the reports on the tests. Only two of the one-way slabs tested at $z < 2.0$ ft/lb$^{1/3}$ were definitely laterally restrained. Although one of these was lightly reinforced (p = 0.15) with no shear reinforcement and with L/d approximately equal to 9, it sustained only "slight" damage when tested at $z = 1.0$ ft/lb$^{1/3}$. Unfortunately, values for support rotation or midspan deflection are not available for these slabs. Damage was described as "heavy" when z was increased to 1.25 ft/lb$^{1/3}$, L/d was decreased to approximately 7, p was increased to 0.65, and looped reinforcement (apparently, a type of stirrup forming a rectangular loop around top and bottom bars) was used. Such variations in the data base are difficult to explain.

A considerable amount of information is available for the two-way slabs that were laterally restrained with L/d greater than 20 and were tested at $z = 2.0$ ft/lb$^{1/3}$. The values of p for these slabs (0.31, 1.0, 1.5, and 2.5 percent) included low, middle, and high values, considering the range of p forthe data base. For p = 1.0 or 1.5 percent, the slabs achieved support rotations of 10 to 12 degrees with no failure of the tension steel and "medium" damage. Even the slab having the low value of p = 0.31 percent with no stirrups sustained a support rotation of 10.4 degrees with medium damage and no rupture of reinforcement. The support rotation was limited to 5 degrees due to the high percentage of principal reinforcement when p equalled 2.5 percent. The slabs that sustained large deflections did not experience breaching, although z was as low as 0.65 ft/lb$^{1/3}$. When the single-leg stirrups (180-degree bends on each end) were used, they were spaced at less than one-half the thickness of the slab.

A review of data for the laterally-restrained laced slabs tested at $z < 2.0$ ft/lb$^{1/3}$ provides some insight into the difference in the behavior of laced and nonlaced slabs. The fact that both a laced slab and a slab with no shear reinforcement incurred heavy damage when tested at $z = 1.5$ ft/lb$^{1/3}$ and 1.25 ft/lb$^{1/3}$ respectively, somewhat questions the significance of lacing. When laced slabs with p = 2.7 percent were subjected to low z values of 0.3 and 0.5 ft/lb$^{1/3}$, they experienced heavy damage and partial destruction, respectively. It is interesting to note that a laterally-unrestrained slab with no shear reinforcement and p = 2.7 incurred only medium damage at

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$z = 0.5\ ft/lb^{1/3}$. This indicates that the effects of the large p of 2.7 percent overshadowed the effects of shear reinforcement on the response of these slabs.

The data base also includes a group of laterally-restrained slabs (components of box structures) tested at $z = 2.0\ ft/lb^{1/3}$. The L/d values for these slabs ranged from approximately 6 to 20 and p was relatively large, 2.0 percent (the upper limit of TM 5-855-1). Support rotations were generally small and the damage was slight (mainly hairline cracks). Support rotations were as high as 26 degrees for a wall slab of a box buried in clay. Typically, the boxes in the data base were buried in sand, which is generally known to result in less structural response than when clay backfill is used. A slab with a L/d value of approximately 6 incurred only slight damage with a support rotation of 2 degrees when z equalled $2.0\ ft/lb^{1/3}$. This slab contained single-leg stirrups, with 135-degree bends on each end, spaced at less than one-half the slab thickness. The slab that was tested in clay contained similar stirrups spaced at greater than one-half the slab thickness. As z was increased to 2.8, 4.0, and $5.0\ ft/lb^{1/3}$ for some walls, support rotations remained very small (1.5, 1.0, and 2.0 degrees).

Another type of loading called the HEST (High Explosive Simulation Technique) was used on the roof slabs of many box structures. The HEST generally consists of a cavity covering the entire surface and containing evenly distributed strands of explosives. The cavity is covered with soil of a particular thickness to result in a desired pressure decay. Although many of the HEST tests are often considered to be "highly-impulsive," it is likely that they may more accurately represent tests that have a charge placed at $z \geq 2.0\ ft/lb^{1/3}$. The parameter p varied from 0.5 to 1.2 percent and the boxes usually contained single-leg stirrups with a 90-degree bend on one end and a 135-degree bend on the other end. The stirrups were spaced at less than one-half the slab thickness and the L/d values ranged from approximately 7 to 17. Generally, very little steel was ruptured in these tests. The only case in which more than 50 percent of the tension reinforcement was ruptured was for a slab with no shear reinforcement and p = 1.2 percent. Also, the principal reinforcement was spaced at greater than the slab thickness and the slab experienced support rotations of 15 degrees. When the principal reinforcement in a similar slab (p = 1.1 percent) was spaced at less than the slab thickness, no steel was ruptured. This slab sustained support rotations of 14 degrees. In

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addition, a slab with single-leg stirrups (90- and 135-degree bends), p of only 0.51 percent (spacing less than the slab thickness), and L/d of approximately 15 achieved support rotations of 16 degrees with no rupture of steel. This group of data indicates that slabs with single-leg stirrups (90- and 135-degree bends) and L/d values from 7 to 17 are capable of sustaining support rotations up to 30 degrees with significant damage and can achieve support rotations of approximately 25 degrees with little to no rupture of steel. Actually, this was the case for some slabs that contained no shear reinforcement.

In addition to the data groups discussed above, many laterally-restrained slabs were statically loaded with uniformly distributed water pressure. In brief, these slabs achieved support rotations up to 25 degrees when no shear reinforcement was used or when single-leg stirrups (90- and 135-degree bends) were used.

Laterally-Unrestrained Slabs

Data for laterally-unrestrained, nonlaced slabs tested at $z < 2.0$ ft/lb$^{1/3}$ are very limited. One of these slabs contained looped shear reinforcement, had an L/d value of approximately 7, and was tested at $z = 1.0$ ft/lb$^{1/3}$. The damage was described as partial destruction. The rest of the slabs in the data base for this category contained no shear reinforcement. The damage levels ranged from slight damage to total destruction for slabs that had an L/d of approximately 10, a p of 0.15 percent, and were tested at z values from 1.7 to 1.0 ft/lb$^{1/3}$. Medium damage occurred when z equalled 1.1 ft/lb$^{1/3}$. When slabs having L/d of approximately 7 were tested at $z = 0.5$ ft/lb$^{1/3}$ one with $p = 0.65$ percent incurred total destruction, and one with $p = 2.7$ percent incurred medium damage. Likewise, an unrestrained laced slab with $p = 2.7$ percent incurred heavy damage when tested at $z = 0.5$ ft/lb$^{1/3}$. Damage was also heavy for two unrestrained laced slabs with $L/d = 7$ and $p = 0.65$ percent when tested at $z = 1.0$ ft/lb$^{1/3}$. It is obvious that unrestrained slabs with low percentages of tension steel are susceptible to major damage when $z < 2.0$ ft/lb$^{1/3}$.

Data for laterally-unrestrained, nonlaced slabs tested at $z \geq 2.0$ ft/lb$^{1/3}$ are also very limited. Four of these slabs had an L/d of approximately 10 and a very low p of 0.15 percent. The damage levels ranged from total destruction when z equalled

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2.0 $ft/lb^{1/3}$ to slight damage when z equalled 2.6 $ft/lb^{1/3}$. Slight damage also occurred when L/d was approximately 14, p equalled 0.40 percent, and z equalled the relatively large value of 3.5 $ft/lb^{1/3}$. All of these one-way slabs contained no shear reinforcement.

Summary

The data indicate that the response (support rotations) and the tendency for breaching of reinforced concrete slabs increase relatively quickly as z decreases below a value of 2.0 $ft/lb^{1/3}$. Lateral restraint is required for large support rotations. The test procedures used in many of the tests that were conducted on one-way slabs in the 1960's and are included in the data base were not consistent with respect to support conditions. The degree of lateral restraint varied and is currently difficult to define from the available information. It is generally known that lateral restraint is inherent to two-way slabs even when support conditions are not laterally restraining.

Although there are gaps in the data base, the data do not indicate that laced slabs respond significantly different than slabs containing a similar amount of shear reinforcement in the form of single-leg stirrups. Actually, the data indicate that slabs with no shear reinforcement can sustain large support rotations in some cases due to the effects of parameters other than shear reinforcement. It appears that both laced and unlaced unrestrained slabs with low values of p are very susceptible to major damage when subjected to blasts at $z < 2.0\ ft/lb^{1/3}$.

In addition to the shear reinforcement spacing, the primary parameters affecting the response of reinforced concrete slabs to blast loads are support conditions, amount and spacing of principal reinforcement, scaled range. and span-to-effective-depth ratio. The data indicate that combinations of some values of these parameters reduce the significance of the other important parameters, including shear reinforcement details.

APPLICATIONS

Much of the data described in Reference 5 were taken from tests on walls or roofs of buried box structures. Other above-ground tests were typically conducted using bare (uncased)

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explosives, which did not produce a fragment loading and consequent degradation of the slabs. A study of the data base has resulted in the development of new shear reinforcement design criteria and associated response limits (Reference 4) for protective structures designed to resist the effects of conventional weapons. This application of the data base reflects an improved understanding of the effects of construction parameters on slab ductility, and it results in improved economy. In brief, the criteria given in Reference 4 are presented in Table 6.

Moderate damage is described as that recommended for protection of personnel and sensitive equipment. Significant concrete scabbing and reinforcement rupture have not occurred at this level. The dust and debris environment on the protected side of the slab is moderate; however, the allowable slab motions are large. Heavy damage means that the slab is at incipient failure. Under this damage level, significant reinforcement rupture has occurred, and only concrete rubble remains suspended over much of the slab. The heavy damage level is recommended for cases in which heavy concrete scabbing can be tolerated, such as for the protection of water tanks and stored goods and other insensitive equipment.

Based on the data base, Reference 4 sets forth some design conditions that must be satisfied in order for one to use the response limits given in Table 6. The scaled range must exceed 0.5 $ft/lb^{1/3}$ and L/d must exceed 5. Principal reinforcement spacing is to be minimized and shall never exceed the effective depth (d). Stirrup reinforcement is required regardless of computed shear stress to provide adequate concrete confinement and principal steel support in the large-deflection region. Stirrups are required along each principal bar at a maximum spacing of one-half the effective depth (d/2) when the scaled range (z) is less than 2 $ft/lb^{1/3}$ and at a maximum spacing equal to the effective depth at larger scaled ranges. When stirrups are also required to resist shear, the maximum allowable spacing is d/2. All stirrup reinforcement is to provide a minimum of 50 psi shear stress capacity. Some guidelines for ensuring adequate lateral restraint are also given in Reference 4 but will not be given in detail here.

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The following types of stirrups are permitted in Reference 4:

a. Single-leg stirrups having a 135-degree bend at one end and at least a 90-degree bend at the other end. When 90-degree bends are used at one end, the 90-degree bend should be placed at the compression force.

b. U-shaped and multilegged stirrups with at least 135-degree bends at each end.

c. Close-looped stirrups that enclose the principal reinforcement and have at least 135-degree bends at each end.

Criteria are given in Reference 4 to account for direct shear problems. It was observed from the data base that flexible slabs that are laterally restrained are much less likely to fail in direct shear because early in the response, lateral compression membrane forces will act to increase the shear capacity, and later in the response shear forces tend to be resolved into the principal reinforcement during tension membrane action. Tests indicate that direct shear failure can occur in slabs subjected to impulsive loads. It is generally known that shear-type failure is more likely to occur in reinforced concrete members with small L/d values than it is in those with large L/d values. Since the data base indicates that laterally restrained slabs with $L/d \geq 8$ are unlikely to experience direct shear failures, Reference 4 only requires design for direct shear for laterally restrained slabs having $L/d < 8$ and for all laterally unrestrained slabs. This is considered to be conservative, but the degree of conservatism is unknown due to gaps in the data base. The design procedures given in Reference 4 for direct shear design will not be presented here.

CONCLUSIONS AND RECOMMENDATIONS

Several parameters play key roles in enhancing the ductility of a blast resistant reinforced concrete slab. Allowable design response limits should not be based solely on shear reinforcement details and the scaled range. Although more data and study may be needed prior to the development of new design methodology and new guidelines for response limits for structures designed to resist the effects of accidental explosions, new guidelines have been developed for response limits for structures designed to resist the effects of conventional weapons. For these structures the primary concern is often the completion of a wartime mission with less emphasis on the continued utility of the structure.

The data base does further indicate that the shear reinforcement design criteria in current manuals are overly conservative. In particular, the study of the data has indicated that the development of the shear reinforcement design criteria in TM 5-1300 was based on a test program consisting primarily of laced slabs and slabs with no shear reinforcement. It is now clear that slabs that contain stirrups and are properly detailed in other aspects of construction (support conditions, L/d, p, and reinforcement spacing) are capable of performing as well as laced slabs.

Some data gaps need to be filled and perhaps proof tests need to be conducted before guidelines are developed that will result in more economical facilities used for explosives handling and storage. A static test series for studying slabs with lacing bars, stirrups, or no shear reinforcement is planned for FY 91. Dynamic tests are also needed, as well as further analytical effort, for evaluating such tests and developing new design guidelines.

ACKNOWLEDGMENTS

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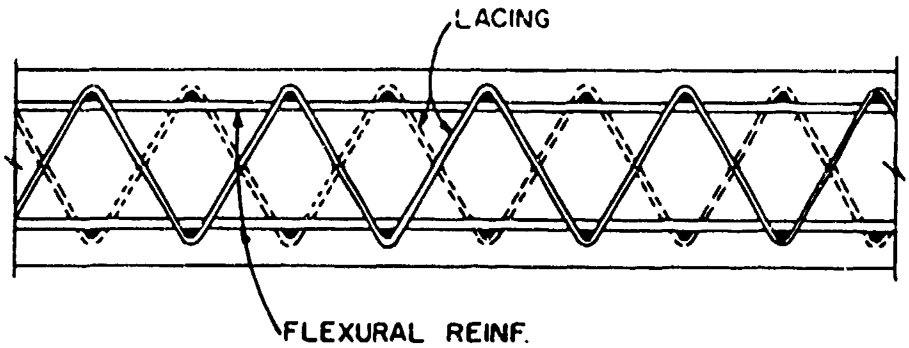
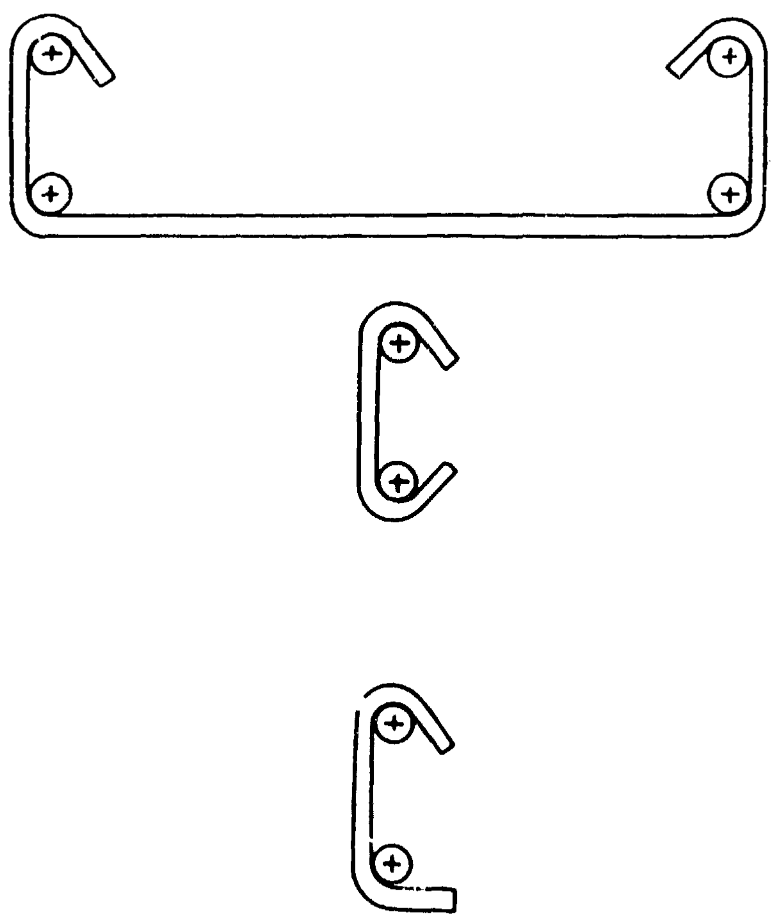


a. Lacing reinforcement



b. Stirrup configurations

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TABLE 1.
LATERALLY-RESTRAINED BOXES

S = principal steel spacing
U = not reported (unknown)
S_s = shear reinforcement spacing
t = slab thickness

z	L/t	θ	Shear Rein.	$s \le t$	$s_s \le t/2$	Damage
1.5	8	29	None	Y	---	Local Breach
1.4	8	28	None	Y	---	U
0.75	6	26	None	Y	---	U
1.9	12	15	None	Y	---	Local Breach
1.2	9	10	None	Y	---	Major Damage
1.5	10	10	135-s-135	Y	N	U
1.2	12	7	None	Y	---	Major Damage
1.0	6	7	None	Y	---	Slight
1.16	18	2	None	Y	---	Slight
1.8	12	2	None	Y	---	Slight
1.8	9	1	None	Y	---	Slight
1.86	18	0	None	Y	---	Slight
1.5	6	0	None	Y	---	Slight
1.0	5	5	135-s-135	Y	Y	U
1.9	9	2	None	Y	---	Slight
			$z \ge 2.0$			
2.0	10	26	135-s-135	Y	N	U
2.3	18	10	None	Y	---	Local Breach
2.0	10	7	135-s-135	Y	N	U
2.0	10	6	135-s-135	Y	N	U
2.0	10	4.5	135-s-135	Y	N	U
2.0	10	4	135-s-135	Y	N	U
2.0	10	3.5	135-s-135	Y	N	Slight

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TABLE 1. LATERALLY-RESTRAINED BOXES (cont'd)

z < 2.0

z	L/t	θ	Shear Rein.	s ≤ t	s_s ≤ t/2	Damage
2.0	10	2.5	135-s-135	Y	N	U
2.0	12	2.5	None	Y	---	Slight
2.0	10	2	135-s-135	Y	N	U
2.0	5	2	135-s-135	Y	Y	Slight
2.8	18	1.5	None	Y	---	Slight
4.0	10	1	135-s-135	Y	---	Slight
2.3	12	1	None	Y	---	Slight
2.0	5	1	135-s-135	Y	Y	U
2.4	12	0.5	None	Y	---	Slight
5.0	7	0.2	None	Y	---	Slight
2.0	9	0	None	Y	---	Slight

HEST LOADING

L/t	θ	Shear Rein.	s ≤ t	$p_{ten}\backslash p_s$	s_s ≤ t/2	Damage
15	30	None	N	1.2	---	near incipient collapse
6	28	135-s-90	Y	1.2\0.5	Y	steel not ruptured
8	26	135-s-90	Y	1.0\1.5	N	< 50% steel ruptured
8	22	135-s-90	Y	1.0\1.5	N	steel not ruptured
14	16	135-s-90	Y	0.51\0.31	N	steel not ruptured
15	15	None	N	1.2	---	> 50% steel ruptured
13	14	None	Y	1.1	---	steel not ruptured
8	14	135-s-90	Y	1.0\1.5	N	< 10% steel ruptured

HEST LOADING (cont'd)

L/t	Θ	Shear Rein.	$s \le t$	$p_{ten} \backslash p_s$	$s_s \le t/2$	Damage
6	11	135-s-90	Y	0.75\0.5	Y	steel not ruptured
6	9	135-s-90	Y	1.2\0.5	Y	steel not ruptured
8	8	135-s-90	Y	1.5\1.5	Y	steel not ruptured
8	4	closed-hoop	Y	0.5\0.25	---	steel not ruptured
13	3.1	double-leg	N	0.69\0.18	N	steel not ruptured
13	2.5	double-leg	N	0.69\0.18	N	steel not ruptured
13	2	double-leg	N	0.69\0.18	N	steel not ruptured
13	2	double-leg	N	0.69\0.18	N	steel not ruptured
8.5	1.5	double-leg	Y	1.0\1.5	N	steel not ruptured
15	1.5	None	N	1.2	---	< 10% steel ruptured
13	1	double-leg	N	0.69\0.18	N	steel not ruptured
15	1	None	N	1.2	---	< 10% steel ruptured
13	0.5	double-leg	N	0.69\0.18	N	steel not ruptured

SD = Slight damage
MD = Medium damage
HD = Heavy damage
PD = Partial destruction
TD = Total damage

TABLE 2. NONLACED SLABS

$z < 2.0$

z	L/t	Shear Rein.	$s \le t$	$p_{tension}$%	Laterally Restrained	Damage
1.7	8	None	Y	0.15	N	SD
1.7	8	None	Y	0.15	N	SD
1.65	8	None	Y	0.15	N	PD
1.6	6	None	N	0.65	U	PD
1.5	8	None	Y	0.15	U	TD
1.5	14	None	Y	0.40	U	SD
1.5	14	None	Y	0.40	U	HD
1.25	6	None	N	0.65	U	TD
1.25	6	None	N	0.44	U	HD
1.25	6	None	N	0.65	U	HD
1.25	6	None	N	0.65	U	PD
1.25	6	Looped	N	0.65	Y	HD
1.1	8	None	Y	0.15	N	MD
1.05	8	None	Y	0.15	N	PD
1.02	7	None	Y	0.15	U	TD
1.0	8	None	Y	0.15	N	TD
1.0	8	None	Y	0.15	N	TD
1.0	7	None	Y	0.15	Y	SD
1.0	6	None	N	0.65	U	TD
1.0	6	Looped	N	0.65	N	PD
0.8	6	None	N	0.65	U	TD
0.5	14	None	Y	0.40	U	TD
0.5	8	None	Y	0.15	N	TD
0.5	6	None	N	0.65	U	HD

TABLE 2. NONLACED SLABS (cont'd)

z	L/t	Shear Rein.	s ≤ t	$p_{tension}$%	Laterally Restrained	Damage
			$z < 2.0$			
0.5	6	None	N	0.44	U	TD
0.5	6	None	N	0.65	U	HD
0.5	6	None	N	0.65	U	TD
0.5	6	None	N	0.65	N	TD
0.5	4	None	N	2.70	N	MD
0.5	2	None	N	0.15	U	TD
1.1	20	None	Y	0.31	Y	$\theta = 10.4°$; no steel failed shear crack @ one support (MD)
0.68	20	180-s-180	Y	1.0	Y	$\theta = 12.2°$; no steel failed (MD)
0.68	20	180-s-180	Y	1.0	Y	$\theta = 10.1°$; no steel failed (MD)
0.65	20	180-s-180	Y	1.5	Y	$\theta = 10.5°$; no steel failed (MD)
0.65	20	180-s-180	Y	2.5	Y	$\theta = 4.8°$; no steel failed (SD-MD)
			$z \geq 2.0$			
2.0	8	None	Y	0.15	U	TD
2.6	8	None	Y	0.15	N	SD
2.6	8	None	Y	0.15	N	PD
2.62	8	None	Y	0.15	N	SD
3.5	14	None	Y	0.40	U	SD

TABLE 3. LACED SLABS

$z < 2.0$

z	L/t	$p_{tension}$%	p_{shear}%	Laterally Restrained	Damage
1.5	6	0.65	0.15	Y	HD
1.25	6	0.65	0.40	U	MD
1.0	6	0.65	0.15	N	HD
1.0	6	0.65	0.40	N	HD
1.0	6	0.65	0.15	Y	HD
1.0	6	0.65	0.15	Y	PD
1.0	6	2.70	1.20	Y	HD
0.9	6	2.70	1.20	Y	HD
0.8	6	0.65	0.15	N	PD
0.8	6	0.65	0.40	N	MD
0.5	6	0.65	0.40	U	HD
0.5	6	0.65	0.15	U	PD
0.5	6	0.65	0.40	U	PD
0.5	6	2.70	1.20	N	HD
0.5	4	2.70	1.20	Y	HD
0.5	2	0.69	0.53	U	MD
0.4	6	0.65	0.40	U	HD
0.4	1.8	0.65	0.53	U	HD
0.35	2	2.70	1.20	Y	HD
0.3	2	2.70	1.20	Y	HD
0.3	2	2.70	1.20	Y	PD

TABLE 4. NONLACED SLABS
STATICALLY-LOADED

Θ	L/t	Shear Rein.	$s \le t$	$s_s \le t/2$	p_{ten}/p_s	Damage
11.2	15	135-s-90	N	N	1.14/0.18	> 50% tension steel ruptured
12.6	10	135-s-90	N	N	0.74/0.18	< 50% tension steel ruptured
13	10	135-s-135	N	N	0.74/0.09	> 50% tension steel ruptured
14	10	double-leg	N	N	0.74/0.19	> 50% tension steel ruptured
14	10	135-s-135	N	N	0.74/0.18	> 50% tension steel ruptured
14	10	135-s-90	N	N	0.74/0.18	> 50% tension steel ruptured
14	10	None	N	N	1.58	No steel ruptured
14.5	10	135-s-135	N	N	0.74/0.18	> 50% tension steel ruptured
14.5	15	135-s-90	N	N	1.47/0.24	No steel ruptured
15	15	135-s-90	N	N	1.47/0.24	No steel ruptured
15.5	10	135-s-135	N	N	0.74/0.18	> 50% tension steel ruptured
16	15	135-s-90	N	N	0.58/0.18	> 50% tension steel ruptured
16.5	10	135-s-90	N	N	1.06/0.27	< 50% tension steel ruptured
16.5	10	None	N	N	0.74	> 50% tension steel ruptured
16.5	10	135-s-135	Y	N	0.75/0.19	> 50% tension steel ruptured
16.7	15	135-s-90	N	N	1.14/0.18	No steel ruptured
17	10	135-s-90	N	N	0.52/0.22	> 50% tension steel ruptured
17	15	135-s-90	N	N	0.58/0.18	> 50% tension steel ruptured
18	10	135-s-90	N	N	0.74/0.18	< 50% tension steel ruptured
18	15	135-s-90	N	N	1.14/0.18	No steel ruptured
18	10	135-s-135	Y	Y	0.75/0.38	> 50% tension steel ruptured
18	10	None	N	N	0.74	> 50% tension steel ruptured
18.8	10	135-s-90	N	N	0.74/0.18	> 50% tension steel ruptured
19.5	10	135-s-90	N	Y	1.13/0.22	> 50% tension steel ruptured
19.5	10	135-s-90	N	N	0.52/0.22	> 50% tension steel ruptured
19.7	10	None	N	N	0.79	> 50% tension steel ruptured
19.7	10	None	N	N	1.13	< 50% tension steel ruptured

TABLE 4. NONLACED SLABS
STATICALLY-LOADED (cont'd)

θ	L/t	Shear Rein.	s ≤ t	$s_s \le t/2$	p_{ten}/p_s	Damage
20	10	135-s-90	N	N	0.74/0.18	> 50% tension steel ruptured
20.5	10	135-s-135	N	Y	0.74/0.36	> 50% tension steel ruptured
20.5	10	None	N	N	1.14	< 50% tension steel ruptured
21	10	None	N	N	1.14	> 50% tension steel ruptured
22.5	10	None	N	N	1.13	< 50% tension steel ruptured
22.5	8.4	135-s-90	Y	N	1.02/1.53	> 50% tension steel ruptured
23.5	10	135-s-90	N	Y	1.13/0.22	> 50% tension steel ruptured
23.5	10	None	N	N	1.14	> 50% tension steel ruptured
23.5	10	135-s-135	N	N	1.13/0.06	> 50% tension steel ruptured
24	10	None	N	N	0.79	> 50% tension steel ruptured
24.5	10	135-s-90	N	Y	1.13/0.22	> 50% tension steel ruptured

TABLE 5. LACED SLABS
STATICALLY LOADED

θ	L/t	p_{ten}/p_s	$s \le t$	$s_s \le t/2$	Laterally Restrained	Damage
8.5	24	0.82/0.19	N	Y	Y	steel condition not reported
9.2	24	2.11/1.37	Y	Y	Y	no steel ruptured
11	24	0.89/0.42	N	Y	Y	steel condition not reported
12.5	24	0.82/0.19	N	Y	Y	steel condition not reported
13.2	24	0.82/0.19	N	Y	Y	steel condition not reported

Table 6. Design Criteria from Reference 4

Lateral Restraint Condition	Damage Response Level	Limit (Degrees)
Unrestrained	------	6
Restrained	Moderate	12
Restrained	Heavy	20

11.

REFERENCES

1. M. Dede and N. Dobbs, "Structures to Resist the Effects of Accidental Explosions, Volume IV, Reinforced Concrete Design," Special Publication ARL-SP-84001, U.S. Army Armament Research Development and Engineering Center, Picatinny Arsenal, New Jersey, April 1987.

2. Department of the Army, "Fundamentals of Protective Design for Conventional Weapons," TM 5-855-1, U.S. Government Printing Office, Washington, D.C., November 1986.

3. S. A. Kiger, S. C. Woodson, and F. D. Dallriva, "Shear Reinforcement in Blast Resistant Design," Minutes of the Twenty-Third Department of Defense Explosives Safety Seminar, Department of Defense Explosives Safety Board, Washington, D.C., August 1988.

4. Department of the Army, "Response Limits and Shear Design for Conventional Weapons Resistant Slabs," Engineer Technical Letter (being prepared for printing), U.S. Government Printing Office, Washington, D.C., July 1990.

5. S. C. Woodson, "Response Limits of Blast-Resistant Slabs," Draft Technical Report, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1990.

BLAST RESISTANT CAPACITY OF 12 INCH REINFORCED CONCRETE SUBSTANTIAL DIVIDING WALLS IN ACCORDANCE WITH TM5-1300

BY

James P. Manthey
AND
Paul M. LaHoud, P.E.

Corps of Engineers, Huntsville Division
106 Wynn Drive, Huntsville Alabama, 35805-1957

ABSTRACT

Twelve-inch reinforced concrete walls have been constructed for many years within DoD munitions facilities and the commercial explosive industry to limit blast effects from accidental explosions. Such walls are a special category of "Dividing Walls" as defined by DoD explosive safety standards. Specific explosive limits are defined for such existing walls. However use of these walls for new operations or new construction requires performance based on rational methods of structural dynamics given in TM5-1300, "Design of Structures to Resist the Effects of Accidental Explosions". This paper discusses the performance of 12 inch Reinforced concrete walls and provides charts and figures which demonstrate the blast resistant capacity of such walls in several common configurations.

BACKGROUND

Existing Department of Defense (DOD) and related military service explosive safety standards address the utilization of "Dividing Walls" as an acceptable means to subdivide explosive quantities and reduce the maximum credible explosive event for siting and operations. One widely used structural element used to achieve this performance is the 12 inch reinforced concrete wall. Reinforcement provided in such walls is normally number 4 (one-half inch diameter) bars spaced at 12 inches on center, with horizontal and vertical bars on each face of the wall. Figure 1 presents a typical configuration for such a wall. Such dividing walls have been constructed in U.S. military and commercial explosive manufacturing, handling and storage facilities for more than 50 years. They have become a de facto standard. The acceptable use of such walls in facilities is addressed in each of the relevant DoD and service explosive safety standards. The description and application in the individual service standards are similar to the DoD standard. However there are subtle differences. These differences provide "grandfather" relief for existing facilities. Because of the past acceptance of these walls for certain applications, limitations for new operations may be misunderstood.

SUBSTANTIAL DIVIDING WALL DEFINITIONS

The governing DOD explosive safety standard which service specific standards must comply with is DoD 6055.9 STD (Ref. 1). This document defines a "Dividing Wall" as:

> "A wall designed to to prevent, control, or delay propagation of an explosion between quantities of explosives on opposite sides of the wall".

To "prevent" or "delay" propagation implies both Category III and Category IV protection. Chapter 9 Paragraph B. 2. b. then states that design of dividing walls in accordance with TM5-1300, AFM 88-22, NAVFAC P-397 (Reference 2) will assure the structural performance needed to function as a dividing wall. No additional guidance is given regarding the use of "12 inch reinforced concrete walls" as a special dividing wall case.

Within the Army, at government owned facilities, application of Reference 1 is implemented through AMCR-385-100 (Reference 3). This reference provides a definition of a "Substantial Dividing Wall" as:

> "An interior wall designed to prevent detonation of quantities explosives on opposite sides of the wall".

In this definition, the implication is that Category III protection is provided and is essentially the same as in the DOD standard. Reference 3 then follows in Chapter 5, paragraph 5-6 with criteria to assure this performance:

> "A substantial dividing wall will be designed in accordance with TM5-1300, 'Structures Designed to Resist the Effects of Accidental Explosions', to prevent propagation of detonation by blast and by ammunition or wall fragments."

This definition is again equivalent to Reference 1. However, unlike the DOD standard, AMCR-385-100 also provides additional specific guidance regarding the use of "12 inch reinforced concrete walls". This guidance states:

> "Reinforced Concrete walls not less than 12 inches thick are effective in preventing propagation between bays when the donor quantity does not exceed 425 pounds of class 1, Division 1 explosives ...... In existing buildings having such walls, operations shall be planned .....".

In this definition "prevention of propagation" is apparently intended to imply sufficient time delay such that a subsequent detonation in an adjacent bay will not coalesce with the initial shock wave. This definition provides no discussion of detailed reinforcement requirements for such walls. An important point in the application of this standard is that it recognizes the use of 12 inch reinforced concrete walls in existing buildings to provide separation for 425 pounds. If completely new construction is planned, then it should be designed to comply with Reference 2.

For ammunition and explosive production by DoD contractors, required safety standards are prescribed in DoD Standard 4145.26-M (Reference 4). This document provides a definition of a "Substantial Dividing Wall" as:

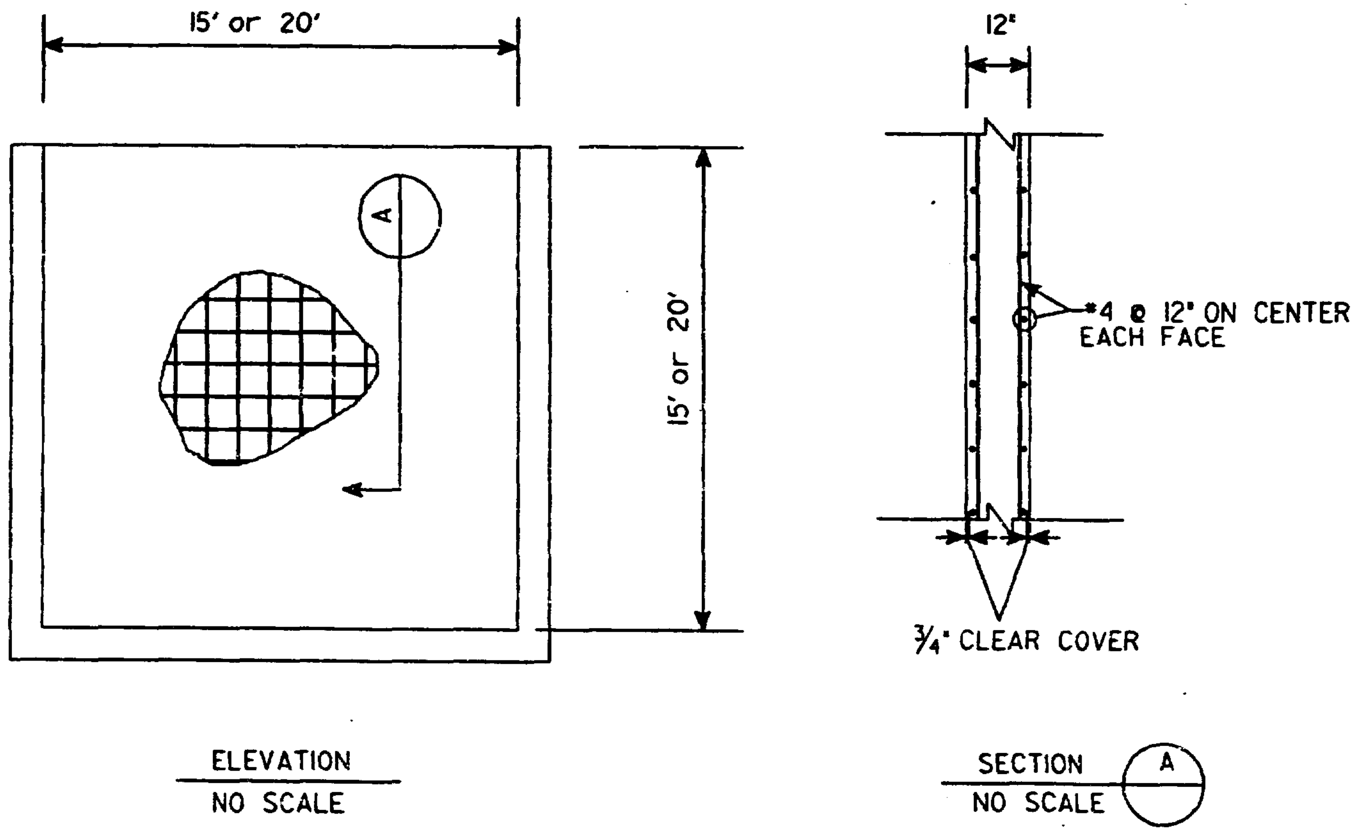


Figure 1 - Typical 12" Reinforced Concrete Dividing Wall

"An interior wall designed to prevent 'simultaneous detonation' of explosives on opposite sides of the wall. However such walls may not prevent propagation".

This definition, while similar to those in References 1 and 3, is the most complete and accurate of the three, recognizing both Category III and IV performance. As with Reference 3, this document also provides specific guidance for the use of "12 inch reinforced concrete" walls.

This guidance is also similar to reference 3 in that it allows use of such walls for bay limits of up to 425 pounds. It is more specific in that it describes in detail the design requirements of such walls:

"Reinforced concrete walls may vary in thickness, but will be at least 12 inches thick. At a minimum, both faces will be reinforced with rods (deformed reinforcing steel) at least 1/2 inch in diameter. The rods will be spaced at not more that 12 inches on center horizontally and vertically, interlocking with the footing rods and secured to prevent overturning. Rods on one face will be staggered with regards to rods on the opposite face and should be approximately 2 inches from each face. Concrete should have a minimum of 2500psi compressive strength"

A significant difference regarding reference 4 is that it is silent on the issue of the use of this type of walls for "existing" or "new" construction. It seems clear that Reference 3 intended to provide a "grandfather clause" for existing construction. Reference 4 however can be interpreted to allow newly constructed 12 inch reinforced concrete walls to prevent propagation for limits up to 425 pounds per bay. As will be demonstrated, analysis of these walls in accordance with Reference 2 will not allow such limits. To summarize, existing 12 inch reinforced concrete walls are generally recognized as acceptable by current standards for preventing simultaneous detonation (Category IV) for up to 425 pounds of explosive. Most existing walls of this type are reinforced as described by Reference 4. This explosive quantity was arrived at through limited full scale testing involving lightly cased explosives. Analysis in accordance with Reference 2 would not support such a value.

CURRENT APPLICATIONS

Existing facilities, both at government and contractor owned facilities, are continuously being modified to incorporate new production, maintenance or storage missions. These modifications must comply with the latest interpretation of explosive safety regulations. Thus operating conditions for which an existing substantial dividing wall was originally acceptable, may now be unacceptable. An example of this would be a new requirement to assure personnel protection in adjacent bays for operations which are now considered hazardous. The definition of personnel protection in Reference 1 is overpressure not to exceed 2.3 psi and no exposure to fragments with greater than 58 ft-lbs of energy. The 425 pound limit for non-propagation is clearly not compatible with such a personnel protection requirement. These personnel protection limitations are recognized by reference 3 in Chapter 25, paragraph 4 which discusses operational shields. This requirement limits explosive quantities to 15 pounds when a 12 inch reinforced concrete wall is used to provide personnel protection. This limit has been arrived at through analysis based on reference 2 and is a prescriptive value accepted as providing the desired personnel protection. It should be emphasized that all new construction of dividing walls should comply with the principles of reference 2 to assure the desired protection level.

ANALYSIS OF TYPICAL 12 INCH WALLS

The remainder of this paper will present the results of analysis and discussion of some recent test data on 12 inch reinforced concrete walls. The information presented is sufficiently accurate to provide an insight into the expected performance of such walls. It is not intended to represent an exact structural analysis of the capacity for all such walls. The analysis is based on methods consistent with reference 2.

Reference 2 provides design criteria for maximum wall rotation limits intended to provide personnel protection and to prevent simultaneous propagation. Shown in Table 1 are the limits for various conditions.

TABLE 1 - STRUCTURE FAILURE CRITERIA TM5-1300

SECTION TYPE	SUPPORT ROTATION	
	INCIPIENT FAILURE	MAXIMUM DESIGN ROTATION
[illegible] STIRRUPS	2°	1°
FLEXURAL W/ STIRRUPS	4°	2°

Most existing 12 inch reinforced concrete walls are only lightly reinforced for flexure, and have neither stirrups nor lacing to resist shear Therefor the 1 degree rotational limit will govern for personnel protection (Category I) and 2 degree rotational limit for non-propagation (Category IV). Spall fragments and overpressures for personnel exposure are treated separately. The response of several typical 12 inch walls will be represented using Pressure-Impulse (P-I) Diagrams for a 2 degree rotation limit. The pressure and impulse capacities for 1 degree rotations are very similar to those for 2 degree rotations. Therefore this paper will use 2 degrees to represent both category I and IV damage. P-I Diagrams describe the approximate pressure and impulse capacity that exist for any structural element given specified limits of rotation. The asymptotes that describe the pressure and impulse limits are connected by a transition region which represents the pressure-time response region. A detailed discussion of P-I Diagrams is found in Reference 5.

Figure 2 through 4 illustrate approximate Pressure-Impulse (P-I) Diagrams for walls with three different boundary conditions; cantilever, two adjacent sides supported and three sides supported. Each figure shows the results for both a 15x15 and a 20x20 foot wall. The data for these figures were derived using Single-Degree-Of-Freedom (SDOF) analysis over a range of donor sizes and stand-offs. Superimposed on these figures are selected explosive quantity curves which allow the user to estimate whether the limiting 2 degree rotation design criteria will be exceeded at the charge weight and stand-off distance being considered. The explosive quantity curves are based on the reflected pressure and impulse data taken from Figure

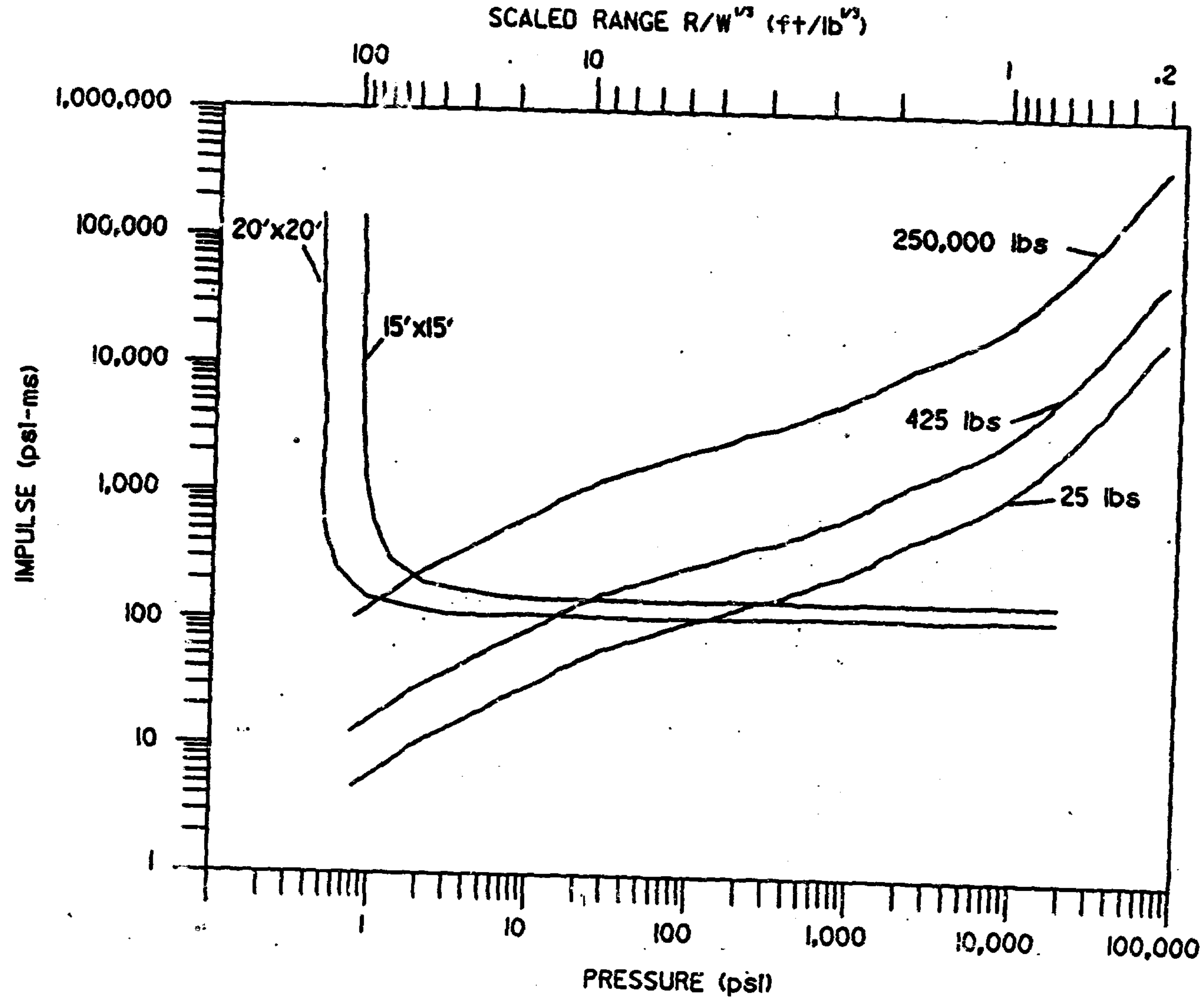


Figure 2 - P-I Diagram for 15 and 20 ft Cantilever Walls

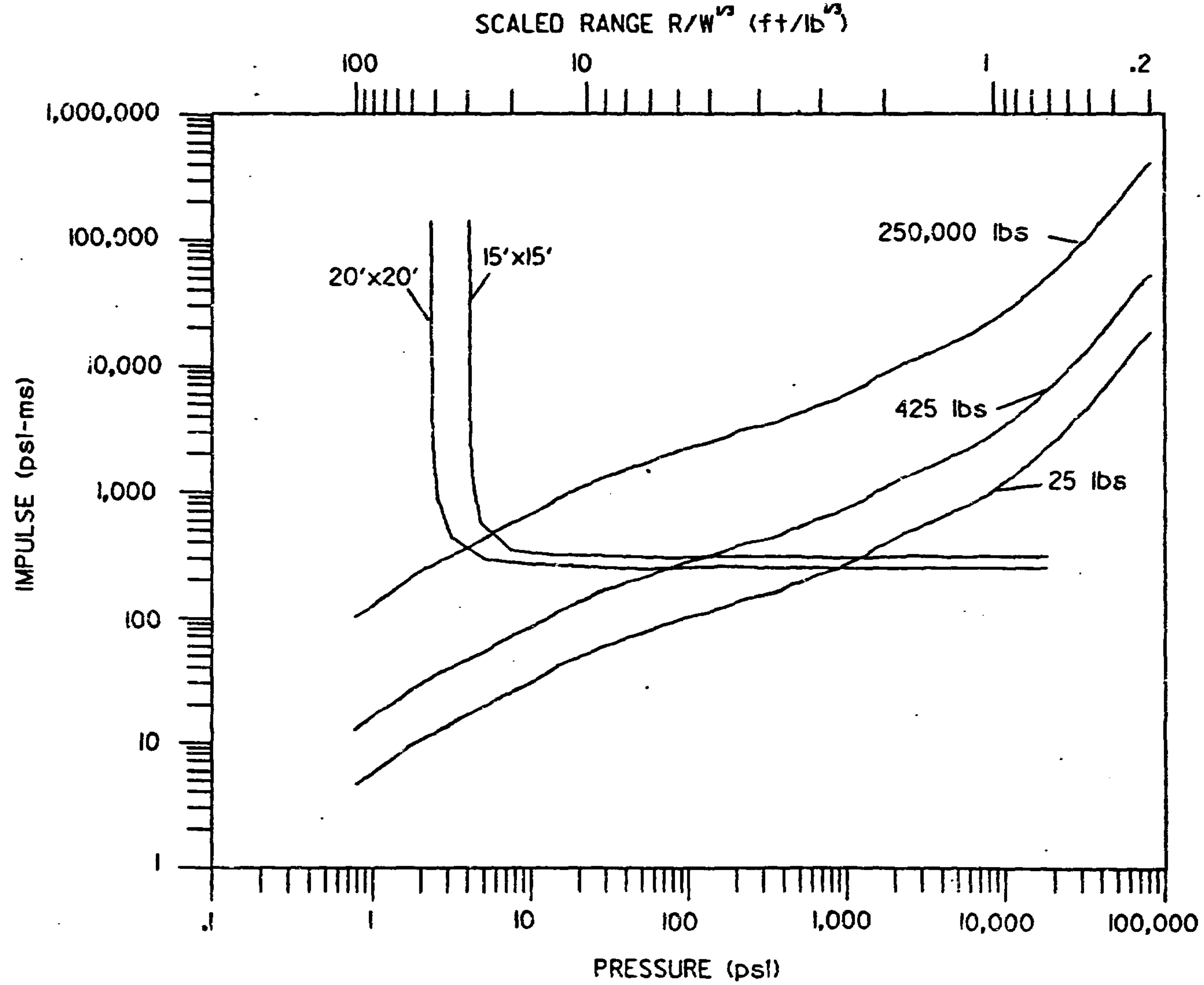


Figure 3 - P-I Diagram for 15 and 20 ft Wall Supported at Base and One Side

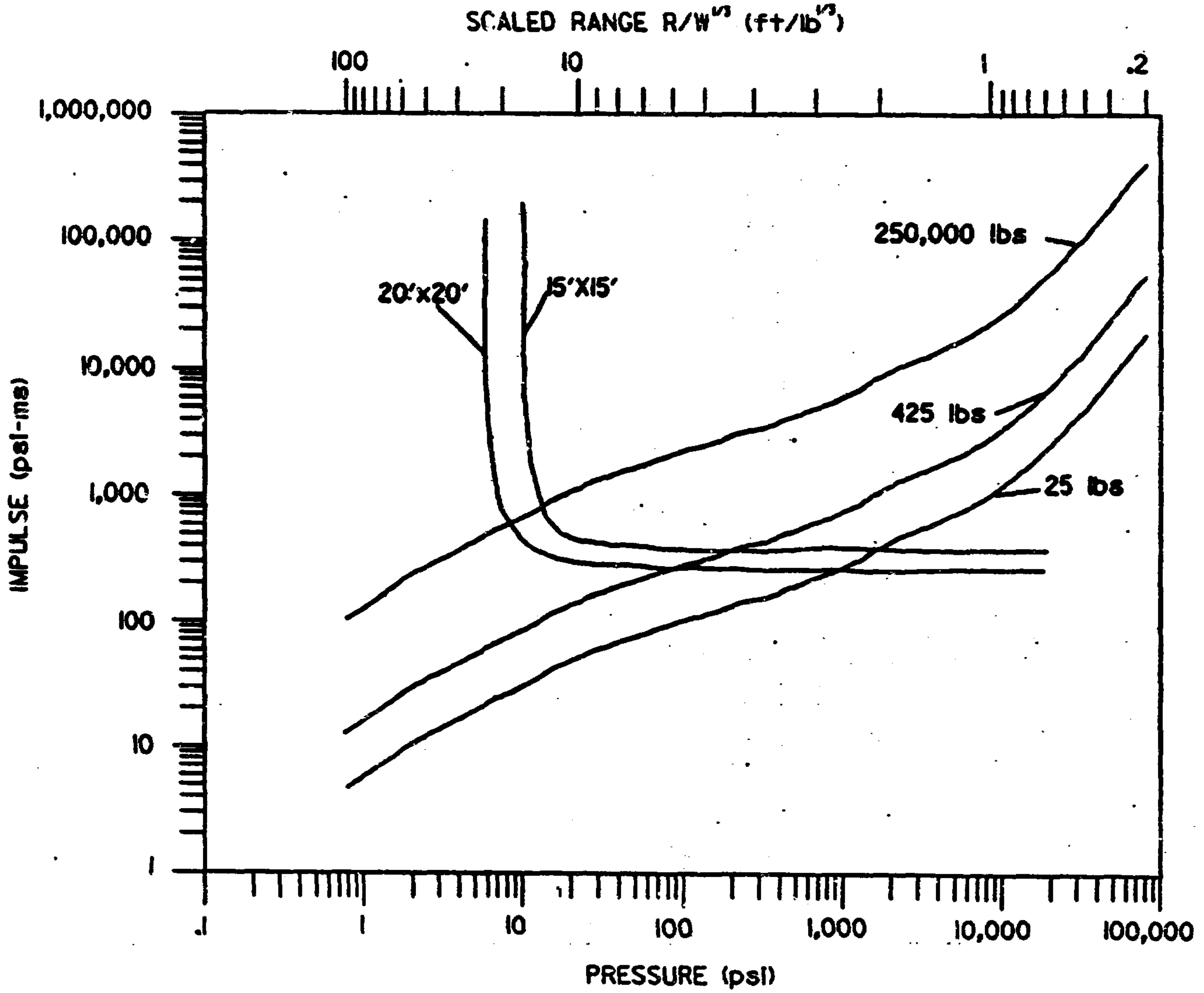


Figure 4 - P-I Diagram for 15 and 20 ft Wall Supported at Base and One Side

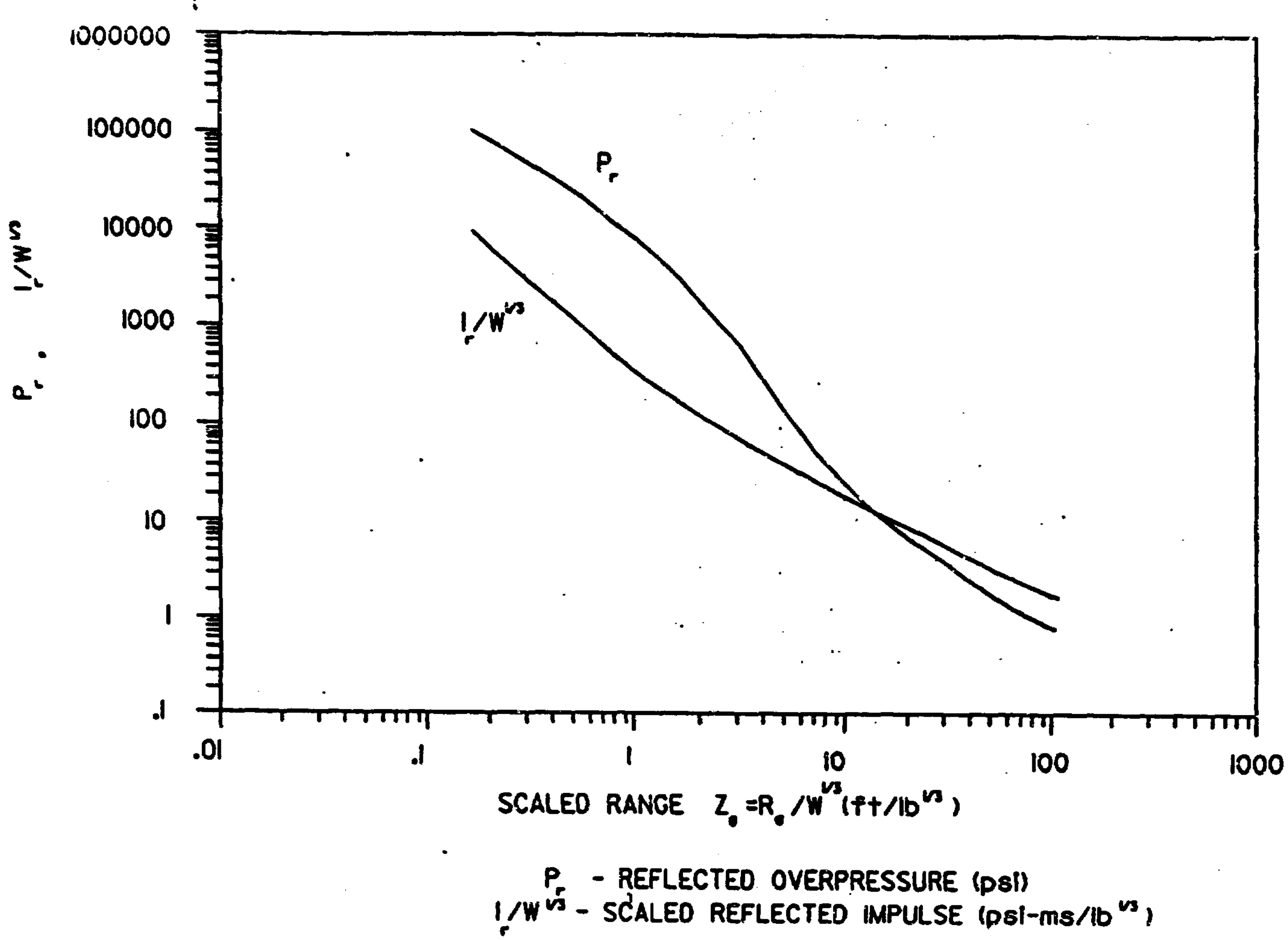


Figure 5 - Scaled Range vs. Pressure and Scaled Impulse

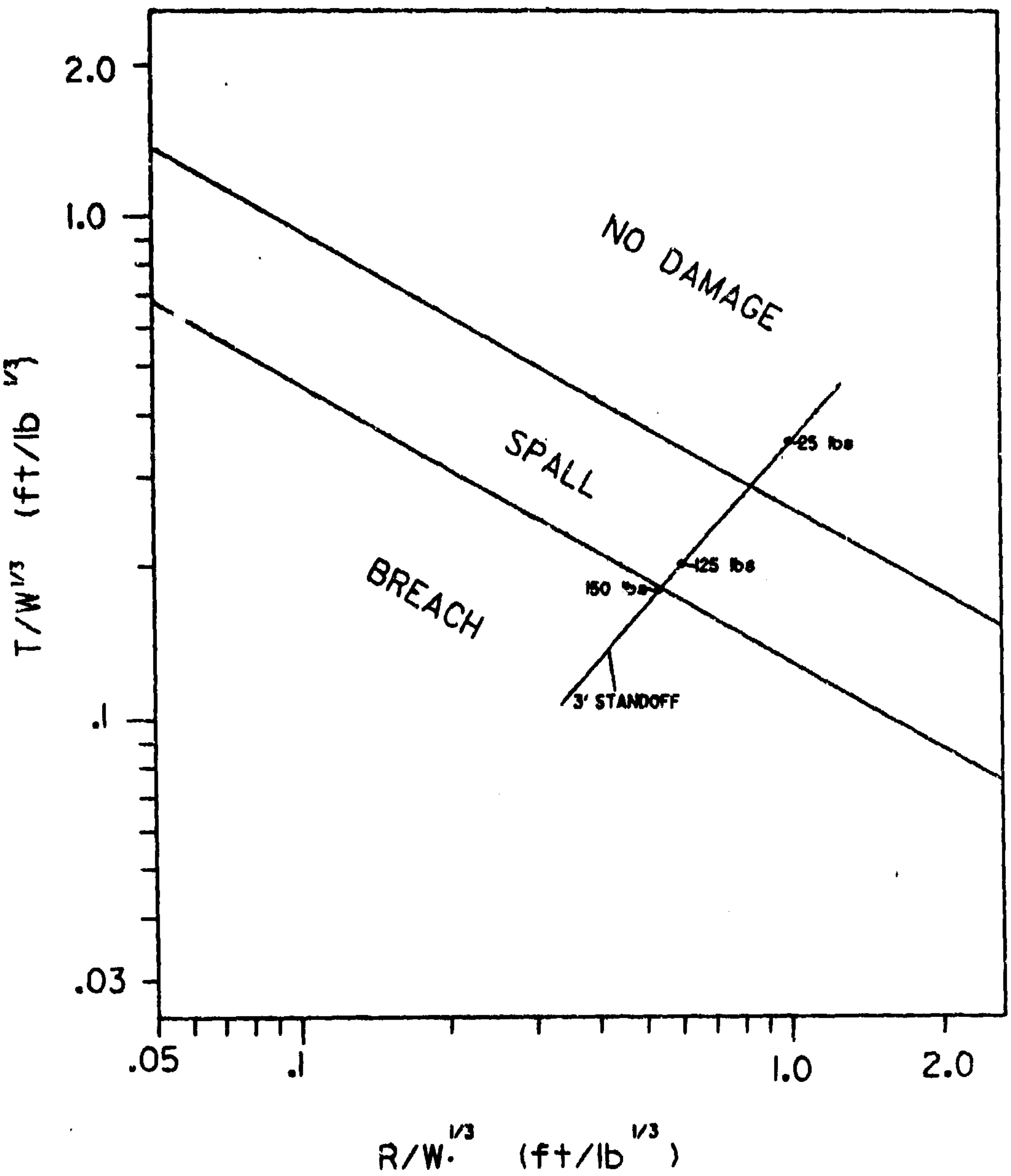
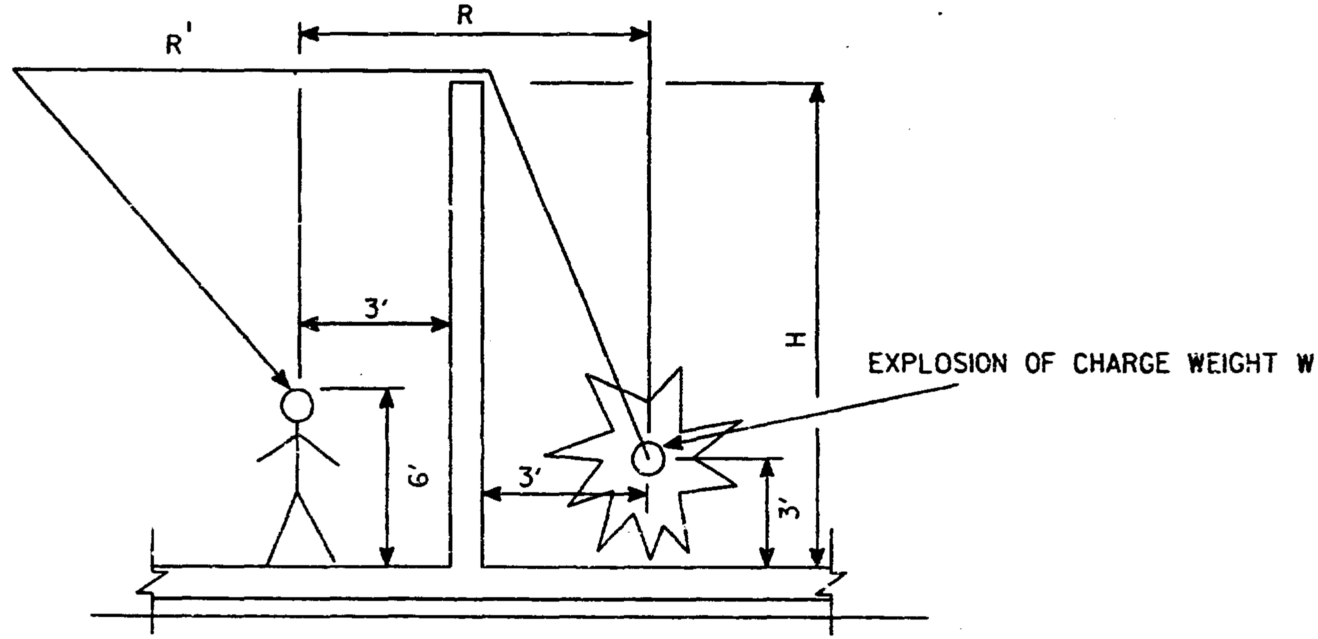


Figure 6 - Spall Damage Chart



W lbs	H ft	R ft	R' ft	$R'/W^{1/3}$ ft/lbs$^{1/3}$	P_{so} psi
5	15	7	39.65	23.18	2.45
	20	7	55.40	32.39	1.45
10	15	7	39.65	18.40	3.33
	·20	7	55.40	25.71	2.00
15	15	7	39.65	16.07	4.33
	20	7	55.40	22.46	2.50
20	15	7	39.65	14.60	5.00
	20	7	55.40	20.40	2.90

Figure 7 - Spillover Pressures For Personnel Protection

5 for any particular scaled range. As an example we will use Figure 4 which is for a wall supported on 3 sides. This would be representative of the back wall of a 3 wall cubicle. This figure shows that for a 20 by 20 wall, peak reflected pressures less than 7 psi will never cause wall rotations to exceed 2 degrees regardless of the total impulse. It also shows that for a total reflected impulse less than 250 psi-msec, regardless of pressure, the wall displacement will never exceed 2 degrees rotation. Consider now a 425 lbs explosive donor. For this donor the explosive quantity line crosses the limiting impulse asymptote of 250 psi-msec at a scaled range of approximately 6. This equates to a stand-off distance of about 45 feet. the peak reflected pressure at this distance is about 90 psi. At any stand-off closer than this, the wall will exceed the maximum allowable 2 degree rotation. This demonstrates the discrepancy between the arbitrary 425 lb allowable limit for all storage stand-offs and the approved criteria in reference 2. Now consider a quantity of 25 lbs of explosive. In this case, The explosive quantity line crosses the impulse asymptote at a scaled range of about 2.5. This results in a peak reflected pressure of approximately 1000 psi and the stand-off distance would be about 7 feet. Observations of wall rotation in an actual test of a 9 foot wall recently performed in Reference 6 agree well with this analysis. A general observation from this P-I diagram is that for for the small quantities typically stored in cubicles (less than 425 lbs) the duration of the load will be small with respect to the period of the wall and response will be governed by the impulse capacity. Assuming a typical 3 foot stand-off, the explosive storage limit for a 20 foot square 12 inch wall would be about 20 pounds for structural damage through rotation only. This would be the limit of explosive to prevent incipient failure of the wall as defined by reference 2. We will now evaluate the same wall for spall damage and leakage overpressure to determine the personnel protection limits for the adjacent bay.

Reference 2 and 7 provide methods for estimating the presence of spalling. Based on this approach, several donor quantities at a typical 3 foot stand-off are plotted on Figure 6. This shows that backface spall would begin to occur for a quantity of 25 lbs at a stand-off distance of 2 ft or less. Since spalling would likely generate fragments which would exceed the 58 ft-lb limit, this stand-off is distance is too close to be allowed for personnel protection. The occurrence of spall for this quantity and stand-off agrees reasonably well with recent test data (Reference 6). Reducing to a donor limit of 15 lbs would eliminate the spall risk and result in acceptable protection at the same stand-off. This result is consistent with the quantity allowed in Reference 3 for operational shields.

Last we will look at overpressure and the 2.3 psi limit required by Reference 1. Figure 7 is based on methods given in Reference 8. This procedure is based on test data and estimates an effective range from the Donor to the receiver which empirically accounts for the refraction of the shock waves over the wall. This data indicates that to limit overpressure on a standing operator behind the back wall of a three wall cubicle, the donor explosive limit must be limited to less than 5 lbs for a 15 high ft wall and just under 15 lbs for a 20 ft wall. These estimates assume that the cubicle walls do not extend through the roof of the building. If the walls reached or penetrated the roof, then the spillover pressure would be resisted by the roof over the receiver bay. If this roof was capable of resisting the pressure then the receiver would be protected. If not, then the roof would collapse and become a fragment hazard to the receiver personnel. In this example, without a roof, the requirement of 2.3 psi for personnel protection limits the explosive quantity substantially below the general limit of 15 lbs allowed in reference 3. A comment is appropriate here. The 2.3 psi limit is considered a threshold value for temporary hearing loss. If the operators were wearing hearing protection, then an overpressure of 5 psi would not pose a significant injury risk considering the short duration and impulse of these quantities. If we consider an overpressure limit of 5 psi, then the explosive limit will lie between 15 and 20 lbs for the 15 and 20 foot walls. The results of this analysis agree well with effects observed in several accidental explosions (References 9-11). This result also agrees well with the general guidance in Reference 3. In any event, the personnel exposure to overpressure is clearly the governing criteria for explosive limits of dividing walls in the configurations considered in this example. For cubicle walls that are cantilever or supported on two sides (a side wall and the floor), the shock wave would also refract around the side wall and this would reduce the allowable explosive limits even further.

CONCLUSIONS

Twelve inch reinforced concrete walls have been given special consideration within DOD explosive safety standards. This consideration recognizes the large number of walls that are in existence and performing a valuable safety function at this time. The 425 lb explosive limit for category IV protection was established based on limited test data. Design criteria for new construction as required by reference 2 would not support such a limit. The 15 lb limit for personnel protection (operational shields) is an acceptable limit for gross wall damage and spalling. Is marginal for overpressure protection at the 2.3 psi level for wall heights less than 20 feet unless they extend through the roof. It is even less conservative for short walls that are cantilever or supported on the floor and one edge.

It is clear that when an existing 12 inch wall is being considered for a new operational function requiring personnel protection, a detailed analysis should be provided to assure its performance.

There is room for differences in interpretation of References 1, 3 and 4. Reference 1 implies compliance with Reference 2 is required. reference 3 limits use to existing facilities. Reference 4 is silent on the subject of such walls in new construction. It is believed that the intent should be for all new construction to comply with Reference 2. It is also believed that the performance of 12 inch walls with 425 lb storage limits should be clearly defined as Category IV. Future revisions of these standards should be coordinated and reconciled.

ACKNOWLEDGEMENTS

Several individuals are acknowledged who provided valuable input used in the preparation of this paper. Dr. Chester Canada, DDESB-KT and Mr. Cliff Doyle of USATCES for their review of the content. Thanks to Tricia Bowles from Southwest Research Institute and Steve Young from Mason-Hanger Pantex, for providing access to supporting test data regarding fragmentation and damage effects from concrete walls. Also to Dave Douthat Chief of Safety at the Huntsville Division and Don Pittenger at the office of the Chief of Engineers Facility Army System Safety Office for their support.

REFERENCES

1. Department of Defense Ammunition and Explosive Safety Standards, DOD 6055.9-Std, Change 2 October 1988

2. Design of Structures to Resist the Effects of Accidental Explosions, TM5-1300, NAVFAC P-397, AFM 88-22, June 1969

3. Army Material Command Standards for Explosive Safety, AMCR-385-100, Change 1 March 1990

4. Contractor Manual for Explosive Safety, DOD Standard 4145.26M, July 1985

5. A Short Course on Explosion Hazards Evaluation , Southwest Research Institute, Instructors: Dr. W.E. Baker, Mr. P.A. Cox, Mr. P.S. Westine, Mr. J.J. Kulesz, Prof. R.A. Strehlow , 1978

6. Fragment and Debris Hazard Evaluation Test Program, Southwest Research Institute Project 06-2945, for the Department of Energy, Ongoing Study

7. Spall Damage of Concrete Structures , Mark McVay, U.S. Waterways Experiment Station, T.R. SL-88-22 June 1988

8. Blast Environment From Fully and Partially Vented Explosions in Cubicles, Naval Civil Engineering Laboratory ,TR-828 , November 1975

9. Explosion Damage Assessment and Structural Integrity Evaluation, Load Assembly and Pack, Building A2 Milan Army Ammunition Plant, Huntsville Division Army Corps of Engineers HNDTR 85-70-SD-SE ,October 1985

10. Explosion Damage Assessment and Structural Integrity Evaluation, Load Assembly and Pack, Building A2 Milan Army Ammunition Plant, Huntsville Division Army Corps of Engineers, HNDTR 88-CS-3 ,March 1988

11. Explosion Investigation and Structural Evaluation,Load Assembly and Pack Building 9324, Press Cubicle Room #124, Mississippi Army Ammunition PLant, Huntsville Division Army Corps of Engineers, HNDED-CS-86-7, 1986

MICROCOMPUTER ADAPTATION OF A TECHNICAL MANUAL

David W. Hyde
US Army Engineer Waterways Experiment Station
Vicksburg, Mississippi 39180

ABSTRACT

The Tri-Service Manual "Structures to Resist the Effects of Accidental Explosions", has recently been revised and published. The latest version of this technical manual contains updated information on a variety of explosion effects and structural response. The manual has been adopted for microcomputer usage by the Structural Mechanics Division, Structures Laboratory, US Army Waterways Experiment Station, in the form of a microcomputer program presented by this paper. This program allows the user to display the text of the manual on a microcomputer monitor, search for key words and phrases, display the figures from the manual on a monitor, produce hard copies on a plotter, retrieve data points from curves, and perform a variety of response calculations.

MICROCOMPUTER ADAPTATION OF A TECHNICAL MANUAL

David W. Hyde
US Army Engineer Waterways Experiment Station
Vicksburg, Mississippi 39180

Introduction

The U.S. Army Armament Research, Development and Engineering Center (ARDEC) has recently completed a revision of the Tri-Service Manual "Structures to Resist the Effects of Accidental Explosions". Pending approval of this draft revision as a Tri-Service Manual, the six-volume set has been published as Special Publication ARLCD-SP-84001 by ARDEC (Reference 1). To avoid confusion, this manual will be referred to by its Army designation, TM 5-1300, throughout this text. The latest version of this technical manual contains updated information on a variety of explosion effects and structural response. The manual has been adopted for microcomputer usage by the Structural Mechanics Division, Structures Laboratory, U.S. Army Engineer Waterways Experiment Station (WES), in the form of the computer program presented here -- TM.

TM allows the user to display the text of the manual on a microcomputer monitor and search for key words and phrases. It also allows the user to display the figures from the manual on a monitor, produce hard copies on a plotter, retrieve data points from curves, and compare test data to the theoretical curves from the manual.

Displaying Text

TM is a menu-driven program written for commonly available desktop computers using the Disk Operating System (DOS). From the program's main menu, the user may select to: read or print the table of contents, appendices, or body of any of Volumes 1-6 from TM 5-1300; select a subject from an index; or display the figures of the manual.

While displaying text from TM 5-1300, all of the functions of TM are controlled by the PC's cursor control keys and function keys. The cursor control keys are used to scroll up or down one line or one screen at a time. Scrolling may be repeated rapidly by holding down the cursor control keys. In addition, the function keys enable the user to search either forward or backward through the text for a key word or phrase. The search is not case sensitive. The user may also place a temporary "bookmark" at one place in a passage of text for later return. With the proper hardware, the user may also: change the current screen colors; switch to 43 lines of text per screen (rather than the normal 25); and speed up the keyboard response for faster scrolling.

Displaying Figures

Data for most of the figures from the manual is stored in separate files. The data files for illustrations are of one of three forms: 1) Hewlett-Packard Graphics Language (HPGL) instructions, 2) Tagged Image File Format (TIFF) bitmapped images, or 3) Files containing drawing instructions recognized by TM (see Figures 1 and 2). The data files for figures consisting of curves (Figure 3) contain either the data points necessary to recreate the curves, or the coefficients and exponents of polynomial equations used to generate the curves. In the latter case, TM will generate 200 equally spaced data points for each curve in the figure. Figures may be reproduced on most commonly available microcomputer graphics adapter/monitor combinations and on pen plotters supporting the Hewlett-Packard Graphics Language.

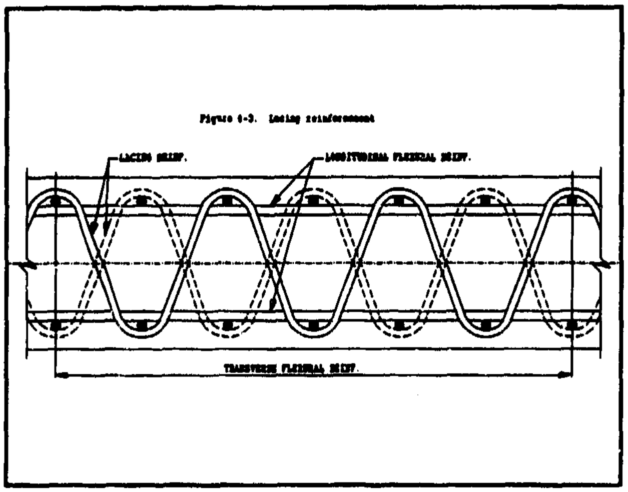


Figure 1. Illustration of lacing reinforcement (Fig. 4-3, Ref. 1)

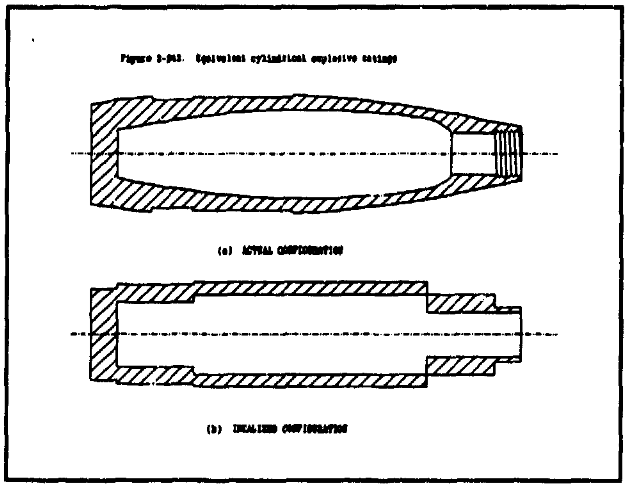


Figure 2. Equivalent cylindrical explosive casings (Fig. 2-242, Ref. 1)

If the selected figure consists of a curve or a set of curves (rather than an illustration), the user has the options of retrieving data points from a curve or zooming in on a portion of a curve. An example of the zoom feature is shown in Figures 3 and 4. The data retrieval function returns a Y value which is interpolated from the data points for each figure. The accuracy of this function is dependent on the spacing between data points, not on the resolution of the display monitor.

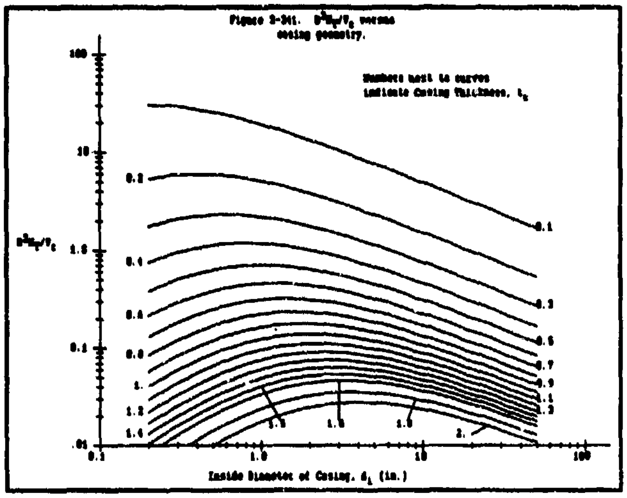


Figure 3. Fragment size parameters (Fig. 2-241, Ref. 1)

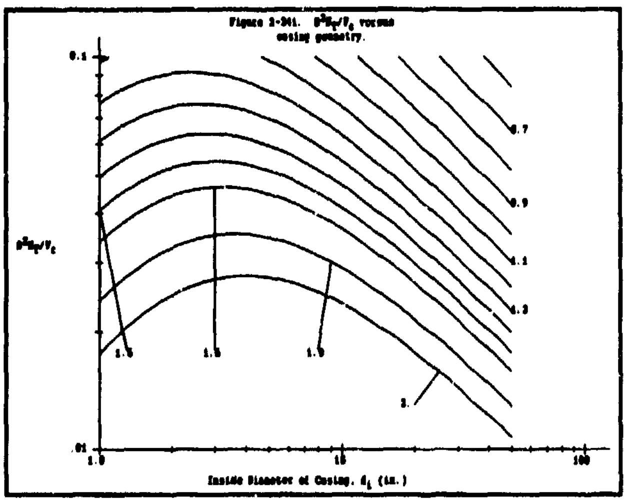


Figure 4. Zoomed Figure 2-241, Ref. 1

While data for most of the curves from the manual are stored in separate files, this was not a practical solution for recreating the response charts found in Volume 3 of the manual. Volume 3 contains over 200 response charts for maximum displacement, time of maximum response, and time of yield for a single-degree-of-freedom system with a bilinear resistance function due to a bilinear loading. Since a closed-form solution for the response of these systems is mathematically awkward, a numerical method is generally used to find the displacement-time history. To adequately reproduce each of these figures with data points would require a large amount of storage space; however, since the numerical solution for the response is fairly straightforward, TM generates the response charts at run-time rather than reading the data from separate files. One advantage to this technique is that the user will not have to interpolate between charts when his loading does not match one of the loadings in the printed manual; all parameters for the loading are specified by the user. An example of a maximum response chart generated by TM is shown in Figure 5.

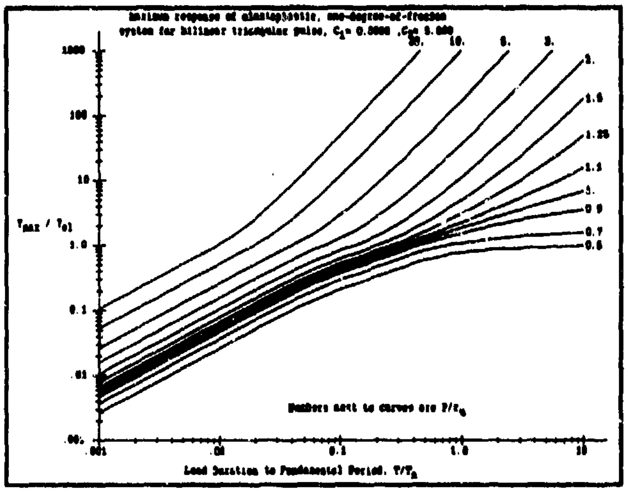


Figure 5. Response chart for bilinear pressure-time loading

Portability

The major routines of TM are written in ANSI standard FORTRAN-77. However, the program makes considerable use of assembly language subroutines to perform graphics operations, scroll menus, and achieve fast screen writing. TM achieves fast screen output by writing directly to display memory, bypassing the slower Basic Input/Output System (BIOS) video functions. Because of extensive use of assembler routines for menu generation and other video output, it would be difficult at best to move TM to another computer and/or operating system.

Graphics

All of the graphics routines used by TM were developed for microcomputers at WES. TM supports graphics on the following standard graphics adapters, and exploits the capabilities of certain "super" EGA's and VGA's.

Graphics Card	Resolution x Colors
Hercules Graphics Card	720 x 348 x 2
Color Graphics Adapter (CGA)	640 x 200 x 2

Enhanced Graphics Adapter (EGA)	640 x 350 x 16/64
Video Graphics Array (VGA)	640 x 480 x 16/256K

Plotters that support the Hewlett-Packard Graphics Language are also supported.

Availability

TM is currently in a draft stage and is being reviewed by the sponsors at the Department of Defense Explosive Safety Board (DDESB). When approved for release, the program will be available to government agencies from the DDESB.

REFERENCES

1. U.S. Army Armament Research, Development and Engineering Command, 1987, "Structures to Resist the Effects of Accidental Explosions," Picatinny Arsenal, New Jersey.

NATO Insensitive Munitions Information Center
(NIMIC)

Presented at Department of Defense Explosives
Safety Board Seminar
August 1990

St. Louis, Missouri

By:

Edward A. Daugherty

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This paper presents the history, organization, operation, assessment, and future of the NATO Insensitive Munitions Information Center *(Vugraphs 1 & 2)*.

The conference of National Armament Directors (CNAD) of the North Atlantic Treaty Organization (NATO) recognized that a lack of an agreed assessment methodology for safety and suitability for service was a major impediment to increased interoperability of conventional munitions within the Alliance *(Vugraph 3)*. To remove this impediment CNAD formed the Action Committee (AC)/310 in December 1979 as a tri-service cadre group. AC/310 is tasked to establish agreed international terminology, design principles, criteria, procedures and tests to cover all aspects of the assessment process for safety and suitability for service.

AC/310 was organized into four Sub Groups reporting to a Main Group *(Vugraph 4)*. The Sub Groups are chartered to work on qualification of explosive materials (explosives, propellants and pyrotechnics); qualification of fuzing systems (including safe and arming devices for rocket motor ignition); the development of environmental tests (mechanical, climatic, chemical, and electrical); and qualification of the assembled munition system. The Main Group coordinates efforts within AC/310 and with other Groups within NATO.

In 1983, prompted by input from U.S. Representatives, AC/310 became aware of the emerging requirements of "Insensitive Munitions" (I.M.) programs *(Vugraph 5)*. AC/310 recognized that these requirements should be considered an adjunct to the munitions safety program. The rationale for this being that safety and I.M. programs both deal with the survivability of munitions to environments, e.g. safety to those presented by the user in normal handling, storing, etc. evolutions as well as in reasonably forecast accident scenarios, while the I.M. program deals with munition survivability in the abnormal or combat induced environment. The very restrictive "acceptance" criteria which were being identified for I.M. related tests indicated to AC/310 that achieving the criteria would be virtually impossible without knowledge of appropriate technology to apply to the design. AC/310 considered that a Focal Point within NATO may be beneficial to advise munition developers of existing or emerging technologies to facilitate their efforts in meeting the new more stringent safety and I.M. requirements.

An Ad-Hoc Group was formed under AC/310 and entitled the "Restricted Editorial Working Group" (REWG) to determine if such a Focal Point was desireable, and if so where in NATO was a logical location *(Vugraph 6)*. Based on a REWG report, AC/310 decided that such a Focal Point was desireable and that it was logical to be associated with AC/310. Since the NATO structure did not allow formation of another Sub Group another method of formation was required. An Information Exchange Working Party (IEWP) was formed to validate within NATO that the Focal Point was desired and to determine how it should be structured. To this aim a workshop was held in London in October 1986. During the workshop, technical presentations were given relative to a particular I.M. problem area, namely Sympathetic Detonation. Attendees were polled after the three day session whether such information would be beneficial for the stated purpose of facilitating munition design to requirements. The attendees from government and industry of various NATO nations, as well as from various NATO groups, concluded a NATO Focal Point for information exchange would be of value. Accordingly, AC/310 decided to push forward with its efforts and formed an Information Center Working Group (ICWG) to establish the Focal Point.

The ICWG concluded that an immediate need existed for information exchange and that development of the Center warranted priority attention. It was therefore decided to form a Pilot NATO Insensitive Munitions Information Center (Pilot NIMIC) and a Memorandum of Understanding (MOU) was developed with the U.S. agreeing to act as the host nation.

In April of 1988 the MOU was signed by France, Netherlands, Norway, United Kingdom, and United States *(Vugraph 7)*. Canada signed an amendment one year later. The Pilot NIMIC became operational in Columbia, Maryland. The funds for salaries of the core staff of Program Manager, Information Specialist and Technician and a Secretary were provided by the host nation, as were funds for the operation of the physical plant. Other participating nations provided either technical specialists or funds. The Pilot phase was for a three year term concluding in April 1991.

The Pilot NIMIC operates under the provisions of its MOU which prescribes the daily management functions of the Center to be the responsibility of the Program Manager. The Program Manager is ultimately responsible to the Steering Committee for all matters. The Steering Committee is composed of a representative of each participating nation with an elected Chairman.

The MOU directed that Pilot NIMIC establish and validate an Information Analysis System and will *(Vugraph 8)*:

(a) Collect, store, and disseminate scientific and technical information on I.M.

(b) Provide and maintain a comprehensive data collection to facilitate design efforts for I.M. and minimize R&D efforts.

(c) Respond to technical inquiries by using the data base to analyze and generate recommended design approaches for I.M.

(d) Identify technology deficiencies that prevent requirements from being achieved and propose remedial actions.

(e) Analyze data and prepare data books and "state of the art" reports on I.M.

(f) Prepare for the transition to a permanent NIMIC at NATO Headquarters.

The above functions are to involve three major areas of concern namely *(Vugraphs 9 & 10):*

(1) Combat Threats - Fragment impact, bullet impact, sympathetic detonation, fuel fire, etc.

(2) Explosives and Munitions - Rockets, missiles, bombs, torpedoes, fuzes, propellants, etc.

(3) Technical Areas - Ignition, thermal explosions, deflagration to detonation transition, mitigation devices, etc.

Pilot NIMIC realized, early on, that the I.M. concept was new, and that not all nations recognized the designation of I.M. (e.g. the U.K. preferred "low vulnerability" and the French "Munitions a Risques Attenues" (MURAT) *(Vugraph 11)*. Consequently, search strategies using the I.M. term even in the U.S. may prove fruitless. Nations were therefore requested to search their archives on safety.

Pilot NIMIC provided all nations with guidance in performing searches by identifying areas of interest in the "Pilot NIMIC Thesaurus" *(Vugraphs 12 & 12a)*.

Information has been received from participant searches of formal data bases such as the U.S. National Technical Information Service (NTIS), Defense Technical Information Center (DTIC); the U.K. Defence Research Information Center (DRIC); Canadian Defence Scientific Information Service (DSIS), the French CEDOCAR, and others *(Vugraph 13)*. Other inputs have been received from industrial and government agencies in all the participating nations, as well as from searches of the world patent index, chemical abstracts, etc.

Information is stored in two types: Hard copy and machine-readable and searchable. The former make use of a conventional file system in which the documents are identified and located by numerical sequence (NIMIC TR numbers). The machine-readable data is in a text-based data base (Bibliographic Retrieval Services (BRS) search format on a hard disc backed up on magnetic tapes. A multi-user version of BRS is used for searching the data bases. The most efficient and rapid method for entering data is to receive it in machine-readable form such as a floppy disc, or directly from a national information storage system. Some reformatting is usually required but significant time in abstracting and manual input efforts are saved.

The Pilot NIMIC maintains seven data bases *(Vugraph 14)*. The major ones being the NIMIC Information Data Base (NIDB) which contains bibliographical data on reports for which hard copies are available (over 4,000); The Patent Data Base of worldwide patents of interest (over 260); the Journal Article Data Base which is self explanatory as to content; STANAG containing AC/310 developed test and requirement agreements and the Insensitive Munitions Points of Contact

(IMPOC) (over 400). This latter base contains a listing of individuals or laboratories having expertise in specific areas related to Insensitive Munitions related programs. These individuals and facilities have agreed to council the Pilot NIMIC staff as required to solve problem areas referred to the Pilot NIMIC.

Statistically Pilot NIMIC has reviewed over 14,000 citations for relevance to the data base and has entered over 5,700 into the data base system. Other documents await entrance into the system. Interestingly Pilot NIMIC has some 180 documents originating in non participating nations in the system. These have been either submitted by the originating nation or provided by a participating nation.

The subject matter in the data bases by type of information is as follows *(Vugraph 15):* The leading three categories are energetic materials, munitions, and detonics (DDT, XDT, etc.) with munition components, tests and trials, requirement statements, mitigation and fixes, platforms, accidents and cost benefits following in order. The first three subjects cover about 60% of the data available. The oldest documents in the system date back to 1969. However, about 35% are dated in the 70's and 54% in the 80's. Obviously input from the 90's is just commencing and much more data from the 80's is anticipated.

What is it that sets Pilot NIMIC apart from any of these documentation sources from which it has drawn or from efforts taking place under existing Data Exchange Agreements (DEA's) *(Vugraphs 16 & 17)*? The answer is that Pilot NIMIC performs an analysis function. This function is performed in two fashions: One in response to technical inquiries received from government and industrial agencies within a participating nation. These inquiries, if originated by a government agency are forwarded directly, if by industry via the national Focal Point, to Pilot NIMIC where the data base is examined and when coupled with the technical expertise of the staff a response is drafted. Since the achievement of all I.M. goals can seldom be achieved by the application of a single technology, often seemingly unrelated technologies are recommended together, (e.g. energetic materials and mechanical stress relief devices). The response often will deal with the synergistic effects of applying recommended design fixes, since indeed the environments of the full logistic life cycle must be considered in evaluating the true ability of design fixes to solve a stated problem. The expertise of the technical staff is often complemented by using the national experts identified in the IMPOC data base. Nowhere else in NATO or the western world does such a capability exist.

The second type of analysis performed by the staff involves a critical review of the data bases to identify gaps in the technology available and make recommendations to the participating nations which may lead to collaborative programs to fill the gap. Such collaboration will reduce the cost of R&D efforts as well as redundancy. Also resultant from such reviews will be state-of-the-art reports on specific technology areas which will provide comprehensive summaries of data on a specific technology topic. The state-of-the-art reports are published as developed and made available to participants.

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Pilot NIMIC recognizes that its data base is in its infancy and therefore immature for providing in depth responses to some technical inquiries. This situation places added emphasis on the technical expertise of the staff and the ability to access information from the POC to provide meaningful responses. By the same token, since I.M. initiatives are relatively new, the I.M. policies and programs of many participating nations are in their infancy, a situation reflected in the essence of many inquiries and in the type of data submitted to Pilot NIMIC. As the concept of I.M. matures nationally so will the NIMIC data base mature, allowing the Center to respond to the more demanding inquiries certainly to be developed in future years. The success of NIMIC in providing quality responses to the needs of munition developers will always require the expertise of the technical staff to research the constantly increasing data base with respect to a given problem area.

As of 1 July 1990, 156 inquiries have been received and responses have been developed for 125 *(Vugraph 18)*. The three leading subject categories numerically are: energetic materials, munitions, detonics (SDT, XDT, etc.). Next in line are questions on munition components, requirements, tests and trials. The remaining subject categories in order are: mitigation and design fixes, platforms, accidents, and cost/benefit analyses. The frequency of receipt does not necessarily reflect the importance of a given subject category in the realm of I.M. programs as understood today. As a matter of fact one of the most significant subject categories in national I.M. policy making decisions is that of cost/benefit analyses. Obviously this topic is one of the more demanding to deal with on the part of the technical staff.

This stated immaturity of the Pilot NIMIC data base also hinders the ability of the staff to identify gaps in the technology which would be worthy of additional effort to remedy *(Vugraph 19)*. At present the staff is aware of certain areas requiring technical solutions but confirmation is required before a recommendation for action is appropriate. Confirmation will be possible with the growth of the data base. As an example of a potential area of deficiency is the availability of small scale tests to predict the outcome of full scale munitions to I.M. tests and trials. The costs in required hardware and personnel to perform full scale munitions tests limit the number of tests performed to a quantity representative of low statistical value. The capability to predict and validate the few full scale test results with data from small scale tests has not been achieved. Specific areas for added effort need to be identified.

A more readily identifiable data base problem is in determining gaps in the data base itself. Pilot NIMIC has made known gaps in its data base and has requested participants take action to search for and input data in specific areas such as: physical and thermal data for energetic materials and munition construction materials, Hugoniot and critical-diameter data on energetic materials.

Pilot NIMIC has developed and is currently developing state-of-the-art reports on the topics of *(Vugraph 20)*: Norwegian Multipurpose Ammunition; Methodology for I.M. Cost Benefit Analysis; LOVA Propellants; Thermal Stress as Related to Munitions. Pilot NIMIC also recognizes the need to develop synopsis papers on mechanical (impact) and shock stresses in relation to I.M. test requirements.

As has been stated, Pilot NIMIC began operations in May 1988 for a three year period. Based on an assessment of the ability of the Pilot NIMIC to perform the assigned tasks, a determination was to be made to proceed with the final phase, a permanent NIMIC to be located at NATO HQ in Brussels. A formal assessment report was drafted in April 1990 *(Vugraph 21)*. This report was provided to the participating nations for staffing. (Copies were also provided potential future participating nations for their review and comment).

At the June 1990 meeting of the AC/310 Main Group nations were polled relative to their "willingness to participate" in the NIMIC phase. All current participants indicated this willingness as did three other nations. Based on the results of this poll, AC/310 requested the Conference of National Armament Directors (CNAD) to approve the formation of NIMIC as a NATO Project Office. Given an affirmative reply by CNAD, a MOU governing NIMIC will be placed for signature before CNAD at their October 1990 meeting. Operation of NIMIC in Brussels would then commence 1 May 1991.

As one of the stated functions of Pilot NIMIC is to prepare for transition to NIMIC in Brussels, much recent effort has been given to this planned action *(Vugraph 22)*. Resultant from this effort some items of interest are:

- NIMIC Staff was Defined as:

	Program Manager	A-5
	Information Technician	A-3
	Information Specialist	B-6
	Secretary	B-3
(4)	Technical Specialist	A-4

- Facility needs and availability at NATO HQ have been established.
- Administrative support is available from NATO International Staff and a Letter of Agreement has been developed.
- Funding is to be furnished by participants on share basis. Based on the relative size of the dispense budgets nations will provide either one or two shares.

All NIMIC positions will be filled by selectees under the NATO hiring procedures. The NIMIC Steering Committee will have influence in the final selection process particularly for the Program Manager and Technical Specialists. Technical Specialists will be required to have a broad experience in the field of munition design, acquisition, and use.

In conclusion, it is to be noted that Pilot NIMIC is a small international data base and likely will remain of moderate size even in the NIMIC phase. By virtue of its unique requirement to perform

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data analyses in the field of I.M. and safety of munitions it stands apart from any other data base. After less than three years of operation, (the first portion of which involved many administrative tasks such as establishing the physical plant, drafting procedural and security guidelines, etc.), Pilot NIMIC has realized the goals assigned to it. It has also established the fact that the NIMIC concept is capable of providing the required assistance to munition developers to facilitate meeting the more stringent design requirements and thus improve the potential for munition interoperability within the alliance.

PILOT
NATO INSENSITIVE MUNITIONS INFORMATION CENTER (NIMIC)

pilot NATO INSENSITIVE MUNITIONS INFORMATION CENTER

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History

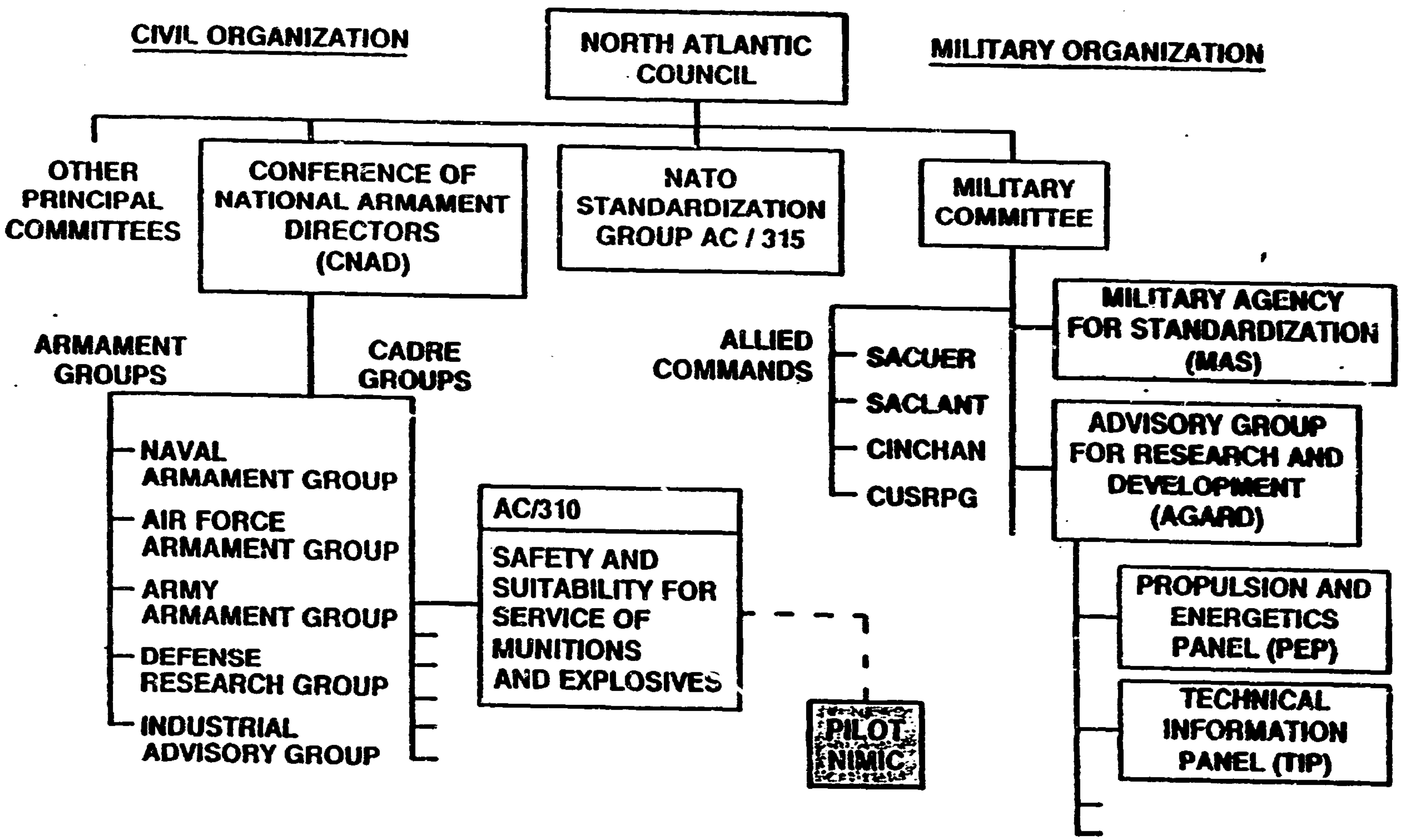
Oganization

Operation

Assessment

Future

NATO



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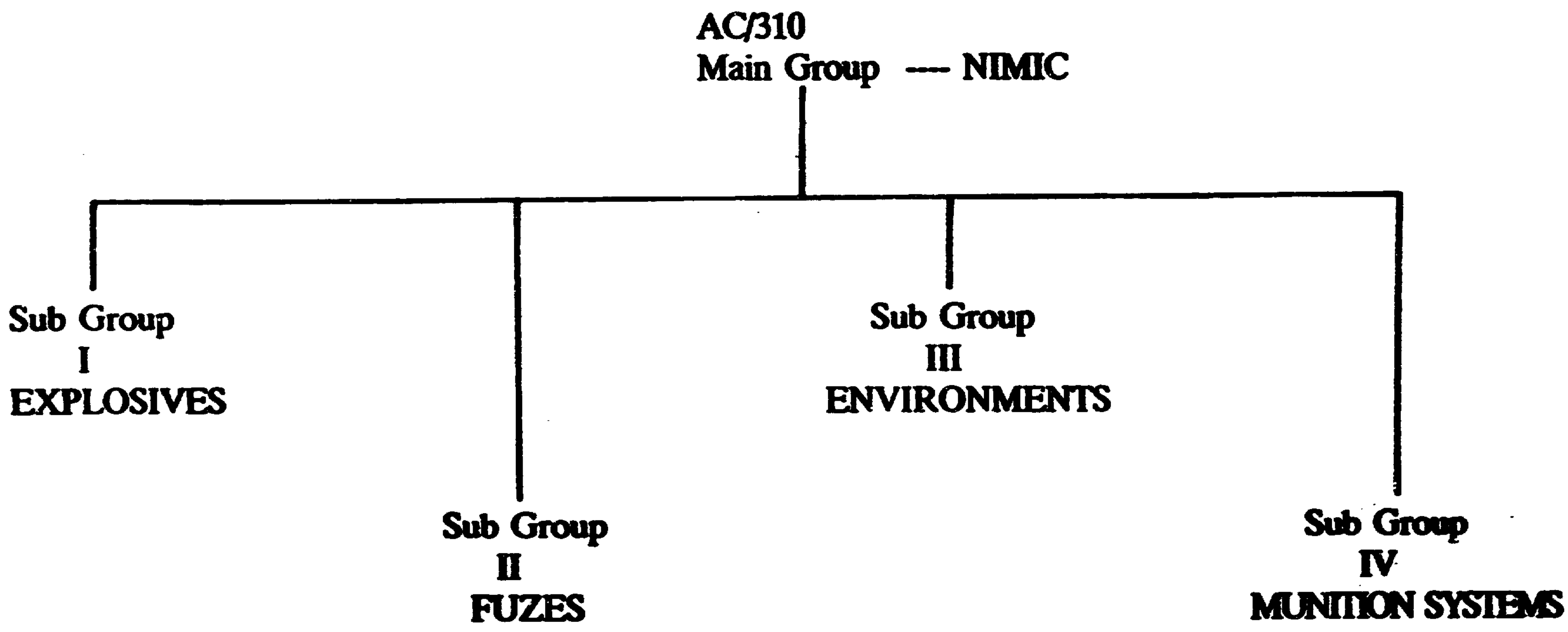
AC/310
Main Group --- NIMIC
Sub Group
I
EXPLOSIVES
Sub Group
II
FUZES
Sub Group
III
ENVIRONMENTS
Sub Group
IV
MUNITION SYSTEMS

4

AC/310

- Improved Interoperability
- Safety & Suitability for Service
- Insensitive Munitions/Safety Related
- Requirements in STANAG's, AOP's
- Sponsored Pilot NIMIC

HISTORY

1983-84	Restricted Editorial Working Group
July 85	AC/310 Decision (Information Exchange Working Group)
October 86	Workshop
October 86	Information Center Working Group
April 88	MOU for Pilot NIMIC Operation in U.S.
April 88	Steering Committee
October 90	MOU for NIMIC
April 91	Operation in NATO HQ, Brussels

PILOT NIMIC

- Participating Nations - Canada, France, Netherlands, Norway, U.K., U.S.
- Host Nation - U.S.
  - Staff - Program Manager
    Information Technician
    Information Specialist
    Secretary
  - Facilities - Space, Supplies, Etc.
- Other Participants - Technical Experts (4)
- Steering Committee - Member from each Participant

Assigned Tasks (Pilot NIMIC):

1 - Collect, store and disseminate scientific and technical information on insensitive munitions (IM)

2 - Provide and maintain a comprehensive data collection so as to facilitate design efforts for IM and minimize the cost of research and development efforts

3 - Respond to technical enquiries by using the data collection to analyze and generate recommended design approaches/solutions for IM

4 - Identify technology deficiencies that prevent requirements from being achieved and make proposals for remedial action

5 - Analyze data provided to the pilot NIMIC and prepare data books and "state of the art" reports on IM

6 - Prepare plans and documentation for:

a) the establishment of a permanent NIMIC at NATO HQ
b) the transition of the Pilot NIMIC to NIMIC

AREAS OF CONCERN

- **Combat Threats** -
  - Fragment Impact
  - Bullet Impact
  - Sympathetic Detonation
  - Fire
  - Etc.
- **Explosives and Munitions** -
  - Rockets
  - Missiles
  - Bombs
  - Fuzes
  - Propellants
  - Etc.
- **Technical Areas** -
  - Ignition
  - Thermal Explosions
  - Detonation to Deflagration Transition (DDT)
  - Mitigation Devices
  - Etc.

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NATO AC/310
IEWP MEETING (9/85)

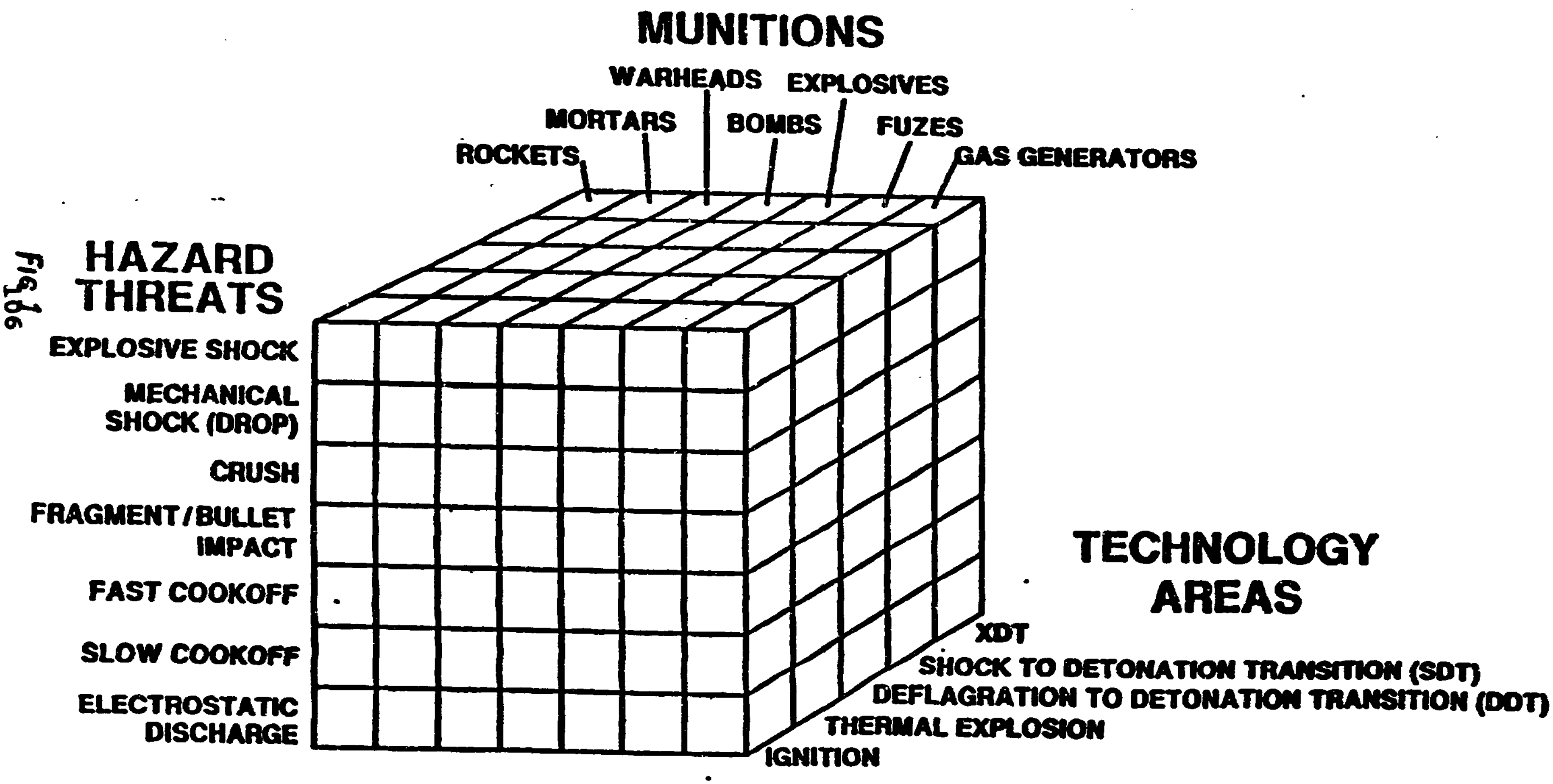

Fig 1
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DEFINITION

Insensitive Munitions are those munitions which reliably fulfill their performance, readiness and operational requirements on demand, but which will minimize the violence of a reaction and subsequent collateral damage when subjected to unplanned stimuli.

TECHNOLOGY TERMS - MAIN AREAS OF INTEREST

BULLET IMPACT
BULLET IMPACT
BURNING
COOK OFF
DEFLAGRATION
DETONATION
DETONATIONS
DROP TESTS
ELECTROMAGNETIC RADIATION
ELECTROSTATIC CHARGE
ELECTROSTATIC FIELDS
ENERGETIC MATERIALS
EXPLOSIONS
FIRE SAFETY
FIRE HAZARDS
FIRE PROTECTION
FRAGMENT ATTACK
FRAGMENT IMPACT
FUEL FIRE
HAZARDS
IMPACT SHOCK
IMPACT SENSITIVITY
IMPACT TESTS
INSENSITIVE
LIQUID FUEL FIRE
LOVA (PROPELLANTS)
LOVUM (ROCKET MOTORS)
LOW VULNERABILITY
MULTIPLE FA
MULTIPLE BI
MULTIPLE BA
MULTIPLE FI
RATTAM (RESPONSE TO ATTACK OF AMMUNITION)
SAFETY
SENSITIVENESS
SENSITIVITY
SHOCK TESTS
SPALLATION
STORAGE MAGAZINES
SYMPATHETIC DETONATIONS
TRIPLE BASE (PROPELLANTS)

HIERARCHICAL LISTING OF HARDWARE TERM COVERAGE:

AMMUNITION COMPONENTS
. . Ammunition fragments
. . Bursting charges
. . Cartridge cases
. . . Combustible cartridge cases
. . Depth charge components
. . Explosive trains
. . . Boosters(explosives)
. . . . Mine boosters
. . . Delay elements (explosive)
. . . Explosives initiators
. . . . Detonators
. . . . . Electric detonators
. . . . Primers
. . . . . Electric primers
. . Firing mechanisms(ammunition)
. . . Arming devices
. . . Fuzes(ordnance)
. . . . Bomb fuzes
. . . . . Tail fuzes
. . . . Electric fuzes(ordnance)
. . . . Electromagnetic fuzes
. . . . . Infrared fuzes
. . . . . Optical fuzes
. . . . Exploders
. . . . . Torpedo exploders
. . . . Fuze functioning elements
. . . . . Arming devices
. . . . . Clock delay mechanisms
. . . . . Fuze setters
. . . . . Primer cups
. . . . Grenade fuzes
. . . . Guided missile fuzes
. . . . Impact fuzes
. . . . . Base detonating fuzes
. . . . . Point detonating fuzes
. . . . Mechanical fuzes
. . . . Mine fuzes
. . . . Miniature fuzes
. . . . Mortar fuzes
. . . . Nose fuzes
. . . . Point detonating fuzes
. . . . Point initiating fuzes
. . . . Projectile fuzes
. . . . Proximity fuzes
. . . . . Electrostatic fuzes
. . . . . Hydrostatic fuzes
. . . . . Magnetic fuzes
. . . . . Radio proximity fuzes
. . . . Rocket fuzes
. . . . Self destroying fuzes
. . . . Superquick fuzes
. . . . Time delay fuzes
. . . . Time fuzes
. . Powder bags
. . Projectile caps
. . Projectile cases
. . Rotating bands

AMMUNITION
. . Aircraft ammunition
. . Ammunition cases
. . Antiaircraft ammunition
. . Antiarmor ammunition
. . . Antitank ammunition
. . . Armor piercing ammunit.
. . Antimateriel ammunition
. . Antipersonnel ammunition
. . . Antipersonnel mines
. . . Canister projectiles
. . Antiship ammunition
. . . Antiship missiles
. . . Antisubmarine ammunit.
. . . . Antisubmarine missiles
. . . . Depth bombs
. . . . Depth charges
. . . Torpedoes
. . . . Acoustic torpedoes
. . . . Aircraft torpedoes
. . . . Antitorpedo torpedoes
. . . . Homing torpedoes
. . . . Quiet torpedoes
. . . . Torpedo components
. . . . . Torpedo exploders
. . . . . Torpedo motors
. . . . . Torpedo propellants
. . . . . Torpedo turbines
. . . . . Torpedo warheads
. . Artillery ammunition
. . Cartridges
. . . Cartridges(pad)
. . . Photoflash cartridges
. . Caseless ammunition

INFORMATION SOURCES

NTIS (U.S.) - National Technical Information Service

DTIC (U.S.) - Defense Technical Information Center

World Patent Index (U.S.)

DRIC (U.K.) - Defence Research Information Center

HSELine (U.K.) - Health and Safety Executive

DSIS (Canada) - Defence Scientific Information Service

CEDOCAR (France)

National Organizations/Laboratories/Industry

Major Data Bases

IMDB (I.M. Data Base)	=	Name given to function that allows simultaneous searching of NIDB, BRDB, FRDB, PTDB and JADB (see below). Soon to include database of Grey Literature.
NIDB (NIMIC Informational Data Base)	=	The main database which contains the bibliographies of technical reports concerning insensitive munitions, safety, testing, etc.. All documents reference have corresponding hard copy in our files.
STANAG (Standardization Agreements)	=	AC/310 Document Status INformation System. to date, 40 AC/310 STANAGS have been collected from various sources.
IMPOC (I.M. Points of Contact)	=	An address, telephone, fax and area of expertise listing of International experts (points of contact) & newsletter recipients.
PTDB (Patents Data Base)	=	Data base of IM relevant patents found by French Representative.
JADB (Journal Articles Data Base)	=	Data base of Journal Articles received as a consequence of searches made in Chemical Abstracts, etc.

Subject Matter in Pilot NIMIC

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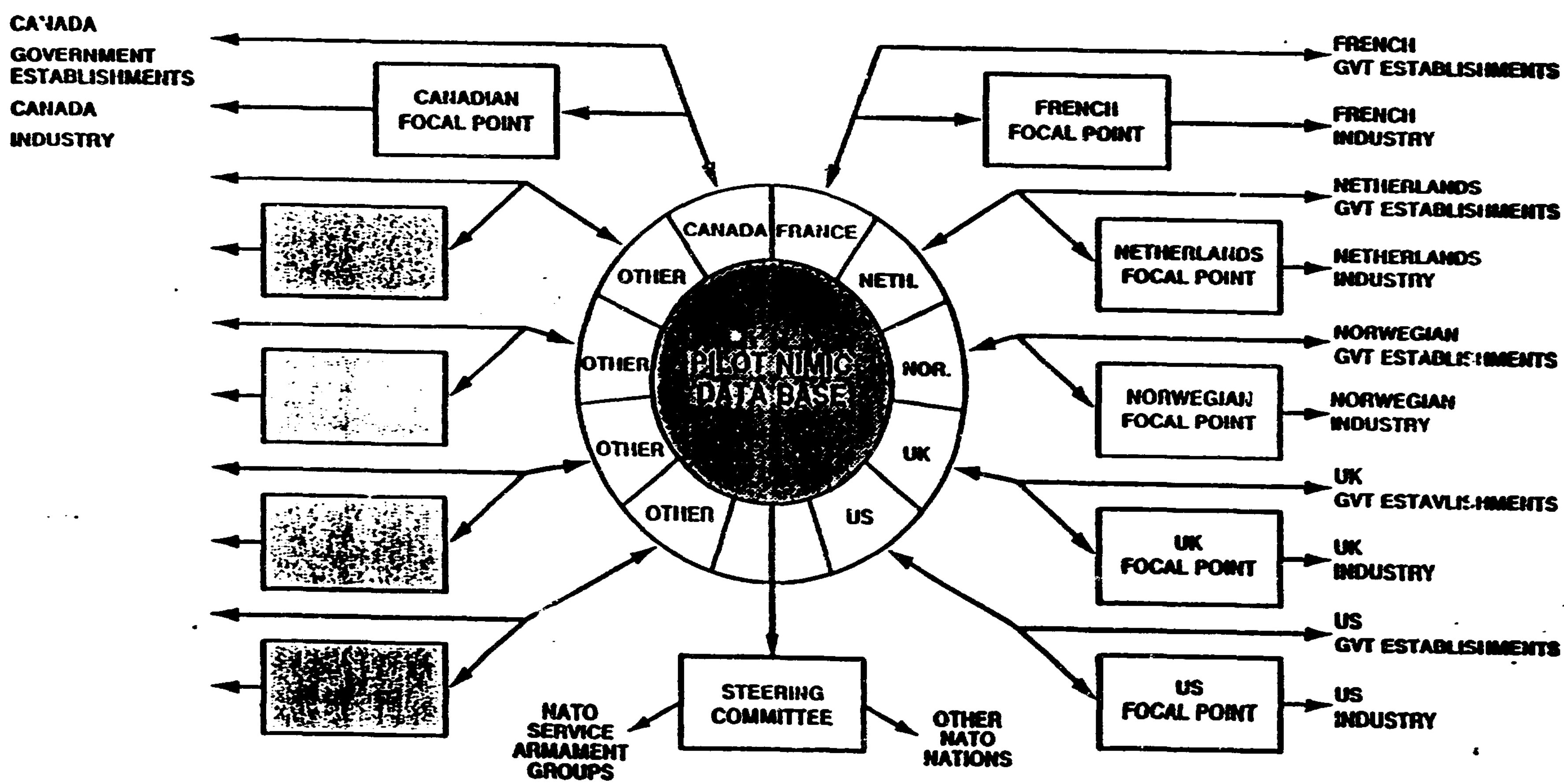
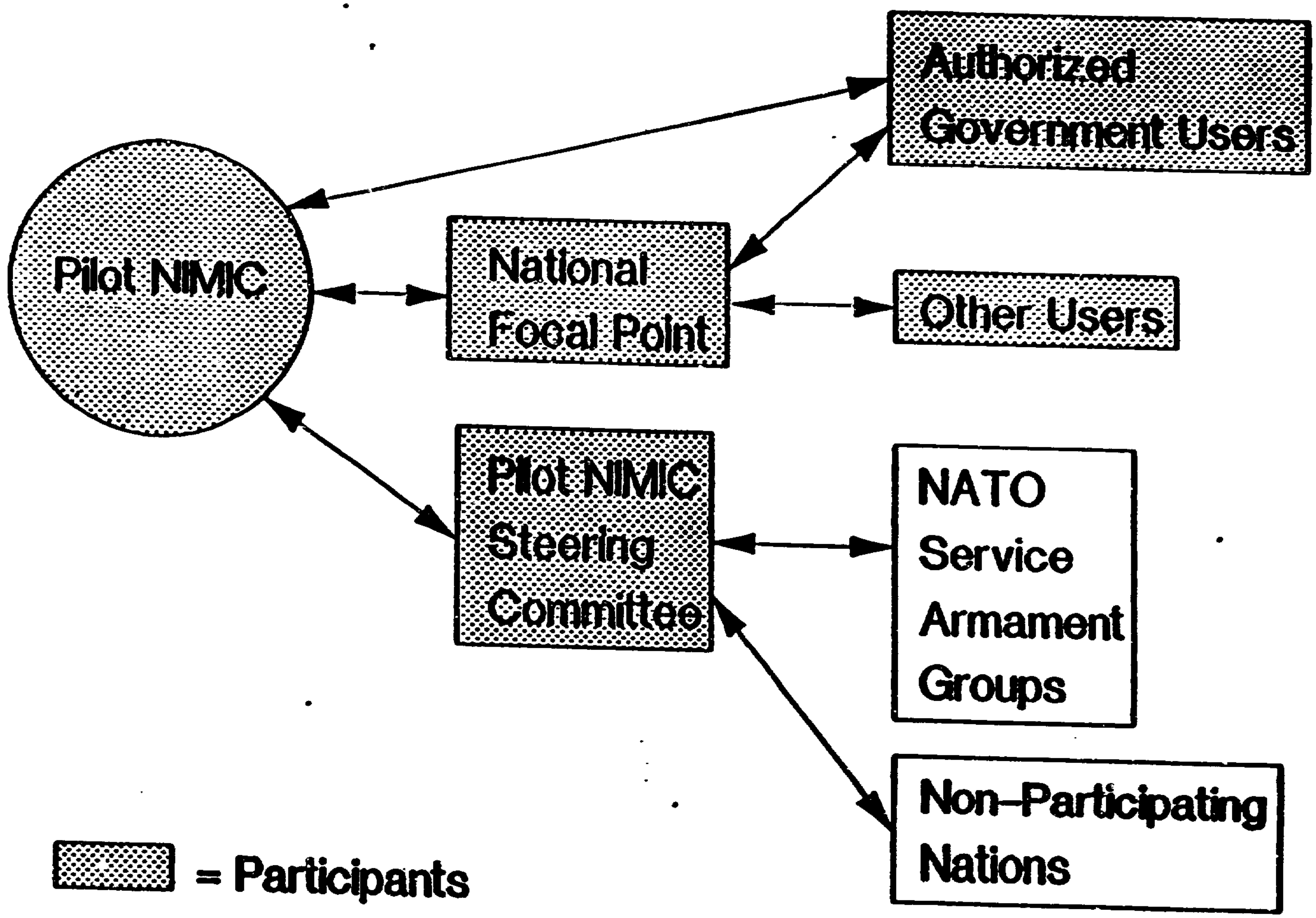
Cost-Benefit Analysis	14

Pilot Nato Insensitive Munitions Information Center

PILOT NIMIC



Using the Center



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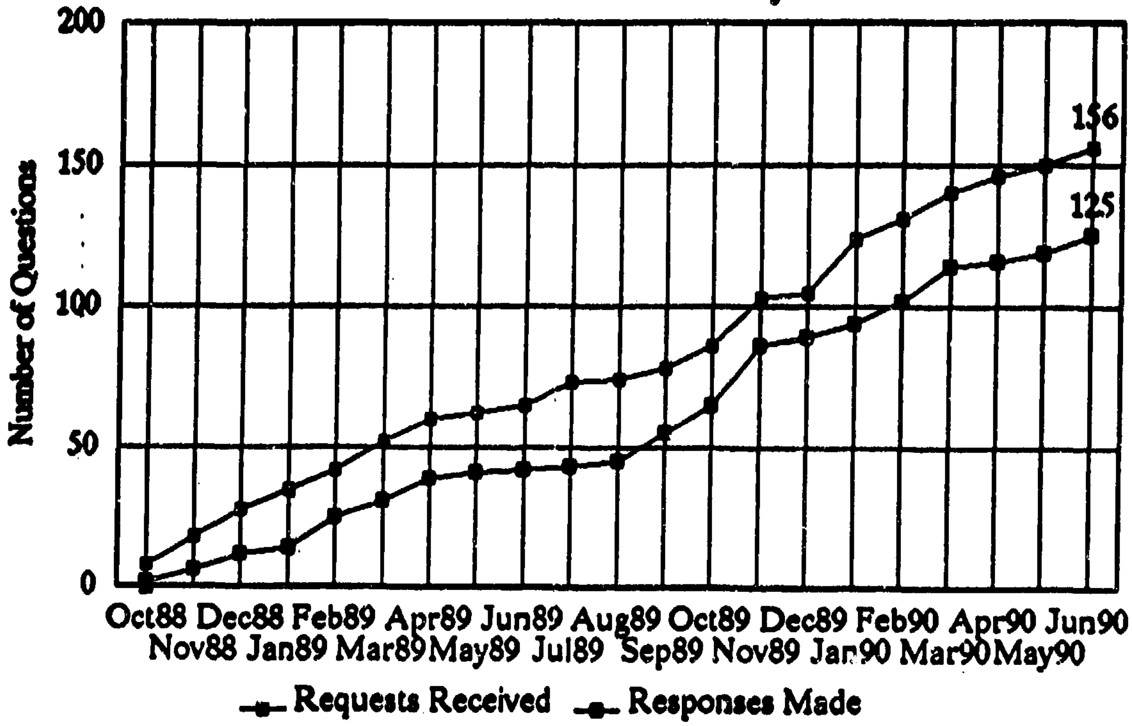
Pilot NIMIC Requests and Responses

Accumulative Summary



Identification of Deficiencies

- DEFICIENCIES IN TECHNOLOGY
- DEFICIENCIES IN DATA BASE

State-of-the-Art Reports

- Norwegian Multipurpose Ammunition
- Methodology for I.M. Cost/Benefit Analysis
- LOVA Propellants
- Thermal Stress as Related to Munitions

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SYNOPSIS
(Assessment Report)

Cumulative international experience arising out of major accidents in which munitions were involved has demonstrated the need to design weapons that are inherently less vulnerable to accidental or combat action stimuli. Weapons that meet specific criteria for reduced vulnerability are known as "insensitive munitions." As design technology for insensitive munitions evolves, it is desirable that it does so to the benefit of all the NATO community.

To meet the need of making information available to munitions designers, the concept of a NATO Insensitive Munitions Information Center (NIMIC) was conceived. The NIMIC concept provides a forum for technology information exchange that is intended to facilitate the efforts of munitions designers to satisfy the reduced vulnerability or "insensitive munitions"requirements.

In May 1988, a pilot NIMIC was established with the object of determining whether the NIMIC concept is viable. This report provides the evidence on which is based the conclusion that implementation of the NIMIC concept is capable of achieving the desired objective.

FUTURE

NIMIC	- 1 May 1991	
Facilities	- At NATO Headquarters Building, Brussels, Belgium	
Funding	- By participating nations on a share basis	
Staff	- NATO Employees	
	Program Manager	A-5
	Information Technician	A-3
	Information Specialist	B-6
	Secretary	B-3
	(4) Technical Specialists	A-4
Administrative Support	- NATO International Staff	

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INSENSITIVE MUNITIONS TECHNICAL REQUIREMENTS

Dr. Richard E. Bowen
Director
Insensitive Munitions Office
Naval Sea Systems Command
Washington, D.C.
August, 1990

FOREWORD

The views expressed herein represent the Joint Service Requirements for Insensitive Munitions. These requirements will be applicable to all Departments and Agencies of the Department of Defense.

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ABSTRACT

The Navy's efforts to make munitions insensitive to unplanned stimuli is known throughout the ordnance community and coordinated with other services through the Joint Ordnance Commanders Group (JOCG) and with industry and NATO allies.

Standardization test procedures, data requirements, and assessment methods are called out in MIL-STD-2105A (Navy), Draft, dated 19 June 1990, "Hazard Assessment Tests for Non-Nuclear Munitions". This revised document incorporated the U.S. Military Service comments only. This is one milestone that has near and long term impact on weapon and ship design, and safety/vulnerability testing.

INTRODUCTION

The revised MIL-STD-2105A (Navy), Draft, dated 19 June 1990 provides the basic mandatory tests and test requirements to be conducted for the assessment of safety and insensitive munitions characteristics for all non-nuclear munitions, munition subsystems and explosive devices and passing criteria. The tests called out in this document are to characterize the munitions and provide the WSESRB information with which to make a decision. This draft document, applies to all non-nuclear munitions (i.e., all-up missiles, rocket, pyrotechnics), munitions subsystems (e.g., warheads, fuzes, propulsion units, safe and arm devices, pyrotechnic devices, chemical payloads), and other explosive devices. Nuclear systems will be excluded.

MIL-STD-2105A (Navy) lists the passing criteria for all the basic tests. Results will be reviewed by the appropriate service review organization for compliance with safety, operational and insensitive munitions requirements. The lead service will have the responsibility for implementing these requirements.

DEFINITIONS

Explosive. An explosive is a solid or liquid substance (or a mixture of substances) which is in itself capable, by chemical reaction of producing gas at such temperature, pressure and speed, of causing damage to the surroundings. Included are pyrotechnic substances even when they do not evolve gases. The term explosive includes all solid and liquid materials variously known as high explosives, propellants, together with igniter, primer, initiation and pyrotechnic (e.g., illuminant, smoke, delay, decoy flare and incendiary) compositions.

All-up-round (AUR). Refers to the completely assembled munition as intended for delivery to a target or configured to accomplish its intended mission. This term is identical to the term all-up-weapon.

Exudation. A discharge or seepage of material. The material may be either a component of a chemical payload or a component of an explosive/propellant payload.

Detonation Reaction (Type I). The most violent type of explosive event. A supersonic decomposition reaction propagates through the energetic material to produce an intense shock in the surrounding medium (e.g., air or water) and very rapid plastic deformation of metallic cases, followed by extensive fragmentation. All energetic material will be consumed. The effects will include large ground craters for munitions on or close to the ground, holing/plastic flow damage/fragmentation of adjacent metal plates, and blast overpressure damage to nearby structures.

Partial Detonation Reaction (Type II). The second most violent type of explosive event. Some, but not all of the energetic material reacts as in a detonation. An intense shock is formed; some of the case is broken into small fragments; a ground crater can be produced, adjacent metal plates can be damaged as in a detonation, and there will be blast overpressure damage to nearby structures. A partial detonation can also produce large case fragments as in a violent pressure rupture (brittle fracture). The amount of damage, relative to a full detonation, depends on the portion of material that detonates.

Explosion Reaction (Type III). The third most violent type of explosive event. Ignition and rapid burning of the confined energetic material builds up high local pressures leading to violent pressure rupturing of the confining structure. Metal cases are fragmented (brittle fracture) into large pieces that are often thrown long distances.

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Unreacted and/or burning energetic material is also thrown about. Fire and smoke hazards will exist. Air shocks are produced that can cause damage to nearby structures. The blast and high velocity fragments can cause minor ground craters and damage (break-up, tearing, gouging) to adjacent metal plates. Blast pressures are lower than that of a detonation reaction.

Deflagration Reaction (Type IV). The fourth most violent type of explosive event. Ignition and burning of the confined energetic materials leads to nonviolent pressure release as a result of a low strength case or venting through case closures (leading port/fuze walls, etc.). The case might rupture but does not fragment; closure covers might be expelled, and unburned or burning energetic material might be thrown about and spread the fire. Pressure venting can propel an unsecured test item, causing an additional hazard. No blast or significant fragmentation damage to the surroundings; only heat and smoke damage from the burning energetic material.

Burning (Type V). The least violent type of explosive event. The energetic material ignites and burns, non-propulsively. The case may open, melt or weaken sufficiently to rupture nonviolently, allowing mild release of combustion gases. Debris stays mainly within the area of the fire. This debris is not expected to cause fatal wounds to personnel or be a hazardous fragment beyond 50 feet.

Propulsion (Type VI). A reaction whereby adequate force is produced to impart flight to the test item in its least restrained configuration as determined by the life cycle analysis.

Service review organization. The organization within the DOA, DOAF or DON which assess the explosives safety and IM characteristics of weapon systems and makes recommendations to the appropriate approval authority.

Weapon Systems Explosive Safety Review Board (WSESRB). A board chartered by the Chief of Naval Operations to assess the explosives safety of weapon systems. The Board is chaired by the Naval Sea Systems Command and its membership is drawn from all the Naval Systems Command.

Weapon system. A munition and those components required for its operation and support.

Munition. An assembled ordnance item that contains explosive material(s) and is configured to accomplish its intended mission.

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Munition subsystem. An element of an explosive system that contains explosive material(s) and that, in itself, may constitute a system.

Explosive device. An item that contains explosive material(s) and is configured to provide quantities of gas, heat, or light by a rapid chemical reaction initiated by an energy source usually electrical or mechanical in nature.

Hazardous fragment. For personnel, a hazardous fragment is a piece of the reacting weapon, weapons systems or container having an impact energy of 58 ft-lb (79 joules) or greater.

Sympathetic detonation. The detonation of munition or an explosive charge induced by the detonation of another like munition or explosive charge.

Bare round or configuration. A munition with no external protection or shielding from the environment such as container, barrier or shield.

Threat hazard assessment. An evaluation of the munition life cycle environmental profile to determine the threats and hazards to which the munition may be exposed. The assessment includes threats posed by friendly munitions, enemy munitions, accidents, handling, etc. The assessment shall be based on analytical or empirical data to the extent possible.

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GENERAL REQUIREMENTS

The program manager shall be responsible for planning and executing a hazard assessment test program which includes a master test plan based on a realistic life cycle environmental profile. The profile shall establish the environmental conditions and limits the munitions will encounter throughout the life cycle. The program manager shall ensure that the conducted test program uses the minimum of test units required in MIL-STD-2105A (Navy), Figure 1, to complete the basic tests. Safety design goals for the test plan shall be established by the program manager and approved by the service review organization.

Program managers and munition developers shall be aware that additional testing may be required to assess the tactical and logistical vulnerability of the given weapon system against the probable threats to which the system may be subjected. The program manager shall generate and submit a detailed test report to the WSESRB, consistent with the master test plan. The test report shall include rationale for deviations from the test plan, the test item configuration and identification, test date, test results, and safety and vulnerability related conclusions.

The conditions that simulate or duplicate the hazards of credible normal, abnormal, and combat situation(s) identified by the threat assessment shall determine the safety and sensitivity characteristics of the test item. The test parameters shall be selected to reflect maximum stress levels forecast. Unless otherwise specified, all items shall be tested at 77 $\pm$ 18°F.

The test item shall either be production hardware, or equivalent. The test plan shall indicate if the item is different from production hardware.

Test equipment/fixtures shall not interfere with the test stimulus imposed on the test item. The test item configuration shall be the same as the configuration of the item in the life cycle phase being duplicated by the test, and be specified in detail in the test plan and approved by the WSESRB.

Prior to testing, the test item shall be inspected visually and radiographically to assure no existence of unusual conditions. All unit safety mechanisms and devices shall be set or otherwise adjusted to a safe condition. Photographs of the test setup including identification information in the field of view shall be taken.

The test item shall be inspected visually and radiographically after the test is complete to determine its structural integrity and to compare with the pre-test examination results. The following are requirements to be documented whenever the test item is destroyed: a complete description of significant post-test remains of the munition (Figure 2), Post-Test Remains Map (Figure 3) including the distance from the original test positions, dimensions and weight of each recovered part, and Post-Test Remains Tabulation(Figure 4).

DETAILED REQUIREMENTS

The basic safety tests consist of: 28-Day Temperature and Humidity (T&H); Vibration; 4-Day T&H; 40-Foot Drop; Fast Cook-off; Slow Cook-off; Bullet Impact; Fragment Impact; Sympathetic Detonation; Shaped Charge Jet Impact and Spall Impact. Results of each test shall be documented on the appropriate data sheet. The following is a brief description of these tests.

28-Day T&H Test

The test item is exposed to alternating, no less than 24-hour, periods of high and low temperatures at fixed relative humidity levels specified in the environmental profile for 28 days. The test procedures shall reflect the temperature and humidity conditions measured or forecast. Each test item shall be visually examined prior to testing and record the appropriate critical dimensions to determine the material condition. A minimum of three units shall be tested. The passing criteria listed below are based on the final observation:

1. No reaction of the explosive.
2. No exudation of the explosive.
3. Rocket motor propellant and pyrotechnic candles shall not crack or separate from case lining in a manner which would create a hazardous condition in handling or use.
4. All safety devices shall remain in the safe position.
5. The structural integrity of the item shall not be compromised by corrosion, loosening of joints or other physical distortions.

Vibration Test

The test item is exposed to the most severe vibration environment that it normally encounters during the logistic cycle. The test shall be conducted at low and elevated temperatures along the appropriate mutually perpendicular axes, and may consist of one or a combination of the following: random vibration, vibration cycling and resonant dwell. The vibration schedule shall be selected from the environmental profile. Test procedures shall reflect vibration modes and temperatures anticipated in the item's environment. A minimum of three items which have undergone and passed the 28-day T&H test shall be tested. The passing criteria are the same as those listed under the 28-day T&H test.

4-Day T&H Test

This test is a version of the 28-day T&H test. All data relative to the 28-day T&H test are required for the 4-day T&H test. A minimum of three items which have undergone and passed the 28-day T&H and Vibration tests shall be tested. The passing criteria are the same as those listed under the 28-day T&H test.

40-Foot Drop Test

This field test is designed to evaluate the safety response of the test item to the stress loads associated with a free-fall impact onto a striking plate in various attitudes.

The test item is dropped from the lowest point of the item to the point of impact of 40 feet, complying with following orientations:

a. Longitudinal axis horizontal

b. Longitudinal axis vertical (aft-end down)

c. Longitudinal axis vertical (forward-end down)

The test consists of free-fall drops of the environmentally pre-conditioned items (Figure 1) in the configuration of the item in the life cycle phase being duplicated by the test (one drop per item) onto the striking plate. The passing criteria include the following:

1. No reaction of the explosives in the item

2. No rupture of the item resulting in exposed explosives

3. The item shall be safe to handle and be disposed of by normal EOD procedures.

Fast Cook-Off Test

The test item is engulfed in the flame envelope of a liquid fuel fire and the reaction is recorded as a function of time. The item shall be tested in the configuration in the logistic phase being duplicated by the test. Items configured with rocket motors shall be restrained to avoid launching due to a propulsive reaction. The restraining and suspension method shall not interfere with the heating of the item. The test item shall be positioned so that its horizontal center line is 36 inches above the surface of the fuel or in the attitude most probable in the weapons life cycle environment. The test item shall not fall into and being quenched by the fuel. Four thermocouples with time constants of 2 seconds or less shall be located 4 to 8 inches outside the ordnance skin for each item tested. The thermocouples shall be positioned on each end and side of the ordnance skin in a horizontal plane through the center line. A minimum of two tests shall be conducted. The test item shall have no reaction more severe than burning.

Slow Cook-Off Test

This test determines the reaction temperature and measures the overall response of major munition subsystems to a gradually increasing thermal environment at a rate of 6°F per hour until a reaction occurs. The test item is placed in an oven of materials, wall thickness, etc., designed to minimize the confinement of the test item reaction. A minimum of eight inches separation between all outer surfaces of the test item and the inner walls of the oven is required. Figure 5 displays the test configuration. A minimum of two tests shall be conducted. Temperature recording device shall be utilized to record temperatures. Steel witness plates shall be positioned beneath the test item to provide evidence of the item reaction. No reaction more severe than burning shall occur.

Bullet Impact Test

This test is conducted to determine the reaction of the test item when impacted by at least three 0.50 caliber type M2 armor-piercing (AP) bullets at 2800 ± 200 ft/sec. Figure 6 displays the test configuration. The firing interval shall be 50 ± 10 milliseconds (ms). A minimum of two test items shall be tested. In the first test item the bullets impact the largest quantity of explosives. The bullets impact the most sensitive location in the second test item. The airblast overpressure of the test item is measured and steel witness plates are positioned beneath the test item to provide evidence of the test item reaction. No reaction more severe than burning shall occur.

Fragment Impact Test

This test determines the response of the test item to the impact of one-half inch, 250 grain, mild-steel cubes traveling at 8300 ± 300 ft/sec with an impact of at least two but no more than five fragments upon the test item. Figure 7 presents the sample test configuration. A minimum of two items shall be tested with fragments impacting the largest quantity of explosives in one test item and fragments impacting the most shock-sensitive area of the other test item. Steel witness plates positioned beneath the test item shall be used to provide evidence of the test item reaction. The test shall have no reaction more severe than burning.

Sympathetic Detonation

This test evaluates the likelihood a detonation reaction may be propagated from one unit to another within a group or stack of munitions. Generally, one munition (donor) is adjacent to one or more like munitions (acceptors). The test setup should replicate the packaging conditions and stowage arrangement for the logistics life cycle phase deemed to pose the greatest threat of sympathetic detonation. The test setup shall incorporate one or more acceptors positioned (relative to the donor) at location(s) deemed most vulnerable to sympathetic detonation. Where appropriate, the test setup shall also incorporate simulated (or dummy) units to provide additional confinement of the donor and the acceptor(s) as illustrated in Figure 8. The donor may be initiated using an external stimulus that simulates initiation by the threat stimuli most likely to cause detonation of the test item as determined by the threat hazard assessment. Alternatively, if the test item is designed to detonate when functioned, the donor may be initiated using its normal booster system or a booster charge of similar power. For items that are not designed to detonate, the donor may be initiated axisymmetrically using a booster charge of sufficient size/output to ensure sustained, stable detonation of the explosive. The donor may be modified to accommodate the required booster provided the modifications are not expected to have a significant effect on the fragmentation or blast of the item. The test design shall incorporate either high-speed motion picture cameras to record the reaction(s) of the acceptor(s), or steel witness plates beneath the test items to provide rough indications of the shock pressure within each acceptor relative to the shock pressure within the donor. Transducers shall be placed along each of two mutually perpendicular axes illustrated in Figure 9. The transducers shall be mounted flush with the ground surface or in elevated fixtures with the sensing face of each transducer parallel to the direction of flow. Baseline overpressure data shall be obtained by conducting a calibration test firing using either a single test item or an explosive charge of approximately the same yield as the donor test item. The setup for the calibration test shall be identical to the actual test setup with respect to test item mounting, transducer placement, and sensitivity and response of the measurement system. The test shall not have a detonation of any acceptor. For ordnance stored in containers, there shall be no acceptor weapon detonation in any other container.

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Shaped Charge Jet Impact Test

This test determines the reaction of the test item when impacted by the jet of a M42/M46 grenade, representative of a top attack or an 81-mm precision shaped charge (or both), representative of a hand-held HEAT attack. Figure 10 provides a schematic of a typical test configuration. The munition shall be tested in the transport/storage or operational use configurations or both, including shielding, which reflect credible threats. The 81-mm shaped charge shall be initiated in a manner that ensures proper formation of the shaped charge jet. The shaped charge shall be aimed to impact the test item so that the jet passes through the greatest possible length of energetic material. A minimum of two test items shall be used. Steel witness plates shall be placed under and on two opposite sides of the test item as witnesses to the degree of reaction. No detonation shall occur as a result of the shaped charge jet impact.

Spall Impact Test

The response of munitions to impact of hot spall fragments is determined in this test. The test setup is illustrated in Figure 11. The spall fragments are produced by impacting a 1-inch thick rolled homogeneous armor (RHA) plate with the shaped charge jet of an 81-mm precision shaped charge. The standoff distance between the shaped charge and the RHA plate shall be 5.8 inches. The placement of the test item behind the RHA plate shall be selected so that it is impacted by spall fragments only. A minimum of 4 spall fragments/10 in^2 of presented area (up to 40 fragments) shall impact the test item. The test item configuration shall be a bare munition subsystem. Closed-circuit video, real time motion picture photography shall be used to document the test events. A minimum of two test items shall be used. No sustained burning shall occur as a result of the spall impact test.

REFERENCES

Government documents. Unless otherwise specified, the following standards form a part of this document to the extent specified herein.

Military

MIL-STD-331 Fuze and Fuze Components, Environmental and Performance Tests for

MIL-STD-453 Inspection, Radiographic

MIL-STD-810 Environmental Test Methods and Engineering Guidelines

MIL-STD-1670 Environmental Criteria and Guidelines for Air-Launched Weapons

FIGURES

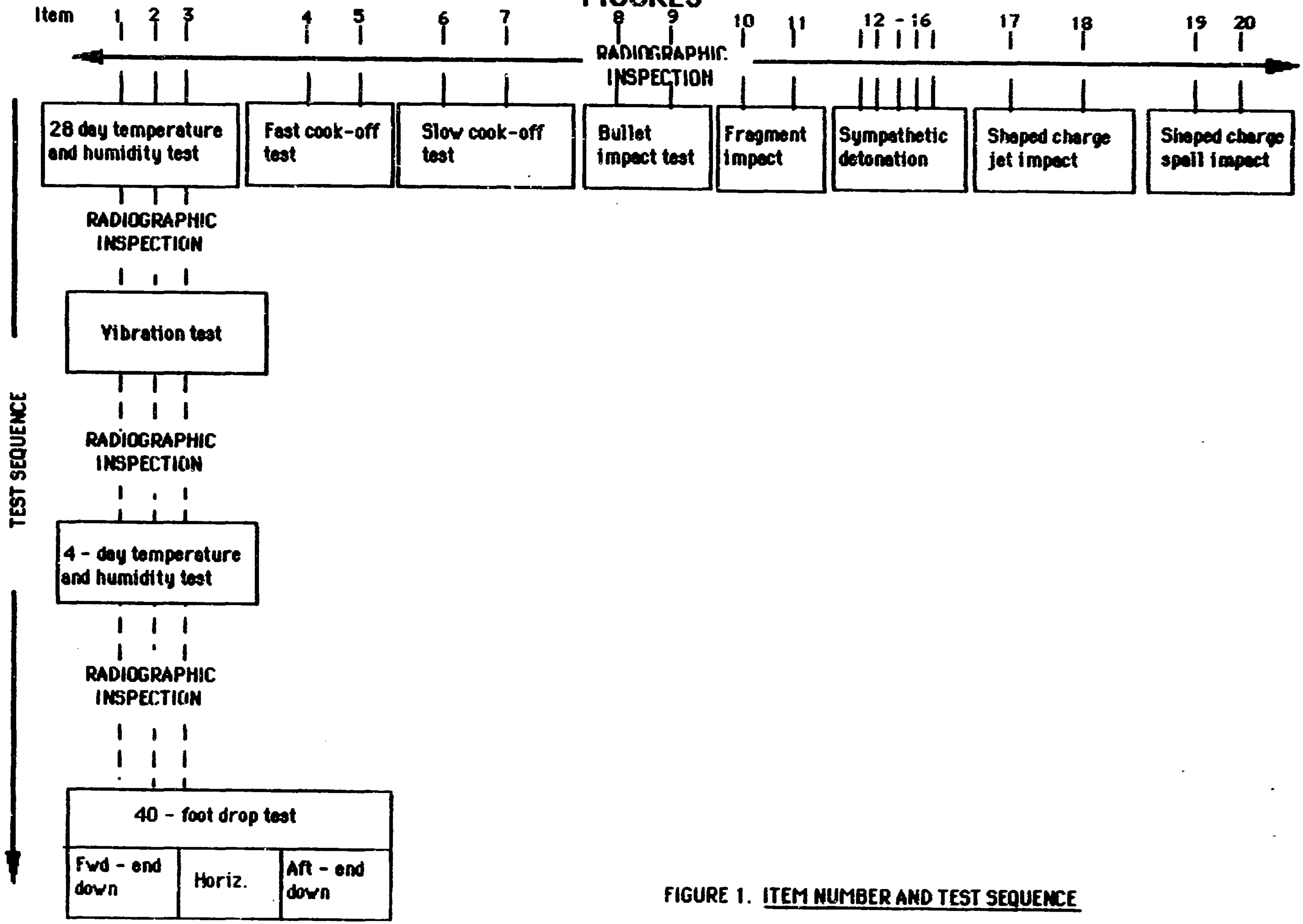


FIGURE 1. ITEM NUMBER AND TEST SEQUENCE

SAMPLE
POST-TEST REMAINS MAP
DATA SHEET

Item Tested: ____________________

Lot # __________ S/N __________

Ambient Conditions: ____________________

Test Facility: ____________________ Date: __________

Test Item Description: ____________________

Fragment Projector Description: ____________________

Test Setup (attach sketch): ____________________

____

Test Results

Narrative Description: ____________________

____

Explosive reaction level: __________

Post-Test Description

Number and location of impact fragments: __________ Impact Velocity: ____

* Airblast overpressure _____ psi at _____ ft, time to peak _____ msec

_____ psi at _____ ft, time to peak _____ msec

_____ psi at _____ ft, time to peak _____ msec

* Airblast overpressure data shall be supplied if there is an explosive reaction.

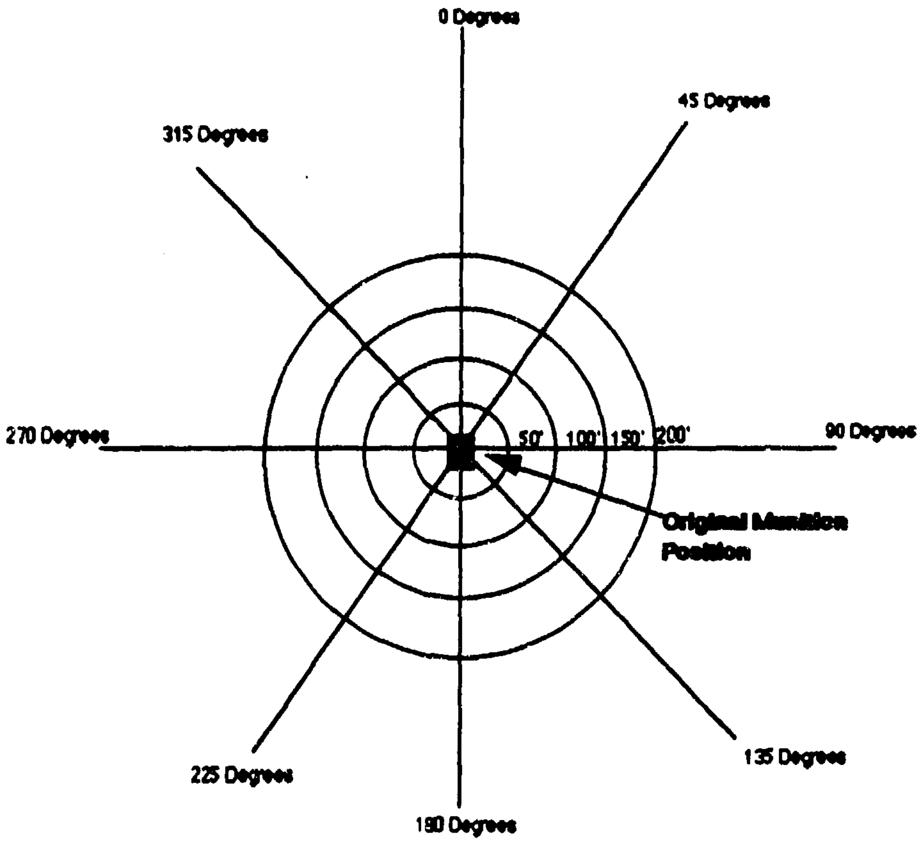
Witness Plate Description: ____________________

Test Engineer: __________

Signature: __________

FIGURE 2. Fragment impact test data sheet.

SAMPLE
POST-TEST REMAINS MAP



NOTE: Identify shotline and test item orientation.
Identify each fragment numerically (see Figure 3).

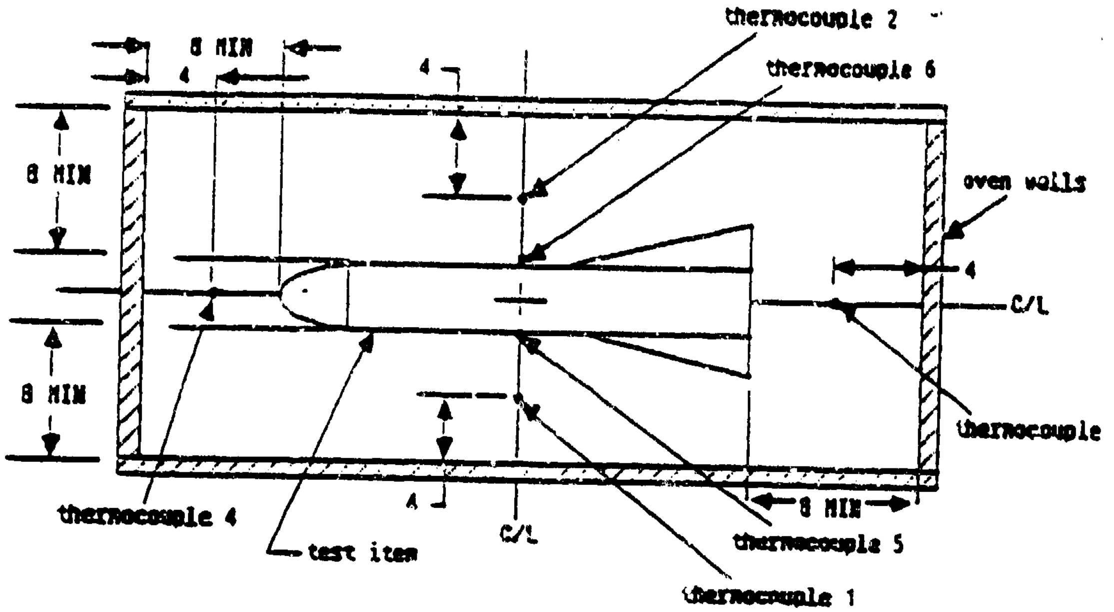
FIGURE 3. Post-test remains map.

SAMPLE

POST-TEST REMAINS TABULATION

DISTANCE	WEIGHT	ANGLE	DESCRIPTION

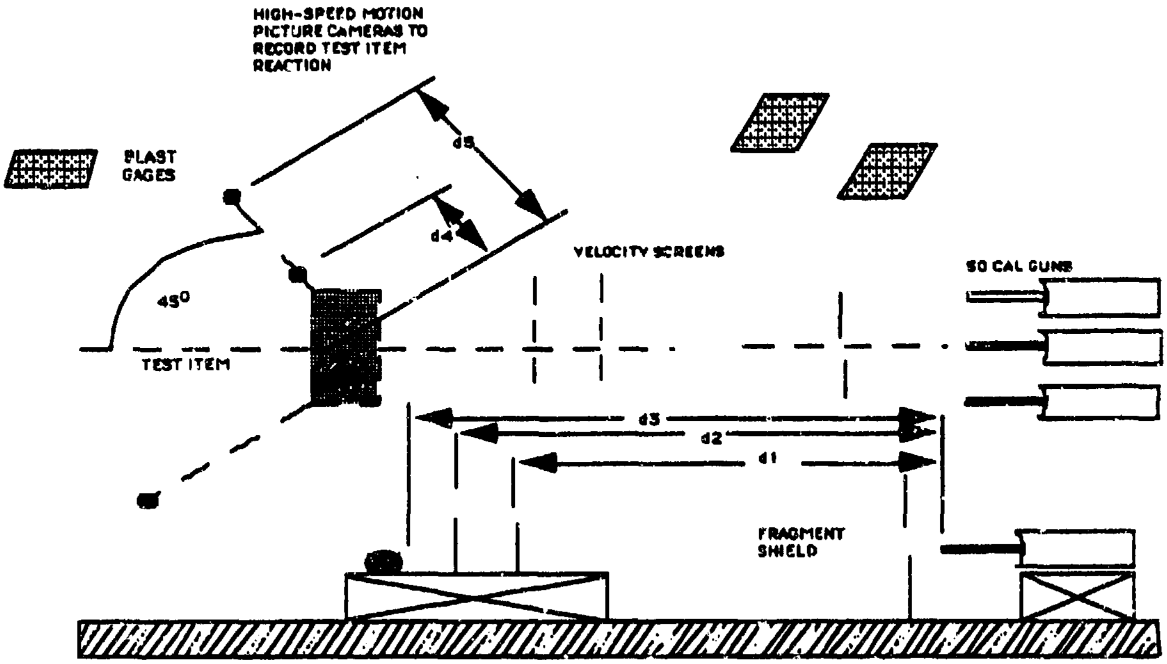
FIGURE 4. Post-test remains tabulation.



Plan View

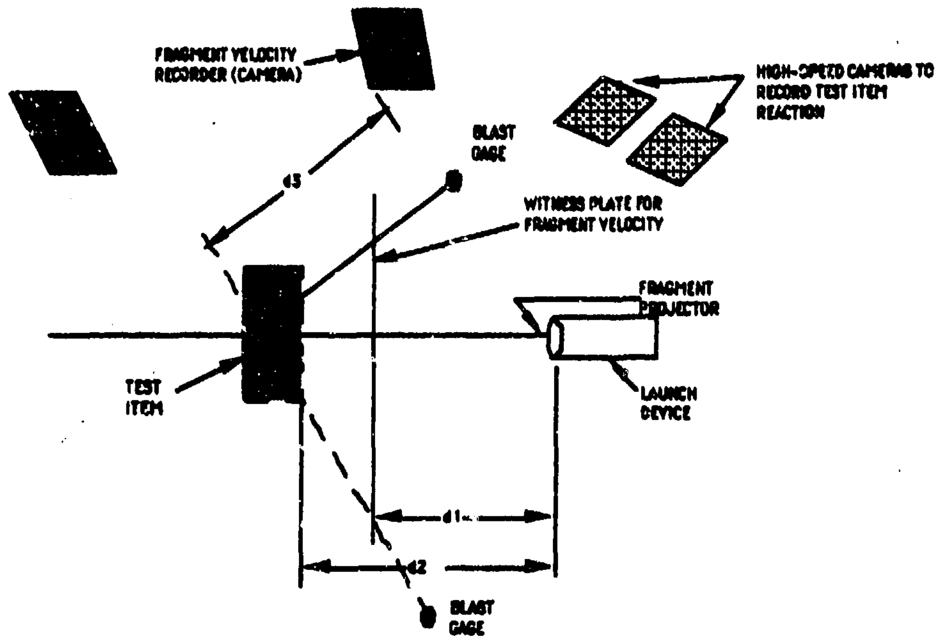
Notes: All dimensions are in inches; all measurements are taken from internal oven walls.

FIGURE 5. "Typical" slow cook-off oven with thermocouple locations.



NOTES d1 = DISTANCE TO FIRST VELOCITY SCREEN
d2 = DISTANCE TO SECOND VELOCITY SCREEN
d3 = DISTANCE TO TEST ITEM
d4 = DISTANCE TO FIRST BLAST GAGE
d5 = DISTANCE TO SECOND BLAST GAGE(S)

FIGURE 6. "Typical" bullet impact test configuration



d1 = DISTANCE FROM FRAGMENT MAT TO WITNESS PLATE
d2 = DISTANCE FROM FRAGMENT MAT TO TEST ITEM
d3 = DISTANCE FROM TEST ITEM TO BLAST GAGE(S)

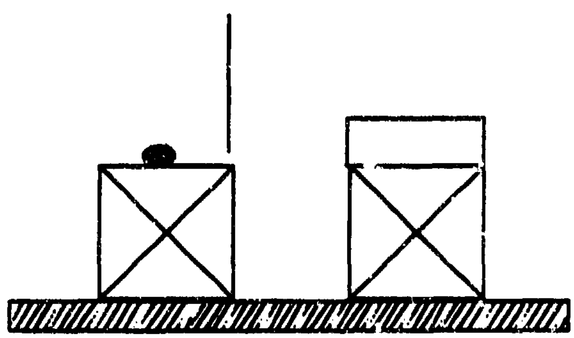
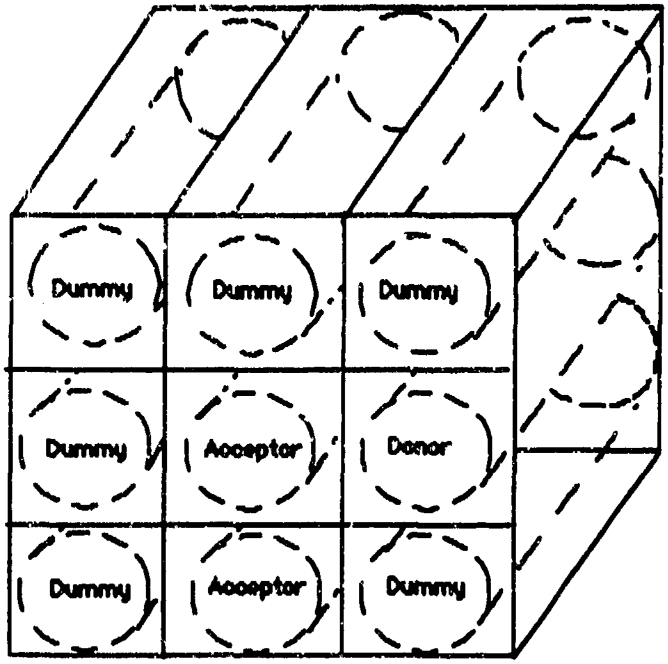
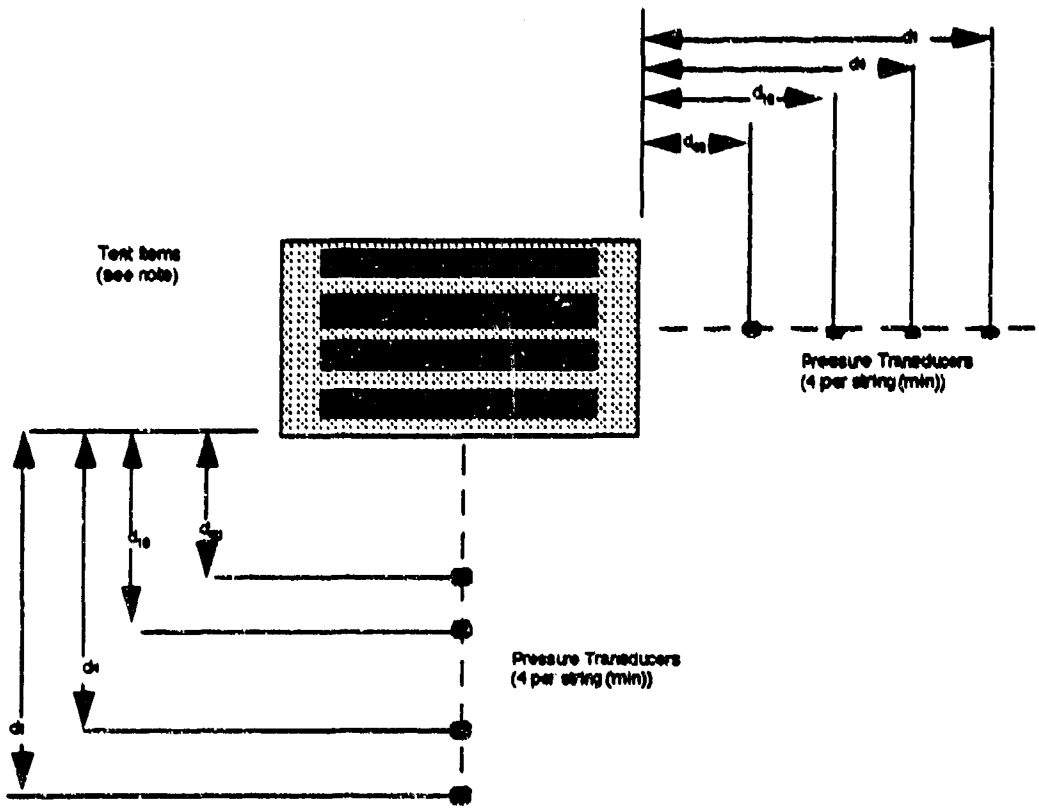


FIGURE 7. "Typical" fragment impact test setup.



NOTE: For illustrative purposes only; packaging, arrangement of test items, and number and placement of acceptors shall be determined based upon the threat hazard assessment.

FIGURE 8. Sample arrangement of test items for sympathetic detonation test.



d40 = Distance at which peak airblast overpressure is expected to be approximately 40 psig if all test items detonate.
d10 = Distance at which peak airblast overpressure is expected to be approximately 10 psig if all test items detonate.
d4 = Distance at which peak airblast over pressure is expected to be approximately 4 psig if all test items detonate.
d1 = Distance at which peak airblast over pressure is expected to be approximately 1 psig if all test items detonate.

Figure 9. Sample placement of pressure transducers for sympathetic detonation test (plan view).

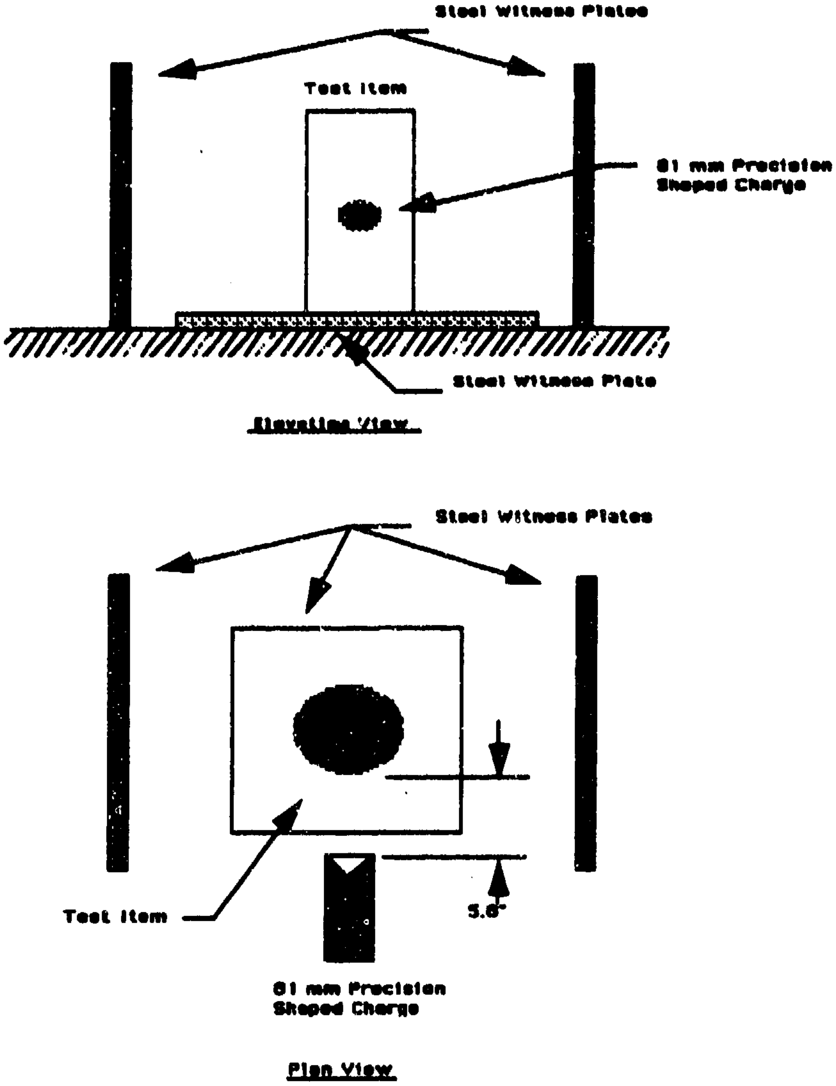


FIGURE 10. "Typical" shaped charge impact test configuration.

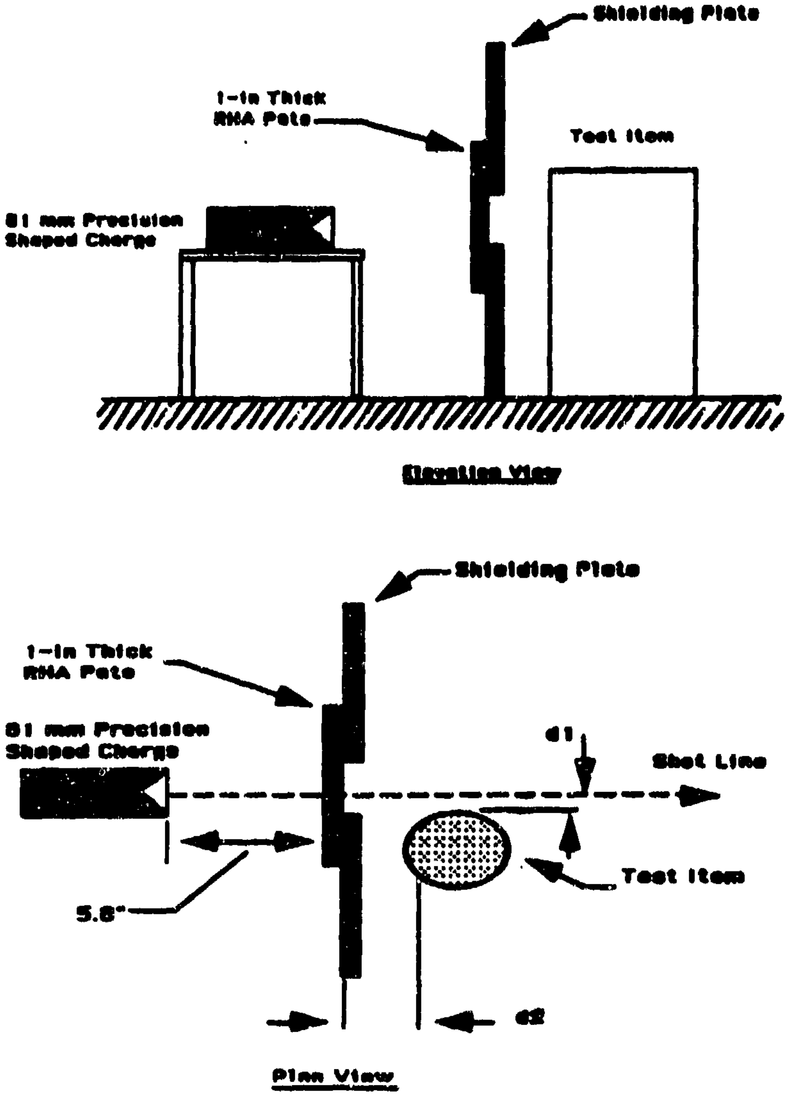


FIGURE 11. "TYPICAL" SPALL IMPACT TEST CONFIGURATION

24 th DOD EXPLOSIVES SAFETY SEMINAR

28-30 August 1990

The french way of providing the industry of insensitive missiles and munitions with appropriate high explosives and propellants

By Brigadier General (Armament Corps)
René AMIABLE
French MOD/DGA
Service Technique des Poudres et Explosifs

INTRODUCTION

In the western world, explosive safety is a permanent worry of the ammunition designers, manufacturers and users. The absence of main accidents in France for many years proves the efficiency of the regulations and /or the chosen technical solutions.

Yet, the improvement of munitions performances means an increase of their potential hazards ; besides, their directions for use evolve and the threats, particularly during crisis, increase. So, it is a prime effort to keep watchful and to study all the solutions allowing to adapt oneself to the new pyrotechnical hazards.

PYROTECHNICAL HAZARDS DUE TO AMMUNITION

All the munitions (from a general point of view : for all calibers guns, missiles, rockets, bombs, mines, torpedoes...) contain energetic materials (gun propellants, high explosives, solid rocket propellants) with pyrotechnical hazards. After an accidental or a deliberate stimulus (shock, fire, bullet...), these materials are likely to decompose or to react. This reaction means that the munition produces thermal fluxes, projections, shock waves, aerial overpressures...
This reaction may on its turn, from the first munition hit, propagate to other neighbouring munitions and lead to very huge accidents. The explosion of the Ojiri store, in Pakistan, in april 1988, which deathtoll rose to several thousands, or the Forrestal (US Navy) accident in july 1967, are two examples that can be put forward. That is the reason why the safety and the survival of combat-platforms and munitions stores are factors considered more and more important by western armies.

THE SOLUTIONS

Pyrotechnical safety is a problem that has been studied for many years and which is in France very precisely and strictly regulated (safety of workers, storage, transport...)
Some technical dispositions can fix today a satisfying safety level :

- protections by materials that decrease the energy of the first stimulus,
- dividing walls that slow or stop the propagation of the accident,
- arrangement of the munitions with each other and use regulations,
- intervening devices.

But, all these solutions apply to the external environment of the munition ; technological progress of the two last decades allow now, in order to decrease risks, to choose other solutions to be applied directly to explosive materials or the other components of the munitions.

These progresses lead in the western world to the concept of "Munitions à Risques Atténués" (MURAT in french, IM for Insensitive Munitions in american, or LOVA for Low Vulnerability Ammunitions in english) or "muratisation".

THE "MURATISATION" IN FRANCE

In France, the first studies applied to the "muratisation" have been initiated in the beginning of the 80's and leaded by the Service Technique des Poudres et Explosifs (STPE), Technical Board for solid energetic materials in the DGA (General Delegation for Armament).
The DGA is the organism in the french ministry of defense in charge with :

- the development and the acquisition of ordnance that fit the needs of the french armies.
- the good health of the french industrial armament companies (under state control, nationalized or private)
- the development of armament exports

Within DGA, the STPE is the official board in charge with the orientation and contracting of the studies of synthesis, formulation and development of energetic substances (gun and rocket propellants, high explosives) for military use. SNPE is contracted for most of these studies but several DGA research centers are in charge with the assessment phase (GERBAM and GERPY of the Directorate of Navy Armament, ETBS of the Directorate of Army Armament, CEL of the Directorate of Missiles) and the understanding of detonics phenomena (CEG of Directorate of Research and Technical Studies, franco-german research institute ISL).

EVALUATION OF THE SENSITIVITY OF ENERGETIC MATERIALS LINKED WITH THE CONCEPT OF MURAT

If a MURAT label can be granted to a given munition and a level of immunity set for target linked with the use and the mission of this munition, it is not the same for energetic materials.

Indeed, it has been known that the reactivity of these materials when submitted to a stimulus will depend on :
- their confinement
- the masses to be considered
- the geometry of the charge

Besides, the immunity of a munition can be assessed rigorously only through scale 1 and rather important numbered tests ; these tests cost much money and can be realized only at the end of the development phase, so too late.
That is why the effort has been devoted for several years in France to the development of a set of tools allowing to predict the behaviour of such an energetic material. These are :
- the tools for the fundamental knowledge of the detonic behaviour
- the tools for the fundamental knowledge of the reaction mechanisms linked to the stimulus
- the laboratory scale tests (involving small quantities of products)
- numerical modelings to be applied to the real case of the munition
- the tests on analogues (allowing a first overview of mass and confinements effects)

1- Fundamental knowledge of the detonic behaviour

For example, these classical tests can be put forward :
- failure dimensions of detonation (diameter, thickness, predetonation length...)
- measurements of POP PLOTS
- cylinder tests, ballistic properties

2- Fundamental knowledge of the reaction mechanism linked to the stimulus

The main mechanisms that could lead to the detonation of an energetic material are :

- the shock to detonation transition (SDT) (example of the impact of a shaped charge jet)
- the deflagration to detonation transition (DDT) (example of the bullet impact)
- the delayed shock to detonation transition (XDT) (example of a bullet impact on an energetic rocket propellant)
- the detonation after a slow heating (cook-off phenomenon)

3- The laboratory scale tests

They can check the behaviour of products and, considering elementary stimuli representative of accidental ones, rank them.
These are for example :

- the card gap tests for the phenomenon of SDT
- the dangerous friability test for DDT
- the pick-up tests or ability for delayed detonation for XDT
- the slow and fast cook off tests..

4- The numerical modelings

For the most, designed by SNPE and CEG, these computing codes allow, owing to fundamental data on the detonic behaviour of the products and after checkings with model tests, to predict the real behaviour of pyrotechnical substances at the munition scale (type of reaction and time before reaction).

Such computing codes have been developed for :

- the bullet impact
- the fragment impact
- the heatings
- the shaped charge jet
- the spigot

5- The tests on analogues

These tests, launched by the STPE several years ago, are intermediate between laboratory tests and scale 1 tests. These stimuli are the accidental ones that will be considered for the MURAT labels :

- 12,7 mm bullet impact
- heavy fragment impact (250 g ball)
- fast cook-off (fuel fire) test
- slow cook-off (3,3°C/hr)
- crush with an 8 kg bullet
- shaped-charge jet impact (ø 62 mm)
- sympathetic detonation

These stimuli can generate six reaction levels : no reaction, combustion,pressure burst, deflagration, partial detonation, detonation.

In order to take into account the mass and confinement effects, the products are assessed in analogues fitted to their operational use (the mass considered in the followings is the product mass)

- for the high explosives :

  .5 kg analogue model with a 10 mm steel confinement
  .soon, 5 kg analogue model with a 3 mm aluminum confinement
  .soon, 50 kg analogue model with a 15 mm steel confinement

- for the gun propellants :

  . 2 kg steel cartridge (Ø 90 mm)
  . 2 kg combustible case (Ø 90 mm)

- for the rocket propellants :

  . 5 kg steel model Ø 120, grain with a bore
  . soon, 15 kg steel model Ø 190

<u>WORKS ON LOW SENSITIVE PYROTECHNICAL MATERIALS FORMULATION FOR MURAT</u>

Owing to the methods that have been described above, the knowledge of the pyrotechnical behaviour of substances and of the reaction phenomena that occur have allowed the orientation of synthesis and formulation works towards MURAT compositions.

For example, it has been showed that :

- a good behaviour to bullets impacts requires high mechanical properties.
- a good behaviour to heatings requires the use of plastic binders
- in both cases, low sensitive molecules (NTO, TATB) should replace HMX or RDX.

The followings describe, for the 3 families of pyrotechnical products, the french main works of these last years and the improvements obtained, as far as sensitivity is concerned.

1/ <u>Solid rocket propellants</u>

One of the main activities of STPE is related to the research and development of solid propellants that are to be used in the future French missiles.

For several years, we have been devoting ourselves to the design of a wide variety of energetic compositions suitable for the different applications considered : tactical weapons (air to air, air to surface, surface to air, surface to surface) as well as missiles for the French nuclear deterrence force (ICBMs and SLBMs).

Studies are carried out on the following propellant families :

- cast modified double base (CMDB)
- elastomeric modified cast double base (EMCDB)
- composite propellants, including fuel-rich propellants for ram-rockets
- crosslinked composite double base (XLDB)

For the past few years, efforts have been focused on low-vulnerability propellants in order to meet the MURAT challenge.

This concerns the improvement of existing families by incorporating new additives (for example additives that lower the vulnerability of composite propellants to cook-off or to bullet impact, additives that lower the burning rates at atmospheric pressure, additives that improve cracking aging), as well as the elaboration of new families of propellants based on glycidyl azid polymer (GAP).

Fundamental studies are carried out in conjunction with formulation works with the aim to understand the different mechanisms involved when the propellant is under aggression. Important results have been obtained concerning the discovery and explanation of the so-called "bore effect" that leads to the detonation of propellant grains presenting a cylindrical bore in the bullet impact tests.

2/ Gun propellants

In the gun propellants field, most of the studies were devoted to :

- the study of new gun propellants with polymeric compounds filled with energetic materials, low sensitive to different stimuli and with good mechanical properties at low temperatures
- the laboratory scale characterization of these gun propellants (sensitivity tests)
- the vulnerability tests on analogues which provided the following results :

  . crush : no reaction
  . fuel fire : ordinary combustion
  . bullet impact : no or locally limited reaction

The shaped charge sensitivity test is about to be performed.

3/High explosives studies

The main effort has been devoted these last years to the formulation of low sensitive to accidental stimuli (fire, light or heavy fragment impact, sympathetic detonation) cast plastic-bonded explosives and to the knowledge of these products on the detonics, vulnerability and mechanical points of view.

More precisely, these compositions have been formulated :

- cast PBX (PU binder) with a high HMX loading rate (86 %) and an average particle size (200 microns) less sensitive to bullet impact than compositions with coarser HMX grain size (350 microns) (respectively octoranes 86 A and B)

- cast PBX (B 2188) for booster use (HMX/PETN/PU binder = 40/44/16) less sensitive to fire and bullet impact than its pressed PBX booster-counterparts

- cast PBX with a high NTO loading rate and an inert HTPB binder (B 2214 : 72 % NTO, 12 % HMX) or an energetic (NC, NGl) binder (B 3017 : 76 % NTO) both much less sensitive to a 250 g fragment impact or to sympathetic detonation than melt cast explosives or HMX or RDX-based cast PBX ; for instance, a 250 g fragment impact at 1500 m/s leads to detonation in a 250 kg GP bomb loaded with TNT or RDX- based cast PBX whereas it leads at 2000 m/s to an ordinary combustion with NTO-based B 2214 !

In a parallel direction, the following actions have been leaded :

- improvement of the thermal behaviour and the aging due to cracks of cast PBX with nitroglycerine-based energetic binders.
- full study of the NTO synthesis and making at the industrial scale on a continuous process (2500 kg) after having given up the TATB-based compositions studies because of their low performances.
- study of the own influence of the type of binder, the HMX and RDX grain sizes, the ammonium perchlorate and aluminum grain sizes and loading rates on the detonics and vulnerability data.
- study of the mechanical behaviour of these high explosives to high strain rates (10000 s^{-1}), to thermal shrinking after loading and study of the cracks propagation.
- boostering of low sensitive compositions
- designs of a blast test and an underwater assessment test at small scale (1 kg)

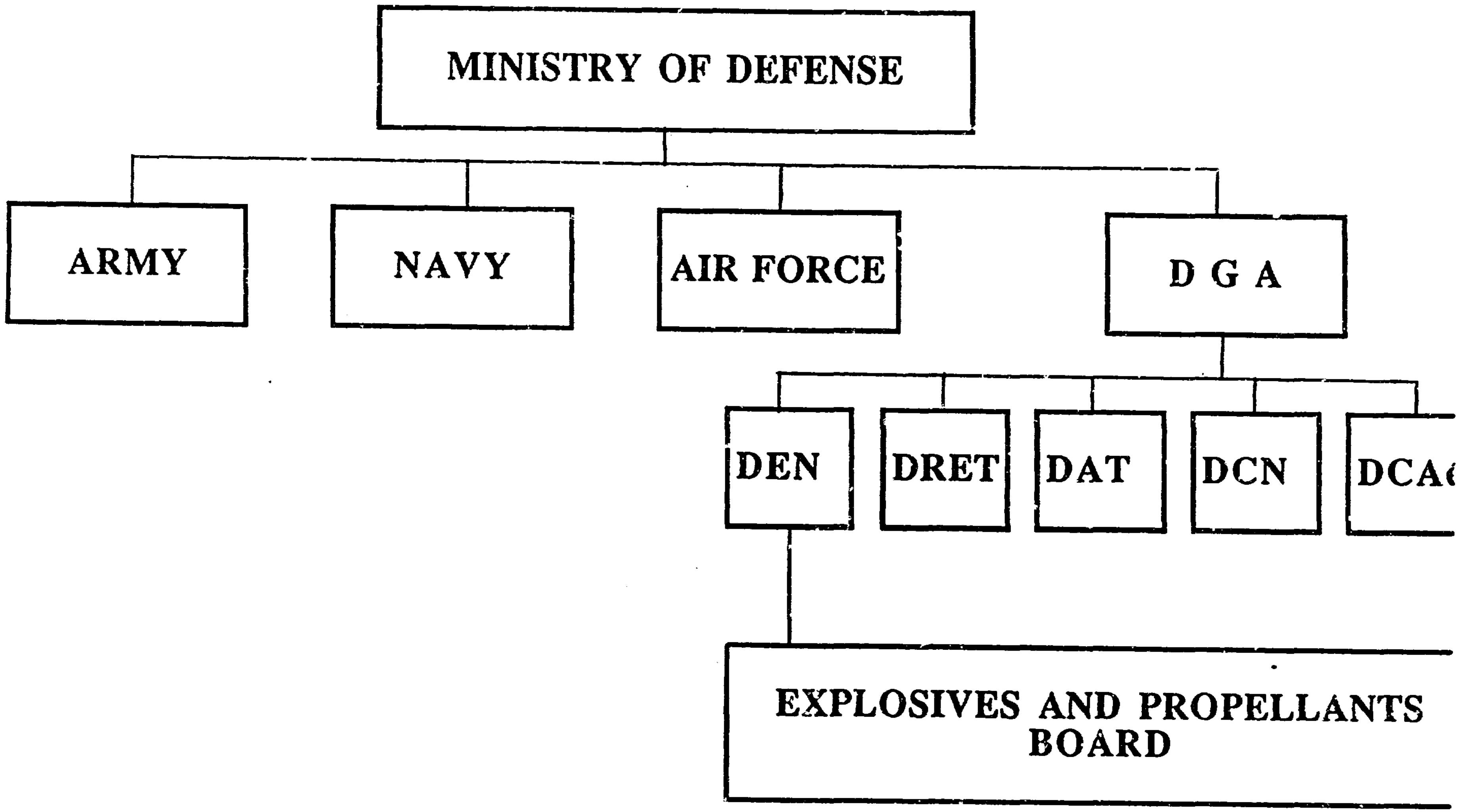
High performance pressed PBX have also been formulated for munitions like the MLRS and a theoretical study of the coating of the grains by the binder has been launched.

THE MURAT ECONOMIC BET

So, all these data allow to define a MURAT policy. According to that policy, the major economic bet must be taken into account.
Indeed, the application to MURAT munitions is not costless ; for instance, the new propellants and high explosives families will be, at least in the short term, more expensive than former ones. Therefore, the whole problem must be considered. If the fact that 90 % of the accidents involving a munition take place not during an operational phase but during "passive" phases (storage, transport...) is taken into account, the improvement expected owing to these materials (lighter protections, smaller storage areas allowing savings in sub. and understructures...) can be easily pictured. But, as for every insurance, this improvement is very difficult to assess before the accident takes place ; and everybody knows that the insurance is expensive only before the accident.

CONCLUSION

Energetic materials for MURAT are available in France today ; the first works linked to parts of munitions (warheads for example) have been completed and technical and operational studies are under way (connected with the nuclear aircraft-carrier for instance).
Owing to STPE, France leads an important research policy concerning the energetic substances to be loaded in the MURAT.
In order to know more about the french realizations, you are invited to attend the second "Journées Paul Vieille" in Paris during the 1991 autumn.


MINISTRY OF DEFENSE
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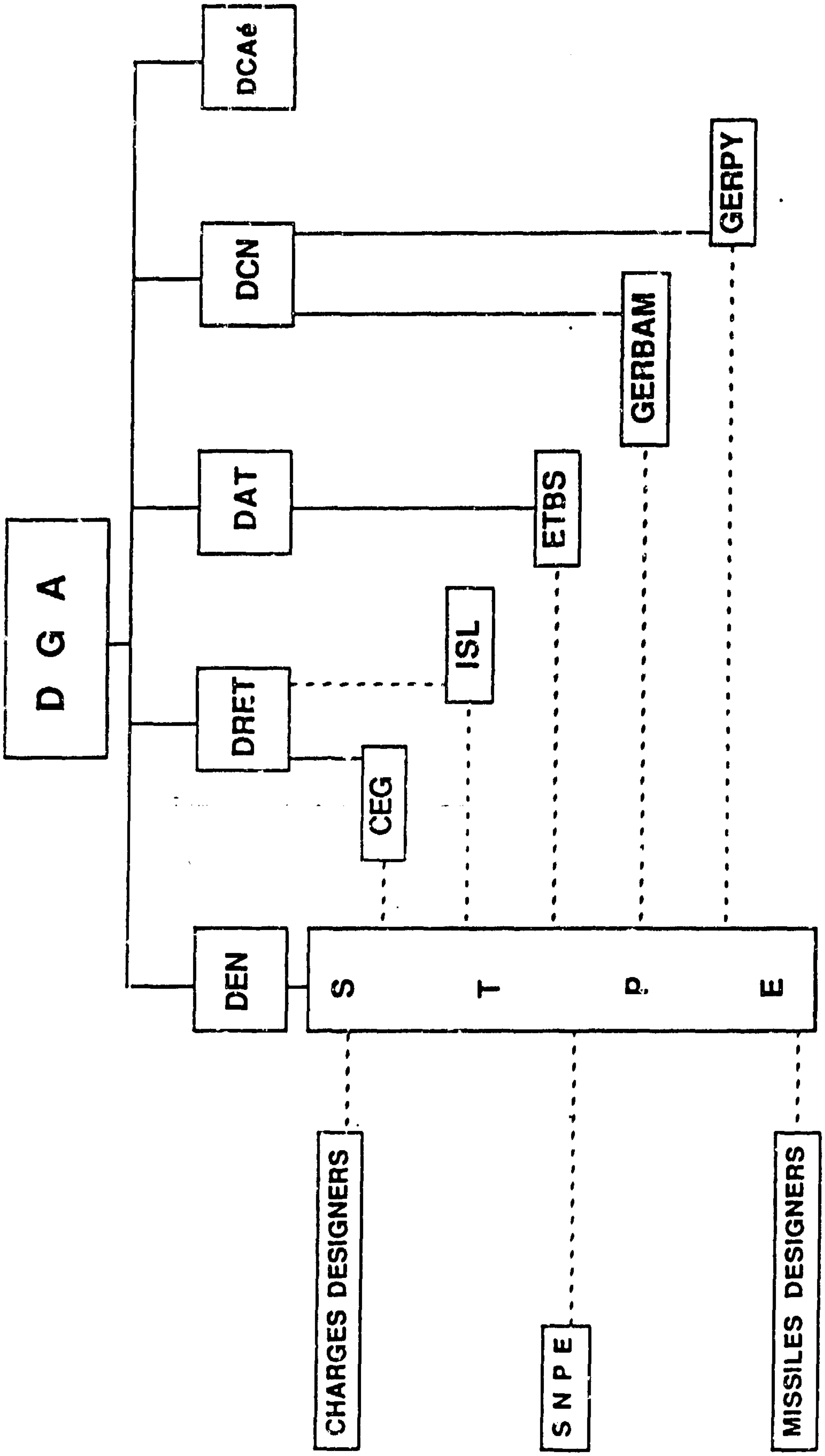
EXPLOSIVES AND PROPELLANTS BOARD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DELEGATION GENERALE POUR L'ARMEMENT

(D G A)

* IT IS THE DEPARTMENT OF DEFENSE ORGANIZATION RESPONSIBLE FOR MANAGING ALL ARMAMENT PROGRAMS

* THEREFORE, THE DGA IS RESPONSIBLE FOR :

  - THE MANAGEMENT OF ARMAMENT PROGRAMS (ARMY - NAVY - AIR FORCE)
  - THE MONITORING OF THE ARMAMENT INDUSTRY
  - PRODUCTION AND REPAIRS OF SOME MILITARY EQUIPMENTS
  - COOPERATION AND EXPORTS FOR ARMAMENTS.

EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON HIGH EXPLOSIVES ANALOGUES.

	CRUSH TEST	FAST COOK OFF
TNT or TNT/AL	O	B
MELT CAST X	D	D
PBX (inert or energetic binder)	O	B
PRESSED PBX (with RDX or HMX)		D
PRESSED PBX (with TATB)		B

O	NO REACTION
A	COMBUSTION
B	OVER PRESSURE BURST
C	DEFLAGRATION
D	DETONATION

EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON HIGH EXPLOSIVES ANALOGUES.

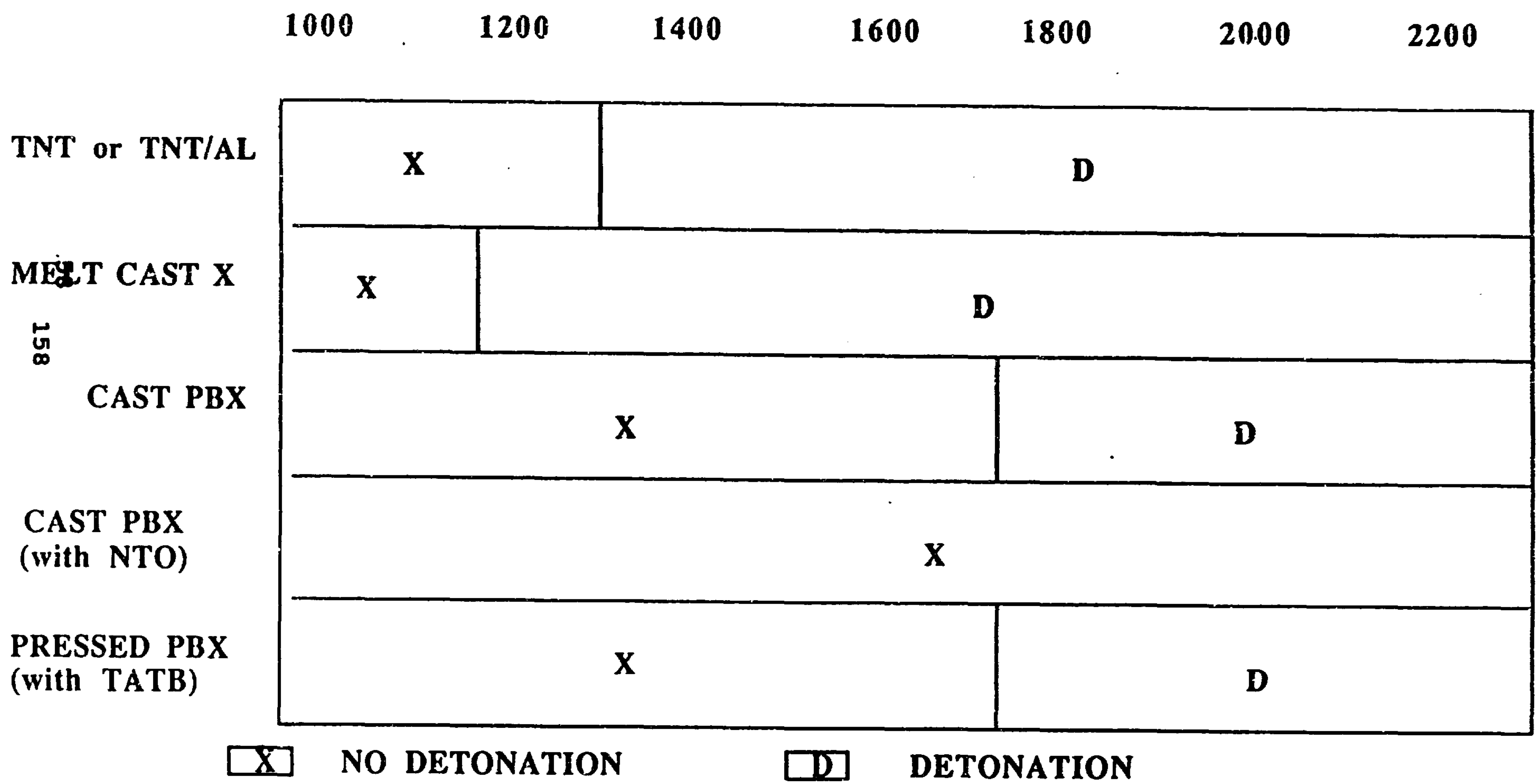
0,50 CAL. BULLET IMPACT TEST

	400 M/S	600 M/S	800 M/S	1000 M/S	1200 M/S
TNT or TNT/AL	O	B	B	B	B
MELT CAST X	D	D	D	D	D
PBX (inert or energetic binder)	O	B	B	B	B
PBX (with TATB)	O	O	A	A	A
PRESSED PBX (with RDX or HMX)	D	D	D	D	D
PRESSED PBX (with TATB)	B	B	B		

O	NO REACTION
A	COMBUSTION
B	OVER PRESSURE BURST
C	DEFLAGRATION
D	DETONATION

EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON HIGH EXPLOSIVES ANALOGUES

HEAVY FRAGMENT (250 G) IMPACT TEST



EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON GUN PROPELLANT ANALOGUES.

0,50 CAL. BULLET IMPACT TEST

	400 M/S	600 M/S	800 M/S	1000 M/S	1200 M/S
SINGLE BASE OR DOUBLE BASE G.P.	C	C	C	C	C
ENERGETIC-SMALL WEB DOUBLE BASE G.P.	C	D	D	D	D
CAST DOUBLE BASE (RDX) G.P.	A	A	A	A	B

A	NO REACTION OR COMBUSTION
B	OVER PRESSURE BURST
C	DEFLAGRATION
D	DETONATION

EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON GUN PROPELLANT ANALOGUES.

	FAST COOK OFF	SLOW COOK OFF	CRUSH
SINGLE BASE OR DOUBLE BASE G.P.	C	C	C
ENERGETIC-SMALL WEB DOUBLE BASE G.P.	D	D	D
CAST DOUBLE BASE (RDX) G.P.	B	B	A

A	NO REACTION OR COMBUSTION	C	DEFLAGRATION
B	OVER PRESSURE BURST	D	DETONATION

THE DIFFERENT ROCKET PROPELLANT FAMILIES

PROPELLANT	CONSTITUTION	ISP (EXPERIMENTAL)	APPLICATION
C M D B	NC + NG + RDX	230 s	ANTI-TANK
E M C D B	NC + NG + RDX + (PREPOLYMER)	230 s	TACTICAL
COMPOSITE	HTPB + AP HTPB + RDX or HMX CTPB or HTPB + AP +AL	240 s 235 s 245 s	ALL TACTICAL GAS GENERATORS ICBM, SLBM, BOOST MOTORS
X L C D B	POLYURETHANE + NC + NG + RDX or HMX + (AP) + (Al)	235 - 254 s	ALL
?	GAP + NA GAP + ...	236 s (THEORETICAL) 262 s (THEORETICAL)	ALL IM ALL IM + ICBM + SLBM

LOW VULNERABILITY ROCKET PROPELLANTS

FORMULATIONS

* EXISTING FAMILIES :

RESEARCH FOR NEW ADDITIVES TO REDUCE

- VULNERABILITY TO COOK-OFF
- VULNERABILITY TO IMPACT
- BURNING RATE AT ATMOSPHERIC PRESSURE
- CRACK FORMATION
- ....

* GAP/AN FAMILY

BASED ON AN INSENSITIVE PROPELLANT, THE GOAL IS TO IMPROVE PERFORMANCE

FUNDAMENTAL STUDIES

* ANALYSIS OF TRANSITION PHENOMENA :

SDT, DDT, XDT

* THERMAL BEHAVIOUR TOWARDS SLOW AI FAST COOK-OFF

* INVESTIGATION OF THE MECHANISMS INVOLVED IN DIFFERENT TESTS (BULLET IMPACT, ...)

GUN PROPELLANTS

- NEW FORMULATIONS

- SENSITIVITY AND VULNERABILITY TESTS

* LABORATORY SCALE
* ANALOGUES

G.P. / TESTS	SINGLE BASE	M U R A T
CRUSH	DEFLAGRATION	NO REACTION
BULLET IMPACT (.50)	DEFLAGRATION	LOCALLY LIMITED OR NO REACTION
FUEL FIRE (FCO)	"	ORDINARY COMBUSTION

COMPARISON WITH CLASSICAL COMPOSITIONS

CRITERIA / COMPOSITION	BULLET IMPACT (12,7 mm)	FIRE	HEAVY FRAGMENT IMPACT (250 g)	PERFORMANCE (ρ, D)
TNT	O	O	-	-
OCTOL 85/15	- -	- -	- -	+ +
OCTORANE 86 A	O	+	O	+
OCTORANE 86 B	+	+	O	+
B 2214	+ +	+ +	+ +	O
B 3017	+ +	+	+ +	+
B 2188 (BOOSTER)	+	+	?	+
CLASSICAL PRESSED PBX BOOSTER	- -	-	?	+

SENSITIVIY LEVEL : FROM - - (VERY SENSITIVE) TO + + (LOW SENSITIVE)

NTO CHRONOLOGY IN FRANCE

SUMMARY

1906	1st synthesis in Germany
1979 - 1980	1st synthesis at the laboratory scale at SNPE/CRB (30 g). Beginning of characterization
1981 - 1982	Scale up to 200 g : recrystallization and rest of characterization (SNPE/CRB)
1983 - 1984	First use in cast PBX
1984 - 1985	Attempts to formulate gun and rocket propellants and pressed PBX with NTO
85/06/30	SNPE patent n° F 22, 584, 066
1985	Scale-up to 20 then 50 kg (plant of Sorgues)
1985 - 1987	Comparison between TATB and NTO as desensitizers in high explosives
1987	SNPE communications at the ICT Karlsruhe and at the Peking ISPE congresses
1989	SNPE communication at the 9th symposium on detonation
1990	Communication at the ADPA congress SNPE patent on NTO-based cast PBX with energetic binders Synthesis at the industrial scale (2,5 t) in the SNPE plant of Sorgues

STPE MAIN ACTIVITIES

PROPELLANTS MATERIALS

- XLDB PROPELLANTS
- COMPOSITE PROPELLANTS
- RAMJET PROPELLANTS
- SMOKELESS PROPELLANTS
- FAST BURNING PROPELLANTS
- LOVA PROPELLANTS
- LINERS, INHIBITORS...

- MECHANICAL BEHAVIOR
- INTERNAL BALLISTICS

- NEW TACTICAL MOTOR DESIGNS
- POST BOOST SYSTEMS & GAZ GENERATORS

- PROCESSES (incl. continuous)

EXPLOSIVES

- XLDB EXPLOSIVES
- CAST PBX
- NEW INGREDIENTS
- BULK EXPLOSIVES

- MECHANICAL BEHAVIOUR
- DETONICS

- PROCESSES

GUN PROPELLANTS

- LOVA, COMPOSITE (GP)
- NEW ENERGETIC FORMULATIONS
- NEW INGREDIENTS

- STABILITY
- INTERNAL BALLISTICS

- FUTURE SYSTEMS (Careless GP)

- PROCESSES

VULNERABILITY-RAW

- SYNTHESIS
  . GAP
  . BUTACENE
  . CATOGENE
  . HTPB, ...

- VULNERABILITY :
  . METHODOLOGY
  . TESTS

- IMPACT (BULLET-FRAGMEN
- COOK-OFF (Slow-Fast)
- SYMPATHETIC DETONATIO
- SHAPED CHARGE
- ESD
  + taking account of a munition point of view

- SAFETY : - PROCESS
  - COMPATIBILITY

STPE MAIN RESEARCHES

	GUN PROPELLANTS	HIGH EXPLOSIVES	ROCKET PROPELLANTS
NEW MOLECULES	NQ GAP	TNAZ NTO GAP	GAP DPA AN
NEW FAMILIES	C A S T	P B X	•RDX LOADED XL DB •RAMJET PROPELLANTS •DPA or GAP BASED •FORMULATIONS •NON-BURNING RP at •ATM PRESSURE
PHYSICS OF MATERIALS	COARSER	GRAIN	SIZES
PROCESSES	• AIR MILLING	• OF CONTINUOUS	NITRAMINES PROCESSES
	USE OF SCREWERS	- EXTRUDERS	
		•NEW PROCESSES •HMX SYNTHESIS	
SYSTEMS APPROAC ES	COMBUSTIBLE CASES	•LASER BOOSTER •MACH WAVE GENERATOR •BI-COMPOSITIONS •COMPO + "INERT" (HTPB, POROUS AL)	•COMPOSITE CASES •APPROPRIATE EXTERNAL AND BORE Ø •RAMJETS
	EXTERNAL	PROJECTING	DEVICES

U. S. AIR FORCE
INSENSITIVE MUNITIONS PROGRAM

by

Joseph Jenus, Jr.

POLICY

NEAR TERM

REDUCE HAZARDS PRESENTED BY INVENTORY MUNITIONS BY DEVELOPING AND INCORPORATING ENERGY SUPPRESSION DEVICES, PACKAGING REDESIGN, APPLYING INNOVATIVE STORAGE AND HANDLING TECHNIQUES, AND UTILIZATION OF STORAGE FACILITIES

LONG RANGE

TRANSITION TO INSENSITIVE OR LESS SENSITIVE MUNITIONS IN ALL MAJOR WEAPONS SYSTEMS AS SOON AS PRACTICAL WITHOUT LOSING OPERATIONAL EFFECTIVENESS / CAPABILITY

WHAT THE IM PROGRAM DOES

- **PROVIDE A MORE EFFICIENT AND EFFECTIVE AIR FORCE**
  - ELEVATE MOBS AND COBS TO FULL CAPABILITY
    - MUNITIONS ON BASE
    - NEAR HARDENED A/C SHELTERS
  - INCREASE SURVIVABILITY OF AIRBASE AND ASSETS
    - MINIMIZE MAXIMUM CREDIBLE EXPLOSIVES EVENT
  - FREE UP TRANSPORTATION RESOURCES
- **SAVE MONEY**
  - COST AVOIDANCE
  - REDUCE COSTS

SUPPORT

- HQ TAC / LG message to HQ USAF / XOO / LEY / AQT, Mar 89 ---"...IM Program believed to have significant impact on effort to maintain current levels of operational support..." "Tac will submit IM as separate candidate for the FY 91 TAF RD&A list."
- AFISC / CC message to HQ USAF / XOO / LEY, May 90 --- "...IM Program has great potential benefit by providing operational capability within existing safety constraints and in permitting the use of new safety criteria which more accurately reflect the actual risk posed by munitions and explosives."
- SAC / CS letter to HQ USAF / LEY / LEE / XOX, December 89 --- "...IM program will benefit the Strategic Air Command by enhancing personnel and ordnance safety and increasing our munitions storage capability without increasing construction costs..."
- HQ PACAF / DO / LG message to HQ USAF / XOO / AQT / LEY, May 90 --- "...this command strongly supports the benefits of the insensitive munitions (IM) program offers. We believe it offers great potential, decreases cost and increases our command's combat capability."
- HQ USAF / XOX message to MSD / CC, April 90 --- "...expect IM will offer high payoff in terms of reduced munitions malpositioning problems, increase air base survivability, safer and less costly transportation and storage."
- HQ USAFE / LGW / DEV / SEW message to HQ USAF / LEY, October 89 --- "...capability to store munitions is presently restricted by inaccurate, inflated, or undetermined explosive criteria. IM program provides a near-term avenue for resolving these problems. Request immediate support..."

PROGRAM
ACTIVITIES / STATUS

HQ / TAC BRIEFED 8 JUNE 90

- DR DRAFTING PDP FOR SUBMISSION IN TAC'S FY91 RD & A LIST
- DR NOTIFIED AIR STAFF OF THEIR INTENT
- DR MESSAGE 26 JULY 90 TO ALL MAJCOMS REQUESTING THEY INCLUDE THE IM PROGRAM ON THEIR FY91 RD & A LIST

HQ USAF / XOO / LEY / LEX BRIEFED 3 JULY 90

- REACTION - FULL SUPPORT
- XOO BRIEFING DO LOGISTIC COMMANDERS
- ACTIONS TAKEN TO IDENTIFY POTENTIAL FUNDING SOURCES

BACKGROUND

- SEPT 87 — INSENSITIVE MUNITIONS MOU SIGNED BY JCS
- SEPT 87 — CSAF/CV DIRECTED THE DEVELOPMENT AND IMPLEMENTATION OF AN IM PROGRAM
- SEPT 87 — IM PROGRAM OFFICE CADRE FORMED
- MAR 88 — AFSC SUBMITTED DRAFT MASTER PLAN TO CSAF/CV
- APR 89 — MASTER PLAN APPROVED BY HQ USAF/XOX
- MAY 89 — TAF SON 309-88 VALIDATED
- JAN 90 — PMD BEING STAFFED AT AIR STAFF

HOW IM WILL BE ACCOMPLISHED

- PROVIDE SITE SURVEY / MUNITIONS HAZARD REDUCTION PLANNING
- DEVELOP / IMPLEMENT PROGRAMS TO MITIGATE REACTIONS BETWEEN MUNITIONS

CROTONE AIR BASE SURVEY

- USAFE / DEE REQUESTED A REVIEW OF A&E'S 35% DESIGN OF CROTONE AB EXPLOSIVES FACILITIES
- FACILITIES RE-SITED TO ELIMINATE DISCREPANCIES, REDUCE COST AND IMPROVE EFFICIENCY

A&E DESIGN

- 55 IGLOOS (31 RESTRICTED)
- 34 NATO SURVIVABILITY CRITERIA VIOLATIONS
- MUNITIONS OPERATING FACILITIES RESTRICTED

DESIGN RECOMMENDED BY SURVEY (SAME LAND AREA)

- 60 IGLOOS (NONE RESTRICTED)
  24 ADDITIONAL (FUTURE EXPANSION)
- NO SURVIVABILITY VIOLATIONS
- NO RESTRICTIONS

OMAN SITE PLANNING

- IN SUPPORT OF CENTAF / LGW
- REVISED SITINGS OF THREE AIR BASES IN OMAN
- SIGNIFICANT INCREASE IN NET EXPLOSIVES WEIGHT (NEW)
  - 4.6 MILLION POUNDS NEW WITH NO CONSTRUCTION
  - ADDITIONAL 1.7 MILLION POUNDS BY CONSTRUCTING EARTH BARRICADES
- ALL GAINS MADE WITHIN EXISTING CLEAR ZONES

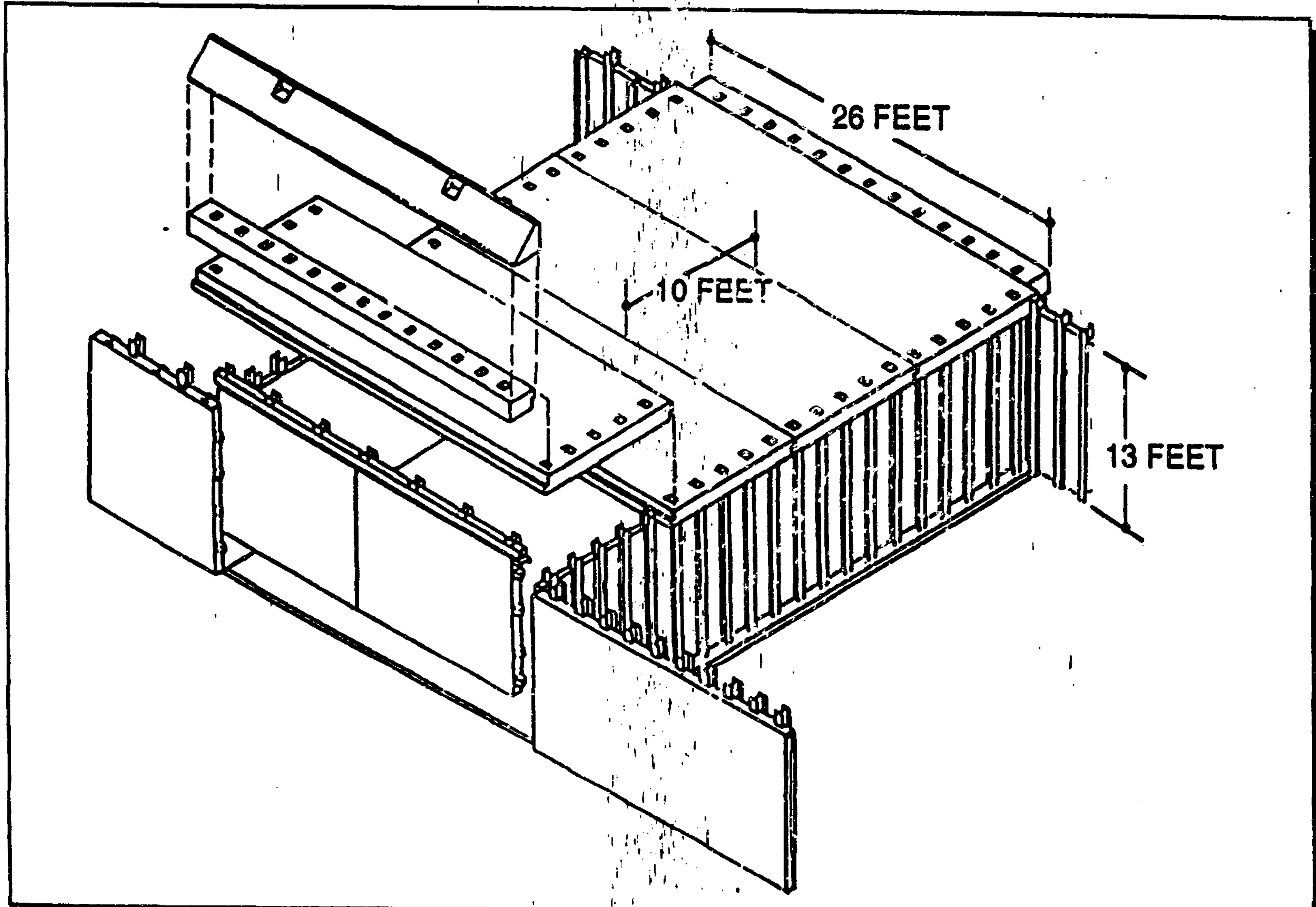
IM DEVELOPMENT PROGRAM / TEST TASKS

⊙ MUNITIONS STORAGE MODULE(S)
- HARDENED AIRCRAFT SHELTER
- GENERIC BUFFER FOR STORAGE
- 1.2 HAZARD REDUCTION

⊙ FLIGHTLINE STORAGE BINS
- LIGHTNING PROTECTION
- CBU 87 / 89
- AIM-7 / AIM-9 HAZARD REDUCTION

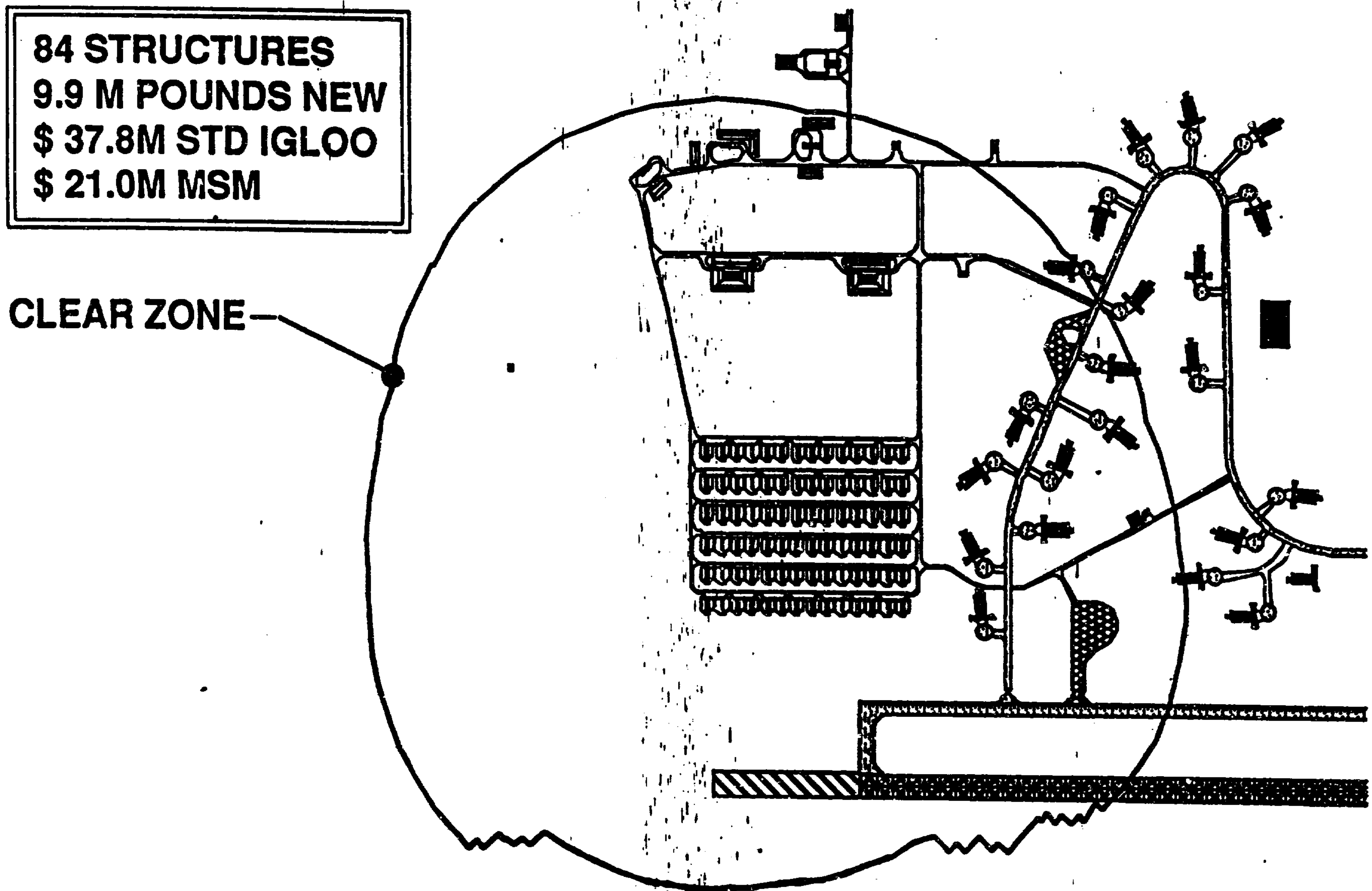
⊙ 40MM GRENADE (M433)
- AGM 65 PROPAGATION TEST
- AGM 65 MOTOR CONTRIBUTION TEST
- AGM 45 HAZARD CLASSIFICATION TEST
- MK 20 HAZARD REDUCTION
- STANDARDIZED BUILD-UP AREA

MUNITIONS STORAGE MODULE (MSM)



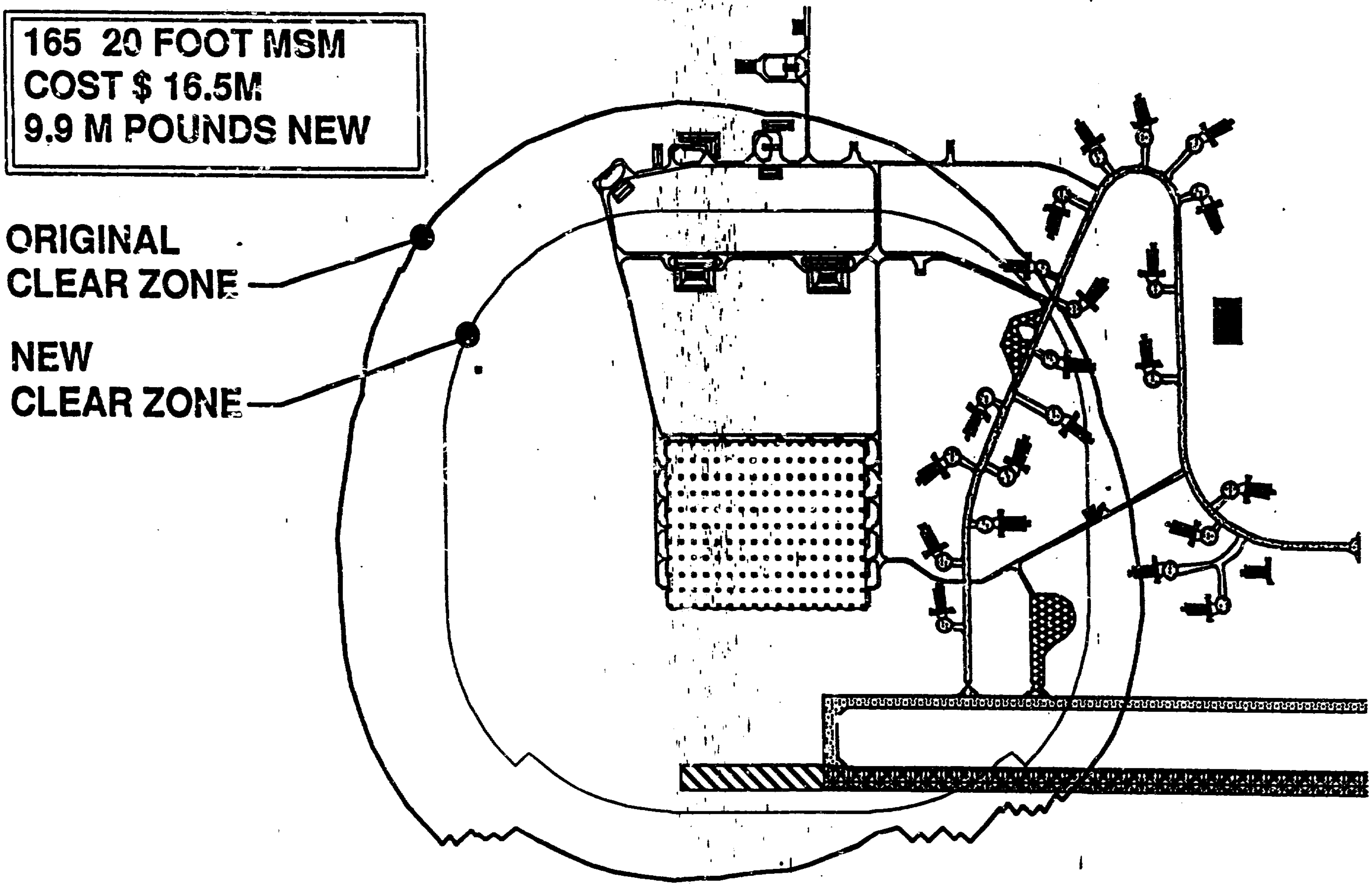
CONVENTIONAL SITING

84 STRUCTURES
9.9 M POUNDS NEW
$ 37.8M STD IGLOO
$ 21.0M MSM



MUNITIONS STORAGE MODULES SAME FOOTPRINT

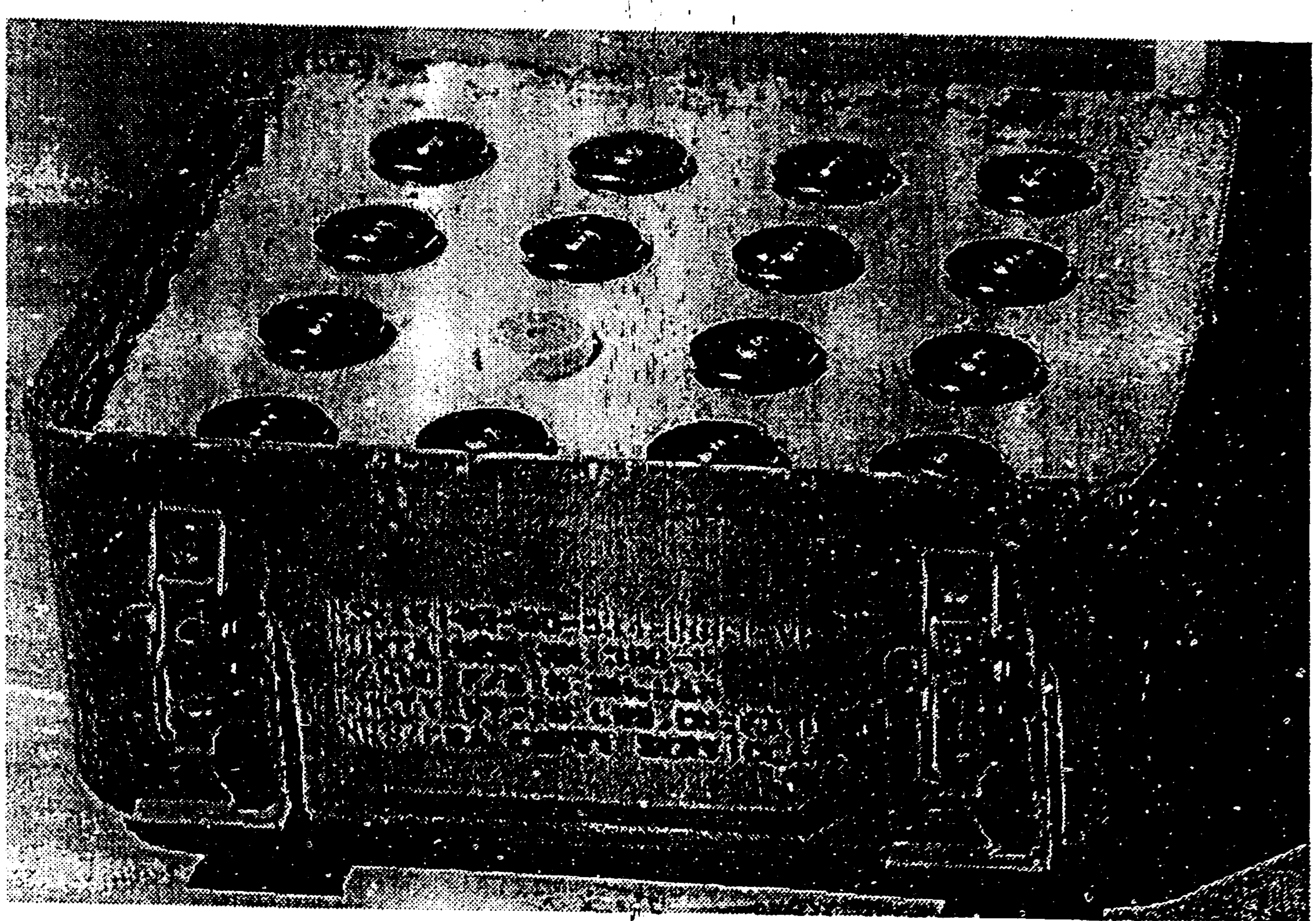
165 20 FOOT MSM
COST $ 16.5M
9.9 M POUNDS NEW



MSM PAYOFF

- OPERATIONAL
  - MORE MUNITIONS ON BASE
  - INCREASED SURVIVABILITY
  - SITE ADAPTABLE
- COST
  - STANDARD 80 FOOT IGLOO ≈ $450K
  - 80 FOOT MSM ≈ $250K
- COST SAVINGS (POTENTIAL)
  - GREATER THAN $ 20 M PER YEAR OVER NEXT SEVEN YEARS
- STATUS
  - $950K REQUIRED TO COMPLETE
  - SCHEDULE - ONE YEAR

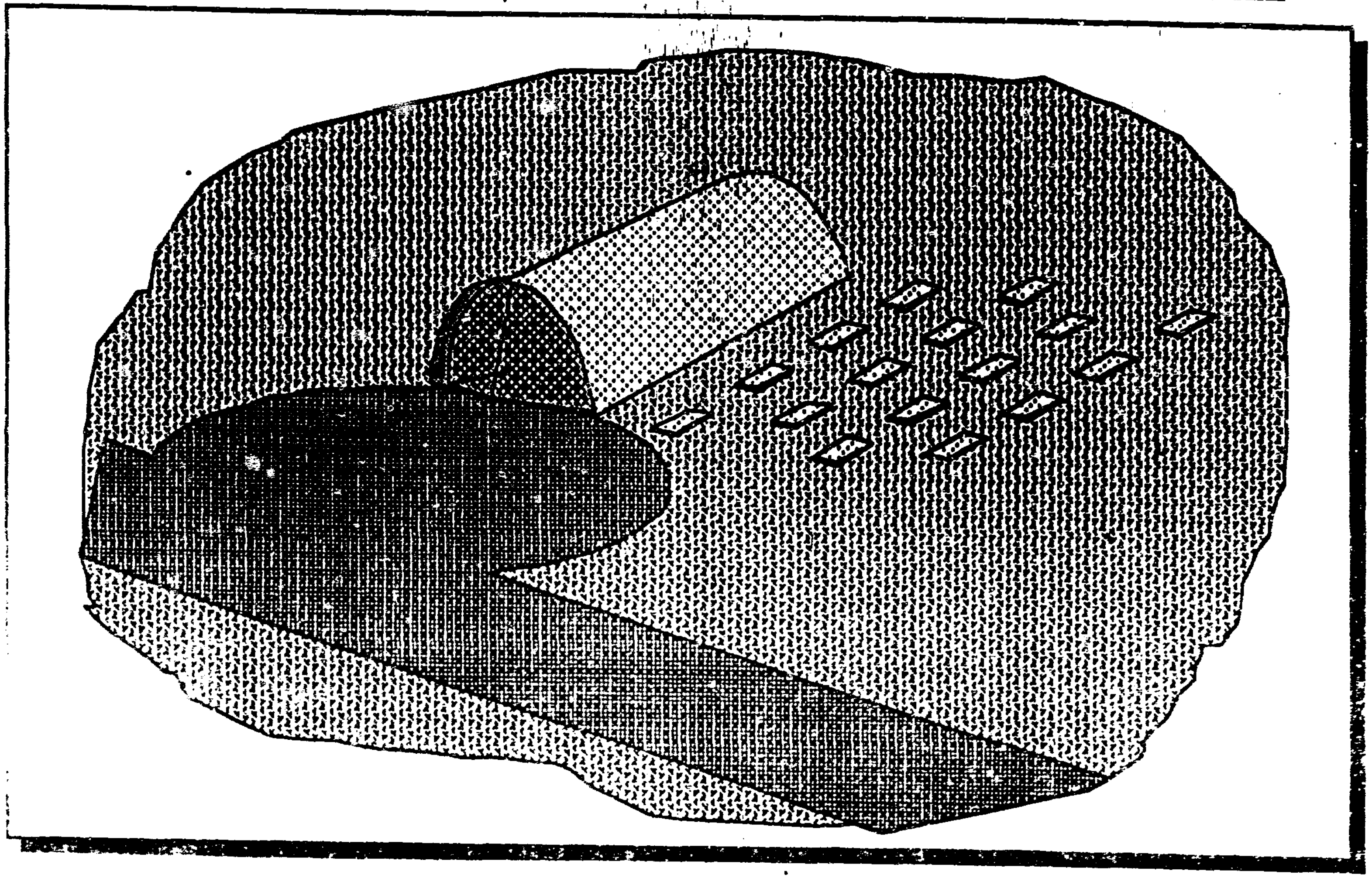
40 MM GRENADE (M433)



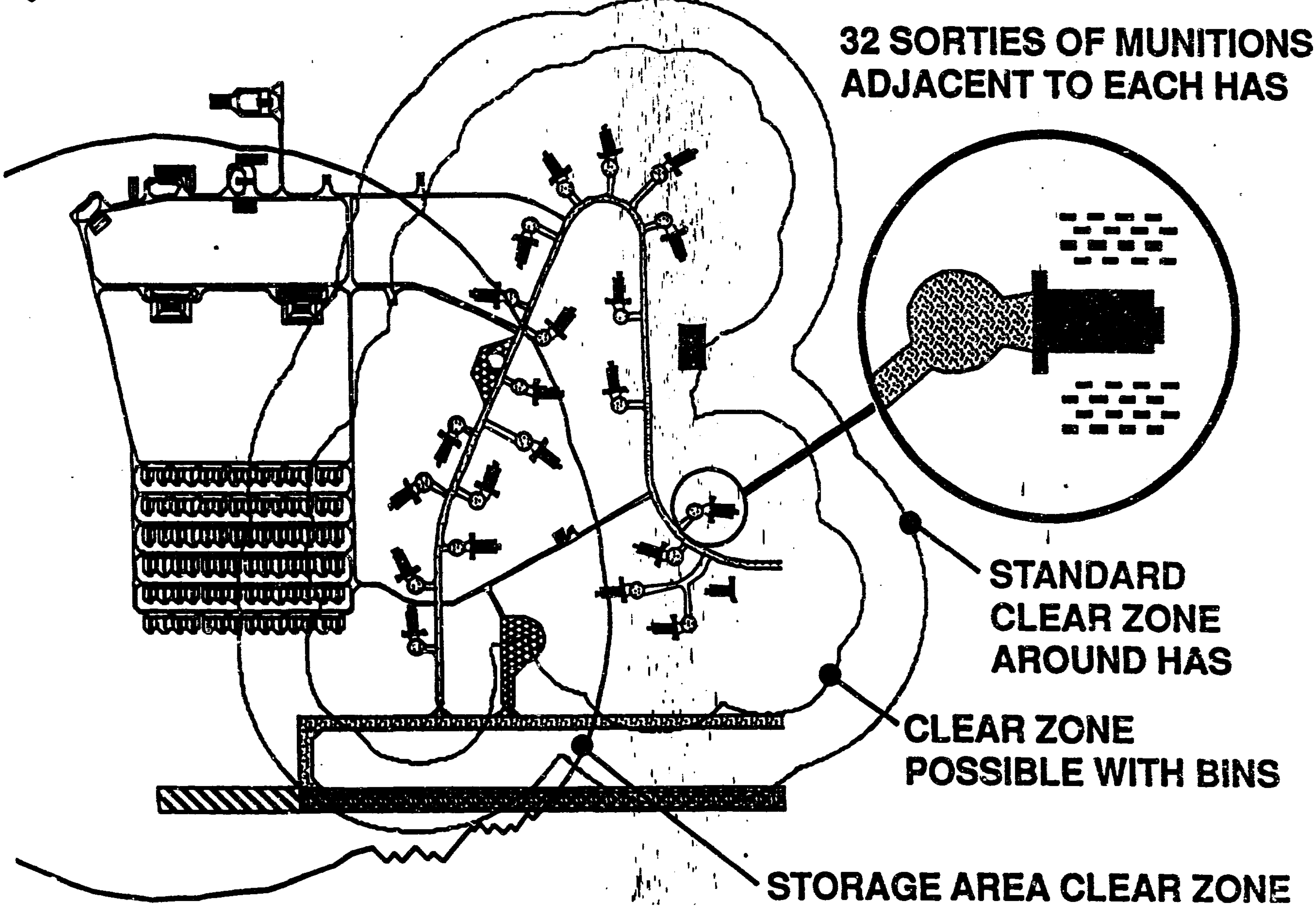
40MM GRENADE PAYOFF

- GRENADES IN ARMORY WHERE NEEDED
- MASS DETONATION HAZARD ELIMINATED
- STATUS
  - FEASIBILITY DEMONSTRATED
  - $200K REQUIRED TO COMPLETE
  - SCHEDULE - ONE YEAR

FLIGHTLINE STORAGE BINS



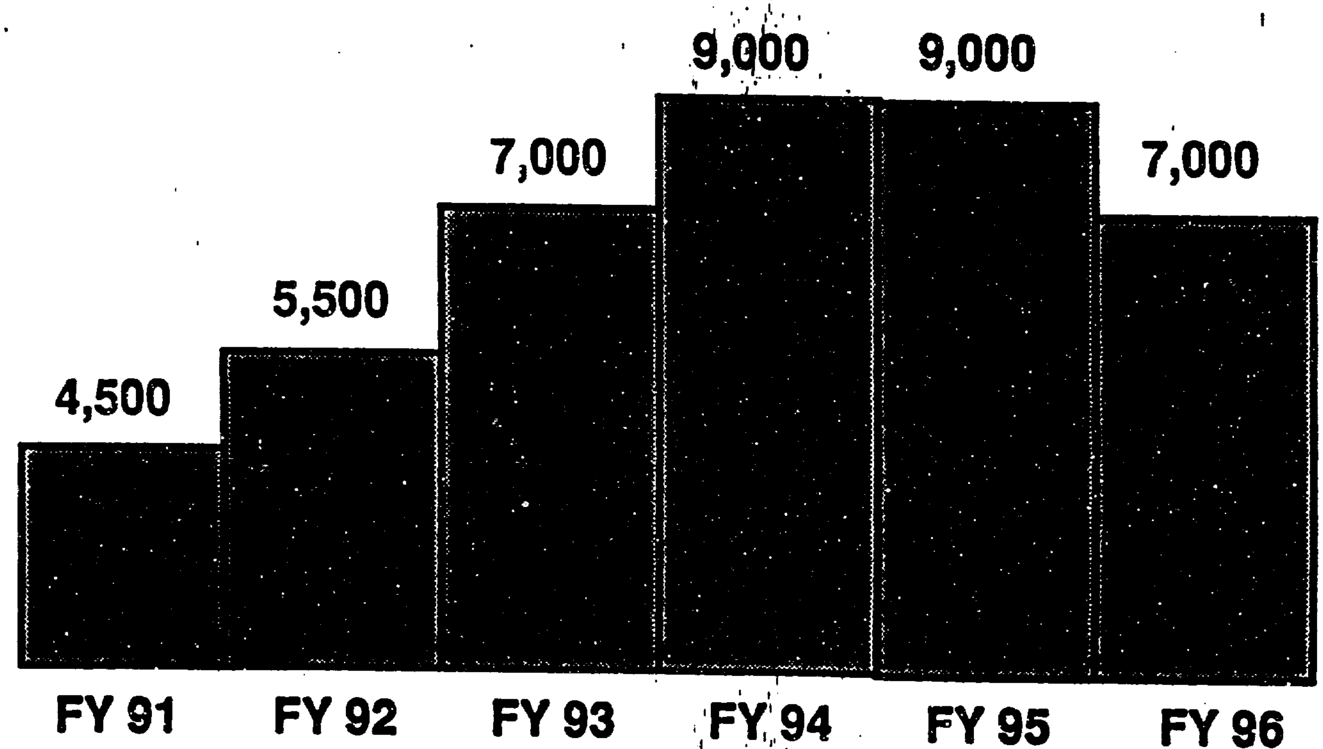
FLIGHTLINE STORAGE BINS



FLIGHTLINE STORAGE BIN PAYOFF

- OPERATIONAL
  - MUNITIONS AT HAS-WHERE NEEDED WHEN NEEDED
  - INCREASED SORTIE GENERATION CAPABILITY
  - INCREASED WARFIGHTING CAPABILITY
  - INCREASED SURVIVABILITY
- COST
  - COULD REDUCE IGLOO REQUIREMENTS
- STATUS
  - FEASIBILITY DEMONSTRATED
  - $ 1.5 M REQUIRED TO COMPLETE
  - SCHEDULE - TWO YEARS

AF IM REQUIRED FUNDING PROFILE
(DOLLARS IN THOUSANDS)



SUMMARY

- IM PROGRAM WILL IMPROVE OPERABILITY AND SURVIVABILITY
- SIGNIFICANT COST AVOIDANCE / COST SAVINGS
- AFSC POSTURED TO EXECUTE THE IM PROGRAM
  - BASIC PROGRAM OFFICE ESTABLISHED
  - IM EFFORTS ORGANIZED AND CENTRALIZED
  - PROGRAM IMPLEMENTATION APPROACH IDENTIFIED

Twenty-Fourth DOD Explosives Safety Seminar
28 th - 30 August 1990
Saint-Louis, Missouri, USA

Quantity-Distance Assessment Session

WHAT DO QUANTITY-DISTANCES MEAN ?

by Jean Gabriel GOLIGER

ABSTRACT

Quantity-Distances ensure the minimum practicable risk to life and property, including ammunition. Several kinds of QD are traditionally provided by safety manuals towards internal facilities (explosive magazines and workshops, other workshops and office buildings) and external facilities (public traffic routes, inhabited buildings, other categories of meeting places and buildings). Levels of protection against instantaneous propagation of explosion for 1.1. products, and against propagation of combustion for 1.3 products are well described. Levels of damage to persons and properties are well described from 1.1. products. They have to be precised from 1.2 and 1.3 products. This implies to define consistent levels of acceptable damage towards each category of possible exposed item.

French regulation defines six potential damage zones, separated by five (red, orange, yellow, green, blue) lines with defined decreasing potential damage. It provides a list of accepted exposed items, to be tolerated in these damage zones.

* SNPE - GTS - 91710 - VERT LE PETIT - FRANCE.

WHAT DO "QUANTITY-DISTANCES" MEAN ?

SUMMARY

- INTRODUCTION
- THE NEED
- THE FRENCH REGULATION APPROACH
- SUGGESTIONS
- CONCLUSIONS

INTRODUCTION

- QUANTITY-DISTANCE = QD

QD = THE MINIMUM PERMISSIBLE DISTANCE BETWEEN A POTENTIAL EXPLOSION SITE CONTAINING A GIVEN QUANTITY OF EXPLOSIVES AND AN EXPOSED SITE. IT IS BASED ON AN ACCEPTABLE RISK TO LIFE AND PROPERTY (INCLUDING AMMUNITION)

THERE ARE 4 KINDS OF QD

INTER-MAGAZINE DISTANCES.
EXPLOSIVES WORKSHOP DISTANCES.
PUBLIC TRAFFIC ROUTE DISTANCES.
INHABITED BUILDING DISTANCES.

- PES = POTENTIEL EXPLOSIVE SITE
- ES = EXPOSED SITE
- MANUALS PROVIDE QD

WHAT LEVELS OF ACCEPTABLE DAMAGES DO THESE QD IMPLY ?

THE NEED

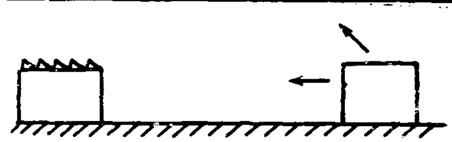
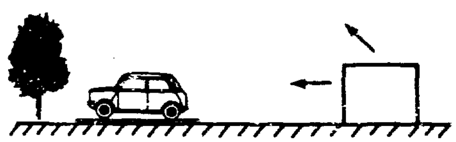
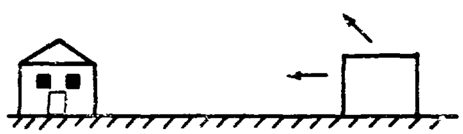
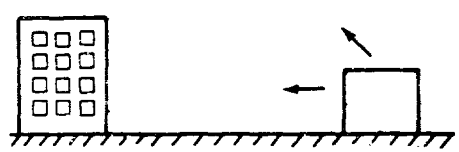
- LEVELS OF PROTECTION AGAINST INSTANTANEOUS PROPAGATION OF EXPLOSION FOR 1.1 PRODUCTS, PROPAGATION OF COMBUSTION FOR 1.3 PRODUCTS ARE WELL DESCRIBED IN MANUALS IN FUNCTION OF QUANTITIES AND DISTANCES FROM THE PES.

- LEVELS OF DAMAGE TOWARDS PERSONS AND PROPERTIES, FROM 1.1 PRODUCTS ARE WELL DESCRIBED, AS WELL.

- LEVELS OF DAMAGE FROM 1.2, 1.3 AND 1.4 PRODUCTS IN FUNCTION OF QUANTITIES AND DISTANCES ARE POORLY DESCRIBED, IN GENERAL.

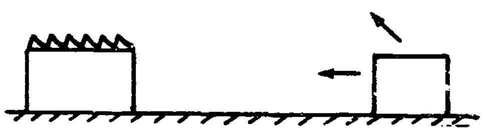
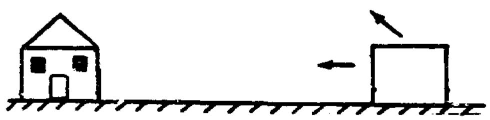
EXAMPLE OF LEVELS OF DAMAGES TOWARDS PERSONS
DECRIBED BY NATO MANUAL D/258
FROM 1.1 PRODUCTS

PES = LIGHT STRUCTURE, UNBARRICADED

CONFIGURATION ES/PES	RECOMMANDED QD	EXPECTED INJURIES AT THESE QD
	QD = 8 Q 1/3	SERIOUS INJURIES WHICH MAY RESULT IN DEATH.
	QD = 15 Q 1/3 QD = 22 Q 1/3 (Busy roads)	NO SERIOUS INJURIES INJURIES CAUSED BY GLASS BREAKAGE OR DEBRIS AND FRAG.
	QD = 22 Q 1/3	POSSIBLE INJURIES CAUSED BY GLASS BREAKAGE OR FLYING/FALLING DEBRIS.
	QD = 44 Q 1/3	POSSIBLE INJURIES ONLY BY GLASS BREAKAGE.

EXAMPLES OF LEVELS OF DAMAGE TOWARDS PERSONS
DESCRIBED BY MANUALS
(1.3 PRODUCTS, COMPATIBILITY GROUP C)

PES = LIGHT STRUCTURE, UNBARRICADED

CONFIGURATION ES/PES	RECOMMANDED QD	EXPECTED INJURIES
	3.2 Q 1/3	IMMUNITY FOR PERSONNEL WITHIN THE EXPLOSIVES WORKSHOP
	6.4 Q 1/3	NO DEATH, NOR SERIOUS INJURIES TO THEIR OCCUPANTS

USING A SNPE COMPUTER CODE "THAFT" WE HAVE TRIED TO DESCRIBE ACTUAL DAMAGES AT RECOMMENDED QD. THE COMPUTER CODE THAFT PROVIDES TWO DISTANCES :

DSR = DISTANCE WITH STATIC RECEPTOR : THE MAXIMAL DISTANCE AT WHICH A STATIC PERSON IS BURNT AT THE 2nd DEGREE, BARE SKIN.

DDR = DISTANCE WITH DYNAMIC RECEPTOR : THE MAXIMAL DISTANCE AT WHICH A DYNAMIC PERSON IS BURNT AT THE 2 nd DEGREE, BARE SKIN. DYNAMIC, MEANS THAT THE PERSON IS SUPPOSED TO RUNAWAY AT 5 m/s IN THE GOOD DIRECTION AFTER A TIME OF REACTION EQUAL TO TWO SECONDS.

PES

a) 10,000 Kg OF GUNPROPELLANT IN PLASTIC BAGS SUPPOSED TO BURN IN 15 s,

b) 70,000 Kg OF GUNPROPELLANT IN PLASTIC BAGS SUPPOSED TO BURN IN 30 s.

	10,000 Kg	70,000 Kg
QD FOR EXPLOSIVES WORKSHOP	70 m	140 m
QD FOR INHABITED BUILDINGS	135 m	265 m

ES	10,000 Kg	70,000 Kg
EXPLOSIVES WORKSHOP	EVEN IF THEY RUNAWAY, PEOPLE IN THE OPEN ARE BURNT AT THE 2nd DEGREE BARE SKIN	
INHABITED BUILDING	EVEN IF THEY DON'T MOVE PEOPLE ARE NOT BURNT	IN THE OPEN, IF THEY RUNAWAY PEOPLE ARE NOT BURNT. IF THEY ARE STATIC, THEY ARE BURNT AT 2nD DEGREE, BARE SKIN

ACTUAL EXPECTED INJURIES AT RECOMMANDED QD FO PEOPLE IN THE OPEN

WHAT DOES IT MEAN ?

1 - FOR INHABITED BUILDINGS THE SAME QD DON'T PROVIDE CONSISTENT LEVELS OF PROTECTION FROM 1.3 PRODUCTS.

2 - WE REALIZE THAT FOR AN EXPLOSIVES WORKSHOP, PEOPLE IN THE OPEN CAN BE BURNT AT THE 2nd DEGREE, BARE SKIN, EVEN IF THEY RUNAWAY.

3 - WE REALIZE THAT FOR INHABITED BUILDINGS, PEOPLE IN THE OPEN HAVE TO RUNAWAY AND LOOK FOR A SHADOW.

FURTHER WORK MUST BE DONE ON LEVELS OF ACCEPTABLE DAMAGE FROM 1.3 PRODUCTS.

FRENCH REGULATION APPROACH

FRENCH REGULATION DEFINES 6 AREAS OF DECREASING LEVEL OF POTENTIAL DAMAGES TOWARDS PERSONS AND PROPERTIES DIVIDED BY 5 (RED, ORANGE, YELLOW, GREEN, BLUE) LINES.

Z1 RED LINE	LETHAL INJURIES IN MORE THAN 50 % OF CASES, VERY SEVERE DAMAGES TO PROPERTIES
Z2 ORANGE LINE	SERIOUS INJURIES WHICH MAY BE LETHAL, SEVERE DAMAGES
Z3 YELLOW LINE	INJURIES, MEDIUM AND SLIGHT DAMAGES
Z4 GREEN LINE	POSSIBILITIES OF INJURIES, SLIGHT DAMAGES
Z5 BLUE LINE	VERY LOW POSSIBILITY OF SLIGHT INJURY, VERY SLIGHT DAMAGE
NDZ	NO DANGER ZONE

IN FUNCTION OF THE PROBABILITY OF ACCIDENT, CLASSIFIED IN FIVE LEVELS P1 TO P5, AND OF THE NATURE OF THE POTENTIAL EXPOSED SITE, FRENCH REGULATION DESCRIBES IN A TABLE WHAT IS ACCEPTABLE OR NOT

EXAMPLE : ES = INHABITED HOUSE

(Nota P1 = PROBABILITY FOR A STORAGE CONFIGURATION)

<table>
<tr><th>Pi / Zi</th><th>P1</th><th>P2</th><th>P3</th><th>P4</th><th>P5</th></tr>
<tr><th></th><th colspan="5">INCREASING LEVEL OF PROBABILITIES OF ACCIDENTS</th></tr>
<tr><td>Z1

Z2
Z3</td><td colspan="5">NOT ACCEPTABLE

YELLOW LINE</td></tr>
<tr><td>Z4</td><td colspan="2">INHABITED ISOLATED HOUSES ONLY OR LINKED TO THE ESTABLISMENT
GREEN LINE</td><td colspan="3">NOT ACCEPTABLE</td></tr>
<tr><td>Z5</td><td colspan="4">INHABITED HOUSES EXCEPT (SEE UNDER)

BLUE LINE</td><td>ISOLATED HOUSES ONLY</td></tr>
<tr><td>NDZ</td><td colspan="5">BUILDINGS OF GREAT HEIGHT, DENSELY INHABITED AREAS, GATHERING PLACES (CHURCHES, ...)</td></tr>
</table>

ASSOCIATED TECHNICAL CRITERIA CAN COMPLETE THE DEFINITION OF DAMAGE (EXAMPLE FROM SNPE)

- Z2 = "SERIOUS INJURIES WHICH MAY BE LETHAL"
  ----- FOR FRAGMENTS HAZARDS.

ASSOCIATED CRITERION FOR Z2 is CPL $<$ 0.1

WHERE CPL IS THE CONDITIONAL PROBABILITY OF LEHALITY DEFINED AS THE PROBABILITY OF KILLING SOMEBODY, SUPPOSING HE IS PRESENT IN A GIVEN AREA, SUPPOSING THE EXPLOSION HAS OCCURRED, TAKING INTO ACCOUNT THE DEGREE OF LEHTALITY (DEPENDING ON ITS KINETIC ENERGY) OF EACH PROJECTION.

LIMIT	DAMAGE DUE TO PROJECTION	
RED LINE	CPL = 0.5	
ORANGE LINE	CPL = 0.1	
YELLOW LINE	CPR = $3 \; 10^{-2}$	BY PROJECTIONS WITH AN ENERGY ABOVE 8 JOULES
GREEN LINE	CPR = 10^{-2}	
BLUE LINE	YFR = 10^{-7}	

CPL = CONDITIONAL PROBABILITY OF LETHALITY OF SOMEBODY *
CPR = CONDITIONAL PROBABILITY OF REACHING OF SOMEBODY *
YFR = YEARLY FREQUENCY OF REACHING OF SOMEBODY *

* SUPPOSING HE IS PRESENT ON THE LINE, SUPPOSING THE EXPLOSION HAS OCCURRED.

SUGGESTIONS

1 - WE SUGGEST THAT THE DIFFERENT MANUALS INTRODUCE THE NOTION OF COLOURED LINES WHICH WOULD MATERIALIZE HAZARDOUS ZONE LIMITS.

EXPECTED ADVANTAGES

THREE MAIN ADVANTAGES ARE EXPECTED THROUGH THIS NEW PRESENTATION OF QD. THESE ARE :

- CONSISTENCY

THE LEVEL OF POTENTIAL DAMAGES IS SIMILAR BETWEEN TWO LINES, WHATEVER IS THE HAZARD DIVISION AND THE TYPE (ABOVEGROUND OR UNDERGROUND) OF THE STORAGE.

- ACCURACY

QUANTITY-DISTANCES MAY BE CIRCULAR, BUT, FOR EXAMPLE IN UNDERGROUND MAGAZINES, THE EFFECTS ARE MAINLY ORIENTED. LINES TO DRAW SEEM MORE APPROPRIATE TO USE THAN CIRCLES.

- SIMPLICITY

USING THE SAME COLOURED LINES BETWEEN THE DIFFERENT COUNTRIES WOULD MAKE TECHNICAL EXCHANGES BETWEEN EXPERTS EASIER.

EXAMPLE = "IN FRANCE, ISOLATED INHABITED BUILDINGS MUST BE LOCATED BEYOUND THE YELLOW LINE". THIS SENTENCE SEEMS SIMPLE.

SUGGESTIONS

2 - DEFINITIONS AND DESCRIPTIONS GIVEN BY THE MANUALS FOR HAZARD DIVISION 1.1 COULD BE A GOOD START FOT THE REFLECTION ON ACCEPTABLE DAMAGES AND TECHNICAL CRITERIA FOR 1.2 AND 1.3 PRODUCTS.

CONCLUSIONS

EXISTING QD DON'T IMPLY ALWAYS CLEAR AND CONSISTENT ACCEPTED DAMAGES.

A PROGRESS COULD BE ACHIEVED THROUGH ADOPTION OF COLOURED LINES MATERIALIZING DEFINED DAMAGE ZONES.

TWENTY-FOURTH DOD EXPLOSIVES SAFETY SEMINAR

ADAM'S MARK HOTEL, ST LOUIS, MISSOURI

28 - 30 AUG 90

TITLE OF PAPER: EXPLOSIVES SAFETY IN THE NATO ENVIRONMENT

TIME FOR PRESENTATION: 20 MINUTES

TYPE OF PAPER: SUMMARY/INFORMATIONAL

AUTHOR/PRESENTER'S NAME: LT COL THOMAS J. POWELL

EXPLOSIVES SAFETY IN THE NATO ENVIRONMENT

ABSTRACT

This presentation consists of a summary of the current situation regarding weapons safety operations in United States Air Forces in Europe (USAFE). It will address some differences in national (U.S.) versus NATO criteria, potential impacts of recent nationalistic movements, problems with enforcement of U.S.-only rules, and proposals on how to redress the current difficulties.

The current situation regarding U.S. explosives and munitions in Europe is the result of the U.S.-NATO response to the massive Soviet-Warsaw Pact military build-up of the early 1980s. This period saw a growth of collocated operating bases (COBs), expansion of the prepositioning of munitions in support of the concept of forward deployment, and an exacerbation of the problem of already limited real estate to accommodate expanded base facilities, enlarged missions, and greater quantities of munitions required in support of higher sortie rates tasked and able to be supported. Introduction of improved hardened aircraft shelters (HASs) and other standard NATO facilities contributed to the complexity of explosives site planning in that no mutually-agreed upon criteria existed to determine acceptable explosives quantity-distance (Q-D) separation criteria between these facilities and associated explosives operations, or between them and non-associated exposures. The introduction of air base operability considerations highlighted the situation which was evolving, in that it soon became evident that past siting practices had created numerous "two-for-one" targeting opportunities and allowed our own explosives to hazard other of our own operations.

Currently, USAFE is engaged in precisely defining the number and types of explosives hazards through the risk assessment program for commanders. Other initiatives include supporting the insensitive munitions program, supporting the explosives testing program, encouraging and working toward a theater-wide approach to off-base explosives site planning (especially at railheads and waterports), and working to devise munitions storage approaches and operating procedures which will minimize Q-D separation requirements, provide a larger margin of safety, and ensure our capability to rapidly build-up/generate munitions in support of contingency operations.

Projections of future requirements are driving current efforts. Some of the future requirements we are preparing to support

include possible continued positioning of munitions at COBs, reduction of in-theater munitions maintenance personnel, fewer main operating bases (MOBs) with fewer wings, fewer aircraft, increased reliance upon NATO for support and probable major munitions releveling/redistribution using both overland (rail and truck) and over water transportation.

BACKGROUND:

During the early 1980s, there was a significant mission enlargement in terms of number of airframes assigned to existing bases and an increase in the numbers and types of munitions assigned to support them. From 1977 to 1985, the number of waivers and exemptions increased from 64 to 681, and, eventually, to nearly 800. This increase was driven by the necessity to quickly field the Ground Launched Cruise Missile (GLCM), to increase the percentage of prepositioned munitions which would be located at over 90 COBs, MOBs, or forward operating locations (FOLs), and to increased Q-D separations resulting from Distant Runner testing. In the effort to protect airframes, related equipment, and munitions, many types of facilities normally involving munitions operations were approved with zero or very low explosives weight. This produced HASs which could not accommodate sortie-required munitions and severely impacted non-related facilities within the Q-D arc of these potential explosives sites (PESs). Not only were mission areas impacted, but services and facilities normally located on CONUS air bases could not be constructed due to their proximity to these PESs. The real estate available on most NATO bases was inadequate to accommodate both living/recreation areas and mission areas. Not only were on-base areas constrained, but off-base civilian areas were impacted as well. Since additional real estate was not readily available, the solution was to waive or exempt on-base exposures and seek "restrictive easements" or exemptions to off-base exposures. The result was an astronomical growth in waivers and exemptions and an increased level of risk in on-base munitions operations as more and more dissimilar operations were consolidated within a relatively confined area. As the use of exceptions to Q-D rules became more and more widespread, the awareness of risks associated with their use appeared to decline. The exception had become the rule. This situation reached a climax in about 1985 when, following an Air Force Inspection and Safety Center (AFISC) explosives safety staff assistance visit in 1983, the Department of Defense Explosives Safety Board conducted a periodic survey. This survey highlighted the serious state of explosives operations and established a baseline upon which command actions to correct previous expedient measures had been based. Also in the 1983 - 1985 period, the explosives testing program was initiated to seek ways to improve the accuracy of and, where possible, reduce Q-D separations which unnecessarily constrained operations which could be safely conducted within the vicinity of explosives clear zones (Tab 5), and to attempt to develop explosives fillers and munitions which would be less sensitive to unintentional initiations. One of these programs was Have Block.

When the Have Block Program was initiated, USAFE suggested use of the International Shipping Organization (ISO) container and the Have Block pallet as a means of placing munitions at, or near, aircraft shelters. It was determined that this concept was inadequate and flawed. Although the diverter theory was valid, it was not operationally feasible as it required too much storage space, thus off-setting many of the intended benefits. The interim Have Block pallet, proposed for use within munitions storage igloos, was rejected because it did not allow use of maximum igloo volume. It was determined (in about 1985) that buffered storage provided greater benefits. It has subsequently been determined that buffered storage is beneficial in a bulk storage environment, but that it creates many restrictions in an operational environment.

The munitions testing program was beginning to be formalized in 1985. Tests initially proposed included AIM-7 with WAU-17 warhead for propagation both in and out of all-up-round (AUR) containers, Durandal in aircraft shelters, General Purpose (GP) bomb propagation to missiles in AUR containers stored in igloos, validation of minimum required distances for separately-packed components by subjecting them to explosives in quantities needed to build complete rounds, security police munitions in armory configurations, each munition in its various environments (e.g., transport, storage, in HAS, in open built-up areas), validate service life restrictions on unpackaged components to determine whether there is a reliability impact by having more pre-built bombs, all missiles (AGM-45, AGM-78, AIM-120, AGM-65, AIM-9) both in and out of their AUR containers. As early as July 1985, NATO countries were asking for results of the explosives testing program. They appeared to be willing to be more flexible in their national rules based on findings we had made to date. Tests at Hill AFB, Utah, were designed to determine if GP bombs cause cluster bomb units (CBUs) to detonate completely, or whether only part of the CBU contributes to the explosion; if CBUs placed between adjacent stacks of bombs prevent propagation between stacks; if inert items such as fins are placed between adjacent stacks of bombs, will prevent propagation? Conclusions indicated that (a) GP bombs normally cause CBU detonation, but specific nose-tail alignment of CBUs in relation to the bombs may prevent some CBUs from exploding; (b) CBUs in wooden crates provide a buffer which prevents propagation between bomb stacks about 25% of the time, while CBUs in metal containers prevent propagation about 50% of the time; (c) inert items between stacks of bombs prevent propagation between stacks; (d) 20mm ammunition/explosives bomb components reduce stack-to-stack propagation to a large extent; (e) use of metal fuze well covers greatly reduces a bomb's susceptibility to propagate; (f) fuzed bombs also more effectively reduce propagation; (g) current fuzes effectively withstand blast overpressures and fragments from a 21,000 lbs net explosives weight (NEW) explosion. These findings led to the following:

Reduced Q-D between munitions storage and overseas runways/taxiways from K30 to K4.5. Adopted by NATO.

Reduced GLCM Q-D based on insensitive high explosives (IHEs).

Reduced Q-D for 20/30mm through DDESB approval of modular storage concept.

Reduced combat aircraft-related functions from K40 to K18.

Allowed use of lower Q-D for small numbers of bombs.

Eliminated Q-D for class 1.2 CBUs and 20/30mm ammunition in shelters.

Reduced Q-D for bombs in aircraft shelters by 60%.

Reduced Q-D for AGM-65, AIM-7/9, and AGM-82 missiles from 1,250 feet to between 400 feet and 500 feet.

Developed emergency Q-D for wartime storage of predirect munitions.

Eliminated Q-D for under 110 lbs 1.1 explosives in HASs.

Reduced Q-D for igloos containing less than 100,000 lbs NEW.

Reduced Q-D for AIM-7/9 missiles stored in AUR containers, based on propagation between containers.

Reduced Q-D between igloos and modules, and vice versa.

Reduced Q-D between shelters and munitions storage sites from K18/30 to K5/8.

Reduced 1.4 explosives Q-D from 80 feet to 50 feet.

Achieved approval for reduced Q-D between interservice facilities (from K40 to K11/18).

Established public traffic route distance for 1.2 explosives at 60% of inhabited building distance.

Reduced Q-D from igloos to aboveground magazines from K6 to K4.5.

Reduced Q-D from aboveground magazines to igloos from K6 to K4.

Reduced Q-D for igloos containing bombs, CBUs, and 20/30mm ammunitions from K1.25 to K1.1.

Explosion-proof fixtures are now required only where a hazardous atmosphere (explosives vapors, dust) exists. This is normally limited to laboratories, production facilities, or manufacturing activities. At operational Air Force units, the only environments which require explosion-proof fixtures would normally be areas where paint, solvent, or fuel vapors were present. However, all electrical installations in explosives facilities must meet host nation codes. In the case of the United Kingdom, we must meet the requirement for explosives-proof fixtures.

Proposed future tests included the following: (a) AGM-65 to reduce non-propagation spacing requirements, (b) test propagation distances and maximum credible event (MCE) of "ready use" munitions on trailers in igloos and in aircraft shelters with bulk munitions stores, (c) determine propagation probabilities of explosives bomb components separated from bomb bodies by bomb fins in a storage facility, (d) determine propagation probabilities between MK-82/-84 bombs and the MK-20 in storage, (e) test MK-20 to obtain 1.2 rating, (f) verify that AGM-45 and AGM-65 motor do not contribute to warhead explosion, (g) verify AIM-9 22-inch non-propagation distance, (h) conduct scale model aircraft shelter tests to reduce Q-D zones currently associated with them.

CURRENT SITUATION/INITIATIVES:

The USAFE Weapons Safety Program consists of both explosives and nuclear safety elements. Our program encompasses 20 MOBs, 76 COBs, 7 FOLs, 12 munitions support squadrons (MUNSS), and

2 GLCM sites. Our main base installations occupy an area smaller than Eglin AFB.

One of the major initiatives still supported by USAFE is the new Munitions Testing/Insensitive Munitions Program. The following USAFE-proposed tests are designed to determine, and where possible reduce, required separation distances: (a) HAS fragment hazard test to determine the amount of NEW it takes to destroy a HAS from an internal explosion and whether there are any munitions placement schemes able to be used to reduce the likelihood of large chunks of concrete from the resulting destruction, (b) development of insensitive munitions, (c) final testing and deployment of 40mm grenade carrying cases, (d) Lightning protection tests to determine the effect of lightning on a variety of munitions, (e) obtaining a larger variety of buffering materials for use in buffered storage arrays. (This is essential if buffered storage will have any value in a tactical environment.) and (f) munitions storage module--efforts are being made to obtain approved module designs and future maintenance cost comparisons to reduce costs of munitions igloo construction. USAFE is trying to work the problems, but, due to the SECAF freeze on construction, it is difficult to determine what the application of the answers will be. We need to develop sound procedures to gain concurrence with our proposals. To develop these procedures, we need logical, validated databases derived through commonly-determined test criteria. We need to properly plan explosives operations, and gain site plan approval before start of construction.

Since 1987, HQ USAFE/SEW has emphasized the need for an interface with NATO to help implement new concepts in explosives separation distance and resulting Q-D separations and to help establish a common ground of understanding. To date, the DDESB has taken the lead in presenting the U.S. views on explosives operations issues and criteria. However, theater participation as an advisor to DDESB on current operations in the command would benefit both USAFE and the DDESB. This is due to many differences of approach and assumptions in Q-D criteria. Some examples of country-to-country differences in standards or limitations resulting from them include the following:

There are no USAFE airfields possessing the 3,200-foot explosives clear zone required by the U.S. for Durandal use without the DD-2 safety device.

Base comprehensive plans in some countries were identified as a problem in 1985. Units were requested to identify those areas where clear zones entered off-base land, and to identify any facilities that may have been within the clear zones.

Construction of facilities without approved explosives site plans has been a concern since at least 1986. HQ USAF/IG requested guidance on how to preclude funding for such projects prior to U.S. safety review and approval. Significant problems with explosives sitings were again addressed in 1988 by AFISC. It appeared that everyone thought there was no problem with the logic that "provision of these wartime facilities, at a reasonable price, was more important than perfection of their siting." This did not consider the "basic survivability and operability" of the facilities. USAFE then expressed concern for proper site planning and emphasized that enforcing proper Q-D was essential operationally. To date, many explosives plan packages (EPPs) remain to be approved by NATO-member command authorities. Some proposals have been made by member countries to expedite siting: site munitions igloos at a maximum of 45,000 kg NEW, base HAS NEW on operational needs, prevent violations of U.S. explosives safety criteria by basing allowable exercise NEW on distance to existing host facilities. Reduce the exercise NEW to keep the aircraft shelter loop "violation-free." These restrictions were acceptable to the USAFE staff; however, we expect continued problems of this type unless political questions not related to the siting can be resolved.

Explosives site plans were not developed and submitted early enough in the planning process. Often Q-D requirements were not adequately considered in initial planning and constrained the project. (See Tab 1.)

The U.S. basis for Q-D separation requirements is the MCE--the worst single event likely to occur in a given quantity and configuration of munitions. (See Tab 2.)

Waivers/exemptions (host nation and NATO exposures). Historically, and even today, the U.S.-NATO-host nation waiver/exemption process is complicated, lengthy, vague, and frustrating. Tab 3, "The U.S. Waiver/Exemption Process at COB Locations," could be streamlined if the process were standardized for all NATO countries.

AC/258, Part I, para 101c, could be amended to process waivers/exemptions to NATO criteria in the same manner and at the same level as waiver/exemptions to AFR 127-100, provided the theater representative coordinates with the host. The Commander-in-Chief (CINC) would then be able to approve an exemption meeting 75% of U.S. criteria, but not meeting 75% of NATO criteria.

When waterports are owned and operated by the host nation (reference criteria in DOD Standard 6055.9) we should recognize host rules. If there are none, we should conclude agreements stating how we will operate. Military Traffic Management Command simply manages the traffic and acts as a focal point for U.S. interests. Neither EUCOM nor component commands have any control over port operation or those of railheads. We must abide by the port's operating rules, and U.S. waivers have no impact because we are unable to reduce any risks (except by reducing the total NEW on-site at a given time). So long as we have done a current port survey, identified the risks, and notified the host of the risks, and the host nation has accepted them as consistent with their criteria, they will normally accept the associated risks.

Regardless of our successes in establishing valid Q-D separation requirements, we are still required to live by host nation and NATO standards in our explosives operations risking other than U.S. resources. In the past, many hosts have accepted our criteria; however, we must live by theirs until they accept ours, if theirs is more restrictive. (It is established in DOD Standard 6055.9, para 1a3, that we must apply the more restrictive of U.S. or NATO criteria to on-base or off-base exposures. The problem comes in when we seek to obtain host nation acceptance with the U.S. standard. Since neither NATO, nor the host nations recognize the primacy of U.S. public law or departmental administrative rules, the services in-theater are powerless to enforce U.S. criteria on an unwilling host.)

In some cases, in order to expedite action, we had to buy unacceptable facilities or beddown conditions when we put new missions into bare bases and are forced to accept unreasonable risk. For example, prior to 1982, explosives weights for facilities were computed on available distance to the nearest restricting resource. They were seldom based on warfighting requirements. "Exercise waivers" could be approved locally and were used to meet wartime tasking. They were not included in the database for base development; thus, real risk was not considered in base development. Facilities required to be abandoned or destroyed to get approval for explosives facilities were not destroyed or abandoned. Real risk remained or increased. Facilities were sited for the current usage only. This often limited them to a single use in the future as well. Risk management actions such as hardening, controls on type and quantity of munitions, and dispersal of assets are now used to reduce separation distances.

HQ USAFE/SEW communications concerning a proposed MOB Secretary of the Air Force (SECAF) exemption, in November 1988, agreed with deletion of the proposed incremental public traffic route separation for aircraft generation facilities; inclusion of three phase or transitional siting in the new AFR 127-100, and use of U.S. criteria only if the host does not concur with the exemption. It noted that, especially in some NATO regions, processing times for the exemption may be greater than for normal sitings as host nation coordination is required for off-base areas. (All future U.S. overseas sitings should be done in such a way that all explosives clear zones fall within base boundaries. This would reduce the complexity and political sensitivity of negotiations.)

NATO philosophy does not recognize the HAS as a PES. However, this is not a critical difference since current wartime sortie generation taskings will not create sympathetic propagation as the NATO aircraft shelter survivability separation normally provides adequate protection. But, depending on aircraft load, aircraft survivability may be sacrificed as NATO does not differentiate between AFR 127-100, Tables 5-7 and 5-8, criteria. The chief impact of not considering the HAS as a PES for site planning purposes is to related or supporting facilities. If NATO adopted U.S. criteria, the present situation relative to HAS-to-HAS separation would remain unchanged as the NEWs of a number of shelters are limited due to surrounding resources. If adopted for future construction, U.S. criteria would provide a more dispersed relationship for the HAS and supporting non-explosives facilities, thereby optimizing maximum NEWs and protecting our supporting facilities.

Third generation HASs must meet the NATO separation of 60 meters between adjacent shelters and 100 meters center-to-center. U.S. distances are far less restrictive (except for the USAFE requirement to provide 300-foot separation side-to-side due to findings from Distant Runner). The most important siting features employed in NATO sitings are 60 meters edge-to-edge, 100 meters center-to-center, no more than 4 semihardened facilities or POL tanks in a line within 500 meters, 150 meters from any HAS edge to a POL tank larger than 50 cubic meters, 15 meters from centerline of a taxitrack, 100 meters from centerline of a parallel taxiway, 150 meters from centerline to runway, 7-to-1 side slope from runway lateral clearance zone or parallel taxiway to lateral clearance zone.

U.S. forces deploying to COBs may be restricted from exercising with realistic weapons loads, especially where U.S. aircraft will be positioned in HASs with munitions. This is due to reduction of U.S. NEW to comply with U.S. standards. Where U.S.-titled munitions are employed, sitings must meet U.S. safety criteria. Actions taken concerning considering the HAS as a PES will be pretty much a CINC decision as USAFE and PACAF are the only places with the problem. This is a significant problem, since some MODs will not approve COB sitings and accept the U.S. SECAF COB exemption, which effectively allows exemption of U.S. Q-D separation requirements from U.S. munitions to host nation exposed sites to comply with less stringent host criteria.

The design variants of approved U.S./NATO HASs should have had Q-D criteria developed prior to actual EPP submittal and approval. The main differences should have been addressed and their inputs determined. Testing, after-the-fact is currently proceeding to develop empirical data needed for this evaluation.

The NATO Airfields Section has never considered explosives safety distances when siting HASs for combat aircraft despite the fact that the aircraft in them will be explosives-loaded. As a result, some may be built so close together or to other facilities as to render them operationally useless. The need to consider explosives Q-D was left out of original HAS requirements. Subsequent attempts to rectify the situation have been marginally successful, since there is a perception that safety considerations will require more land and increase costs. They also considered that increased costs would be an additional U.S. expense as the added costs would be national, rather than a NATO requirement. The NATO approach is to keep the HAS free of explosives during peacetime and waiver the requirements away in wartime. It should be noted that some host nations fully load their shelters regardless of NATO wishes once the HAS is constructed. However, many of the aircraft shelters occupied or planned to be occupied by the U.S. Air Force will shelter fully armed combat aircraft during peacetime and wartime. Without proper Q-D separation, secondary explosions may well propagate to other nearby shelters and result in the destruction of most or all of the combat aircraft located on-base. These limitations restrict their combat effectiveness.

In one case, a paper provided to the AC/258 storage subgroup meeting of 22 - 23 November, 1988, indicated one non-U.S. Air Force member will consider the protected aircraft shelter (PAS) to be a PES whenever an aircraft is parked there. It will be considered an explosives site (ES) to other areas where ammunition is stored. In a crisis, two aircraft ammunition loading cycles will be required in this country's PASs and, in wartime, provision of ammunition for aircraft ammunition loading cycles of one full day is the objective. This country also proposed that each nation should be responsible to establish regulations on explosives safety distance. But, they cannot agree to a modification of AC/128/D328 in the sense of not considering the PAS a PES/ES. According to this country's national regulations, only about 30% of its PAS are qualified for storage of live ammunition in crisis/wartime, because safety siting and construction of infrastructure were previously performed without duly observing the applicable explosives quantity safety distances. They are making every effort to improve this situation. Additional infrastructural requirements resulting from the explosives quantity safety distances established at national levels should, therefore, be funded nationally. For example, one MOD announced their intention to equip all new and existent HASs with an "in-shelter refueling system and provide them with emergency power." Up to four aircraft shelters are to be connected to a joint support facility. Design of the system will consider both weapons safety and survivability (weapons effects). The paper develops a weapons effects assessment based on direct hit probabilities from an attack.

Explosives sitings must ensure the best possible use of the available land by giving the best fit of facilities and do not necessarily increase project costs since siting does not impact on shelter design. They do, however, ensure consideration of survivability and operability. The NATO 100-meter and 60-meter HAS-to-HAS separation requirement for survivability is a partial recognition of this problem. Although several low-NEWed first generation HASs were converted to maintenance shelters which will be manned. Many were constructed solely for the purpose of maintenance, not for explosives. Working them through both historical recovery and change-of-use, they were sited under AFR 127-100, Tables 5-7 and 5-8, or were constructed by NATO without any explosives siting considerations. It was suggested to use K18 to the front doors and K9 to the sides and rear without a 300-foot minimum separation.

In some cases, the prior-to-site plan approval of introduction of munitions into storage has been done at the host's request.

HQ USAFE must respond quickly to a host's prefinancing. However, siting information for the specific type of facilities must be available. The siting criteria and location maps are needed. HQ USAFE/SEW has prohibited use of storage facilities until the siting approval could be worked out. This has been a joint HQ USAFE/SEW/DEN/LGW effort which also stopped future shipments there until the siting details can be worked out, and after-the-fact siting accomplished.

NATO and U.S. siting process work separately. (For COBs, the host nation is responsible for siting and conducting the safety review.) While AC/258 is used as the basis for siting, it does not address U.S. HAS or flightline rules and the host nation submits the funding request. The NATO philosophy for facility construction (provide only for current operational needs (wartime facilities), consider flightline areas as related facilities, differences with single nations) conflicts with U.S. and some NATO member nations' criteria.

Land availability. Many sites are no longer protected by easements (or servitudes, as they are called in Italy) for their storage areas' off-base exposures.

A problem for many COBs, and some MOBs, is the proximity of host nation munitions storage areas to U.S. munitions areas. In many cases, the host nation will not provide any information concerning the NEW and hazard class/division of its stored munitions, thus making it difficult for the U.S. munitions personnel to determine whether they have storage violations.

In some cases, two separate services using host nation land, but located on separate installations, have munitions storage areas located adjacent to each other, but separated by a public highway. Each is the target to the other, but since there is an intervening highway between them, the road is targeted by both of them since it is currently used by civilians. The problem in this case, is that the local community has grown accustomed to using the roadway, and although intended only for military use, the local police have become unwilling to restrict traffic, and the military police considered the road outside of their jurisdiction.

An enforcement mechanism such as COB siting boards is needed which stresses versatility in future wartime use for new construction. This body should be able to limit or preclude facility use during peacetime; promulgate bilateral agreements with host on safety requirements and establish joint criteria; obtain NATO siting approval prior to release of funds; establish

HAS as a PES. (This, however, is not a significant problem so long as the host nation recognizes the 300-foot HAS separation requirement.)

We need to identify the proper EUCOM/SACEUR point of contact through which to work the problem as a theater-wide action once we have defined it properly. We can then limit or prevent use of the facility until it is properly sited and approved. HQ USAFE/SEW proposed beginning acquisition of required land to enable ourselves to comply with the AFR 127-100 requirements. Regardless, the CINC must make official notification to NATO that HASs for U.S. combat aircraft must be sited for explosives. In NATO's view, only a CINC's input will be paid attention to since, in their view, no other U.S. agency or individual has the right to input a requirement in this area to NATO. Even though only COBs remain to be built, we should employ proper site planning there for the same reasons as we employ proper site planning at our MOBs--survivability and operability.

A working group was formed in 1988 to discuss and address differences in U.S. and NATO siting criteria and to identify the problems this caused. This group has been recently reactivated to address other siting issues, to identify construction projects and their funding status, and to recommend how these would be controlled. HQ USAFE/SEW continues to work to be included in preliminary review of joint projects in order to ensure projects do not begin until approved by DDESB or they have SECAF safety exemption approval if problems exist. (See Tab 4, "Project Review Procedures.") In order to accomplish these objectives, we participate in a variety of joint U.S./host nation munitions working groups.

CONCLUSION/FUTURE PROJECTIONS:

The solution in establishing commonly-agreed safety criteria in NATO is to improve our risk identification program so we can implement a good risk management program. First, we must identify the hazards and the potential dangers inherent in our existing operations, evaluate the impact to surrounding operations/facilities, and tie the analysis together to see how we can minimize or manage risks while still accomplishing the assigned mission effectively.

We must analyze all of our operations including base closures where operations presently covered by waiver or exemption may have had construction programmed against them to fix the exposure. With the known base closure list out, many of these projects will be cancelled. Do we need to extend the waivers to maintain the coverage? Some other elements to consider are:

Determine the impact of not considering the HAS as a PES, so long as the 300-foot hazard protection zone applies.

Evaluate the site plans for each COB/MOB to determine how may HASs are not separated by 100 meters side-to-side. If all sites have the 100-meter separation, there should be enough protection to store minimum mission-essential NEWs.

If the 300-foot hazard protection zone is adequate to provide minimum Q-D for two sortie loads prepositioned, plus one on the aircraft, there is no problem.

As collocation becomes an issue with "the vault in the HAS" concept, there may be no alternative but to consider the HAS as a PES, but there may be no impact if the 300 feet provide adequate Q-D separation as well as adequate hazard protection. In fact, the in-HAS vault may open the door for more in-HAS storage or conventional munitions in vault-type arrangements. Mini-vaults inside igloos could eliminate the need for munitions storage/iglous/areas, thus providing more space for greater separation between flightline and other base activities.

Performing bomb build-up inside igloos may provide a survivability measure. However, in-igloo build-up may not allow for effective operations due to cramped working conditions. Since munitions maintenance personnel prefer outside build-up, we may need to develop more efficient in-igloo bomb build-up procedures and equipment or develop other types of survivable bomb assembly facilities.

Approve the measures to allow peacetime storage of complete round bombs in tasked combat configuration. However, the question of service life testing for bomb components, particularly fuzes, must be addressed in order to minimize unnecessarily high inspection requirements. This te[illegible]s needed to allow better data for decision-making on whether to pre-build greater quantities of bombs, to thereby enhance storage, safety, and operational readiness. AUR storage may be only a good measure if war is imminent, not a day-to-day peacetime measure. Developing workable procedures now will help ensure the capability to generate the numbers of munitions needed to support potentially-high future conflict sortie rates. AUR storage violates some national compatibility laws. This also points up need for mutually-agreed-upon criteria.

In conclusion, we have overcome many problems, have identified many more, and need to continue the positive cooperative efforts we have begun. So long as we conduct joint operations in support of NATO commitments, we must develop mutually acceptable or standardized approaches to controlling or limiting the hazardous impacts our explosives create in our total operations.

THE U.S. EXPLOSIVES SITE PLANNING PROCESS

If U.S. Q-D standards cannot be met where host country requirements are less stringent, an exemption signed by the SECAF is required. Therefore, a long lead-time action is required after funds become available. Therefore, actions were directed to perform the following:

Identify all construction projects that need explosives site plans early.

Determine user needs at start of siting process and determine if secretarial exemption will be required to meet those needs.

Obtain weapons safety advise as soon as it is known that an explosives site plan is required.

Establish and monitor project milestones at civil engineers.

Submit the explosives site plan at the 35% design stage.

Identify projects past the 65% design which do not have explosives site plan approval and contact concerned agencies if required.

Validate project and explosives site plan data at the 95% design review. Amend project/site plan as required and process the amendment through proper channels.

Ensure the validated/amended site plan is approved and restrict construction start until approval is confirmed.

Actions taken HQ USAFE/DOQ/XPX/XPP all may affect employment concepts, commitments, and munitions storage requirements for current and future USAFE units.

TAB 1

MAXIMUM CREDIBLE EVENT RATIONALE

Previously Department of Defense-based MCE on the assumption that all munitions at a single location would explode at the same time.

USAFE questioned the old MCE assumptions through a series of tests representing actual situations. One problem area was the danger posed from fragments of the HAS as it broke up in an explosion. Due to this danger, a 300-foot safe zone was established around the shelter. Tests were proposed to position munitions differently inside the shelter to ameliorate the effects of an explosion, and reduce probability of sympathetic explosions. Placing bombs at an angle of 15 degrees from the side wall of the shelter reduced exposure to the other munitions to the point that propagation would not occur. This was demonstrated to reduce the MCE to three bombs when loaded on a TER, or to one, when suspended individually. This reduced Q-D from 895 feet to 525 feet. Another problem in a storage environment is that we "Q-D out" before we "cube out," normally in USAFE due to exposure to a critical resource or civilian exposure which should not be placed at risk.

Efforts to use inert components or less sensitive munitions as buffers/barriers to reduce sympathetic detonation were made.

Along with buffers, positioning was used as a means of reducing propagation, along with positioning, bomb configuration was also determined to be important; i.e., the need to keep fuze wells closed with either a metal end plate of a fuze. (According to tests made using a variety of munitions, current fuzes can effectively withstand blast overpressures and fragments of an explosion of 21,000 lbs NEW.

Using the buffered storage principle, and with proper storage planning, we could effectively more than double our NEW storage capacity in existing igloos.

TAB 2

THE U.S. WAIVER/EXEMPTION PROCESS AT COB LOCATIONS

			PES			
			U.S.		HOST	
			AMMO IGLOO	FLIGHTLINE	AMMO IGLOO	FLIGHTLINE
ES	U.S.	AMMO IGLOO	AFR 127-100 CRITERIA WAIVER/EXEMPTION	AFR 127-100 CRITERIA WAIVER/EXEMPTION	* #	* # HOST HAS NO CRITERIA @
		FLIGHTLINE	AFR 127-100 CRITERIA WAIVER/EXEMPTION	AFR 127-100 CRITERIA WAIVER/EXEMPTION	* #	* # HOST HAS NO CRITERIA @
	HOST	AMMO IGLOO	MOST RESTRICTIVE COB SECAF EXEMPTION &	MOST RESTRICTIVE COB SECAF EXEMPTION &		
		FLIGHTLINE	MOST RESTRICTIVE COB SECAF EXEMPTION &	MOST RESTRICTIVE COB SECAF EXEMPTION &		

* There is no sure way to know what the host nation will store in terms of NEW.
1. We must work from unknown quantities if the host will not disclose the information.
2. A host may have a waiver or exemption program that allows an increase in NEW without any requirement to notify us.
3. Countries without criteria may just ignore the amounts they store.
4. There is no integration of an approval process for site plans or exemptions from a host country to the U.S.

\# Minimum criteria to prevent propagation is intermagazine (IM). The host may not have the same IM criteria.

& Three sources of criteria:
1. AC/258.
2. Host criteria, if applicable.
3. AFR 127-100.

@ This is typical for most of the countries. NATO does not recognize the HAS as a PES.

TAB 3

PROJECT REVIEW PROCEDURES

Ensure a preliminary explosives safety review of all NATO construction projects for facilities to be used for U.S. titled munitions command-wide. (This review occurs prior to the "Type B" estimate to our NATO counterparts.)

Stop construction on NATO projects until DDESB approval is received or SECAF exemptions are approved. (This is essentially outside our control if it is a NATO-funded project.)

HQ USAFE/DE provides a computer listing of all known NATO construction projects. These procedures were designed to preserve mission capability and to fulfill U.S. requirements as well as those of NATO.

TAB 4

WHAT CAN BE DONE TO CORRECT/MANAGE THE PROBLEMS

We must encourage the conscientious analysis of risk at the senior manager level so that options allowing achievement of mission objectives most safely are selected.

We must have the energy, resolve, and intelligence to enforce established restrictions.

Long-term solutions center on improved aircraft shelter design, development of an IHE, and land acquisition.

Establish realistic clear zones based on anticipated munitions loads.

Use inert bombs with live fuzes and adapter boosters when possible.

Designate low NEW-authorized shelters for CBU and missile operations.

Use petroleum oil lubricant (POL) shelters for forward storage of CBUs and missiles.

Use shelters with good unwaivered capacity for forward storage of bombs.

Separate AIM-7/9 missiles to prevent propagation.

Place CBU and missile trailers in shelters to eliminate Q-D requirements.

Separate AGM-65 maverick missiles by 130 inches to prevent propagation. (Two missiles will cause extensive concrete spalling.)

Support storage of munitions in HASs. This procedure should be allowed so long as storage of GP bombs is along one HAS wall at a 15-degree angle, with 4-foot separation between MK-84s and other bombs, and 30-inch separation between MK-20 and MK-82s. The NEW of all bombs need not be added together. The shelter NEW for a loaded aircraft with additional weapons in storage becomes the total of BRUs/MERs on one wing (for all aircraft except A-10 and F-4. On these aircraft, the total load on both wings is used. The NEW for MK-84s is the total NEW of all stations. For all munitions, whenever centerline carriage is used, total NEW for all stores on the aircraft should be considered. When munitions are stored in HASs, plans must outline procedures to deal with electromagnetic radiation hazards from aircraft to munitions and to control dangers from forward-firing ordnance.

TAB 5

TWENTY-FOURTH DOD EXPLOSIVES SAFETY SEMINAR

OUTLINE

SECTION I. BACKGROUND

A. MISSION ENLARGEMENT DURING THE 1980'S

1. INCREASE IN RESPONSE TO PRESIDENT REAGAN'S EMPHASIS

(A) LARGER NUMBER OF TACTICAL FIGHTER SQUADRONS

(B) EMPHASIS ON FORWARD DEPLOYMENT/PREPOSITIONING

B. CONSTRUCTION/FACILITIES EXPANSION (NATO AND U.S.)

1. Q-D NOT ALWAYS CONSIDERED IN INITIAL PLANNING

2. EXPLOSIVES SITE PLANS SUBMITTED BEFORE CONSTRUCTION START

(A) JOINT SAFETY-CIVIL ENGINEER PROCEDURES ESTABLISHED TO IDENTIFY AND PLAN CONSTRUCTION (1985)

(B) EXPLOSIVES SITE PLANS SUBMITTED AT 35% DESIGN STAGE

(C) EXPLOSIVES SITE PLAN APPROVAL/REVIEW POINTS CHANGED TO HQ AFISC/SEWV AND DDESB RATHER THAN HQ USAF/LEYW/LEEV

C. GROWTH OF COBS

1. CONSTRUCTED USING NATO FUNDS/HOST CRITERIA

(A) HQ USAFE/DEN/DEP/SEW WORKED TO CONTROL SITING

(B) NO NATO FLIGHTLINE Q-D SITING REQUIREMENTS INITIALLY--RELIED ON HOST CRITERIA (SOME COUNTRIES HAVE NO CRITERIA)

(C) WAIVERS AND EXEMPTIONS INCREASED FROM 64 IN 1977 TO OVER 800 IN 1985

(D) SOME HASS BUILT WITH VERY LOW OR NO NEW CAPABILITY

2. USAFE EXPLOSIVES WORKING GROUP ESTABLISHED (TEMPORARY BODY)

   (A) ATTEMPTED TO RECONCILE U.S. WITH NATO BASING CONCEPTS (ACCOMMODATE PERSONNEL REQUIREMENTS AS WELL AS MISSION REQUIREMENTS IN AIR BASE AREA)

   (B) EVALUATED SITES FOR COB LOCATIONS. LGW NOTES CURRENT SECAF-DIRECTED CONSTRUCTION FREEZE MAY TEMPORARILY CONSTRAIN COB GROWTH

   (C) COORDINATED EXPLOSIVES SITINGS AND SITE STOCKPILE

   (D) WORKED TO RESOLVE DIFFERENCES IN U.S./NATO/HOST CRITERIA

C. EXPANSION OF PREPOSITIONING

1. EFFORTS BEGUN TO INCREASE NUMBER OF DAYS OF SUPPLY AT MOBS AND COBS

   (A) MUNITIONS CALLED FORWARD FROM CONUS/MMS(T)S

   (B) STORAGE CONFIGURATIONS GEARED TO COMBAT SORTIE TASKING

2. EXISTING MUNITIONS STORAGE IGLOO SPACE INADEQUATE

   (A) NEW STORAGE CONFIGURATIONS PROPOSED

   (B) NEW STORAGE CONCEPTS (STRUCTURES) PROPOSED

D. LACK OF REAL ESTATE

1. OFF-BASE EXPOSURES CREATED

   (A) RESTRICTIVE EASEMENTS ESSENTIAL

   (B) HOST NATIONS GENERALLY WILLING TO ACCEPT EXPOSURES

   (C) SECAF EXEMPTION FOR COBS/FOLS

2. ON-BASE EXPOSURES CREATED

   (A) U.S.-TO-U.S.

(B) U.S.-TO-HOST

(C) WHAT CONSTITUTES A RELATED FACILITY

3. MUNITIONS TESTING PROGRAM CRITICAL

(A) HELPED REDEFINE Q-D RELATIONSHIPS/VALIDATE DISTANCE

(B) REDUCED Q-D SEPARATION REQUIREMENTS FOR 19 DIFFERENT MUNITIONS ITEMS/OPERATIONS

(C) PROPOSED "HAVE BLOCK" AND "BUFFERED STORAGE" AS MEANS TO REDUCE MAXIMUM CREDIBLE EVENT (MCE)

(D) PROPOSED LOWER COST STORAGE FACILITIES ABLE TO MULTIPLY STORAGE SITES AT LOWER UNIT NET EXPLOSIVES WEIGHT (NEW)

E. NATO GUIDANCE (AC/258, D/258)

1. MUNITIONS STORAGE AREA (MSA)

(A) NATO GUIDANCE MORE RESTRICTIVE THAN U.S.

(B) WHAT IS RELATED? U.S.-TO-HOST, HOST-TO-U.S., AND U.S. REGULATIONS NOT CLEAR

2. AIRCRAFT DISPERSAL AREA

(A) SHAPE DOES NOT RECOGNIZE A HAS AS A PES

(1) MUNITIONS ARE TRANSIENT

(B) NATO SURVIVABILITY SEPARATIONS ARE EQUIVALENT TO U.S. Q-D CRITERIA IN MANY CASES

(C) NATO SURVIVABILITY CRITERIA

F. HOST CRITERIA

1. RULES OF THUMB

(A) MSA

(1) BE, DK, GE, NL, DO, AND UK--EQUIVALENT OR MORE RESTRICTIVE THAN U.S.

(2) GR, IT, AND TU--LESS RESTRICTIVE THAN U.S.

(B) AIRCRAFT DISPERSAL AREA--HAS, NOT A PES

G. INTEGRATION

1. CHAPTER 32 CODE OF FEDERAL REGULATIONS

(A) REQUIRES MOST RESTRICTIVE OF HOST OR DOD STANDARD 6055.9 AS MINIMUM COMPLIANCE FOR DOD COMPONENTS

(B) WHAT IF HOST COUNTRY EXPOSES THE U.S.-BASED ONLY ON U.S. CRITERIA

2. INTERNATIONAL AGREEMENTS VAGUE

(A) "APPLICABLE REGULATIONS/REQUIREMENTS"

(B) WHAT IF HOST DOES NOT RECOGNIZE U.S. CRITERIA

3. ALLIED COMMAND EUROPE DIRECTIVE 85-1

4. REALITY

(A) COMMON CRITERIA DESIRED, BUT UNLIKELY

(B) U.S. CRITERIA WILL BE USED VIA EXEMPTIONS, WAIVERS, AND LIMITATIONS ON OPERATIONS

H. EVOLUTION OF HARDENED AIRCRAFT SHELTERS AND CRITERIA

1. FRENCH/U.S. TAB VEES

(A) CONSTRUCTED TO PROTECT AIRCRAFT IN OPEN PARKING SPOTS

(B) CRITERIA USED SAME AS FOR WEAPON LOADED AIRCRAFT IN OPEN PARKING SPOT

2. SECOND AND THIRD GENERATION HARDENED AIRCRAFT SHELTERS

(A) HAS LARGER AND MORE VERSATILE THAN TAB VEES

(B) ATTEMPTED TO USE AS PROTECTED LOADING SITE WITH ONE-TO-TWO SORTIES OF MUNITIONS IN EACH

(C) DISTANT RUNNER TESTS IDENTIFIED NEED FOR SEPARATION AT NEWS ABOVE 110 LBS 1.1

3. OVERCOMING NEW LIMITATIONS BY CONTROLLING MCE

(A) ANGLING MUNITIONS AT 15 DEGREES ALONG ONE WALL

(B) USE FULLY-FUZED MUNITIONS AT MINIMUM SEPARATION DISTANCES

4. FURTHER TESTING REQUIRED TO DETERMINE MCE AT WHICH HAS PRODUCES FRAGMENTS IN INTERNAL EXPLOSION

I. MUNITIONS TESTING/QUANTITY-DISTANCE VALIDATION

1. NATO CONCERNED DUE TO UNECONOMIC USE OF LAND CAUSED BY OVER-CONSERVATIVE Q-DS BASED ON IMPRECISE DATA

(A) NATO WORKING PAPER (AC/258-WP/48 (REVISED)), SEP 88, SOUGHT AGREEMENT IN PRINCIPLE TO FUND TESTS TO VALIDATE THE Q-D FOR A VARIETY OF AMMUNITION AND EXPLOSIVES

(B) TESTING COULD BE SPONSORED BY INFRASTRUCTURE COMMITTEE

2. U.S. CONCERNED DUE TO LIMITATIONS ON MISSION CAPABILITY IN A LAND-POOR ENVIRONMENT AND TO ENHANCE AIR BASE OPERABILITY

(A) SEVERAL EFFORTS BEGUN IN 1983. HAVE BLOCK MOST PROMISING, BUT IMPRACTICAL. LED TO BUFFERED STORAGE. BUFFERED STORAGE FINE FOR A WRM ENVIRONMENT, BUT NOT DESIRABLE FOR MOBS (LGW INPUT)

(B) USAFE PROPOSED 16 TESTS IN 1985

(C) FINDINGS FROM DISTANT RUNNER TESTS ALLOWED 19 Q-D SEPARATION REDUCTIONS OR TOTAL ELIMINATION OF SEPARATION REQUIREMENTS--IMPROVED HAS OPERATIONAL EFFICIENCY

(D) MANY USAFE TESTS PROPOSED STILL PENDING COMPLETION

J. DEVELOPMENT OF STANDARD FACILITIES

1. IMPORTANT FOR SITE PLANNING CONSIDERATIONS

2. FIVE TYPES OF STRUCTURES STANDARDIZED FOR NATO USE: THREE GENERATIONS OF HASS, READY SERVICE IGLOOS, AND READY SERVICE MAGAZINE

3. TWO TYPES BEING CONSIDERED--NORWEGIAN AND GERMAN HAS

4. NATO WORKING PAPER AC/258 (ST)WP/158 ADDRESSED THE NEED FOR AN ANNEX TO THE STORAGE MANUAL TO CAPTURE HAS DATA SIMILAR TO THAT FOR IGLOO DATA

SECTION II. CURRENT INITIATIVES

A. RISK ASSESSMENT/CONTROL

1. COMMAND-WIDE EFFORT INITIATED TO REVIEW EXISTING WAIVERS, EXEMPTIONS, AND DEVIATIONS IN LIGHT OF MISSION CHANGES

(A) TOOL FOR COMMANDER TO REASSESS EXPLOSIVES OPERATIONS

(B) ANALYZES RISK INVOLVED IN EXPOSURES CREATED BY NEW CONSTRUCTION/MODIFICATION, AND CHANGES OF USE OF FACILITIES WITHIN EXPLOSIVES CLEAR ZONES

(C) PUTS SAFETY INTO THE BASE PLANNING PROCESS

2. ENSURE THE COMMANDER IS APPRISED OF THE RISKS INHERENT IN WING OPERATIONS

3. PROVIDES ON-GOING REVIEW OF WAIVERS AND EXEMPTIONS

4. PROVIDES PLANNING BASIS FOR MISSION-RELATED (THREE PHASE) SITING

B. LIGHTNING PROTECTION FOR OUTSIDE STORAGE

1. COMMAND ASSESSMENT COMPLETED IN EARLY 1989

(A) ESTIMATED COST TO COMPLY WITH INSTALLATION OF LIGHTNING PROTECTION FOR OPEN MUNITIONS PADS IS WELL ABOVE $2 MILLION

(B) SOME HOST NATIONS OPPOSE USE OF LIGHTNING PROTECTION SYSTEMS

(C) FREQUENCY OF MANNED OPERATIONS NEEDED TO BE CONDUCTED IN THE OPEN NEEDS TO BE DETERMINED

(D) COST TO COMPLY MAY BE PROHIBITIVE BASED ON MISSION REQUIREMENTS

2. USAFE PROPONENT FOR LIGHTNING PROTECTION TEST

(A) DETERMINE IMPACTS OF LIGHTNING STRIKES ON VARIOUS MUNITIONS ITEMS

(B) DEVELOP EMPIRICAL DATA TO DETERMINE IN WHAT ENVIRONMENTS LIGHTNING POSES A HAZARD TO MUNITIONS

(C) TESTS FEASIBLE, BUT ON-HOLD PENDING DETERMINATION OF INSENSITIVE MUNITIONS PROGRAM

C. IN-IGLOO MUNITIONS BUILD-UP

1. PROVIDES PROTECTED ENVIRONMENT DURING ATTACK CONDITIONS

(A) ECONOMICALLY AFFORDABLE ALTERNATIVE TO DEDICATED BOMB ASSEMBLY BUILDINGS

(B) BACK-UP BOMB ASSEMBLY POINTS IN EVENT DEDICATED BOMB ASSEMBLY BUILDING DESTROYED

2. REDUCES BOMB ASSEMBLY TIME BY POSITIONING REQUIRED COMPONENTS IN A SINGLE STRUCTURE

3. EFFECTIVELY UTILIZES MANPOWER REQUIRED DURING CRITICAL SORTIE SURGE PERIODS

4. REDUCES TRAFFIC IN MUNITIONS STORAGE AREA AND MAKES EQUIPMENT AVAILABLE TO SUPPORT FLIGHTLINE DELIVERY

D. ALL-UP-ROUND MUNITIONS STORAGE

1. PROCEDURES APPLICABLE TO SELECTED COBS AND MOBS

2. APPLIES TO ENCASED MUNITIONS ONLY, NOT TO BULK EXPLOSIVES

3. PUTS MUNITIONS INTO OPERATIONAL CONFIGURATION REQUIRED BY AIR ORDER OF BATTLE

   (A) OFFSETS MANPOWER SHORTAGES TO MEET EARLY-ON TASKINGS

   (B) PROVIDES SURVIVABILITY BY DISTRIBUTING ASSETS

   (C) MINIMIZES EXPOSURE OF PERSONNEL AND EQUIPMENT

4. ALLOWS RESUPPLY AND PREDIRECT TO BE BUILT AT RECEIPT SITE AND DIRECT-DELIVERED TO THE FLIGHTLINE OR RESTORED DEPENDING ON THE SITUATION

5. TAKES ADVANTAGE OF STORAGE AUTHORIZATIONS FOR STAMP/ FASTPAK

6. SOLVES THE PROBLEM OF "TRASH" DURING TIME-SENSITIVE BOMB BUILD-UP OPERATIONS

7. REDUCES LIKELIHOOD OF ASSEMBLY ERRORS

8. PROVIDES AN ENVIRONMENT IN WHICH PROPAGATION IS LESS LIKELY THAN IF COMPONENTS ARE UNASSOCIATED

E. IN-HAS MUNITIONS STORAGE WILL:

1. ALLOW PLACEMENT OF MUNITIONS EITHER ALONG HAS WALLS OR WITHIN A VAULT/CASKET INSIDE HAS

2. PROVIDE INCREASED SECURITY

   (A) DISPERSES ASSETS INTO A MORE SURVIVABLE ENVIRONMENT

   (B) REDUCES LIKELIHOOD OF TERRORIST/HOSTILE ACCESS

   (C) INCORPORATES VISUAL AND OTHER ALARM SYSTEMS

   (D) ELIMINATES NEED FOR CONVOY/MOVEMENT

3. ENHANCES MISSION ACCOMPLISHMENT

   (A) PROVIDES PROTECTED ENVIRONMENT FOR BREAKOUT/ BUILD-UP

   (B) ALLOWS EASY TRANSITION TO HIGHER INTENSITY OPERATIONS

(C) PROVIDES PROTECTED ENVIRONMENT FOR AIRCRAFT LOADING

(D) ALLOWS FULL-RANGE OF OPERATIONS WITHOUT EXTERNAL VIEW

F. THREE PHASE (TRANSITIONAL) SITE PLANNING

1. DERIVED FROM SECAF COB/FOL EXEMPTION TO CONTROL EXPOSURES

2. BASED ON TRADITIONAL RULES OF RELATED FACILITY SEPARATION

3. REQUIRED DETAILED MISSION ANALYSIS OVERLAID ON BASE CAPABILITY

4. MAXIMIZES FACILITY USAGE

5. MINIMIZES LAND ACQUISITION TO ACHIEVE Q-D SEPARATION

6. REQUIRES WINGS/BASES TO DEVELOP A FACILITY USAGE/ TRANSITION PLAN TO SUPPORT THE EXPLOSIVES SITE PLAN

7. ALLOWS PLANNERS TO EXERCISE NEEDED CONTROL WHILE PRESERVING REQUIRED SAFETY SEPARATION DISTANCES

G. PROPOSED COMMON EUCOM STANDARDS FOR OFF-BASE ACTIVITIES WILL:

1. IMPLEMENT U.S. PUBLIC LAW REQUIREMENT TO SITE ALL EXPLOSIVES OPERATION SITES

2. ELIMINATE CONTRADICTIONS CAUSED BY SERVICE-UNIQUE REQUIREMENTS WHEN DEALING WITH HOST GOVERNMENTS

3. RECOGNIZE THAT FEW EUROPEAN PORTS/RAILHEADS CAN BE SITED RISK-FREE (INTERNATIONAL SHIPPING ORGANIZATION (ISO) CONTAINERS HAS SHOWN BENEFITS OVER BLOCKING-AND-BRACING REQUIREMENTS IN THAT IT SAVES TIME THROUGHOUT OPERATION)

(A) ALLOWS HOST COUNTRY INPUT INTO DETERMINING SITES

(B) ALLOWS HOST COUNTRY STANDARDS TO INFLUENCE AUTHORIZED NEWS AND PROCEDURES

4. RATIONALIZE THE NEGOTIATION PROCESS BY ESTABLISHING A SINGLE POINT OF CONTACT FOR ALL WATERPORTS AND RAILHEADS AND LETS THAT POINT OF CONTACT SUPPORT ALL USER SERVICES

   (A) REDUCES CONFUSION AS TO WHICH SITES ARE APPROVED

   (B) IMPROVES PLANNING BY ESTABLISHING A LISTING OF SITES AND THEIR CAPACITIES

   (C) DEMONSTRATES U.S. INTENT TO BE A POSITIVE PARTNER

H. DEVELOPMENT OF STANAGS WILL:

1. DEFINE STANDARDS/CRITERIA TO IMPROVE PLANNING AMONG NATO MEMBERS

   (A) ELIMINATES THE PROBLEM OF USER NATION RULE CONFLICTS ON HOST NATION BASES

   (B) PROVIDES A BASIS OF AGREEMENT ON SITING STANDARDS

   (C) CAN ADDRESS A VARIETY OF SUBJECTS

2. CREATE STANAGS FOR:

   (A) EXPLOSIVES SITING FOR RAILHEADS AND WATERPORTS

   (B) EXPLOSIVES SITING OF FLIGHTLINE FACILITIES, SUCH AS HASS, AIRCRAFT PARKING SPOTS, HOLDING AREAS, AND HOT CARGO PADS

   (C) DEFINING THE DESIGNATED ACCEPTANCE LEVEL WITHIN EACH MEMBER GOVERNMENT FOR A VARIETY OF EXPLOSIVES SITING ACTIONS

   (D) DETAILING REAL ESTATE ACQUISITION AND USAGE CONTROL

   (E) AUTHORIZED MUNITIONS STORAGE CONFIGURATION/ LOCATIONS

   (F) TRANSPORTATION OF MUNITIONS ON PUBLIC TRANSPORTATION SYSTEMS (CURRENTLY UNDERTAKEN BY USAREUR)

I. INSENSITIVE MUNITIONS PROGRAM

1. EFFORTS BEING MADE TO COMBINE THE INSENSITIVE HIGH EXPLOSIVES PROGRAM AND MUNITIONS TESTING PROGRAM

   (A) CREATE A SINGLE PROGRAM UNDER MSD/YQI

   (B) CREATE A MULTI-DISCIPLINE EXPLOSIVES OPERATIONS CENTER AT EGLIN AFB

   (C) PROMULGATE STORAGE CONCEPTS AND FACILITIES BASED ON TEST DATA

   (D) COMBINE SAFETY, MAINTENANCE, CIVIL ENGINEER, AND OPERATIONAL REQUIREMENTS INTO AN EXPLOSIVES DISCIPLINE

2. REMAINING TESTS IMPORTANT FOR USAFE OPERATIONS:

   (A) DEVELOPMENT OF INSENSITIVE HIGH EXPLOSIVES FILLER

   (B) TEST TO DETERMINE IMPACTS OF LIGHTNING STRIKES ON INVENTORY MUNITIONS

   (C) QUALIFICATION OF ADDITIONAL BUFFERING MATERIALS (FOR BUFFERED STORAGE) ABLE TO BE CONSUMED IN THE BOMB GENERATION PROCESS

   (D) QUALIFICATION OF DESIGN FOR HARDENED MUNITIONS GENERATION (BUILD-UP) FACILITY

   (E) QUALIFICATION OF DESIGN FOR MODULAR MUNITIONS STORAGE STRUCTURE

   (F) HAS SCALE MODEL TEST

   (G) FRAGMENT HAZARD TEST

SECTION III. CONCLUSION

A. FUTURE PROJECTIONS

1. MUNITIONS POSITIONING CONCEPTS AT COBS

2. REDUCTION OF IN-THEATER MUNITIONS MAINTENANCE PERSONNEL

3. REDUCTION IN NUMBER OF MOBS

4. REDUCTION IN AIRFRAMES

5. INCREASED RELIANCE ON NATO FOR MISSION SUPPORT

6. MISSION REALIGNMENTS

7. MUNITIONS RELEVELING/REDISTRIBUTION MOVEMENTS

8. WE NEED TO CAREFULLY ANALYZE OUR OPERATIONS TO MAXIMIZE THEIR EFFICIENCY, REDUCE COSTS, MAINTAIN RAPID AND IN-DEPTH RESPONSE CAPABILITY

9. MUNITIONS POSITIONING WILL CONTINUE AT REMAINING COBS. COBS CLOSED WILL CONTAIN NO MUNITIONS. SOME ALTERNATIVES TO FEWER USAFE MUNITIONS PERSONNEL ARE INCREASED HOST NATION SUPPORT, CONUS DEPLOYMENTS, ETC. MOST WRM PERSONNEL MUST BE RETRAINED IF WRM STOCKS WILL BE MAINTAINED IN-THEATER. MUNITIONS ARE BEING MOVED AS BASES ARE BEING CLOSED.

DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY SYMPOSIUM

HQ USAFE/SEW

EXPLOSIVES SAFETY IN THE NATO ENVIRONMENT

VU-1

OVERVIEW

- BACKGROUND
- CURRENT INITIATIVES
- CONCLUSION/FUTURE PROJECTIONS

VU-2

BACKGROUND

- MISSION ENLARGEMENT DURING THE 1980'S
- CONSTRUCTION/FACILITIES EXPANSION (NATO AND U.S.)
- GROWTH OF COBS
- LACK OF REAL ESTATE
- DEFINITION OF HOST NATION/NATO SITING CRITERIA
- EVOLUTION OF HARDENED AIRCRAFT SHELTERS AND CRITERIA
- MUNITIONS TESTING/QUANTITY-DISTANCE VALIDATION

VU-3

DIFFERENCES IN CRITERIA

- NATO GUIDANCE
- HOST CRITERIA
- INTEGRATION

VU-4

OVERVIEW: CURRENT INITIATIVES

- RISK ASSESSMENT/CONTROL
- INSENSITIVE MUNITIONS PROGRAM
- DEVELOPMENT OF STANAGS
- COMMON IN-THEATER SITING STANDARDS FOR OFF-BASE ACTIVITIES
- IN-IGLOO MUNITIONS BUILD-UP
- ALL-UP-ROUND MUNITIONS STORAGE
- THREE PHASE (TRANSITIONAL) SITE PLANNING
- IN-HAS MUNITIONS STORAGE
- LIGHTNING PROTECTION FOR OUTSIDE STORAGE

VU-5

CONCLUSION: FUTURE PROJECTIONS

- MUNITIONS POSITIONING CONCEPTS AT COBS
- REDUCTION OF IN-THEATER MUNITIONS MAINTENANCE PERSONNEL
- REDUCTION IN NUMBER OF MOBS
- REDUCTION IN AIRFRAMES
- INCREASED RELIANCE ON NATO FOR MISSION SUPPORT
- MISSION REALIGNMENTS
- MUNITIONS RE-LEVELING/REDISTRIBUTION MOVEMENTS
- WE NEED TO CAREFULLY ANALYZE OUR OPERATIONS TO MAXIMIZE THEIR EFFICIENCY, REDUCE COSTS, MAINTAIN RAPID AND IN-DEPTH RESPONSE CAPABILITY

VU-6

SAFETY WITH EXPLOSIVES AND AMMUNITIONS

PRESENTED BY

SHRI S.K.SHIVLIHA, IOFS.

Addl.General Manager, Ordnance Factory, Chanda.

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INTRODUCTION.

It was with a justifiable amount of pleasure that I accepted the invitation to participate in this seminar on explosives safety. I consider Seminars as excellent forum for free exchange of informtio and ideas and hope the discussions which are going to take place in this seminar will include many interesting topics and provide stimulating and informative material in achievement of safety in dealing with explosives and ammunitions.

The basic idea to discuss explosive safety is to seek possible solutions to problems in order to improve safety and reduce accidents involving explosives to an absolute minimum. For this, I consider that identification of problem areas plays a vital role and then to seek solutions to these problems or atleast to form the basis for further thought and study for developing new methods and approaches to eliminate the possible hazardous situations. Explosives are fraught with risk and every effort has thereflre to be made to eliminate or to minimise such risk by adoption of all possible safety measures by way of choice of most suitable materials, manufacturing processes and techniques, mode of packing, handling, determining suitable storage conditions and safe mode of transportation. Explosive safety philosopny has undergone radical changes in the recent years. The main thrust is to formulate prescriptions which will afford maximum protection to personnel, sophisticated plants, equipments and specialised buildings in the vicinity of a "POTENTIAL EXPLOSION SITE". Armed Forces personnel and civilians engaged in the development, manufacture,storage and transportation of explosives and ammunitions are constantly exposed to the additional risk besides normal hazards of every day life. Judicious planning, better house-keeping and strict adherence to the regulations are the absolute necessity. The basic three elements of efficient Management in safety are (a) the sound safety programme (b) frequent visits to the sites for constant appraisal and in-depth analysis of problems and (c) good house keeping. The production worker or the soldier in the field does not have the information or the freedom to decide for himself whether a particular action is or is not dangerous to perform. The manufacturing items should hve the clear concept of safety requirements and should seek no compromise on these and thiss is kept in view as the greatest responsibility in any hazardous operation such as the production and the use of the explosives and the ammunitions.

GENERAL.

The history of accidents in the Explosives industry begins with man learnt the arts of their manufacture towards the end of the middle ages. Th lack of knowledge of the phenomenon that accompany the explosive ecomposition and perhaps the less respect that was given in these times to human life were the cause of large number of acidents and the seriousness of their consequences. In older days manufacturing workshops were located within the walls of the towns, often in pre-existing buildings. The safety precauutions to prevent accidents were NIL. No allowance was made for the knowledge acquired from past accidents, the cause of hch was ascribed as the will of God. Only the Eighteenth century, after more and more, frequent and deadly explosions followed by fire, that destroyed entire blocks of cities, it was decided to transfer the manufacturing shops to outside the town. Th origin of explosion was generally caused by heat from Mechanical Parts of the Machine or fire lit by an imprudent worker. Safety measures were practised by people only in their individual capacity for self-preservation and defence out of fear of injury and no Organised Safety Programme was practised. From the early years of Nineth century till date though the mechanisation of industries has taken concrete shape in all the fields and disciplines, viz. chemical, engineering Metallurgy, Explosives etc. and a number of accidents were experienced in the early stage of change over, a concerted approach for effecting Safety measures on a scientific basis has been initiated by different Safety Organisations only recently.

In India concepts for Explosives Storage and Transportation and Processing o Explosives have attracted considerable attention of safety specialists since World War II. The U.K.Home office regulations on Qty - Distance were followed in earlier years but were subsequently replaced by Magazine regulations of 1934. During the years 1946 and 1947 the ESTC London staged a series of trials with large Qty.of High

Explosives and Propellants in U.K, Germany and Canada. The revised qty. distance was formulated and were adopted by ESTC(UK) in 1948. STEC in India decided to adopt these tables in 1949. The revised tables introduced the concept of process qty - distance for process buildings which are greater than those for storage buildings to provide a reasonable degree of safety to operators working in such buildings. The process qty.distance is set at 1.5 RB and the outside qty,.distance at 4 RB,. where RB is radius of the circle of B Damage i.e. such severe damage due to explosion that the structure necessiates demolition.The storage qty distance for propellants and bulk high explosives are based on Flame Radius. In the light of recent knowledge and experience, we have, now in India, been able to,lay down Qty.distance prescriptions and have extended major efforts in aiming at providing maximum protection to the personnel ,Plant/machinery and buildings as well as reducing costs of constructing new explosive facilities. For such purpose, careful consideration of the provisions of the reviseed safety distance regulations is being paid and emphasis is given that these are observed strictly while planning new factories or when erecting new buildings in existing factories. Special consideration is however given in regard to qty distance for siting of utilities of different nature. Greater Distance ensures safety in that in the event of an accidental explosion there should not be any chain process which can immobilise the entire factory while by itself it cannot stop any accident. Such a measure is also adopted by provision of Traverses. Explosives and ammunitions belonging to higher hazard division like HD 1.1 which are susceptible to explosion en-masse and have effects of blast, flame high speed fragments and debris are stored and processed in buildings provided with traverses.

A traverse is a solid mass of earth, sand or is made of brick, concrete and built around a building or stack containing explosives and their main functions are to protect explosives/personnel in nearby building or in the vicinity of explosives buildings by way of intercepting Low angle High velocity missiles generated by an explosion and stop them from causing direct propagation of Explosion /fire to adjacent buildings holding explosives. There are various types and classification of traverses and designed based on opinion of many experienced personnel in the field and accepted all over the Globe. In India, the same norms are dopted and traverses as found suitable to our requirements considering from view point of both safety and economy, are constructed as a compulsory requirement.

Further, it will not be superfluous to mention here that there are various types of Explosives in use which present different characteristics and were classified according to their nature, characteristics etc. The erstwhile classification was mainly on the U.K.pattern wherein they were classified under 14 distinct Explosive group. This system of classification suffers from many shortcomings and inconsistencies viz. in some cases items which have very little in common were included in the same group and certain items which are having the same characteristics were placed in two or more groups. Though this system of classification is in vogue over quite number of years, no attempt was made to rationalise it on a scientific basis till the work was taken up by the U.N.Committee of experts, most of the countries are in the process of adopting or have adopted the UN classification system of explosives for the purposes of safety in storage, transport and fire fighting. India is also not trailing behind. To keep pace with the above and to achieve better safety, the new scientific system based on UN Classification has been adopted in a phased mannrad work executed in our explosive installations in this safer and scientific based system.

As far as Safety with Explosives, whether in the manufacturing process or filling of explosives or assembly of various filled components to various types of ammunition are concerned, great care is needed to be exercised. One question immediately comes to mind as to what really contributes to safety in explosives processing and handling. Generally speaking , it is the sum total effect on 3 Ms that is Man, Material and Machine and if the accidents are to be avoided , we must have good combination of the above. In addition, in the event of an unhappy accident resulting in an explosion every effort is to be made to localise the effect so that the devastation does not spread to a wide area dislocating other important facilities or causing injuries to personnel not directly connected to it. They have also an effect on the society and building up morale at the same time besides loss of valuable time and production, restoring to normalcy in production, expenditure by way of compensation, medical treatment and so on. As the Explosive Industry itself is of specialised nature in which safety is of prime consideration, the M s occupy a special position. So far as personnel are concerned, the No.of industries in this field being limited, available trained personnel are only handful and nation cannot afford frequent loss of such trained personnel. Other Junior staff members with requisite technical background are to be trained and placed in position to shoulder responsibility in due course.

Raw materials constitute another source of danger in an explosive industry where apart from quality of finished products, safety in processing plays a very important role. Proper quality control of raw materials is n essential pre-requisite if accidents are to be avoided i.e. the raw materails must be required to the correct specification.

As far as the machineries, equipments, vessels etc. are concerned, the material of construction of these must be compatible with the chemicals/explosives to be used in them. Use of moving machineries particularly, metallic parts which come in tact with explosive materials have undergone a radical transformation over the last few decades. While in the past lead as a material of construction of vessels etc. and air as an agitating medium have ruled over this area for a long time. Slowly they have given way to the use of Stainless steel and other non-ferrous metals and alloys like aluminium , brass or Bronze and plastics for fabrication of plant items and positive mechanical devices for agitation or mixing. It has now been accepted that materials being used in contact with explosives should be sufficiently resistant to corrosion, tough and amenable to high polish so that where in use the surfaces offer the least resistance and friction. Amongst various other factors which are responsible for causn accidents in manufacture and handling of explosive chemicals, the hazard factor is the most dominating one. As varying in degrees all chemical explosives are hazardous from the stand point of their sensitivity to impact, friction, static electricity, spark and ignition. While hazard controlling measures for some of such chemicals are the control of temperature by way of air-conditioning ,humidity control, bonding and earthing of work benches, machines etc., application of modern technology through instrumentation and automation has as well had desired effects of safe operation. However, inspite of great advantage of modernisation from the standpoint of quality and safety, some associated disadvatages are also there which if not looked into properly can paradoxically lead to major problems/accidents. Hence appropriate plant design and operations need greater stress andthese should include preventive measures by having proper in-built safety as well as curative measures like isolation, remote control etc. Apart from what has been said, preventive measures through control of specific unsafe conditions and unsafe conditions and unsafe acts by men in the plant depending on the process and properties of explosives are also to be looked into. Such care and installation of modern safety gadgets give enough confidence to the working personnel. However, poor maintenance and workmanship in the handling of various gadgets can also cause accidents, sometimes bringing more misery than what could have otherwise been avoided in a corresponding conventional plant.

Use of electrical power is another area where considerable development has taken place. In earlier days electrification of rooms etc. where handling or processing of explosives is carried out is used to be discouraged and lighting was arranged from outside. This restriction necessiated all the activities to be conducted during day light hours. Electric sparking from appliances used to be regarded as potention source of danger in an explosive area but with the development of proper type of electrical appliances which do not allow either any spark to come out or any explosive or inflammable vapour to enter the appliances or which do not get overheated during continuous heat, the threat is reduced considerably. Positioning of approved electrical equipmnents including lighting fixtures within an explosive area has been quite common and safe in handling explosives. Periodical checking of lightning protection system, insulation resistance, earthing continuity etc. serve a gret deal in safe handling of explosives in a building.

Besides, it had added to our experience that the packages of explosives/ammunitons play a great role in their proper preservation as well as transportation from one place to the other. If they are not properly developed, mishandling and consequent premature functioning etc. may take place causing injury/damage and devastation. Tremendous research has been done by Indian experts in this regard and new designs in packages have been made which renders a great coverage of safety in transportation and prevents them in coming in contact directly with moisture, sunlight,heat and sparks of fire and static charges. Owing to the explosives being very sensitive as well as powerful, very sttringent and significant regulations have been drawn for their transportation and restrictions imposed for mixingof different items and on the qty. speed of vehicles, type of vehicles and such other factors. Over the conventional explosive vans, specially developed carriages have now been in use for rockets, etc. which move on national highways to too long distances and in India we have been able to do so this very successfully with the safe requirements suiting to the wide range of weather conditions prevailing at one zone or other other.

Lastly, I should add that disposal action of unserviceable or rejected explosives and ammunition demand a great attention. Regular disposal of the same in their proper way should never be neglected. They are the potential source of hazard. Any disregard or negligence will surely lead to unthinkable consequences. We have in our organisation , in every installation, our own disposal ground where these are disposed off by burning or treatment with suitable chemicals. We have designed our appliances for disposal of detonators, caps and other filled components and thus steped forward in achieving safety in shop floors and in the entire installation as a whole.

In conclusion, I may add that safety is more like a welfare activity associated with personnel and the organisation. There should not be any compromise on safety. No deviation from safe norms and regulations should be allowed. Work must be performed in their proper layout under strict inspection and supervision and as necessary the process and other activities shall be reviewed at regular intervals and updated in line with the advance made in the field and safety information disseminated to all through all media as would be available. I shall conclude by uttering that 'safety is directly connected to progress'.

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PUBLIC SCRUTINY OF THE APPLICATION OF THE NATO PRINCIPLES IN AUSTRALIA

LIEUTENANT COLONEL DAVID C. CLYDE

AUSTRALIAN ARMY

ABSTRACT

Australia adopted the NATO Principles for the Storage and Transport of Ammunition and Explosives in 1981. Like many other nations, Australia faces problems of urban encroachment into areas surrounding explosives facilities. In addition, the Public increasingly questions the nature and purpose of Defence activities.

In 1988, the Australian Audit Office tabled a report which was highly critical of the Department of Defence's implementation of explosives safety principles and policy. This report led to a public inquiry by a Joint Parliamentary Committee.

The Committee's findings led to some important changes to the Australian Defence Forces' policy for the storage and handling of ammunition and explosives. In particular, a less prescriptive approach to the application of the NATO Principles was adopted. This permits the exercise of technical judgement in deciding what remedial action, if any, needs to be taken to allow activities which do not strictly comply with the Principles to continue. Other matters which arose from the inquiry included attitudinal changes towards issues of public safety and Ministerial accountability.

PUBLIC SCRUTINY OF THE APPLICATION IN AUSTRALIA OF THE NATO STORAGE PRINCIPLES FOR AMMUNITION AND EXPLOSIVES

INTRODUCTION

1. The Australian Defence Force, like that of many other nations, maintains a network of facilities designed to store, handle and maintain the ammunition and explosives necessary for the conduct of peacetime activities as well as to provide for anticipated requirements in the event of defence contingencies.

2. By their very nature, concentrations of explosives present a degree of risk to employees working with or near them and to the general public where public activities do or may take place adjacent to explosives related facilities. Historically, most explosives sites in Australia were situated in areas well away from housing and public utilities. However, as time has gone by, housing, utilities and recreational areas have encroached into areas around these facilities.

3. At the same time, the public has become more inclined to question the basis, motives and rationale of government, including Defence, activities. Such public questioning may be motivated by any one of a number of factors. It may be a genuine environmental concern; it may be politically motivated against the incumbent Federal, State or Local Government; it may be profit driven by developers who see the opportunity to acquire publicly owned land; or it may be concern that government activities do present a threat to public safety.

4. In our democracy, the motivation for such scrutiny is largely irrelevant: an appropriate response will still be necessary. The form of scrutiny may be through individuals or pressure groups raising issues in the media; through political questioning at one or another of the three levels of government; or through direct questioning of officials through mechanisms such as Freedom of Information legislation.

5. This coincidence of encroachment upon areas surrounding explosives facilities and increased scrutiny of Defence activities has resulted in a reappraisal of the application of safety principles, has emphasised the

importance of public safety, and has seen the Australian Defence Force critically examine the pertinence of their principles for the storage and handling of explosives.

6. This paper will describe the nature of public scrutiny of the storage and handling of ammunition and explosives in Australia and examine the development of policy arising from that experience.

BACKGROUND

Historical

7. From the early 1920s until the late 1970s, Australia followed safety principles for the storage and handling of explosives developed by the United Kingdom. In 1976 NATO undertook a review of Western military storage procedures which resulted in the publication of the NATO Principles for the Storage and Transport of Ammunition and Explosives. These Principles incorporate the United Nations' classification system for explosives which was developed following the establishment in 1953 of the UN Committee of Experts on the Transport of Dangerous Goods.

8. The Australian Department of Defence issued a Departmental Instruction in May 1981 directing the adoption of new procedures for the safe storage and handling of ammunition and explosives. The new procedures were based on the NATO Safety Principles and incorporated the UN classification system. The Departmental Instruction allowed a transition period for adoption of the new procedures; implementation was to be complete by December 1983.

Storage and Handling Facilities

9. The Australian Defence Force operates more than 40 locations for the storage and handling of ammunition and explosives. Between them, these locations contain over 1 000 facilities or potential explosion sites (PES). The functions of these facilities vary widely, ranging from ammunition repair facilities to storage sites holding a wide variety of explosive stores, from small arms ammunition to missiles and aerial bombs. PES include Ordnance Loading Aprons on airstrips and naval moorings for outfitting warships.

10. The nature of the facilities varies from modern, purpose-designed, high capacity storage sites to low capacity

storehouses built before World War 11. The location of facilities also varies widely: from new military airfields located many miles from the nearest town and where there is little foreseeable danger of urban encroachment to long established loading facilities for warships in the middle of Australia's busiest harbour and surrounded by industrial, housing and recreational developments.

11. For many PES, prescribed safety arcs (Outside Quantity Distances (OQD)) are wholly contained within the Defence Property Boundary (DPB) and thus, provided the authorised explosive (NEQ) limits do not increase and the property boundaries do not contract, urban encroachment is of little consequence. There are a number of sites, however, where OQD, particularly the major facilities OQD, do extend beyond the DPB and where encroachment is a significant problem. Safeguarding, that is, the process of ensuring that development which is incompatible with the nature of the use of the defence facility does not take place within particular OQD, is an essential part of managing affected sites.

12. In a number of instances, ammunitioning activities are such that prescribed safety distances are already breached. In these cases, Public Risk Waivers (PRW), always requiring approval by the Minister for Defence, are required. PRW are normally approved only on the basis that action is in hand to remedy the circumstances requiring the PRW. This may be by acquiring the land, building new facilities or by ceasing or altering the non-compliant ammunitioning activities.

PUBLIC SCRUTINY

13. As previously explained, the Australian Department of Defence adopted the NATO Principles in 1981 with full implementation to be achieved by December 1983. The instruction implementing the change was written for a technical audience and, at that time, was not formally submitted for Ministerial approval, a factor which was later to attract criticism.

Ombudsman's Inquiry

14. The first important public scrutiny of the storage and handling of ammunition and explosives within the Australian Defence Forces arose in 1980 - before adoption of the NATO Principles by Australia. This was part of an inquiry by the Federal Ombudsman. The Ombudsman is appointed

by the Government to investigate complaints by the Public concerning decisions or actions by Government agencies, which a member of the Public considers wrong or unfair and which cannot be resolved satisfactorily through the normal legal or appeals processes.

15. In 1980, the Ombudsman considered representations from a complainant relating to attempts by the Department to prevent use of private land in a manner which was incompatible with explosives operations conducted on an adjoining defence establishment. The Ombudsman criticised the Department for not being clear on how it should protect its interests in relation to land adjacent to ammunition and explosives facilities. He recommended that:

- as far as practicable, the Department should ensure that outside quantity distances are confined within the DPB.

- where outside quantity distances extend beyond the DPB, the Department should ensure that all affected landholders are notified and special agreements made.

16. The Department accepted these recommendations but with the proviso that only land out to the inhabited building distance need be wholly contained within the DPB. As will be seen however, the Department's application of the inhabited building distance in all circumstances was to attract later criticism, as was the Department's tardiness in implementing the recommendations. The Ombudsman's inquiry, although not a major event in itself, was a warning of the nature of future public interest in the activities of defence explosives facilities.

<u>Auditor-General's Efficiency Report</u>

17. The Auditor-General heads the Australian Audit Office (AAO) which is a statutory authority responsible to the Australian Parliament. It routinely audits the activities of all Government departments to ensure compliance with relevant government policies and departmental instructions. It is also required to report on the efficiency and effectiveness of the processes used by departments and government agencies in the discharge of their responsibilities.

18. In 1985, the AAO reviewed the implementation of safety principles for the storage and handling of ammunition and explosives as part of a routine audit of the Defence Department's property management. The routine review of

safety principles became a formal efficiency audit in 1986. The objective of the audit was to assess the administrative effectiveness of the department's procedures and practices in implementing its own instructions relating to the storage and handling of ammunition and explosives. It did not attempt to assess the adequacy of the safety principles inherent in the instructions.

19. The audit was a complex affair which lasted until the report was tabled in Parliament in April 1988 and which delved into every important aspect of the way in which the Department managed explosives. The scope of the audit can be gauged from its major findings:

> The Department failed to meet its December 1983 target date for the implementation of the new safety principles, with no evidence of a concerted and co-ordinated effort to implement them until around 1986 and 1987.
>
> By early 1988 there were still many locations at which explosives related operations did not comply with the adopted principles.
>
> Waivers, numbering over 100, had been issued or were pending approval, implying that Departmental operations were being conducted in a manner that imposed a level of hazard to the public that was greater than the level acceptable under the safety principles.
>
> In several situations, non-compliant activities continued without the necessary waiver approval.
>
> At the time of adoption of the new safety principles, the Department gave little consideration to the cost implications, and, despite advice from the Attorney-General that government approval should have been sought, adopted the new principles without seeking government endorsement.
>
> Despite the fact that the Department had adopted a system involving the provision of safeguarding maps to local government planning authorities, these maps were not being provided.

21 recommendations stemmed from these findings.

20. In Australia, Auditor-General's reports are publicly available documents and important or controversial findings are routinely reported in the Press.

21. However, few members of the Press or of the public take time to read all the factors impinging on the key findings of an audit report or to read associated documentation. Thus the fact that the Department has a near impeccable safety record when it comes to handling explosives receives comparatively little emphasis, while non-compliant activities which may endanger public safety are highly newsworthy. That some of the key findings were procedural only (that is, relating to the processing of paperwork, approvals and the like) and did not alter the nature of the actual risk also received little emphasis.

22. This is not to say that the Department did not deserve criticism for its failure to implement fully its own instructions in the timeframe originally planned. Indeed, the Department accepted almost all of the 21 Audit recommendations without equivocation. The point is, however, that the nature of public scrutiny will rarely permit presentation or publicity of the facts in a way that is favourable to the Department. Non-compliance is newsworthy; compliance, or 'doing your job' is not.

23. The effect of the Auditor-General's report was to publicise the issue of public safety and public risk associated with activities adjacent to defence facilities. The public became and remains more curious about the nature of defence activities and more likely to question those activities, either directly or through their Members of Parliament. Within the Department, there was greater awareness of the need to be concerned about public safety and of the need to consult with and to keep the affected public informed.

24. A further aspect which arose from the Audit report was that of Ministerial responsibility. Audit noted that it should be a decision of the Minister, not of Departmental officials, to determine the degree to which the public should be put at risk and hence suggested that only the Minister should approve Public Risk Waivers. This finding in itself caused little difficulty to the Department, but the Audit report went on to contend that in not abiding by this principle, the Department had deliberately misled the Minister. Audit reached this conclusion through its interpretation of a complex sequence of submissions to the Minister and the timing with which these were presented. The assertions were untrue and later accepted as such by the Minister. However, the onus still fell on the Department to disprove the contention, a difficult and time consuming task. The lesson from this episode is, perhaps, that once a public

scrutiny finds areas of non-compliance which it can see or believe to be to the Department's advantage, its suspicions will feed upon themselves and it will tend to assign only the darkest motives to the Department's actions. Openness wherever possible is the best recourse for Departmental officials. At times, however, security considerations will limit the degree of openness available to the Department. It then is even more important that the Minister exercise his responsibility to decide the degree of risk to which the Public may be put.

Joint Parliamentary Committee of Public Accounts Inquiry

25. The Joint Parliamentary Committee of Public Accounts (JPCPA) is a committee of elected Parliamentarians from both Houses of Parliament and including members of all political parties represented in the parliament. The Committee is mainly concerned with examining the accounts of receipts and expenditure of the Federal Government and its agencies. However, its role extends to examining Auditor-General's reports which comment on the efficiency with which responsibilities are discharged. Hence, in practice, it can inquire into the efficiency of most aspects of Government activity.

26. The Committee resolved to inquire into the Auditor-General's report on the storage and handling of ammunition and explosives in April 1988 - immediately the Report was tabled in Parliament. It set itself very broad terms of reference: to examine matters raised by the Auditor-General, and to examine the adequacy of the Department's responses.

27. The inquiry lasted for about eighteen months and resulted in a report which made twelve recommendations. These recommendations did not conflict with or substantially add to those of the earlier Auditor-General's report. They were primarily concerned with the mechanisms that the Department used to implement the recommendations of the Auditor-General. Thus, where the Auditor-General recommended that Departmental instructions provide for timely processing of PRWs, the JPCPA recommended a strict timetable of four weeks for such processing.

28. The principal conclusions of the JPCPA inquiry were that, although Defence had an excellent safety record, its management of the application of the NATO principles left a great deal to be desired and that its implementation of the Auditor-General's recommendations was tardy. Most importantly, the Committee, early in its deliberations, agreed with contemporary Defence opinion that the Department's approach to the application of the NATO

principles was far too prescriptive. That is, the Department had adopted a template approach to quantity distances, leaving little scope for the exercise of technical judgement in the light of local conditions.

29. This situation had largely arisen because of the way the Department accepted and applied the Ombudsman's recommendations described earlier. As a result of those recommendations, it was the Department's policy to equate the DPB with a Group 4 Risk, that is, the inhabited building distance. Thus a non-compliant situation arose when the prescribed safety distance for an inhabited building extended beyond the DPB, despite the fact that there may have been no inhabited buildings affected by the PES. As a result, the degree of public risk assumed by the Department was much higher than the actual risk. Clearly, to remedy non-compliant situations under the Department's interpretation, land out to the inhabited building distance had to be acquired - a costly exercise, and one which, no doubt, contributed to the Department's tardiness in implementing its own instructions.

30. In its recommendations the JPCPA also emphasised the need for a better system of monitoring and auditing the application of the NATO principles, particularly if a less prescriptive approach was to be taken. Each of the services had its own technically competent licensing staff who were able to exercise professional judgement on the application of principles and procedures. However, the Committee was concerned that the NATO principles should be applied uniformly and objectively. Thus an independent, centrally controlled process was necessary to advise, monitor and audit the operations of the Services. Such a centrally controlled system also provided a mechanism for reporting to the Minister and for enabling the Minister to exercise control over a process for which he is ultimately accountable.

31. The JPCPA enquiry represented an important extension of the process initiated by the Auditor-General. Senior Service officers and Departmental officials were called before this public Committee to explain the rationale behind their decisions. No members of the Committee were technically trained or even had much understanding of the way the Services went about their business. Thus, matters which seemed to practising professionals to be elementary or self-explanatory had to be explained and justified in the public domain. The ensuing critical examination of policies and procedures, although painful at the time, led to a better appreciation and a more rational approach to the issues of public safety and accountability.

THE DEVELOPMENT OF POLICY

32. Prior to the JPCPA enquiry, policy for the storage and handling of ammunition and explosives was contained in a 1981 Departmental instruction. A separate instruction detailed the Waiver process. The Department had determined as a result of the Auditor-General's investigation that its policy needed to be revised and re-published. It took advantage of the opportunity to raise policy issues with the JPCPA before developing policy for Ministerial approval.

33. In reviewing policy, the Department started with some premises which, though obvious enough, had been highlighted in both the Auditor-General's report and by the JPCPA. These included the primacy of Ministerial accountability, that is, that it is the Minister who is responsible for determining the degree of risk to which the public may be put; the need to put public safety to the forefront in decision-making; and the need to consult with the public, including land owners and local planning authorities, when the public may be affected by Defence activities.

34. With these basics in mind, revised policy provided for a less prescriptive interpretation of the NATO principles, the appointment of a Defence Central official (the Assistant Chief of the Defence Force for Logistics (ACLOG)) as the central authority responsible for policy, and it gave comprehensive guidance on the waiver and safeguarding processes.

35. A less prescriptive application of the NATO principles demands the exercise of technical judgement. The existence of the Australian Ordnance Council (AOC), an independent body reporting to the Chief of the Defence Force, whose charter includes providing technical advice on all aspects associated with handling explosives, greatly facilitated these policy changes. Each of the Services and every ammunition and explosives facility possesses technically qualified staff able to exercise the necessary judgement in applying the Principles. The ACC represents an authoritative body able to interpret the NATO principles in a consistent manner and able to advise the technical staffs on the ground. It also provides a medium by which experience in applying local Australian conditions at one facility can be passed on to others.

36. As the central authority responsible for policy, ACLOG monitors implementation by each of the Services. He achieves this through a reporting mechanism which also enables the Minister to be kept informed. Each of the Services has established its own technical monitoring authority able to ensure compliance with Service instructions. Overall and fully independent monitoring has been achieved by adding an audit role to the functions of the AOC.

37. One of the major criticisms in the Auditor-General's report and the JPCPA was the loose application of the waiver and safeguarding processes. The revised policy greatly tightens these aspects by formally requiring consultation with State and Local Government authorities and affected members of the public and by stipulating timeframes by which matters such as waiver approvals must be obtained. The policy directive is now specific and comprehensive on issues such as the production and distribution of safeguarding maps, the sequence of the approval process and the need for reporting on these issues.

38. Policy, then, has undergone a quite fundamental philosophical change in its approach to issues of public safety. On the one hand, it is now less prescriptive relying on the application of technical and professional judgement; on the other hand, it now requires much tighter central control over monitoring and reporting on how that judgement is exercised.

CONCLUSION

39. The mechanisms for public scrutiny described in this paper are a part of the established, formal processes of Government in Australia. As mentioned at the outset, the public is much more likely to question the purpose of defence related activities and, in many cases, to seek to have those activities stopped or moved elsewhere. This questioning can be, and increasingly is, through less formal avenues than those described. However, a policy of consulting with the Public on issues of public safety and on the use of land close to explosives facilities goes a long way towards allaying suspicions, forestalling questioning and, in the end, saving time and effort in responding to the more formal official inquiries which might otherwise ensue.

40. The NATO Principles are a widely used mechanism for providing guidance on safety issues for the storage and handling of ammunition and explosives. The Australian experience in applying these principles has been illustrative of the pitfalls of too narrow an interpretation of principles which require the exercise of technical judgement in their application. This shortcoming has undoubtedly been compounded by bureaucratic delays and uncertainty in promulgating and enforcing policy.

41. Policies on explosives ordnance safety are now more widely understood and, as a result of the processes of public scrutiny and review within the Department, are greatly improved. Implementation is rightly devolved to the Services but central monitoring and independent auditing provide a basis for positive and responsible implementation of the NATO Principles. The overriding lesson from Australia's experience is that Defence activities of any sort, but especially those involving a risk to public safety, cannot be isolated from the community. The Minister has, and must exercise, responsibility for issues affecting public safety, particularly where security concerns may preclude full discussion of the issues. Nonetheless, frankness and consultation with those affected must be paramount.

THE HIGH PERFORMANCE MAGAZINE CONCEPT

by

James E. Tancreto
William A. Keenan

Naval Civil Engineering Laboratory
Port Hueneme, CA 93043

BACKGROUND

A new storage magazine is needed by the Navy to solve munitions storage problems. Existing magazines encumber large land areas to meet explosives safety quantity distance (ESQD) requirements. A growing inventory of weapons (requiring new magazine construction), with limited land for new explosive storage magazines, is creating conflicts between safety requirements, operational requirements, MILCON cost, and operating cost to store and retrieve weapons.

NCEL is investigating the feasibility of a new magazine that would reduce the land area encumbered by ESQD arcs and improve the efficiency of weapons handling operations. This new High Performance Magazine (HP Magazine) concept could reduce encumbered land by 80% (or increase storage density on existing land by a factor of up to 8 times) and significantly reduce operational costs. Reduction of encumbered land is achieved by reducing the Maximum Credible Event (MCE) in the magazine to around 10,000 lbs Net Explosive Weight (NEW) of High Explosive (HE) by using cells with walls that prevent sympathetic detonation (SD). The magazine would be designed to store about 250,000 lbs NEW of palletized ordnance (e.g. bombs, bullets, projectiles, torpedoes) or about 60,000 lbs of containerized missiles. However the ESQD arcs would be based on an MCE of only about 10,000 lbs (the NEW in one cell). Soil cover will also be used to reduce fragment and debris safe scaled distances.

The HP Magazine development will include three phases. Phase I will determine the **feasibility** of the wall and roof concepts using existing data bases, analytical procedures, and scale model tests. Phase II will use analytical methods and tests (scale model and one prototype) to develop the final design criteria and to **demonstrate** the magazine concept for explosives safety. Phase III will use full scale operational tests and one full scale explosive test to certify the operational and explosive safety characteristics of the integrated prototype design.

CONCEPT

The High Performance (HP) Magazine concept consists of an earth covered box structure with interior cells where munitions are stored, as shown in Figures 1 through 5. The cell walls are designed to prevent sympathetic detonation between cells thereby limiting the MCE to the NEW stored in any cell. The reinforced concrete box structure and soil cover are designed to limit the safe distance for the MCE from blast, fragments, and debris outside the magazine. Containment by the roof and soil cover forces most of the blast overpressure from the MCE to vent through the door openings before the roof is breached. Consequently, the blast environment outside the magazine is equivalent to that from a tunnel magazine, which results in a major reduction in encumbered land to provide safe distances from overpressure outside the magazine. The roof and soil cover mass also serve to limit the maximum launch velocity of debris, thereby limiting the maximum possible strike range of debris. Weapon fragments are stopped (or slowed to safe velocities) by the reinforced concrete box structure and soil cover before the roof is breached.

Design

The conceptual design for an HP magazine is based on preliminary information on the current and projected inventory of munitions and the existing technology base on explosion effects. The concept consists of a box structure, storage cells, earth blanket and material handling system. The conceptual design for each component of the facility is as follows:

Box Structure. The box structure is a reinforced concrete box about 40 feet wide, 200 feet long, and 15 feet from floor to ceiling, as shown in Figures 1, 2, and 3. The box has no interior columns. Access to the box is through a short tunnel located at either one end of the box (Type A HP magazine) or both ends of the box (Type B HP magazine), as shown in Figure 3. In both the Type A and B HP magazines, each door opening is about 12 feet wide by 11 feet high.

Storage Cells. The storage cells may be arranged as shown in either Figure 4a or 4b, depending on the final details of the material handling system and results of a hazards analysis of handling operations. The storage cells are either about 30 to 60 feet long x 12 feet wide x 8 feet high to accommodate air-, surface-, and subsurface-launched missiles (Figures 5a and 5b) or about 16 x 12 x 8 feet to accommodate pallets of bombs, bullets, projectiles, mines and torpedoes (Figure 5c).

The cell walls are modular and movable to accommodate shifting demands in the cell size needed to store different types of ordnance. Wall materials, yet to be defined, will be chosen to mitigate the mechanisms that would cause sympathetic detonation in the adjacent acceptor cells.

Corridors are provided for access to storage in any cell. The number corridors depends on the arrangement of storage cells, as illustrated in Figure 4. In all cases, the corridors are about 8 feet wide.

Soil Cover. The box structure is covered with soil (about 5 feet deep), as shown in Figure 1. Fabric-reinforced soil cover may be used to increase the mass of soil mobilized when the roof fails. Increasing the mass of the failed roof section reduces the launch velocity of debris and the safe debris distance.

Storage Capacity

The storage capacity of the Type A and B HP magazines is between 200,000 and 250,000 lbs NEW for palletized ordnance and about 60,000 lbs of NEW for missiles.

Maximum Credible Event

The MCE is an inadvertent detonation of the entire quantity of Class 1, Division 1, high explosives stored in one cell. The MCE is assumed to occur during a handling operation when material is being stored or retrieved. For both the Type A and B HP magazines, the MCE is the rated safe storage capacity of any cell which is about 10,000 pounds of Class 1, Division 1, high explosives.

Material Handling System

The material handling system consists of one or more of the following equipment: overhead bridge crane, overhead bridge crane-monorail, railcart, sideloader, and frontloader. The final choice of material handling system will be the system that best accommodates the material packages; minimizes the number, types, and degree of hazards; requires the least number and skill level of operating personnel; and offers the lowest acquisition, operating, and maintenance costs.

The concept for material handling operations might be as follows. The bridge crane shown in Figure 2 travels the full length of the box structure. The bridge crane is designed to lift the heaviest container of missiles or pallet of ammunition in the inventory. The bridge crane lifts the package (container or pallet) and transfers it to an adjacent aisle. The package is then transported to the doorway by either the railcart, sideloader, frontloader, or bridge crane. In the case of the railcart, it is a flatbed cart with wheels which travel in a track located in each aisle. The track steers the cart along a safe path down the aisle and through the door opening to the exterior of the magazine. The other alternatives are to move the packages through the door opening to the exterior of the magazine with either a monorail or sideloader. Depending on the mode of transportation, the magazine would have a loading dock for ease in transferring packages from the magazine to railroad boxcars and flatbed trucks.

PREDICTED PERFORMANCE

Explosives Safety Quantity Distance

The following ESQD distance assume that the HP magazine has a rated safe storage capacity equivalent to 250,000 pounds NEW.

Inhabited Building Distance. The ESQD distance to inhabited buildings (IBD) is about 1,000 feet from the skin of the box (Type A and B) in all horizontal directions, as shown in Figure 6. The ESQD distance is dictated by the safe distance from debris and fragments-not from blast. As shown in Figure 6, the ESQD area for blast lies within the ESQD area for fragments and debris. The equivalent distance for a standard earth covered magazine storing 250,000 pounds NEW is:

$$ESQD = 50\ (MCE)^{1/3} = 50\ (250{,}000)^{1/3} = 3{,}150 \text{ feet}$$

Inter Magazine Distance. The ESQD distance for side-to-side and rear-to-rear spacing of an HP magazine is:

$$ESQD = 1.25\ (MCE)^{1/3} = 1.25\ (10{,}000)^{1/3} = 26.9 \text{ feet}$$

The equivalent ESQD distance for side-to-side and rear-to-rear spacing of a standard earth covered magazine storing 250,000 pounds NEW is:

$$ESQD = 1.25\ (MCE)^{1/3} = 1.25\ (250{,}000)^{1/3} = 78.7 \text{ feet}$$

The ESQD distance for front-to-rear spacing of an HP magazine is:

$$ESQD = 2\ (MCE)^{1/3} = 2\ (10{,}000)^{1/3} = 43 \text{ feet}$$

The equivalent ESQD distance for front-to-rear spacing of a standard earth covered magazine storing 250,000 pounds NEW is:

$$ESQD = 2\ (MCE)^{1/3} = 2\ (250{,}000)^{1/3} = 126 \text{ feet}$$

Summary. The table below summarizes the ESQD distances for a standard earth covered magazine and HP magazine. Both magazines store 250,000 pounds NEW. The MCE is 10,000 pound NEW for the HP magazine and 250,000 pounds NEW for the standard magazine.

Distance	ESQD Distance (ft)	
	HP Mag	Std Mag
Inhabited buildings	1,000	3,150
Intermagazine side-to-side	26.9	78.7
Intermagazine front-to-rear	43.0	126.0
Intermagazine rear-to-rear	26.9	78.7

Encumbered Land

The HP magazine encumbers 83 acres of land to accommodate the magazine footprint plus the ESQD distance required for inhabited buildings. A standard earth covered magazine storing 250,000 pounds NEW encumbers 745 acres of land. Thus, the HP magazine reduces the encumbered land area by 88 percent.

Reduction in encumbered land = (745 - 83) 100% / 745 $\simeq$ 88%

Storage Density

The storage density is the NEW capacity of the magazine per acre of encumbered land based on inhabited building distance. The storage density for an HP magazine is:

Storage Density = 250,000/83 $\simeq$ 3000 lb NEW/acre

The storage density for a standard earth covered magazine is:

Storage Density = 250,000/745 $\simeq$ 336 lb NEW/acre

Thus, HP magazines will increase the munitions storage capacity of any fixed land area by:

Storage Density Increase = (3000 - 336)100% / 336 $\simeq$ 790 %

This means that 7 to 8 times more ordnance could be stored at existing storage sites by using HP magazines instead of standard earth covered magazines.

Noncompatible Storage

Current explosives safety regulations require noncompatible materials to be stored in different magazines. The high performance magazine offers the potential to safely store materials of different compatibility groups in the same magazine, provided noncompatible materials are segregated in different storage cells. This would significantly improve the productivity of storage operations and the utilization of storage space. This approach will not be safe for all compatibility groups, i.e. certain compatibility groups would have to be stored in different high performance magazines.

DEVELOPMENT

Technology

Development of the HP magazine concept requires operational requirements and design criteria for the box structure, storage cells, soil cover, and material handling system. The state-of-the-art and new technology needed to support development of these criteria are summarized below.

Box Structure. The technology base is sufficient to design the box structure to safely resist design dead loads from the soil cover, cell walls, storage contents, and material handling equipment. The technology base is not sufficient to accurately design the reinforced concrete roof (with soil cover) to limit the debris hazard nor to establish the exterior blast load environment (for safe pressure distance and blast loads on adjacent magazines).

Storage Cells. Design of the storage cells require definition of: (a) all possible mechanisms of sympathetic detonation, (b) the explosion environment inside the box structure due to the MCE in any cell, (c) the fragility of ordnance to each mechanism of sympathetic detonation, and (d) structural and architectural criteria for the cell walls to mitigate the MCE environment to safe levels in all acceptor cells (i.e., safe levels below the threshold for all mechanisms of sympathetic detonation and all types of munitions). The technology base for these factors is summarized below.

(a) **Mechanisms of Sympathetic Detonation**. Five mechanisms of sympathetic detonation are known. The mechanisms are blast overpressure, weapon fragment impact, debris impact, kinetic trauma, and thermal shock (cookoff). Additional mechanisms will be added if identified.

(b) <u>MCE Environment Inside Box</u>. Prediction methods for each mechanism of sympathetic detonation must be developed and verified. Empirical relationships are available to approximate the shock and gas pressures in the HP magazine. However, additional test data and computer programs (e.g. hydrocodes) must be utilized to develop better estimates of the extreme shock and gas pressure-time history and temperature-time history. The critical mass/velocity of weapon fragments can be obtained for many ordnance from the existing data base and safely estimated for most other ordnance. However, methods must be developed (using finite element and finite difference methods) and verified (by test) to predict the wall debris impact and kinetic trauma loading on the acceptor.

(c) <u>Munition Fragility</u>. The technology base is not adequate to predict the threshold level for sympathetic detonation of all possible acceptor munitions due to the known mechanisms of sympathetic detonation. Further, there are too many combinations of the critical fragility parameters, such as explosive composition, critical charge diameter, and casing thickness, to establish the threshold level for all munitions in the inventory. Ordnance with similar characteristics will be grouped and safe fragility levels (using both test and analysis) will be established for each group. Ordnance with extraordinary load output or fragility may be excluded from the HP magazine. A mix of ordnance, representing the worst case loads and fragilities of all munitions in the inventory, will be used as the donors and acceptors in tests.

(d) <u>Non-Propogation Cell Walls</u>. The technology base is not sufficient to design the cell wall to prevent sympathetic detonation. Technology exists to design barriers for relatively small MCEs and large standoff distances (less than about 2,000 lb NEW at more than about 4 feet standoff distance). Essentially no technology exists to design a barrier for the MCE associated with an HP magazine (10,000 lb NEW with 2 feet minimum of air space between the explosive charge and cell wall). Concepts must be developed to mitigate the environment at the acceptor to below threshold levels for sympathetic detonation. Analytical methods (using FEM and FDM programs) must be developed to predict the response of the walls and the effect of the walls on the mechanisms of sympathetic detonation. Scale model and full scale tests will be used to help develop and to verify the analytical prediction methods.

Roof/Soil Cover. Design of the roof and soil cover requires definition of: (a) the blast environment outside an HP magazine, (b) the fragment and debris environments outside an HP magazine, and (c) the safety thresholds for pressures, fragments, and debris outside the magazine. The technology base for these factors is described below.

(a) External Blast Environment. There are test data on the blast environment outside tunnel magazines, based on explosive tests of small and large scale tunnel magazines. Theory based on these data are probably adequate to predict the blast environment outside an HP magazine in which the soil cover depth is sufficient to force most of the blast overpressures to vent through the access openings in the box structure before the roof is breached by the MCE.

(b) Fragment and Debris Environments. Some test data and incomplete theory are available to predict the shock and gas loads inside the box structure, and the resulting mass, launch velocity, trajectory, and strike range of debris from partially vented explosions inside earth-covered boxes. However, the theory is based on small scale tests involving 0.5 to 10 pounds NEW detonated inside partially vented earth-covered boxes. More technology is needed to develop a prediction model to characterize the reinforced concrete roof failure, the effective volume of soil in the breached area, and the key fragment and debris parameters (launch velocity, launch angle, size, drag area, and drag coefficient). The probability density functions for these fragment and debris parameters will then be used in a probabilistic trajectory program to predict the debris density vs. range.

(c) Safety Thresholds. The safe pressure, fragment, and debris limits will be those stated and implied in current explosives safety regulations .

Material Handling System. The technology base is sufficient to support development of the material handling system. However, considerable study is needed to identify the best system to minimize the hazards, the number and skill level of manpower, and the acquisition, operating, and maintenance costs.

Development Plan

End Product. Standard designs (construction drawings and specifications) for the HP Magazine.

Major Milestones. The major milestones for research and development of the HP magazine are:

Milestone	Fiscal Year								
	89	90	91	92	93	94	95	96	97
A. Concept Feasibility	—	—	—						
B. Demonstration Tests				—	—	—			
C. Prototype Development & Certification						—	—	—	
D. Standard Design							—	—	—

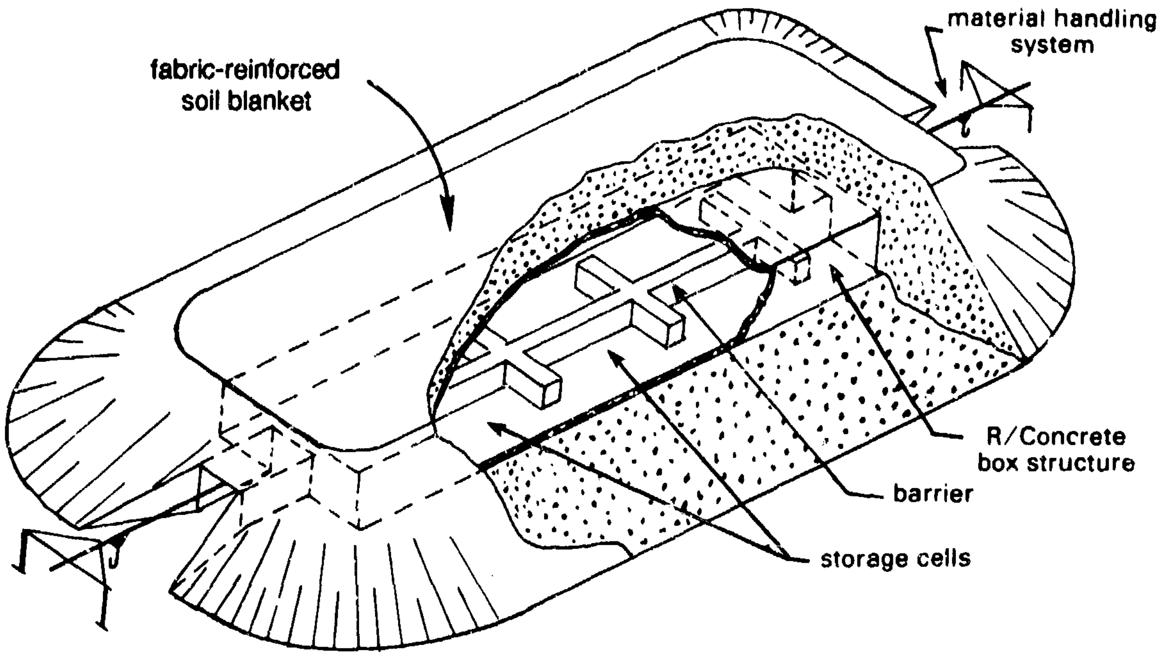


Figure 1. High performance magazine.

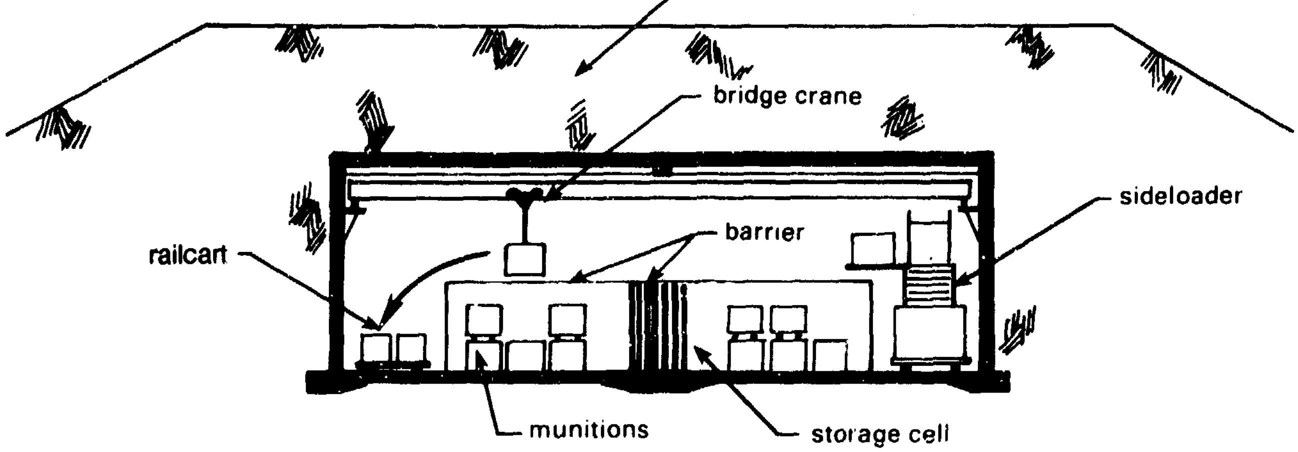
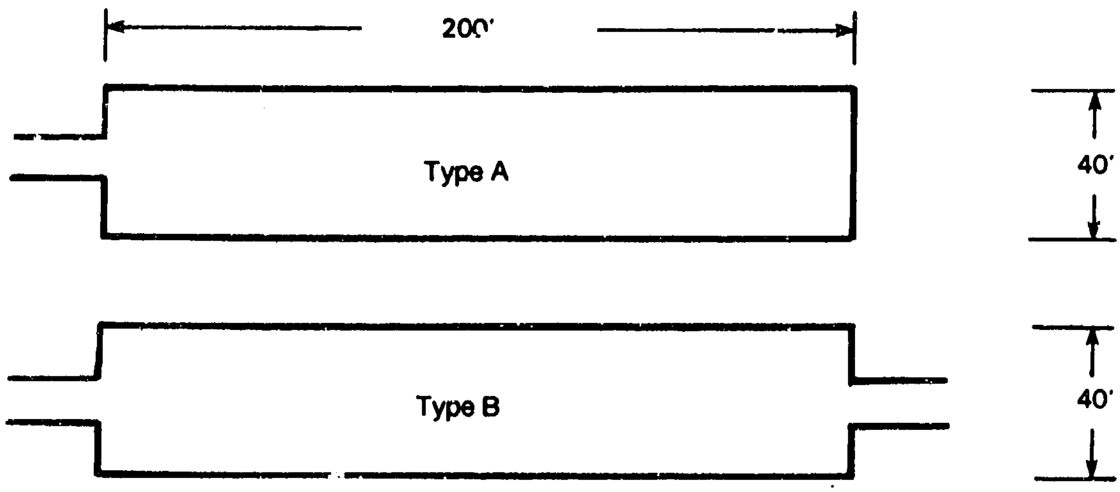
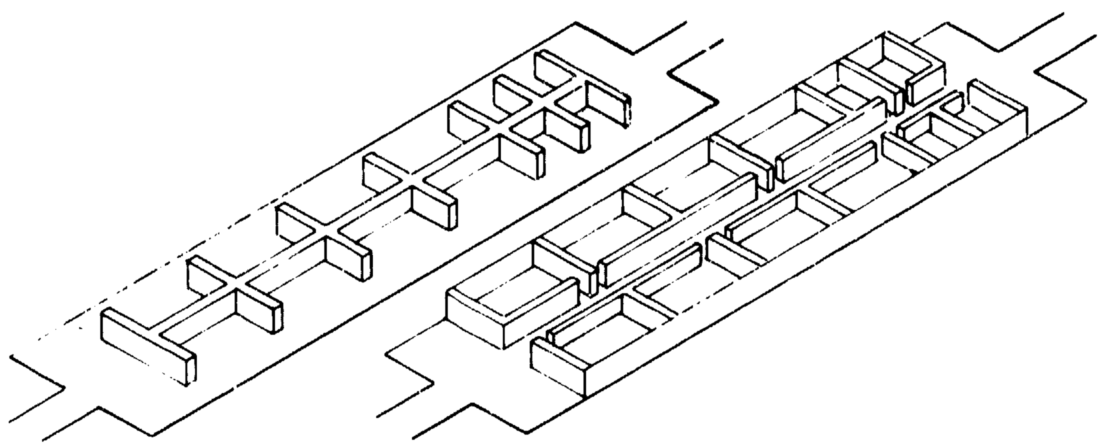


Figure 2. Section view of HP magazine.



Type	Box L x W x H (ft)	Door W x H (ft)	Door No.
A	200 x 40 x 15	12 x 11	1
B	200 x 40 x 15	12 x 11	2

Figure 3. Alternative floor plans for HP magazine.



(a) Two-aisle concept.

(b) One-aisle concept.

Figure 4. Alternative arrangements for storage cells and aisles.

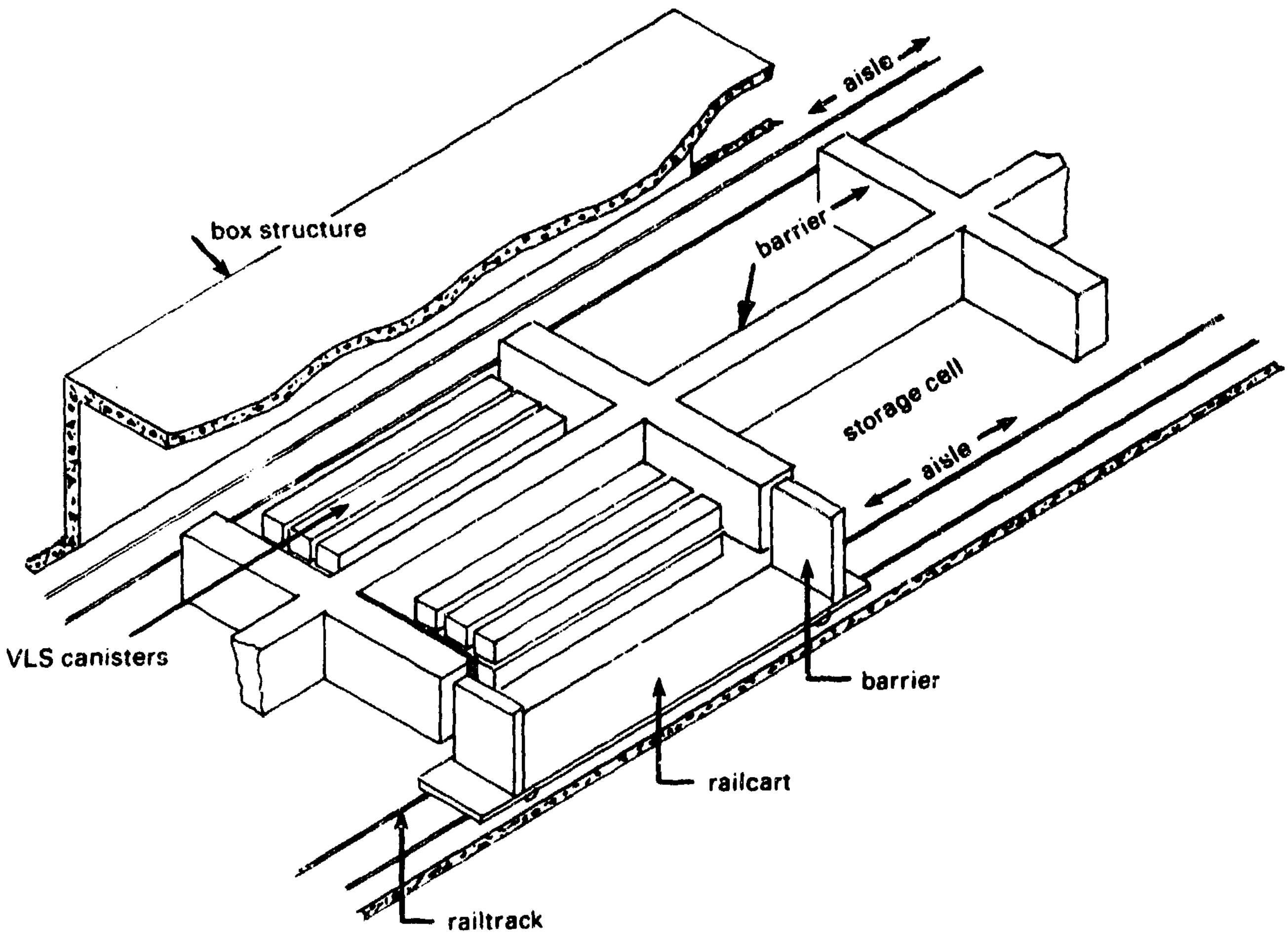


Figure 5a. Storage configuration for surface-launched missiles.

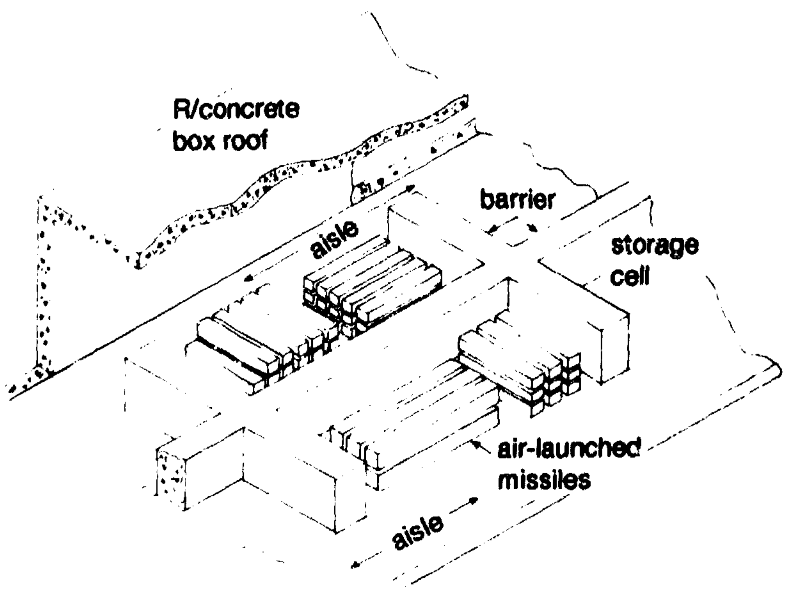


Figure 5b. Storage configuration for air-launched missiles.

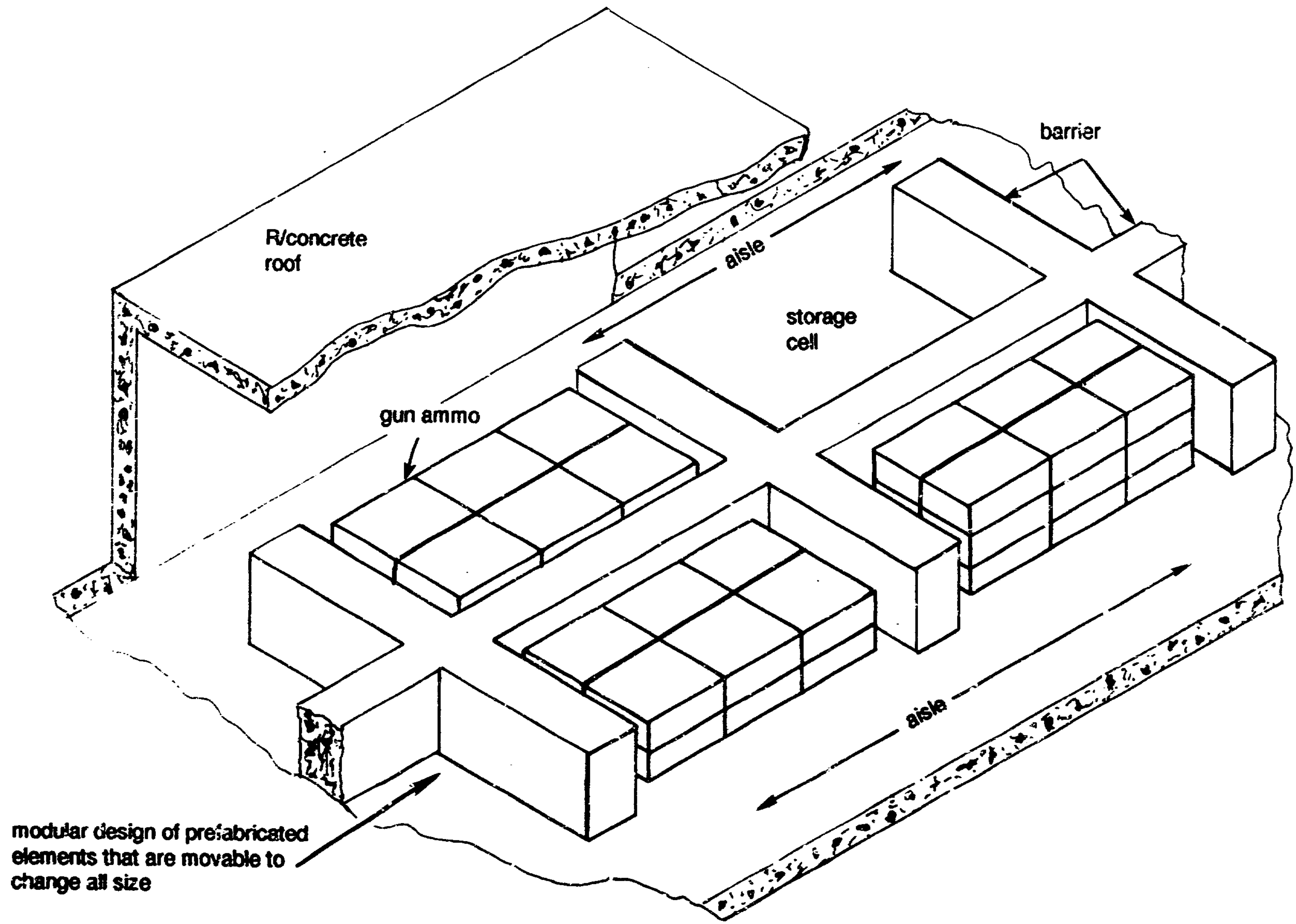


Figure 5C. Storage configuration of palletized munitions.

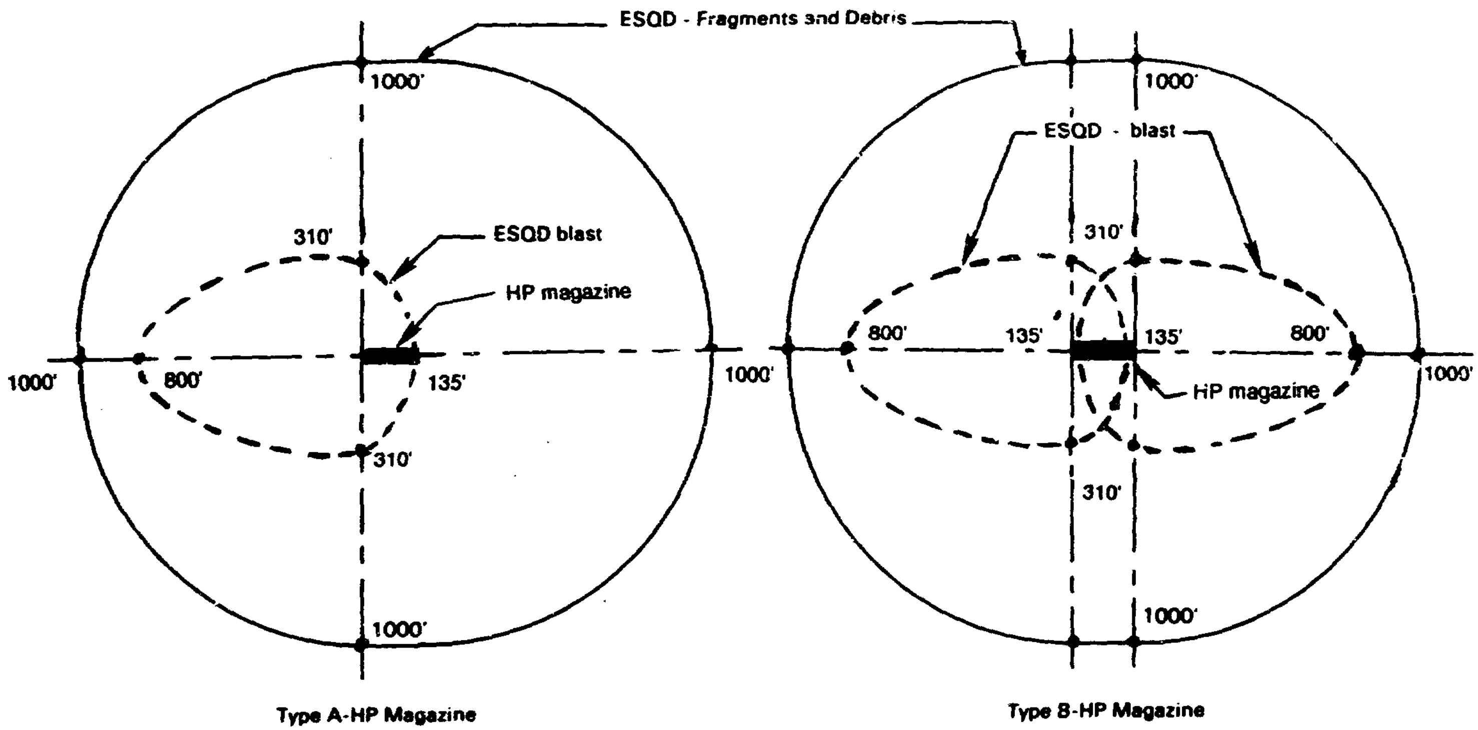


Figure 6. Predicted explosives safety quantity distance (ESQD) arcs to inhabited buildings from an HP magazine storing Class1, Division 1, high explosives.

VALIDATION OF AIRBLAST DAMAGE PREDICTIONS USING A MICROCOMPUTER BASED HIGH EXPLOSIVE DAMAGE ASSESSMENT MODEL (HEXDAM)

Joseph M. Serena, III
and
Paul M. LaHoud

Huntsville Division
U. S. Army Corps of Engineers

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ABSTRACT

A flexible and easy to use microcomputer program has been developed to predict the damage to facilities resulting from the effects of conventional explosions. This High Explosive Damage Assessment Model (HEXDAM) is intended to provide safety engineering offices and facility designers a tool for rapid evaluation of airblast damage to structures. The model was first reported at the 1988 Explosive Safety Seminar and has received widespread distribution within the U. S. Government and industry. This paper presents additional data which verifies the capability of HEXDAM to accurately predict structural damage for a wide range structure types and explosive events.

BACKGROUND

There are large numbers of personnel in the Department of Defense (DOD), other Federal agencies and private industry who must manage, operate or regulate the safety of explosively hazardous activities. Examples of such activities within DOD include ammunition production, storage and maintenance; facility siting and master planning; and the assessment of facility vulnerability to terrorism and conventional weapons effects. In private industry similar activities include planning, siting and operation of hazardous industrial or chemical processes. Most of the persons performing these activities do not have the technical background or time to develop a complete grasp of airblast effects and the resultant damage to structures. With the advent and widespread availability of desktop microcomputers, however, a tool is now available to provide this capability. The Facility Army System Safety (FASS) Office recognized the potential benefits of such a microcomputer based system in 1987 and initiated action to develop such a system.

SELECTION OF DAMAGE ASSESSMENT MODEL

An existing computer code, "Enhanced Nuclear Damage Assessment Model" (ENDAM) was developed by the U. S. Army Strategic Defense Command (Reference 1). This code assesses the damage to structures caused by nuclear weapons effects. It was identified as a potential candidate for adaptation to perform the same damage assessment for conventional weapons effects. ENDAM included suitable algorithms for computing airblast effects, assessing structural damage, and correlating statistical data. Input to the program was provided through a graphics tablet with audio prompting via a voice synthesizer. Output included both graphics and tabular data, in both plan and isometric views, with a dynamic display of the nuclear blast wave. The major limitation of ENDAM was the extensive hardware requirements. The program required a multi-component minicomputer system that would not be readily available to a large number of users.

A decision was made to develop a conventional airblast effects code based on ENDAM but simplified to operate on a widely available microcomputer platform. The platform selected was an IBM PC-XT/AT compatible computer with at least 512 kilobytes of memory and a hard disk drive. The result of this effort was the microcomputer program "High Explosive Damage Assessment Model" (HEXDAM), described in detail in References 2 and 3. Additional development has been performed over the past two years to provide more accurate modeling of structures and enhance the user compatibility of HEXDAM. These changes and other planned improvements are described in more detail in References 4 and 5.

CAPABILITIES OF HEXDAM

HEXDAM provides the user with the ability to quickly model a group of structures and compute expected damage to these structures from a conventional explosion. Up to 200 structures may be included in a given problem. These structures can also contain explosives, and HEXDAM can include the effects of secondary explosions. Structures may be drawn from a master list that includes 178 structure types. Additionally, the user can define his own structure types. Structures can be automatically divided into substructures for more detailed analysis. HEXDAM can also account for shielding of one structure by another structure. HEXDAM has been distributed extensively within the government for the last two years. A commercial version is also available to private industry.

Figures 1 through 3 present typical graphical output from HEXDAM. Figure 1 shows the plan for a typical site layout before evaluation of damage. Figure 2 includes the same plan view after analysis by HEXDAM. This plot includes overpressure contours and gross damage levels, in terms of percent damage, for each structure. Figure 3 provides a plot of structural damage contours for one of the structures in the example site plan.

DAMAGE PREDICTION MODEL

An important goal for HEXDAM is the capability to reasonably estimate damage to many different types of structures for virtually any conventional explosion. This requires that the program accurately model the effects of such explosions and the variation in these effects for varying charge weight, or yield. Figure 4 illustrates this type of variation by showing the idealized blast loads for two explosive events, as computed from References 6 and 7. The first load is the result of a detonation of 500 pounds of TNT at a distance of 95 feet from a structure. The second load is from 75,000 pounds of TNT at a range of 506 feet. Both of these pressure-time loads have a scaled range ($distance/yield^{1/3}$) of 12. The difference in pulse duration and total impulse is significant. For a given scaled range, the overpressures acting on a structure are fairly constant regardless of the charge weight, or yield. However, the duration of the load on the structure varies directly with charge weight. The dynamic response and resulting damage experienced by a receiver structure will be different for these two loadings. For large yields, the pulse duration and resulting damage will be much higher. Figure 5 shows a typical, one-way, reinforced concrete wall panel and its response to the two blast loadings. The first load results in some permanent deformation but only slight damage. The longer duration loading results in significant permanent deflection and severe damage.

HEXDAM DAMAGE PREDICTION ALGORITHM

The damage algorithm in ENDAM uses a "vulnerability number" to express a structure's basic vulnerability to overpressure or dynamic pressure. It uses a "pulse duration factor" and corresponding "reference yield" to consider structural response. In essence, the combined effect of these parameters is used to derive a single effective pressure loading for which damage is estimated. Details of this damage algorithm can be found in Reference 1. The vulnerability numbers and pulse duration factors for ENDAM were derived from damage observed during actual and simulated nuclear weapons tests. ENDAM provides these parameters in a library of 178 existing structure types. Because of the long duration of overpressures for even the smallest nuclear weapons, the damage estimates from ENDAM are only valid for very large quantities of conventional explosives (roughly greater than 100,000 pounds). Additional data is required to estimate damage for smaller quantities of explosives.

The damage algorithm in HEXDAM is similar to that used in ENDAM. This algorithm uses five vulnerability parameters. The vulnerability numbers from ENDAM are replaced with reference pressure levels. Two pressure levels are used, one for "moderate" damage and one for "severe" damage. Two pulse duration factors for the same damage levels and a reference explosive yield are also used. HEXDAM provides these parameters for the same 178 structure types as ENDAM in a library of existing structure types. It should be noted that the levels of damage are expressed in terms of percentage of damage to the structure, where 0% is no damage and 100% is complete destruction. The "moderate" and "severe" damage levels are somewhat arbitrary, although differing damage percentages will require different reference pressures and pulse duration factors. For structures given in the HEXDAM master structure list, moderate damage is taken as 30% and severe damage as 75%.

HEXDAM predicts damage by first computing the peak incident overpressures and dynamic pressures imposed on the structures by an explosive event. These computations are based on pressure curves for nuclear blast effects. The curves are scaled to account for the range, height and weight of the charge, and are modified to account for the difference in blast energy generated by conventional and nuclear explosions. (Conventional explosives produce less thermal energy and roughly twice the blast energy as nuclear explosives.) HEXDAM interpolates between these modified curves to determine the peak pressures at the geometric center of each structure. If the structure has been subdivided, the pressure values are computed for each substructure.

The pulse duration factor is used to include the effect of pulse duration on structural damage. The reference pressure levels for moderate and severe damage are adjusted to account for the duration effect, using the pulse duration factor and the reference yield. The predicted damage

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to the structure is then computed using a bilinear relationship between these modified pressures and the corresponding damage levels. If the structure has been subdivided, the damage level for each substructure is computed. The equations defining the HEXDAM damage assessment algorithm can be found in Reference 8.

VALIDATION OF OVERPRESSURE CALCULATION ALGORITHM

As stated above, HEXDAM computes overpressures acting on each structure through an interpolation of existing curves for nuclear weapons effects. This algorithm was evaluated by computing and plotting overpressure versus range for nine different yields. These plots are shown in Figure 6. Comparison to a similar plot for conventional explosives (Reference 10) shows generally excellent agreement between HEXDAM and other methods of computing overpressure. The curves in Reference 10 appear to decay slightly faster than the HEXDAM curves at longer ranges. However, the difference is very small and will have minimal effect on the ability of HEXDAM to reasonably predict structural damage.

VALIDATION OF DAMAGE PREDICTION ALGORITHM

Excellent recent work in the prediction of damage to structures has been performed in References 9 and 10. This work is based on the development of standardized pressure-impulse (P-I) response diagrams for typical components of building systems. A P-I diagram is essentially an isodamage curve for a given structure or component. For any event resulting in a pressure-time loading that falls on the P-I curve, the damage to the structure will be the same. The P-I diagrams in Reference 10 are based on structural theory and have been modified to reflect experimentally observed damage. Figure 7 is a dimensionless P-I diagram for a one-way reinforced concrete slab. An entire family of P-I isodamage curves, corresponding to different damage levels, can be developed for a structural component. These can be used as a basis for estimating building damage. Reference 11 provides a good discussion of the development of P-I diagrams.

The HEXDAM damage prediction algorithm was evaluated in Reference 12 by using P-I diagrams to define the vulnerability parameters for a family of structural components commonly used in building systems. The components considered are listed in Table 1. Figure 5 includes the details of the one-way reinforced concrete wall panel used in this study. The P-I diagrams for each of the 12 components were computed for 0%, 50% and 100% damage. The five vulnerability parameters for each component were computed from these P-I diagrams, using 30% as the moderate damage level and 75% as the severe damage level.

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These parameters were evaluated by using them to predict damage with HEXDAM. Three test cases were selected, using explosive yields of 250, 2,500 and 250,000 pounds of TNT. Curves showing the variation of pressure and impulse with scaled distance, for each of the three charge weight cases, were superimposed over the P-I diagrams for each structural component. The intersections of these curves denote scaled ranges for each component at which 0%, 50% and 100% damage could be expected. These scaled ranges were used to determine the location for each component from the charge for HEXDAM models. Three HEXDAM models, one for each charge weight, were prepared and analyzed to produce predicted damage levels.

The results of the tests for all structural components are given in Table 2. Specific pressure-impulse-yield diagrams for the concrete wall, pre-engineered building wall and wooden wall systems are given in Figures 8 through 10, respectively. In these diagrams, the pressure-impulse-distance curves for the three charge weights are superimposed over the P-I curves. Damage levels predicted by HEXDAM are shown in boxes.

The damage levels predicted by HEXDAM agree well with the expected damage levels from the P-I diagrams. For the 0% damage case, HEXDAM predicted damage that is somewhat greater than 0%. This can be attributed to the fact HEXDAM uses no zero-damage threshold. The derivation of P-I diagrams includes a small, non-zero load that will cause no permanent deformation and, therefore, no damage. For the 50% and 100% damage cases, HEXDAM computed damage levels that were in very good agreement with the P-I diagrams. In all cases, the small differences in damage prediction were within reasonable limits. These results clearly indicate that the HEXDAM damage algorithm can predict damage with a degree of accuracy that agrees well with other, more detailed analysis methods.

It should be noted that a slight modification of the equations in the HEXDAM damage prediction algorithm was required to match the shape of normal P-I diagrams. The modified version of HEXDAM is available as an upgrade to all Government users.

CONCLUSIONS

HEXDAM provides a fast, reliable tool to evaluate the potential for damage from conventional explosions. This study has shown that P-I diagrams for building components can be easily adapted to provide damage indexes in HEXDAM to accurately estimate overall damage to structures. Future work planned at this time is to develop a library of structures with suitable vulnerability values derived from P-I diagrams. Table 3 is an example of the structure types being developed. The structure database resulting from this effort will be included in future versions of HEXDAM. Users will only have to select a structure, for example, "single story pre-engineered building", and its necessary parameters will be provided automatically. The ability to enter customized structure data will continue to be available to users for unique modeling requirements.

It should be clearly recognized that HEXDAM is not intended to be a replacement for the more rigorous methods of analysis required to design structures or evaluate in detail structural damage from blast effects. Rather, it is intended to give the user with limited background a reasonably accurate estimate of probable gross damage from overpressure for a wide range of building types.

HEXDAM is available to all Government agencies through Reference 8. An equivalent code is available to private industry through Reference 13.

ACKNOWLEDGMENTS

The development of HEXDAM was funded through the Facility Army System Safety Program. The assistance of David Douthat, Chief of the Huntsville Division Safety Office, and Don Pittenger at Headquarters, U. S. Army Corps of Engineers, FASS project coordinator, are gratefully acknowledged. The authors also wish to recognize Mark Whitney of Southwest Research Institute and John Ferrito of the Naval Civil Engineering Laboratory. Their assistance in utilizing the Navy's extensive development of P-I diagrams for damage assessment was of great value in the preparation of this study.

Table 1: Building Components for HEXDAM Validation

Structure Description	Structural Components
Wood Building	Wall: Lightweight wooden wall, 2"x6" wood studs on 16" centers, 1/2" wood sheathing on both sides Roof: Wood trusses, 40'-0" span, 2"x10" truss members, 1/2" wood sheathing on top side only
Metal Frame Building CMU In-Fill Walls	Wall: 8" concrete masonry unit wall with nominal reinforcement Roof: Lightweight concrete slab, 4" thick, reinforcement ratio 0.0056
Metal Frame Building	Wall: Insulated 1-1/2" corrugated steel sandwich panels, 26 gauge, spanning 4'-0" Roof: 1-1/2" corrugated steel roof panels, 26 gauge, spanning 4'-0"
Pre-Engineered Metal Building	Wall: 1-1/2" corrugated steel wall panels, 26 gauge, spanning 4'-0" Roof: 1-1/2" corrugated steel roof panels, 26 gauge, spanning 4'-0"
Reinforced Concrete Building	Wall: 8" thick concrete walls, one-way, reinforcement ratio 0.002 Roof: Lightweight concrete slab, 4" thick, reinforcement ratio 0.0056
Concrete Tilt-Up Building	Wall: 6" thick concrete wall panels, reinforcement ratio 0.02 Roof: Lightweight concrete roof slab, 4" thick, reinforcement ratio 0.0056

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TABLE 2: Comparison of Damage Prediction for P-I Diagrams and HEXDAM

Structure Component	Structure Description	Damage Levels Predicted by HEXDAM (% damage)								
	Yield	25 lbs			2,500 lbs			250,000 lbs		
	P-I Damage	0	50	100	0	50	100	0	50	100
Wall	Wood Building	.61	49.9	100	7.5	50.9	100	7.7	52.9	100
Roof		5.33	43.1	100	15.1	40.1	97.7	16.4	47.3	100
Wall	Metal Frame Building	.06	43.0	100	7.3	37.8	100	11.1	46	100
Roof	CMU In-Fill	1.00	55.1	95.8	.3	47.3	100	3.6	51.3	94.9
Wall	Metal Frame Building	.10	55.3	93.7	4.6	57.3	99	4.7	61.7	100
Roof		1.80	50.0	100	3.2	58.1	100	3.2	58.2	100
Wall	Pre-Engineered	1.80	50.0	100	3.2	58.1	100	3.2	58.2	100
Roof	Building	1.80	50.0	100	3.2	58.1	100	3.2	58.2	100
Wall	Reinforced Concrete	.70	51.1	92.6	.2	49.9	100	4.7	55.1	100
Roof	Building	1.00	55.1	95.8	.3	47.3	100	3.6	51.3	94.9
Wall	Tilt-Up Concrete	.70	56.7	98.3	.5	44.5	100	4.1	50.7	100
Roof	Panel Building	1.00	55.1	95.8	.3	47.3	100	3.6	51.3	94.9

Table 3: Proposed Structures for Future HEXDAM Development

- Reinforced concrete general purpose buildings, single and multiple stories
- Steel frame, concrete floor slab, general purpose buildings, single and multiple stories
- Steel arch magazine for ammunition and explosive storage
- Timber mobilization-type military structures
- Petroleum, oil and lubricant facilities
- Pre-engineered metal buildings, single story
- Civil defense shelters
- Residence structures

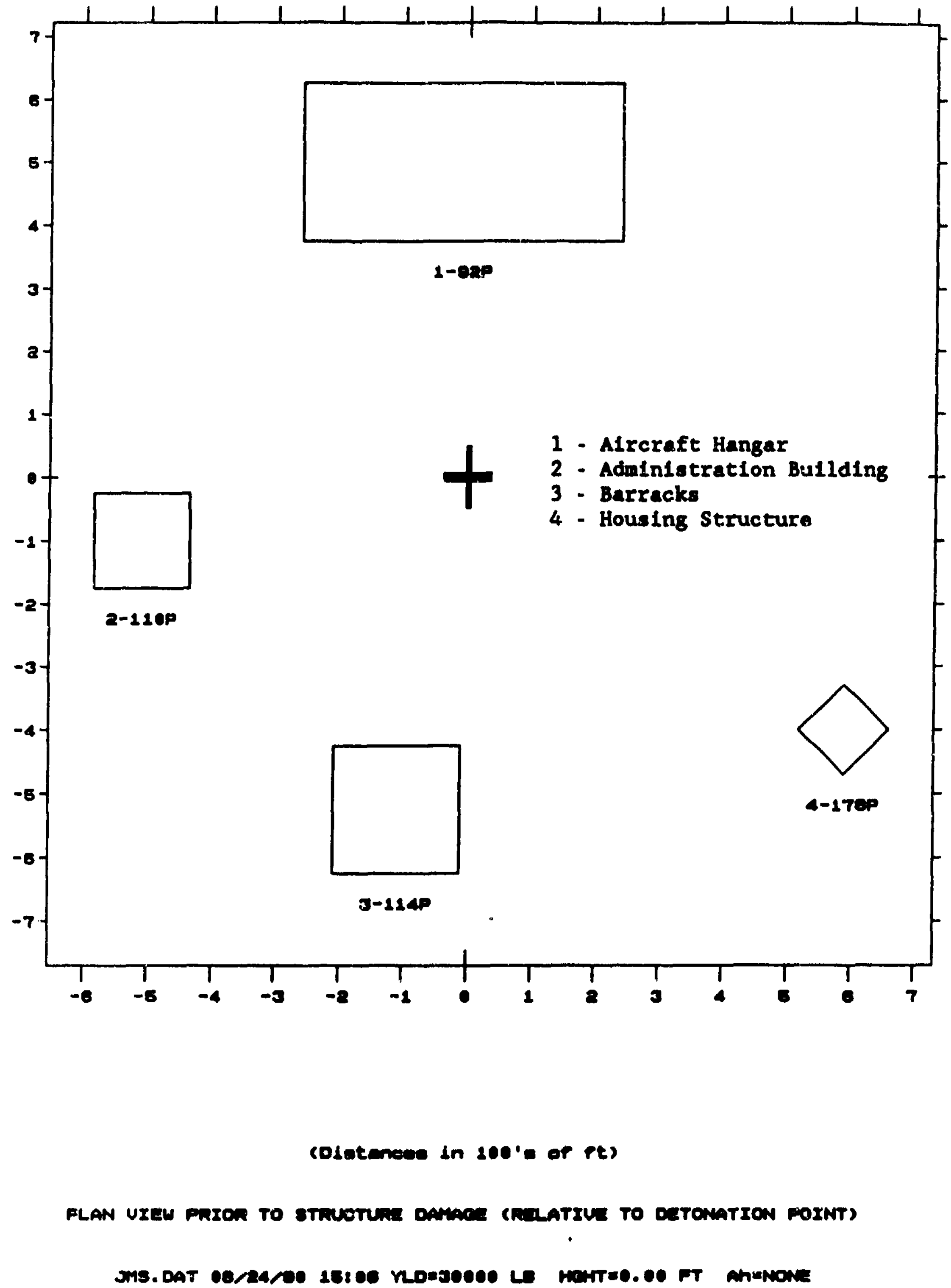
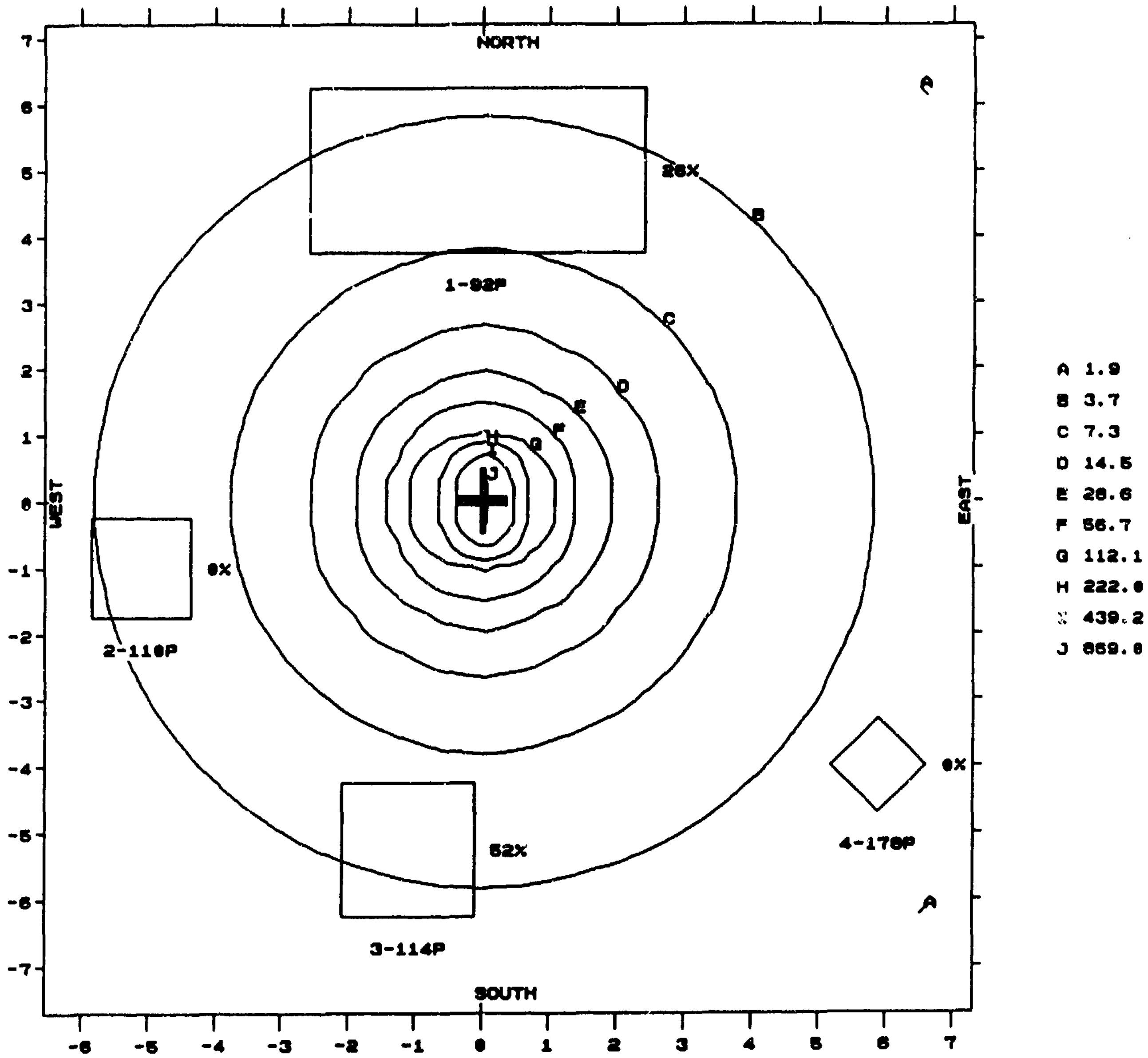


Figure 1: HEXDAM Before Damage Site Plan Plot



(Distances in 100's of ft)

OVERPRESSURE CONTOUR PLOT - ELEVATION = 0.00 FT

Figure 2: HEXDAM Overpressure Contour and Gross Damage Plot

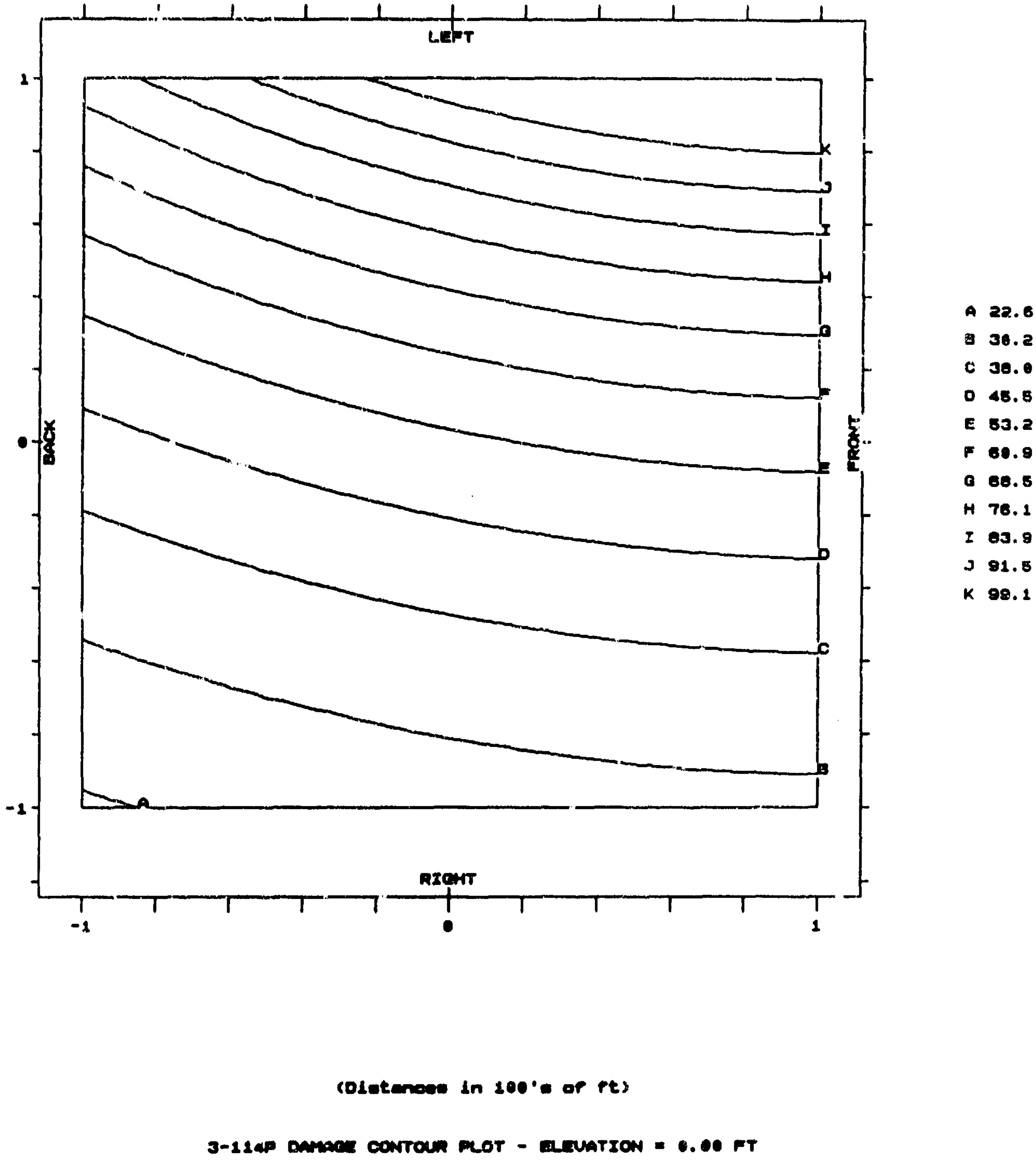
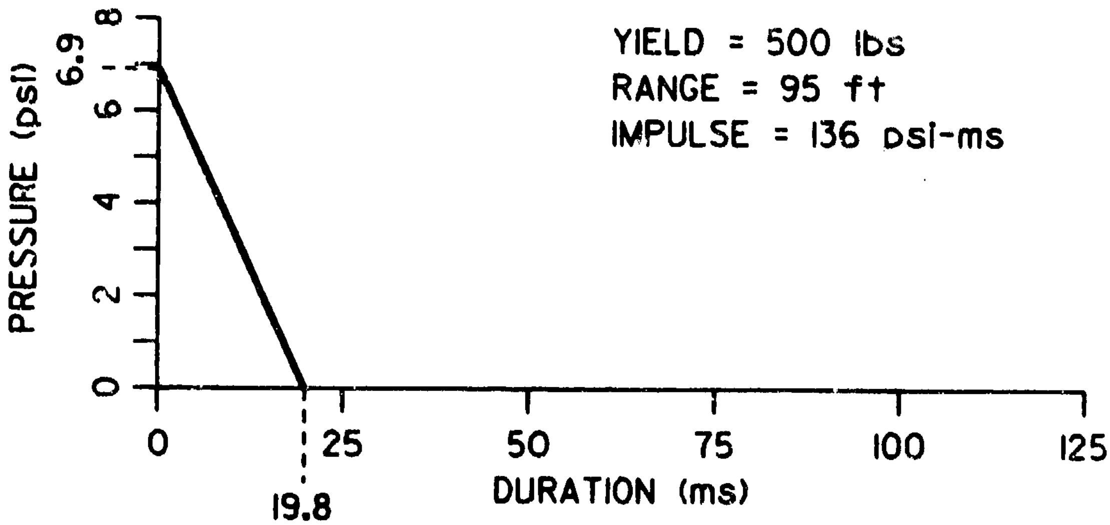


Figure 3: HEXDAM Damage Contour Plot for Barracks Structure



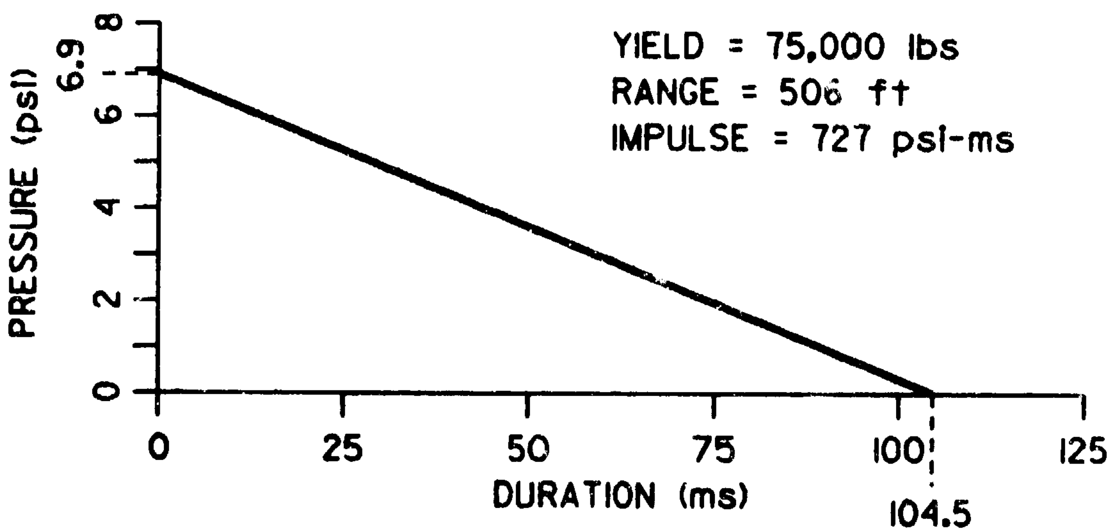
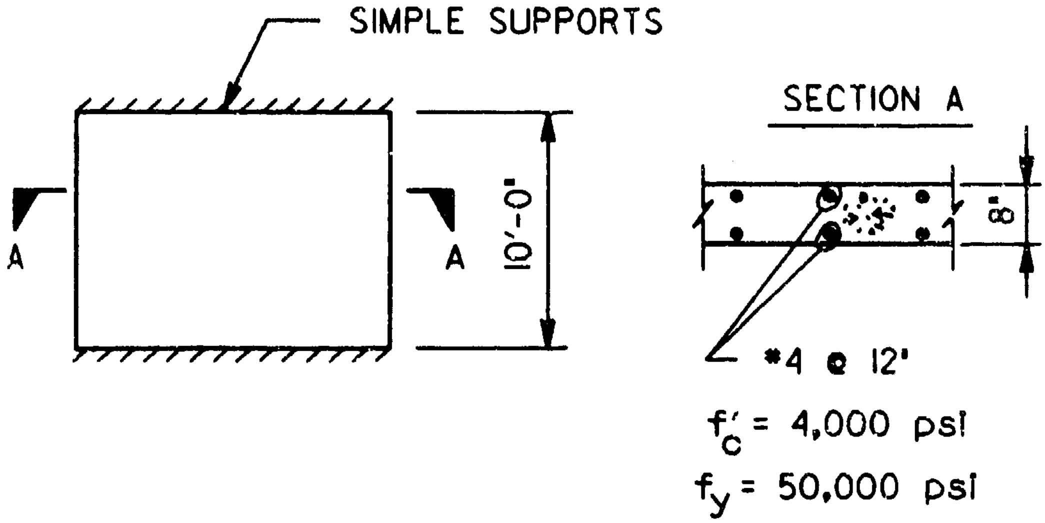


Figure 4: Example Blast Loads for Scaled Range of 12 ft/lb$^{1/3}$



Yield	500 lbs	75,000 lbs
Overpressure	6.9 psi	6.9 psi
Duration	19.8 ms	105.4 ms
Maximum Deflection	0.36 in	6.3 in
Support Rotation	0.34°	6.0°
Damage Level	Slight	Severe

Figure 5: Response of One-way Reinforced Concrete Wall to Example Blast Loads

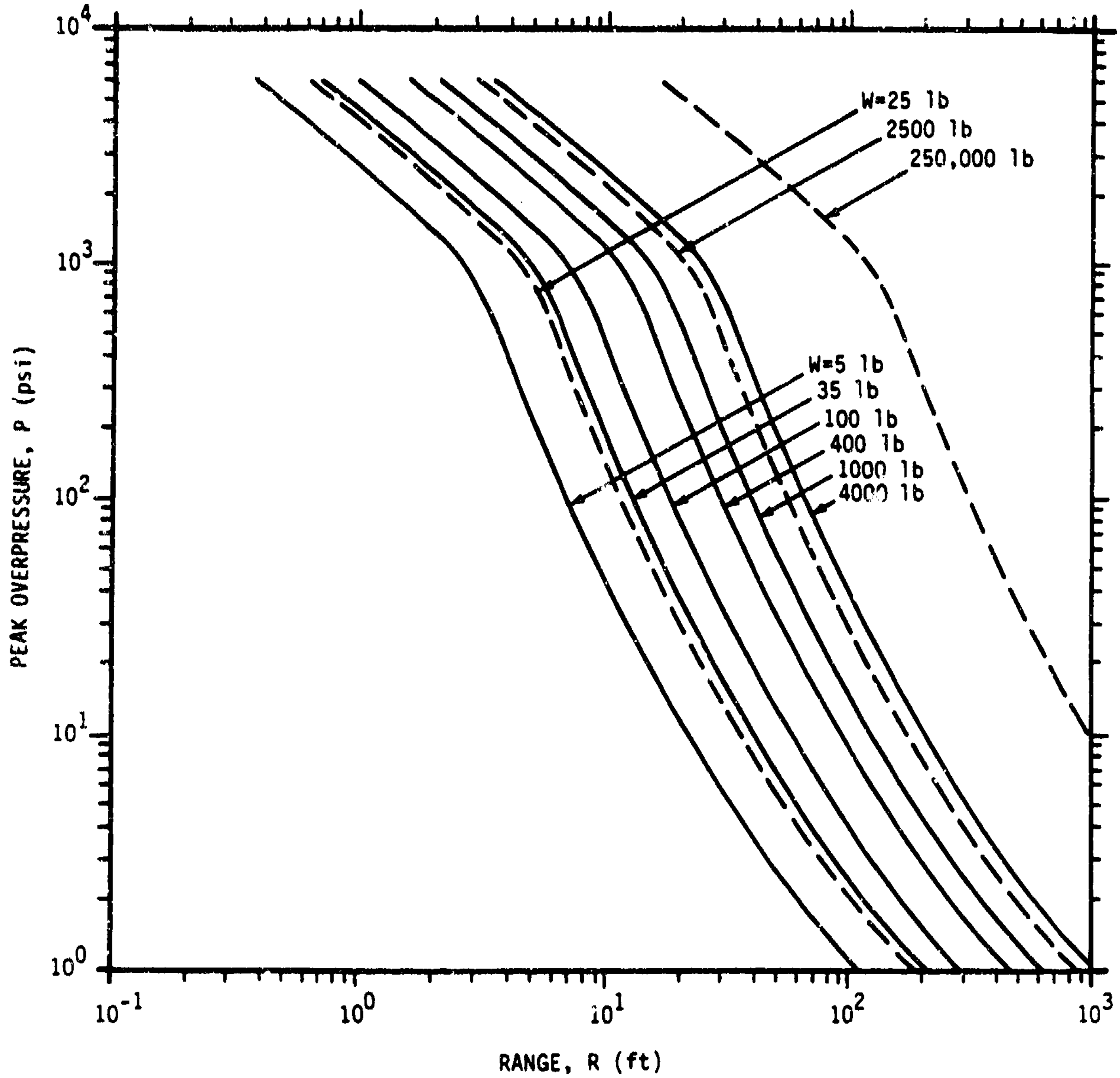


Figure 6: HEXDAM Overpressure vs. Range Curves

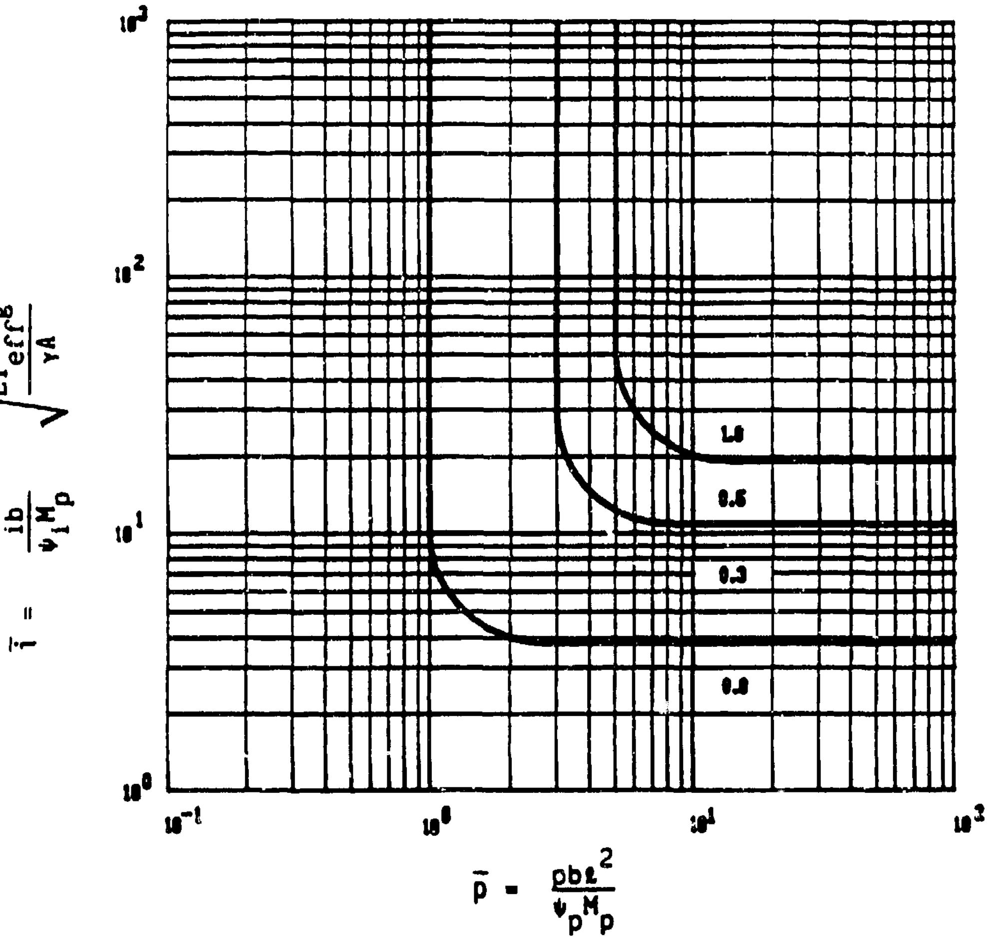


Figure 7: Example Dimensionless P-I Diagram

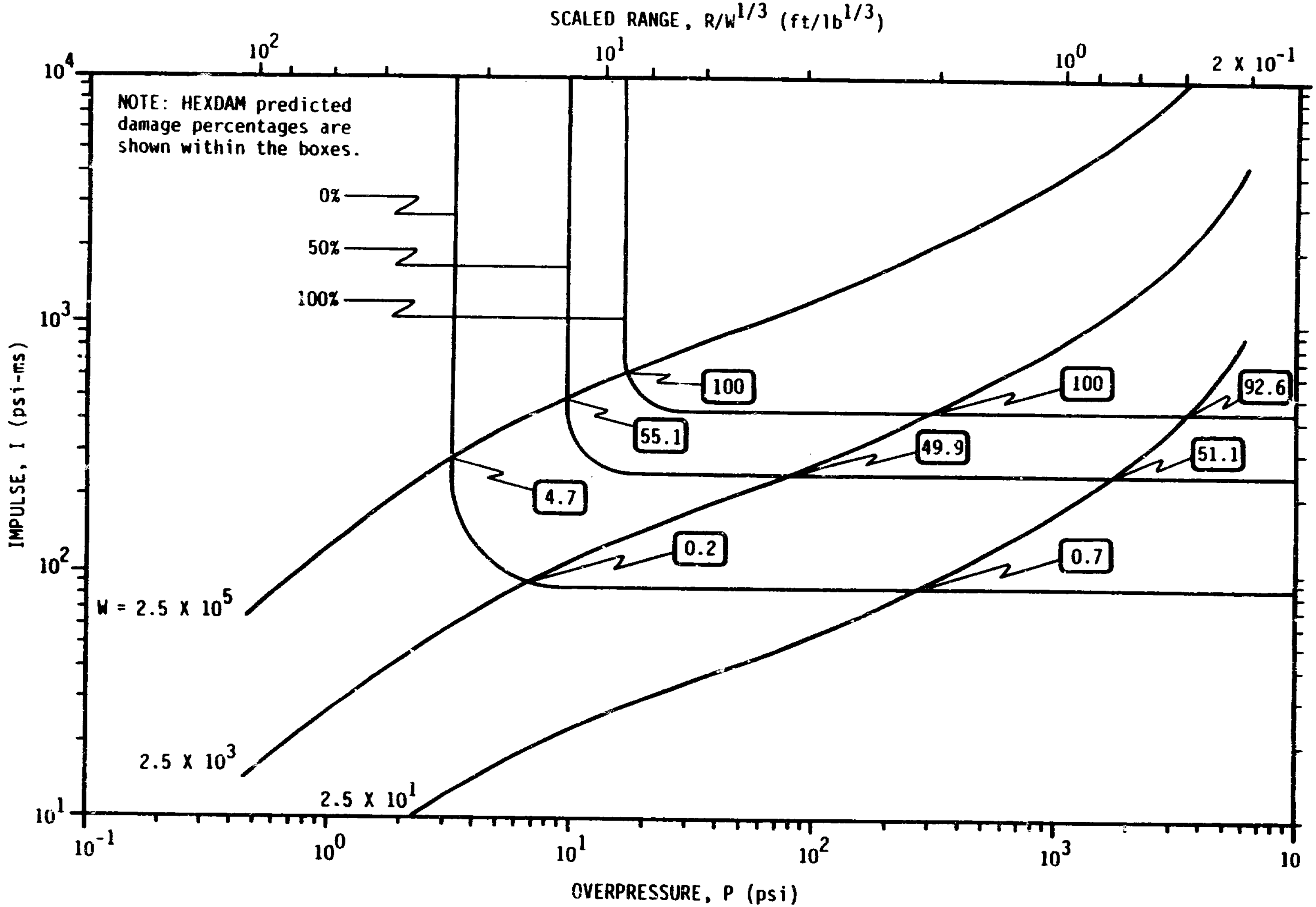


Figure 8: Pressure-Impulse-Yield Diagram for Reinforced Concrete Wall

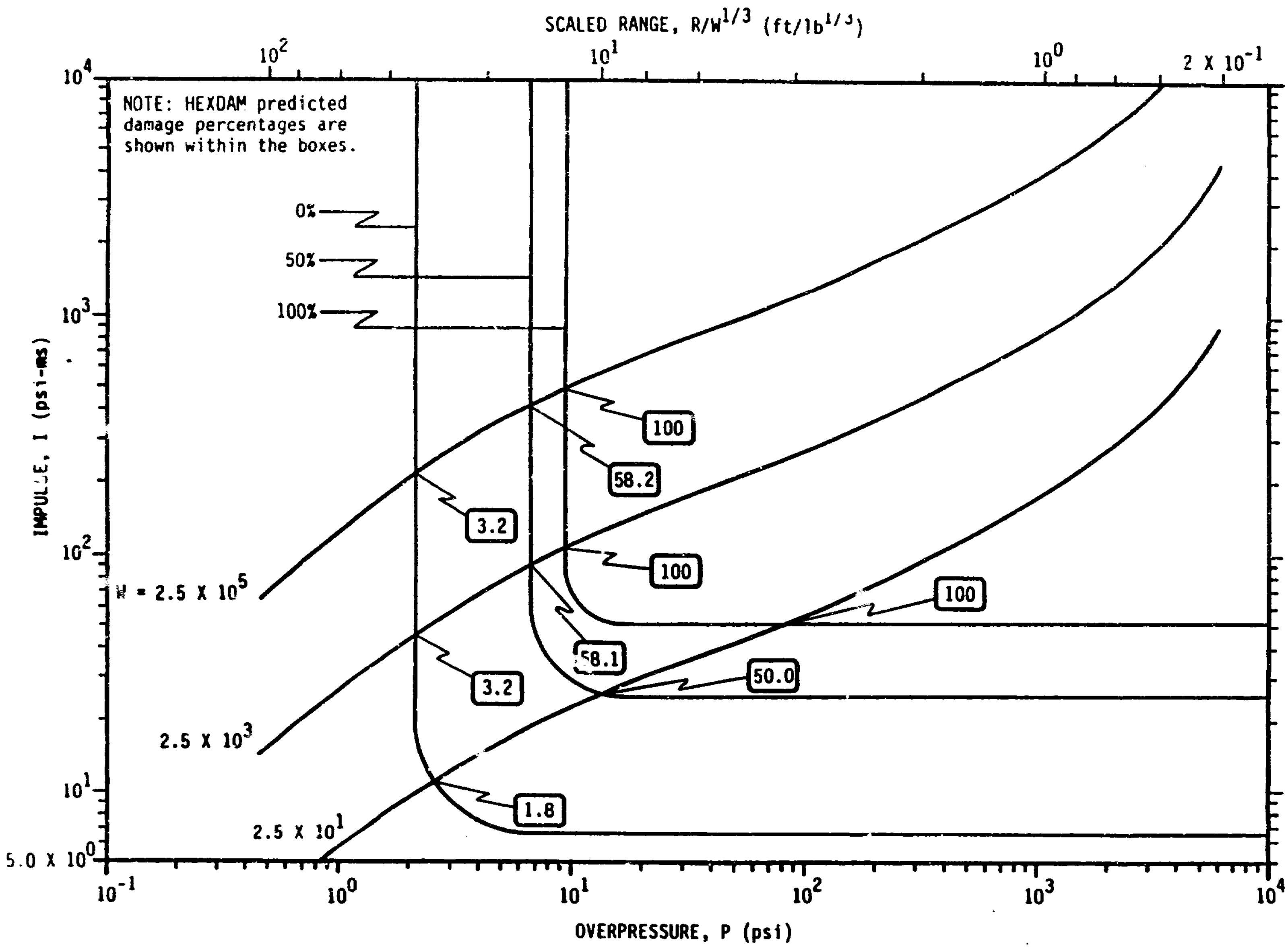


Figure 9: Pressure-Impulse-Yield Diagram for Pre-Engineered Building Wall

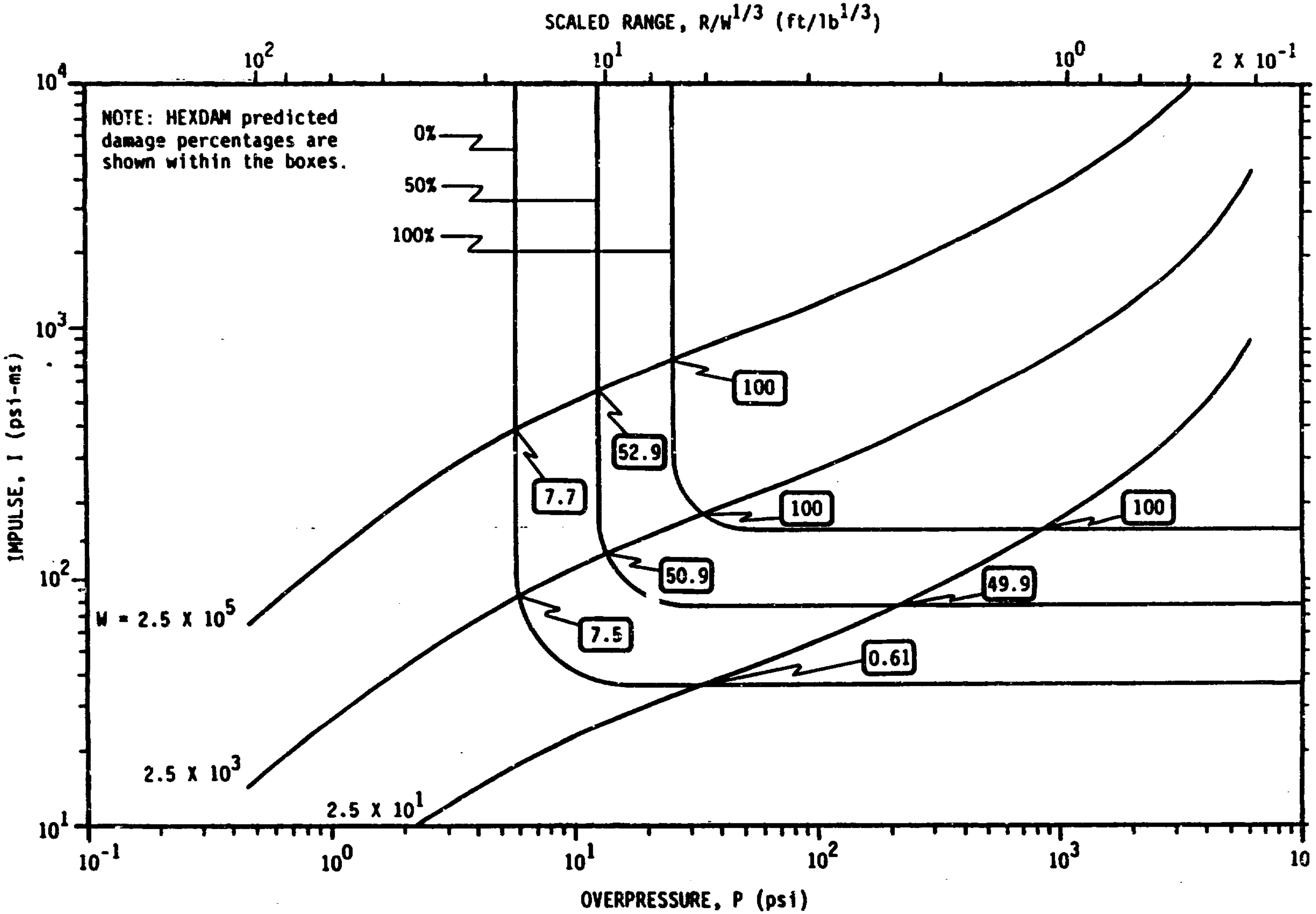


Figure 10: Pressure-Impulse-Yield Diagram for Wooden Wall System

REFERENCES

1. Tatom, Frank B, Spencer, Bruce L., and Roberts, Mark D., ENDAM3 Users Manual, Damage Assessment and Graphics Demonstration, EAI-TR-86-004A, Vol. I and II, Engineering Analysis, Inc., Huntsville, Alabama, October 1986.

2. Hamilton, Julian S., Jr., High Explosive Damage Assessment Using A Microcomputer, Minutes of the Twenty-Third Explosive Safety Seminar, Department of Defense Explosive Safety Board, Atlanta, Georgia, August 1988.

3. Tatom, Frank B. and Roberts, Mark D., High Explosive Damage Assessment Model (HEXDAM) Users Manual, EAI-TR-87-004B, Engineering Analysis, Inc., Huntsville, Alabama, 22 September 1987.

4. Tatom, Frank B. and Roberts, Mark D., Refinements to the High Explosive Damage Assessment Model (HEXDAM), Minutes of the Twenty-Third Explosive Safety Seminar, Department of Defense Explosive Safety Board, Atlanta, Georgia, August 1988.

5. Manthey, James P., LaHoud, Paul M. and Tatom, Frank B., "Structural Vulnerability to Overpressure Using A Microcomputer," Proceedings, Structures for Enhanced Safety and Physical Security, American Society of Civil Engineers, Arlington Virginia, 8-10 March 1989.

6. Structures to Resist the Effects of Accidental Explosions, U. S Army Technical Manual (TM) 5-1300, Headquarters, Department of the Army, Washington, D. C., June 1969.

7. Structures to Resist the Effects of Accidental Explosions, Vol. III and IV, Special Publication ARLCD-SP-84001, U. S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, New Jersey, November 1986.

8. Tatom, Frank B., Enhanced High Explosive Damage Assessment Model (HEXDAM-III) Users Manual, EAI-TR-89-001A, Engineering Analysis, Inc., Huntsville, Alabama, May 1989.

9. Oswald, C. J., Polcyn, M. A., Ketchum, D. E., Marchand, K. A., Cox, P. A. and Whitney, M. G., Blast Damage Assessment Procedures for Common Construction Categories, Final Report, Project No. 06-1473-30, Southwest Research Institute, San Antonio, Texas, October 1987.

10. Whitney, M. G., Ketchum, D. E. and Polcyn, M. A., Blast Vulnerability Guide, Final Report, Project No. 06-1473-040, Southwest Research Institute, San Antonio, Texas, October 1987.

11. Baker, W. E. et. al., A Short Course on Explosion Hazards Evaluation, Southwest Research Institute, San Antonio, Texas, 1978.

12. Polcyn, Michael A. and Tatom, Frank B., Evaluation of HEXDAM Damage Prediction Algorithm, Final Report, Project 06-3173-201, Southwest Research Institute, San Antonio, Texas, 8 December 1989.

13. Enhanced High Explosive Damage Assessment Model (HEXDAM-B) Users Manual, EAI-TR-89-003, Engineering Analysis, Inc., June 1989.

Insensitive Munitions Development for General Purpose Bombs

John D. Corley, Stephen A. Aubert
Air Force Armament Laboratory
Eglin AFB FL (USA)
August 1990

ABSTRACT

The Air Force requires a 1.6 hazard classification of general purpose bombs to reduce restrictions posed by current quantity distance criteria, minimize storage hazards and to increase combat readiness. There has been a concerted effort by industry and Air Force explosive development teams to provide an energetic material which meets these requirements without compromising performance levels. Wax desensitized formulations, nitroguanidine-based formulations and, most recently, NTO-based formulations have been studied in melt-cast and polymeric systems. The relatively large critical diameter of many insensitive candidate formulations has generated a requirement for larger subscale evaluation techniques and practical means of predicting behavior in full-scale hardware. The eight-inch diameter gap test and modified expanded large-scale gap test have been calibrated. A relatively inexpensive technique for measuring casewall fragment velocities and deriving Gurney characteristic velocities has been developed. Experimental results are provided for the in-house candidate material currently in advanced development, TNTO. Hydrocode methods for predicting full-scale pressure and energy profiles in realistic storage configurations are ongoing. A comparison of experiments and calculations for MK-82 bombs in various geometrical arrangements is presented. These technologies and procedures are essential to accomplish the task of arming the services with insensitive munitions. Future munitions must be safe to handle and store while performing as required upon demand.

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Introduction

This is an overview of the Air Force advanced development program for insensitive munitions (IM) technology. The Air Force program focuses on desensitization of the explosive fill for the MK-82 general purpose bomb.

The discussion begins by reviewing the formal requirements documentation upon which this program is structured and by contrasting Hazard Classification Reduction and Joint Service Insensitive Munitions policy. The process used by the High Explosive Research and Development (HERD) facility to study new explosives for insensitive systems is explained. The balance of the paper provides a status report for the Air Force insensitive explosive candidate being developed in-house, TNTO. Finally, an in-depth look at the efforts to marry experimental results for prediction of sympathetic detonation with computational hydrocodes is also presented.

Requirements Documents

The US Air Force requirement for munitions exhibiting reduced hazards was first stated formally by the Air Force Logistics Command (AFLC) in their Statement of Need (SON)-02-83 (Reference 6) for Insensitive High Explosives in Air Munitions in 1983. Later, the Air Force Tactical Air Command (TAC) presented their requirement in TAF SON 309-88 (Reference 5). A Joint Service Insensitive Munitions (IM) policy was ratified in 1987.

AFLC and TAC-SONs

The constraints imposed by AFLC and TAC are severe and include:

1) Munition effectiveness must not be compromised;

2) Warhead configuration changes must be minimal;

3) The life cycle cost of a GP bomb system meeting reduced classification requirements must be no greater than that of existing items;

4) The main charge must be reliably initiated with existing fuzes and boosters;

5) The system must meet the requirements for Insensitive HIgh Explosives (Hazard Class Division 1.6, Insensitive Articles).

AFLC SON 02-83 and TAF SON 309-88 address the fact that Air Force munitions are subject to the Department of Defense (DoD) hazard classification system which is derived from the United Nations (UN) Organization system. The number one priority for reduced hazard classification cited by AFLC, the general purpose (GP) bomb (see Figure 1), is included in Class 1 of this system reserved for explosives.

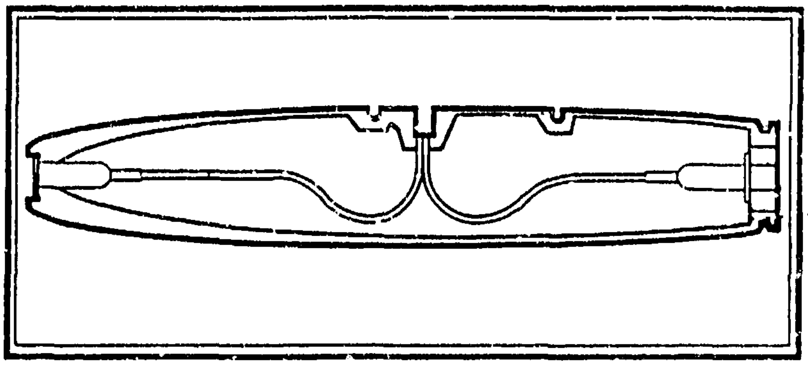


Figure 1. MK-82 500-Pound Bomb with 190 Pounds of Tritonal Explosive

Within this class, GP bombs are designated as Division 1.1, mass detonating (Reference 1). GP bombs are positioned based on the assumption that propagation of a detonation from a small portion of any stack will occur so rapidly that the combined shockwave has the damage-yield characteristics of a single, simultaneous event. This classification places severe restrictions on the number of GP bombs which may be stored near inhabited buildings and critical assets. As a result, only a small fraction of the available storage capacity is currently realized.

Department of Transportation (DOT) regulations impose constraints on transportation routes and carrier frequency for these 1.1 articles. The impact to operational readiness is severe. Munition assets are not available at forward air bases in USAFE or PACAF. If required, these items would need to be shipped from centralized storage depots, making them vulnerable and jeopardizing the Air Force Mission.

Besides the readiness factor, the additional cost of storing and transporting 1.1 munitions is prohibitive. The real estate required to provide clear zones for additional munitions must be purchased along with storage igloos. Potential savings of 263 million (1983) dollars for new construction existed in USAFE alone when AFLC SON 02-83 was penned. An additional 50 million dollars was available in PACAF.

Joint Service IM Policy

The policy statement outlining the joint service requirements for insensitive munitions were provided in a Memorandum of Agreement (MOA) approved in 1987 (Reference 7). This MOA was established as a result of individual service studies, including a report by the Scientific Advisory Board ad hoc committee confirming the urgent Air Force need. The IM policy is intended to make munitions systems and delivery systems more survivable. It is distinctly separate from the requirements in the Department of Transportation (DOT) storage and transportation regulations which the Air Force is attempting to meet.

1.6 Hazard Classification Requirements

The protocol for achieving the newly-created hazard classification, 1.6 -insensitive articles, has been defined in Test Series 7 of the United

Nations Recommendations on the Transport of Dangerous Goods Tests and Criteria (Reference 3). In addition to the screening tests outlined in the DOD Ammunition and Explosives Safety Standards (DoD 6055.9-STD), Series 7 requires the tests shown in Table 1. Classification division 1.6 is reserved for articles containing only Extremely Insensitive Detonating Substances (EIDS), which "demonstrate a negligible probability of accidental initiation or propagation under normal conditions of transport" (Reference 4). EIDS are those materials which have passed the substance tests in Table 1. The blasting cap requirement makes 1.6 Hazard Classification of a fuzed system with conventional detonator/lead/booster initiation trains impractical. Initiation systems will:

1) continue to be stored separately;

2) be incorporated into systems where a Hazard Classification between 1.6 and 1.1 is acceptable; or

3) become electronic/mechanical with no sensitive materials in line. The 1.6 Hazard Classification requirement may be contrasted with the Insensitive Munitions test requirements also shown in Table 1.

TABLE 1. 1.6 Hazard Classification and Insensitive Munitions Testing Requirements

1.6 Hazard Classification Tests	Insensitive Munitions Tests
Substance	Substance
Blasting Cap	Not required
Gap Sensitivity	
Susan Impact	
Bullet Impact	
Fast Cookoff	
Slow Cookoff	
Article	Article
Fast Cookoff	Fast Cookoff
Bullet Impact	Bullet Impact
Sympathetic Detonation	Sympathetic Detonation
Slow Cookoff	Fragment Impact*
	Slow Cookoff*
	Shaped Charge Jet*
	Spall Impact*

* Service specific based on a threat hazard analysis of the munition system being evaluated.

Testing procedures for the four tests common to both protocols are interchangeable. Fuel fire testing may be substituted for the external wood fire in the fast cookoff, although the latter is the method preferred by the United Nations.

Development Process

Figure 2 shows a flow chart of the Air Force in-house development process for candidate extremely insensitive detonating substances. Insensitive molecular materials are studied and then incorporated into

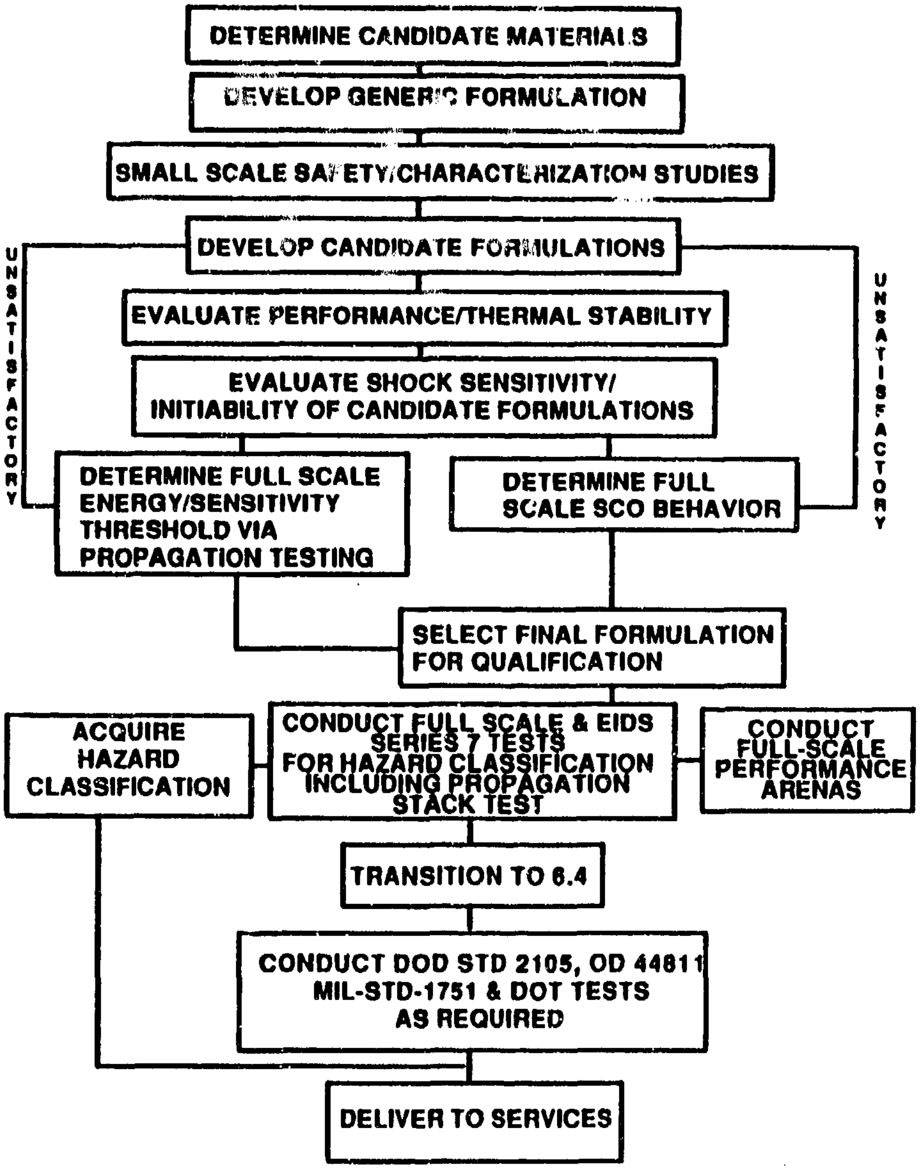


Figure 2. Air Force Insensitive Explosive Development Process

explosive formulations for further evaluation. The safety characterization and material compatibility studies shown in Table II are conducted prior to optimizing the formulation.

Table II. Safety Screening Tests

Test	Criteria
Differential Scanning Calorimetry	No exotherm at 250°C
Impact (Drop Hammer)	Sensitivity less than Explosive D
Electrostatic Discharge (spark)	No reaction at 0.25 Joule
Friction	No reaction
Vacuum Thermal Stability	Maximum 2 cc/g
Chemical Reactivity Test	Maximum 2 cc/g
Critical Temperature (Henkin)	

Thermal stability, shock sensitivity, critical diameter, performance and initiability are evaluated in small-scale and engineering scale units (8-inch diameter, 1/2 inch thick steel cylinders). If a formulation exhibits promising features, it is evaluated in the two most severe full-scale environments -- sympathetic detonation and slow cookoff. Acceptable cookoff behavior allows further sympathetic detonation testing to optimize the performance/sensitivity balance. Unacceptable cookoff behavior returns the developer to the formulation stage of the process. Once a final formulation is selected, it is subjected to the remaining environments prescribed by the United Nations for Hazard Classification.

Full-scale performance tests are conducted to obtain fragment velocity, size and spatial distribution and air blast in the warhead configuration of interest. Final qualification of explosives for Air Force application is accomplished in accordance with MIL-STD-1751 (USAF), Safety and Performance Tests for Qualification of Explosives (Reference 8). This document supersedes NAVORD DD 44811 of the same title.

In parallel with in-house efforts, the Air Force has stimulated commercial industry involvement in explosives research and development. The output from this effort has been the development of several promising plastic bonded explosive (PBX) formulations.

Technological Challenges

To date, none of the formulations developed by the Air Force (in-house or via contract to industry) have met all the performance, sensitivity and initiability requirement simultaneously. These parameters, coupled with the necessary cost constraints for general purpose bomb fills, have made the challenge of developing insensitive high explosives seemingly insurmountable. Less sensitive forms of existing molecules, formulation desensitizers, alternate storage configurations and improved package designs along with new, less sensitive energetic molecules are a few of the technologies which have emerged from efforts by Department of Defense (DoD) and Department of Energy (DoE) laboratories as well as commercial research groups to meet this challenge. The background and test results for the insensitive explosive candidate developed in-house by the Air Force, TNTO, are presented in the following section of this report. This formulation shows promise of striking the proper balance to meet the requirements stated above.

NTO

Desensitization of formulations with inert binders compromise performance parameters. It is preferable to employ less sensitive energetic molecules. One such molecule is 3-Nitro-1,2,4-Triazol-5-one, commonly called nitrotriazolone or NTO (see Figure 3).

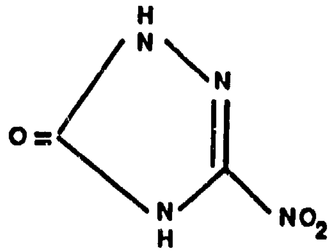
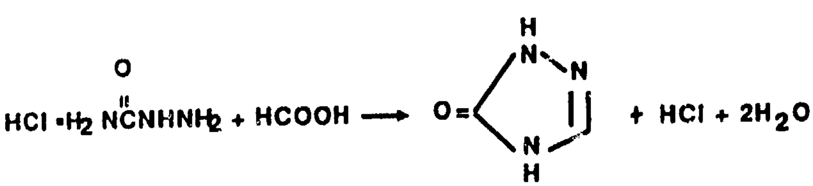


Figure 3. Structural Formula for NTO

It was first synthesized in 1966 (Reference 13). However, not until 1985 did Lee and Coburn (Reference 14) recognize its potential as an explosive. It was first synthesized and incorporated into insensitive explosive formulations for the Air Force by the Energetic Materials Branch of the Air Force Armament Laboratory in 1988. It is synthesized by a two-step process. Semicarbazide hydrochloride (SC) is reacted with formic acid to form 1,2,4-triazole-5-one (TO), followed by nitration in 70% nitric acids at 50-60°C. These reactions are shown in equation 1 and 2. NTO may be recrystallized from hot water (References 14, 15). Particle size is controlled by adjusting the precipitation rate. The stability of NTO is believed to result from resonance and tautomerization.

Equation 1.



(1)

SC TO

Equation 2.

$$\mathrm{TO} \xrightarrow[H_2SO_4]{HNO_3} \mathrm{NTO} \qquad (2)$$

NTO has been incorporated into an H-6 analog called TNTO (see Table III). H-6 is the explosive used to load Navy GP bombs.

Table III. H-6 and TNTO Compositions

H-6	%	TNTO	Mod I %	Mod II %	Mod III %	Mod IV %
RDX	45	NTO	42	42	42	40
TNT	29	TNT	34	32	30	30
Wax	5	Wax	5	7	9	10
Al	21	Al	19	19	19	20

TNTO is a melt castable formulation made by emulsifying wax in molten TNT and adding aluminum powder and NTO. Processing is accomplished in standard steam-jacketed kettles with anchor blades. The mixture is stirred under vacuum for approximately 20 minutes. Vacuum is slowly removed and the product is cast under ambient conditions, achieving charge densities of 94-95% of theoretical maximum density.

As shown in Table III, several modifications of this formulation have been studied. Each demonstrate unique sensitivity, performance and initiation characteristics.

Shock Sensitivity

The shock sensitivity of various formulations has been measured using the modified expanded large scale gap test (MELSGT) configuration shown in Figure 4.

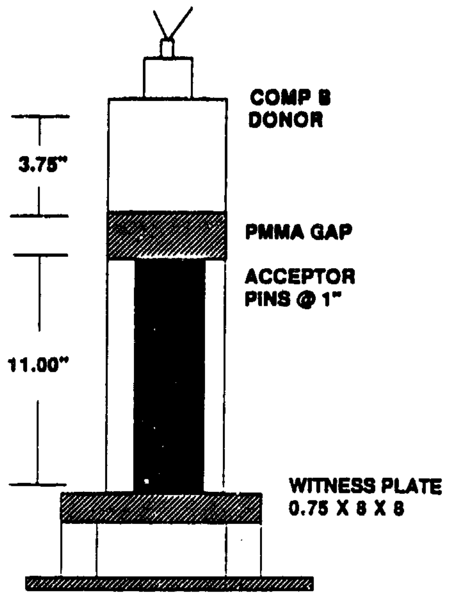


Figure 4. Modified ELSGT Set-Up

Results are provided in Table IV. Tritonal (TNT/Al - 80/20) and PBX-9502 (TATB/Kel-F binder - 95/5) results are provided for comparison. An RP-83 boostered detonator is used to initiate a 1-inch long by 1 inch diameter A-5 pellet. This, in turn, initiates a 3.75 inch by 3.75 inch diameter cast composition B donor charge. Varying thicknesses of polymethylmethacrylate (PMMA) are used to alleviate the pressure from the donor charge. Pressure vs. PMMA thickness for this configuration has been calibrated by the Armament Laboratory (Reference 17).

Table IV. Shock Sensitivity of Explosive Formulations

Configuration	Formulation	Go/No Go PMMA Thickness (in.)	Go/No Go Pressure (Kbar)
MELSGT	TNTO I	2.44/2.50	58.4/56.5
MELSGT	TNTO II	2.19/2.25	66.7/64.5
MELSGT	TNTO III	2.03/2.06	72.3/71.2
MELSGT	TNTO IV	1.91/1.94	76.7/75.6
MELSGT	Tritonal	4.00/4.13	20.7/18.6
MELSGT	PBX-9502	2.00/2.06	73.4/71.2

The acceptor charge is contained in a steel cylinder and machined to accommodate the placement of piezoelectric pins for measurement of the shockwave or reaction wave velocity. The charge is supported above a 0.75-inch thick, 8-inch by 8-inch square, mild steel witness plate.

Fragment Velocity

A technique for measuring the velocity of fragments from 8-inch diameter cylinders has been developed here at AFATL by J. D. Corley and J. G. Glenn (Reference 10 and 19, Figure 5).

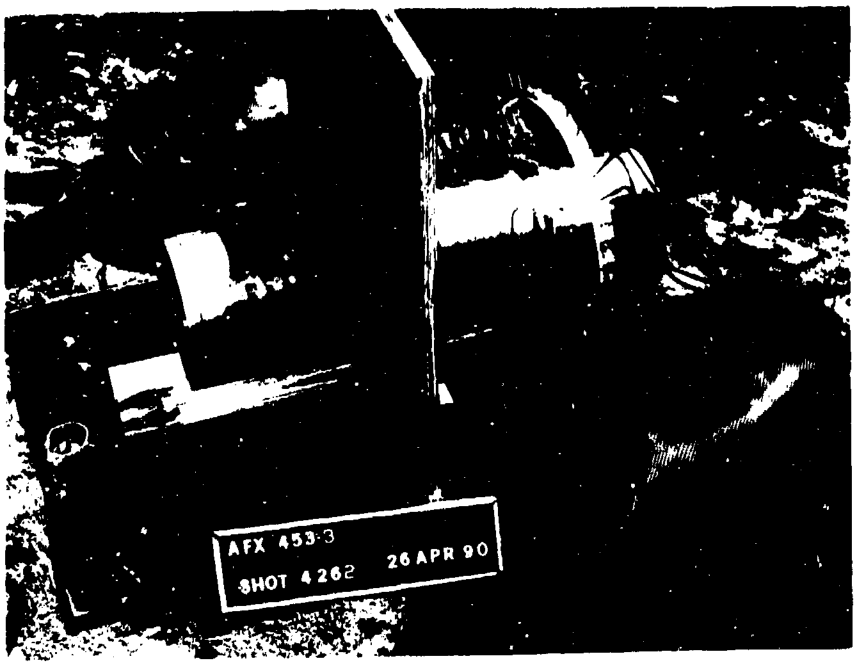


Figure 5. Casewall Fragment Velocity Measurement System

As in the 8-inch diameter gap test, an 8-inch long by 8-inch diameter section of schedule 40 pipe containing a charge of cast Composition B is used to initiate the acceptor charge. The acceptor charge is contained in a 16-inch long section of schedule 40 pipe capped on one end with a 0.5 inch thick steel endplate. Piezoelectric pins are inserted into the acceptor charge at precisely machined intervals (2.00 $\pm$ .005 inches) to measure time of arrival of the detonation wave thus obtaining a velocity profile. This ensures steady state detonation velocity has been achieved in the region where fragment velocity is measured.

Fragment velocity is determined in a plane approximately 4 inches from the rear surface of the acceptor charge using a radial array of piezoelectric pins to measure time of arrival. The pins are positioned normal to the charge using a template machined to $\pm$ .005 inches. They are supported by a plexiglass arch and glued into place. The terminal fragment velocity, V_T, is determined by curve fitting the velocity profile and extrapolating to a point 90 mm from the original casewall position. The Gurney Method is used to determine the metal accelerating characteristics of the candidate explosive from energy and momentum balances (Reference 18). The parameter for quantifying the portion of the explosive's total energy (E) is the characteristic velocity (Vc) given by Equation 3 for cylinders.

Equation 3.

$$Vc = (2E)^{1/2} = V_T \quad (M/C + 1/2)^{1/2} \qquad (3)$$

Where, M is the mass per unit length of the metal case
C is the mass per unit length of the explosive charge

Representative values of characteristic velocities obtained in this manner are provided in Table V. They are useful for comparison purposes but are meaningless in an absolute sense. As is shown, the values for the TNTO formulations are nearly equivalent with that of Tritonal.

Table V. Gurney Characteristic Velocities (km/sec)

Formulation	$(2E)^{1/2}$
Tritonal	2.32
Comp B	2.67
TNTO II	2.52
TNTO IV	2.34

Initiability

TNTO formulations have critical diameters ranging between 1 to 1.5 inches (Reference 22). Booster tests were conducted in 8-inch diameter cylinders with standard fuzewell liners attached to the inside of the forward baseplate (see Figure 6).

Figure 6. Booster Test Cylinder

The initiation trains are inserted into the fuzewell for testing. These items are preconditioned to $-65^{o}F$ to confirm reliability at this extreme service condition. The units are placed above rolled homogeneous armor (RHA) witness panels and instrumented with piezoelectric pins as in the 8-inch gap test. The booster configurations used in the TNTO initiability studies are shown in Figure 7. Configuration 1 consists of an RP-83 boostered detonation, followed by a small piece of Detasheet (Dupont) and the crescent-shaped FZU-2B (45 g tetryl) booster from the FMU-81. This is used to initiate the T-147 auxiliary booster (284 g tetryl) from the M-905 tail fuze. In Configuration 2, the T-147 auxiliary booster is replaced with a 500 g PBX-9503 prototype booster. Configuration 3 consists of an RP-83 inserted into 74 g of C-4 which has been packed into the housing above a 1/4-inch thick piece of Detasheet and the M-148 auxiliary booster (182 g tetryl). The results of the TNTO initiation tests are summarized in Table VI.

Table VI. TNTO Initiation Test Results

Formulation	Booster Configuration Required at -65°F
TNTO II TNT/NTO/D2/Al (32/42/7/19)	M-148 (configuration 3 in Figure 7)
TNTO IV TNT/NTO/D2/Al (30/40/10/20)	T-147 (configuration 2 in Figure 7)

TNTO II was initiated by the M-148 booster while TNTO IV required the PBX-9503 prototype booster.

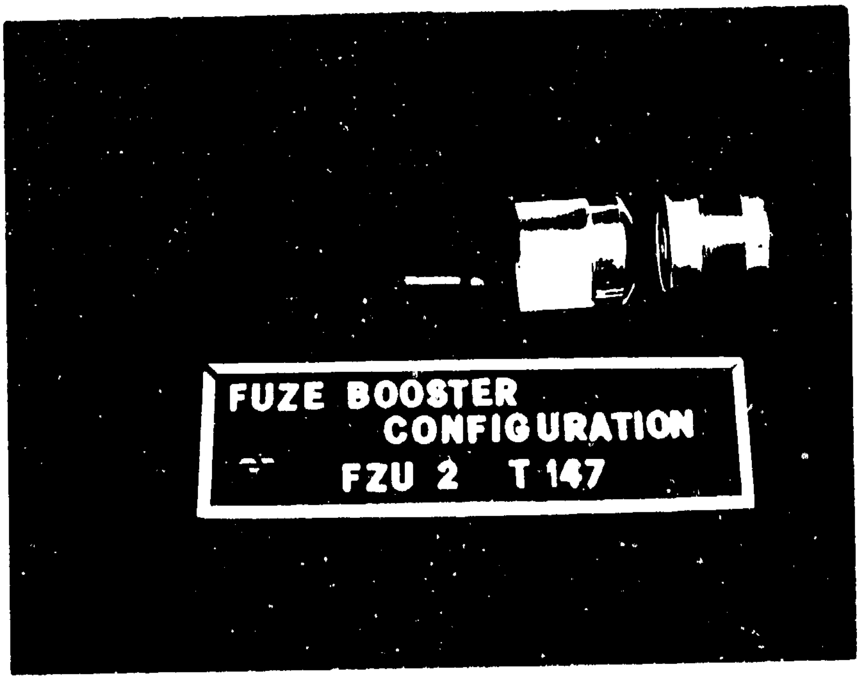


Figure 7a. Initiation Test Configuration 1: T-147 Auxiliary Booster

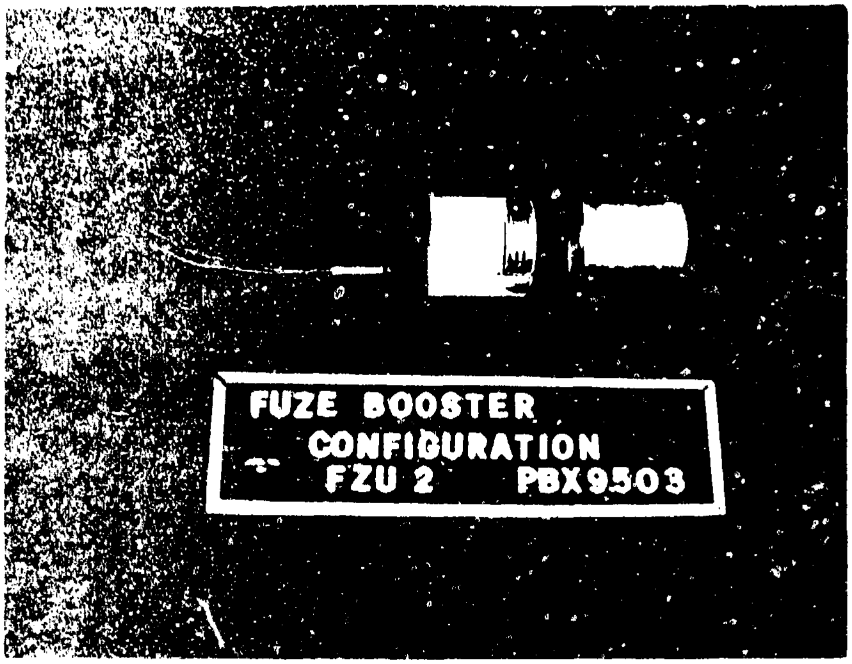


Figure 7b. Initiation Test Configuration 2: PBX-9503 Prototype Auxiliary Booster

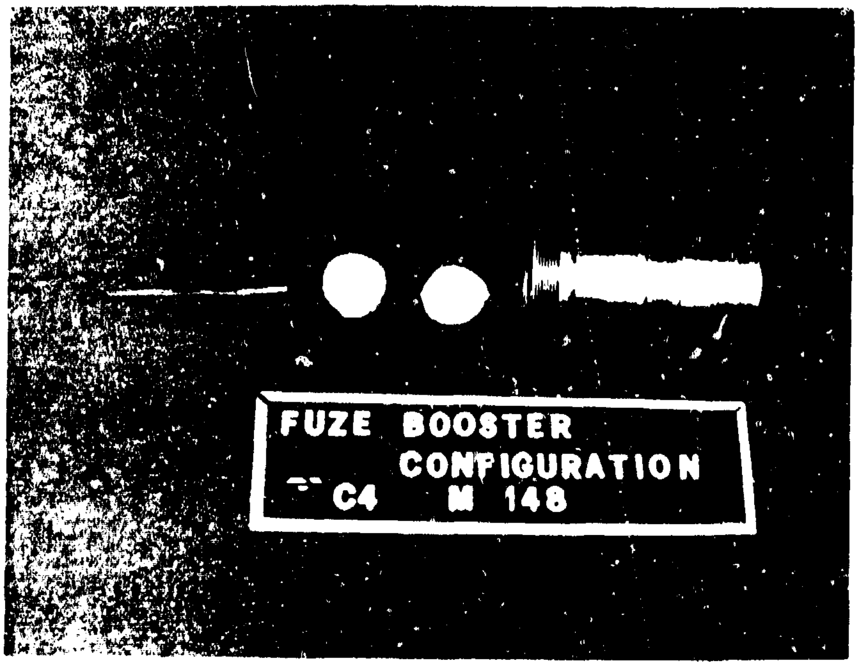


Figure [illegible] Initiation Test Configuration 3: M-148 Auxiliary Booster

TNTC Sympathetic Detonation Testing

Reliable suppression of sympathetic detonation in 500-pound bombs is difficult to achieve. MK-82 bombs are stored in pallets containing 6 bombs as shown in Figure 8.

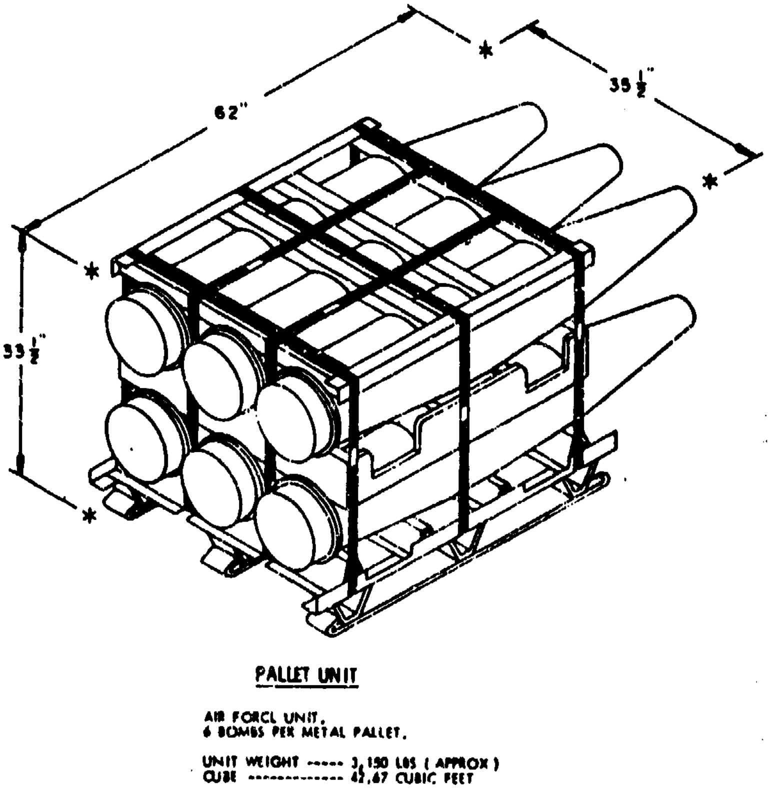


Figure 8. MK-82 Storage Configuration

The separation distance (skin-to-skin) between adjacent bombs in this configuration is approximately 0.5 inches. The bombs are approximately 10.75 inches in diameter, resulting in a separation distance of about 5-5.25 inches for the diagonally spaced bombs. The only barriers between bombs in this configuration are very thin steel cross support members.

Full-scale sympathetic detonation testing begins with the single package test in the configuration shown in Figure 9.

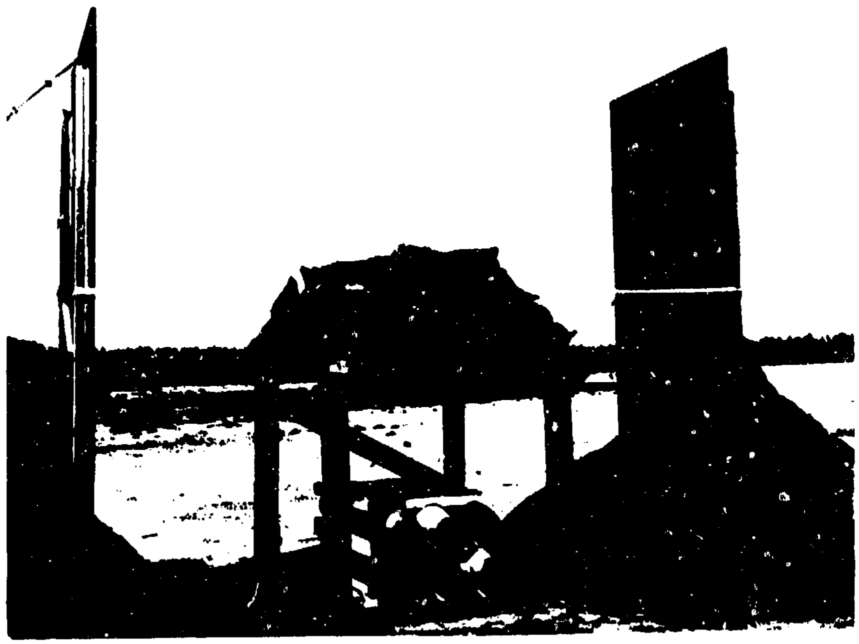


Figure 9. Single Package Test Configuration

The donor bomb is located in the bottom row center position of a standard metal pallet, positioned between a live acceptor bomb and a BDU-50 (inert-filled bomb). The top row of the pallet consists of a BDU-50 positioned between a live acceptor bomb and another BDU-50. The live acceptors are on opposite sides of the pallet to allow individual assessment of the conditions at the adjacent and diagonal acceptor positions. The package is placed on a 1-inch thick rolled homogeneous armor (RHA) witness plate. RHA witness plates are also positioned on each side and above the package to obtain fragment signatures from any detonating items. Piezoelectric pins are spaced precisely along the donor bomb to track the time of arrival of the detonation wave to obtain its detonation. Post test recovery of case remnants and unreacted explosive and the evaluation of the witness plate signatures are used to determine the results of the experiment.

Full-scale (MK-82) testing of TNTO II and TNTO IV formulations in this configuration has been conducted. The results are shown in Figure 10 and summarized in Table VII.

Table VII. TNTO Full-Scale Sympathetic Detonation Testing

	Adjacent Acceptor	Diagonal Acceptor
TNTO II (TNT/NTO/D2/Al) (32/ 42/ 7/ 19)	Violent Explosion	Detonation
TNTO IV (TNT/NTO/D2/Al) (30/ 40/ 10/20)	No Detonation	No Detonation

For TNTO IV, the less energetic and less sensitive of the two formulation tested, no propagation of the donor detonation occurred. The recovered pieces of both live acceptor bomb cases were large and platelike. The charging tube and fuzewell were recovered from the diagonal bomb. The diagonal bomb was broken up more severely than the side acceptor but showed no evidence of detonation. A portion of the adjacent live acceptor bomb casing from the nose region contained heavy impact markings from the impact of the donor bomb. Unreacted explosive was recovered after the test.

The recovered pieces from the inert diagonal acceptor bomb also included a large portion of its nose, heavily scarred by donor fragment impact. Another piece was recovered from the inert diagonal item which appeared markedly different from the adjacent item remnants. It was severely riddled, possibly from the jet impact region where the two adjacent items focused the products and fragments from the donor bomb. The two remnants of the remaining inert items looked quite similar to each other. The signature from the initial "slapper" impact of the donor bomb was observed as was severe deformation of the bomb bodies.

Witness plates from the TNTO IV test were essentially clean except for the severe scarring and cracking of the bottom plate from the donor bomb fragments. The top witness plate was cracked into two pieces from the impact of the inert bomb directly above the donor bomb. No fragment markings from the live acceptor bombs were observed.

For TNTO II, the more energetic and more sensitive of the two formulations tested, propagation of the donor detonation occurred in the diagonal acceptor bomb. Only a small portion of the diagonal live acceptor bomb casing was recovered. It showed evidence of multiple impacts from high velocity fragments and detonation products. Large, platelike pieces of the adjacent live acceptor bomb were recovered. No unreacted explosive was recovered after the test. The adjacent inert item was damaged severely, having been directly exposed to two detonations. Likewise, only a small portion of the inert acceptor bomb from the top center position was recovered. The diagonal inert bomb was not recovered. The bottom witness panel was scarred heavily by fragments and cracked into two pieces. The portion of the plate beneath the live adjacent item was clean. The top and side plates contained multiple perforations from the high velocity fragments of the detonating acceptor bomb. By comparison the other side panel (on the side of the adjacent live acceptor bomb) was relatively clean except for a few significant penetrations from large, high velocity fragments. The live adjacent acceptor bomb reacted violently but did not propagate the donor detonation like the diagonally position live acceptor.

The latter test was conducted to determine if the energy to sensitivity ratio for this formulation was small enough to prevent propagation in this configuration and to aid in establishing a margin of safety for the TNTO IV formulation.

Figure 10a. Remnants of Live Diagonal Acceptor from TNTO IV Single Package Test

Figure 10b. Remnants of Live Adjacent Acceptor from TNTO IV Single Package Test

Figure 10c. Live Adjacent Acceptor Panel for TNTO IV

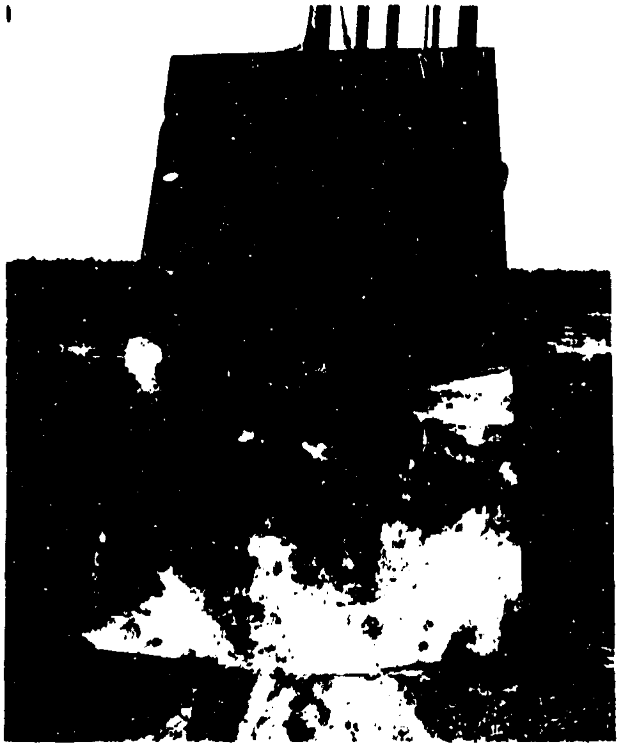


Figure 10d. Live Diagonal Acceptor Panel for TNTO IV

Figure 10e. Case Remnants of [illegible] Adjacent Acceptor from TNTO II Single Package Test

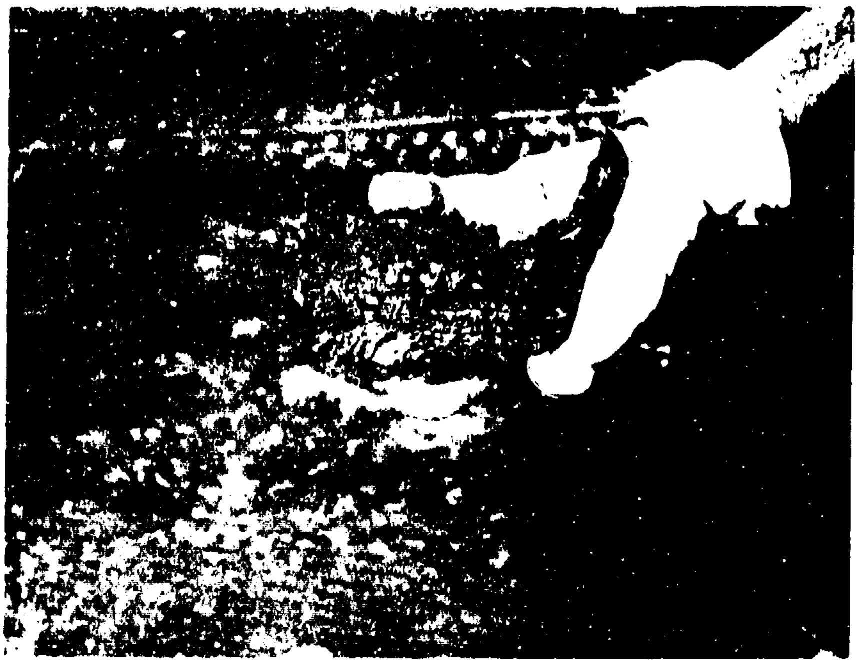


Figure f. [illegible] Diagonal Acceptor from TNTO II **Single** [illegible]

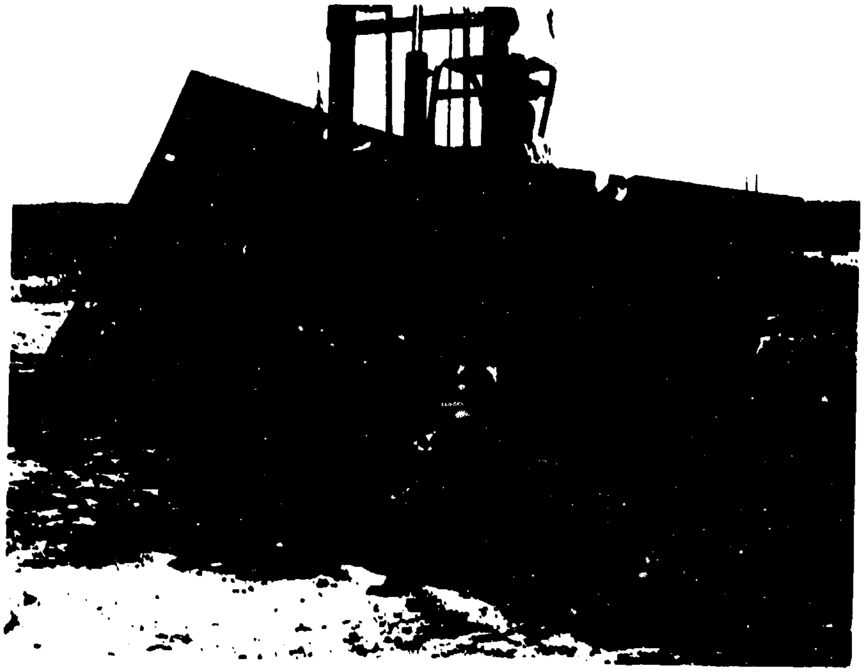


Figure 10g. Vertical Witness Plate from Live Adjacent Acceptor Side for TNTO II

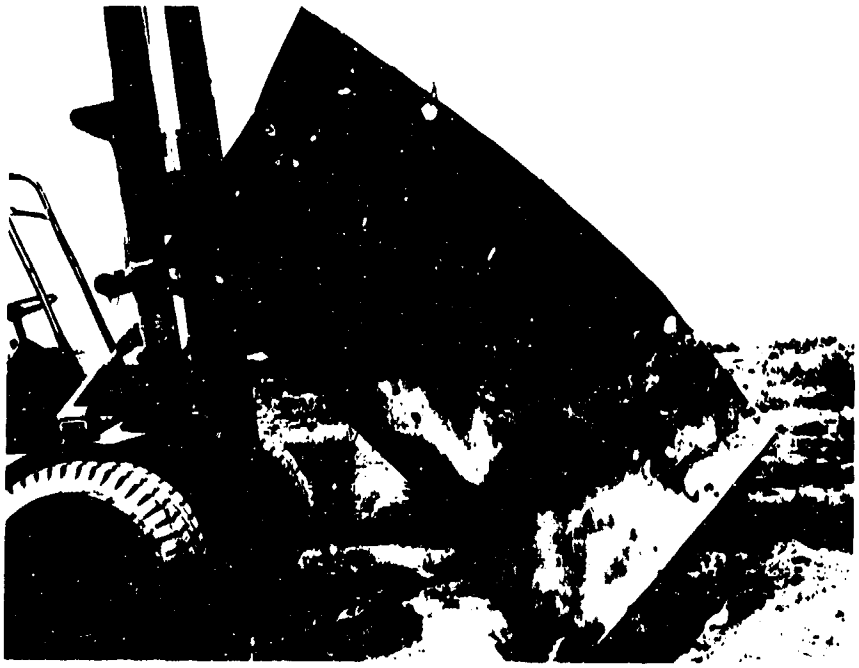


Figure 10h. Vertical Witness Plate from Live Diagonal Acceptor Side for TNTO II

TNTO IV Full-Scale Slow Cookoff

A full-scale (MK-82) slow cookoff was conducted for TNTO IV in the configuration shown in Figure 11.

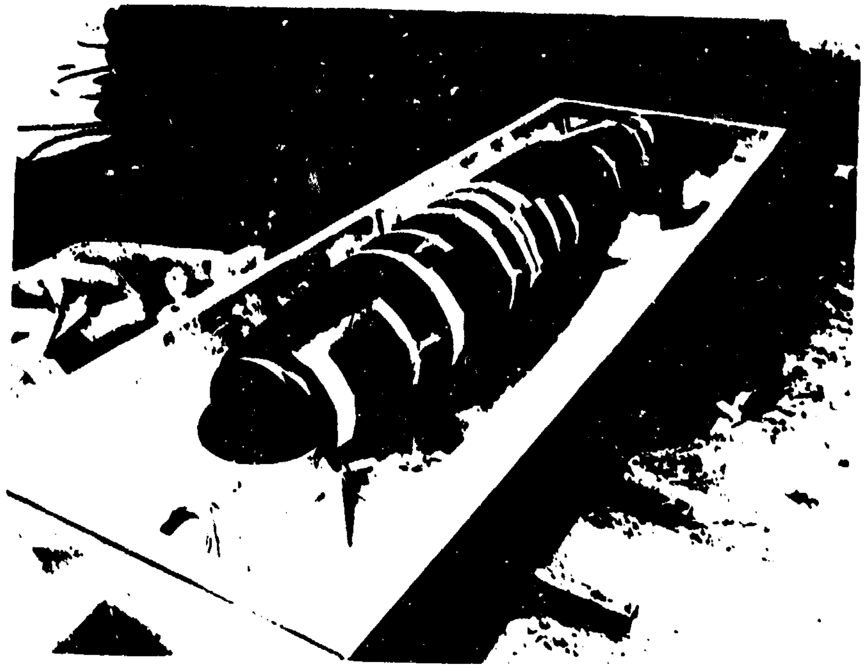


Figure 11a. Internal View of Oven Showing Exudation Troughs and Thermocouples

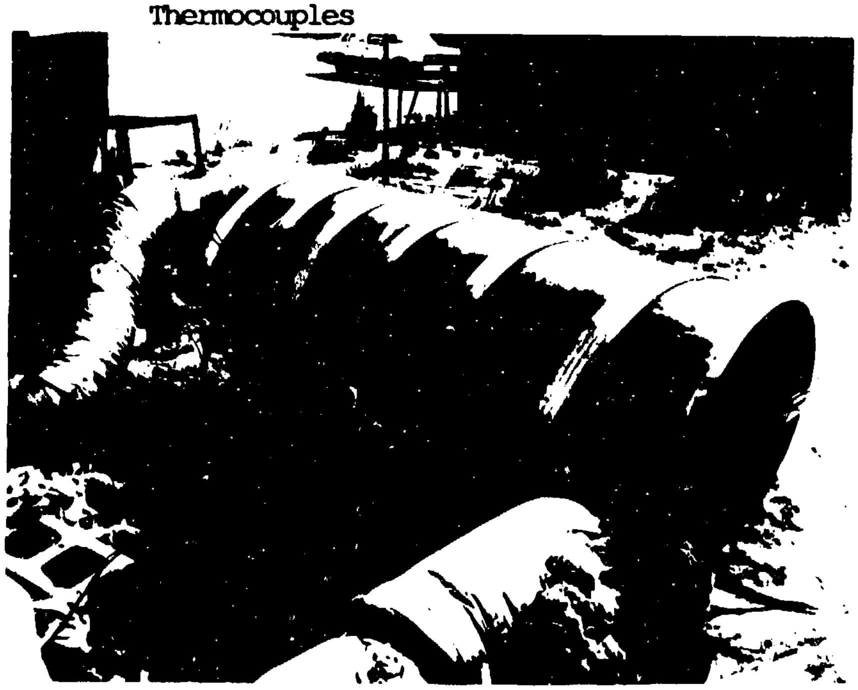


Figure 11b. Slow Cookoff Oven with Resistive Element Heat Tapes

Figure 11c. Insulated Slow Cookoff Oven Prior to Testing Note: No Video Monitoring Ports Shown in This Set Up.

In this set-up, the item is enclosed in an aluminum oven with windows in each end to allow video monitoring. The bomb is supported by a steel, angle-iron stand. Exudation troughs are provided for the removal of any molten explosive prior to reaction. The oven is equipped with ducts which circulate air driven by a blower to maintain a uniform temperature throughout the oven. Heating is provided by electrical resistive element tapes wrapped around the exterior of the oven. Insulation covers both the oven and the air ducts and thermocouple wires are placed on and around the test item. The thermocouple positions and temperature profiles for the TNTO IV slow cookoff are shown in the drawing in Figure 12. The average of the temperatures recorded for thermocouples 3, 4, 5, and 6 was used as the control for the heat tapes in this experiment.

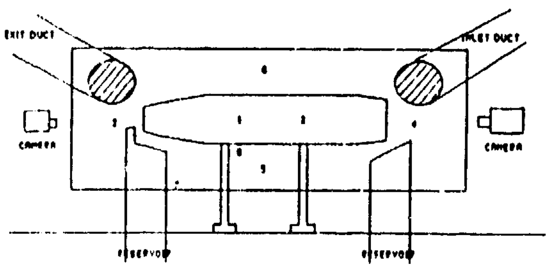
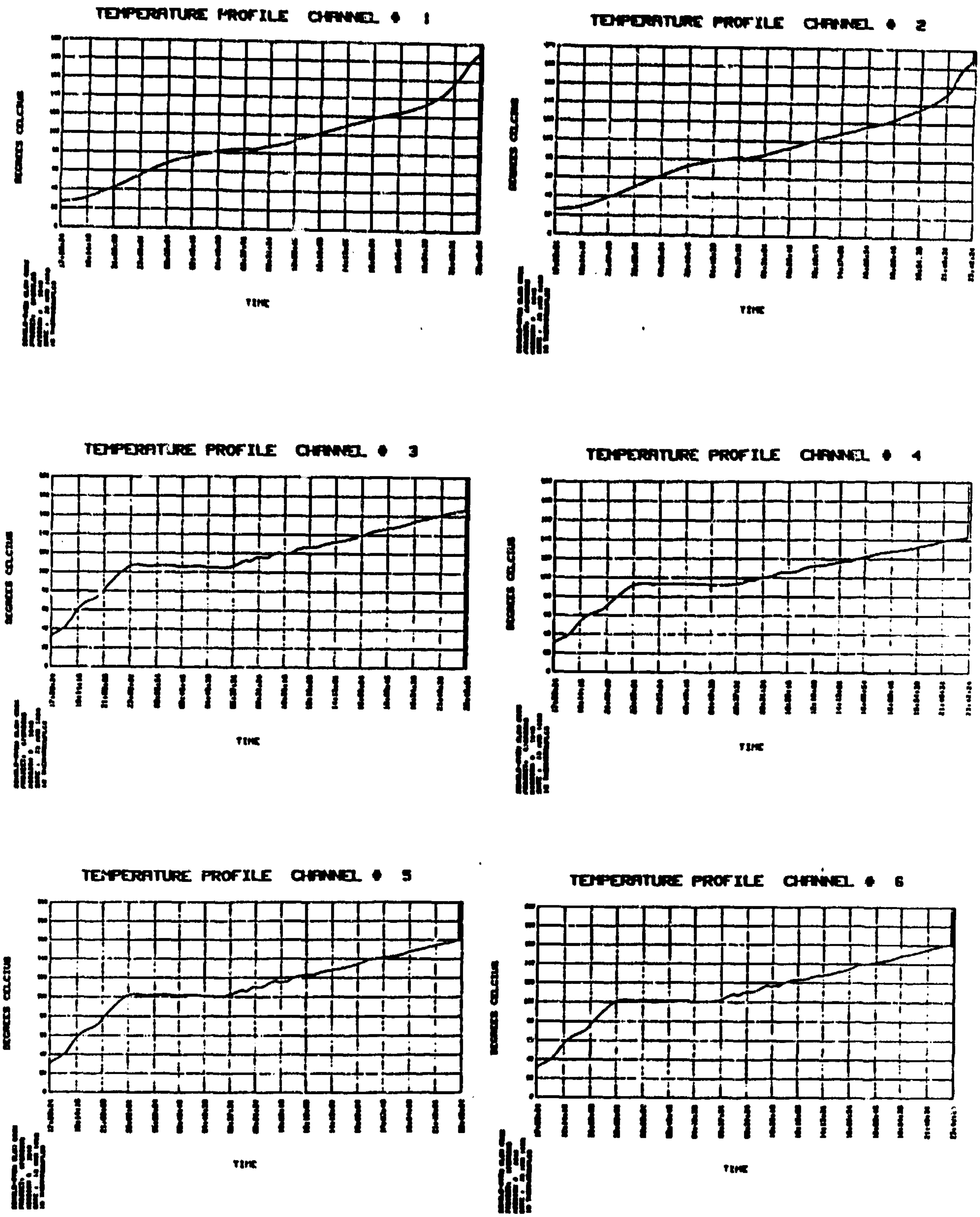
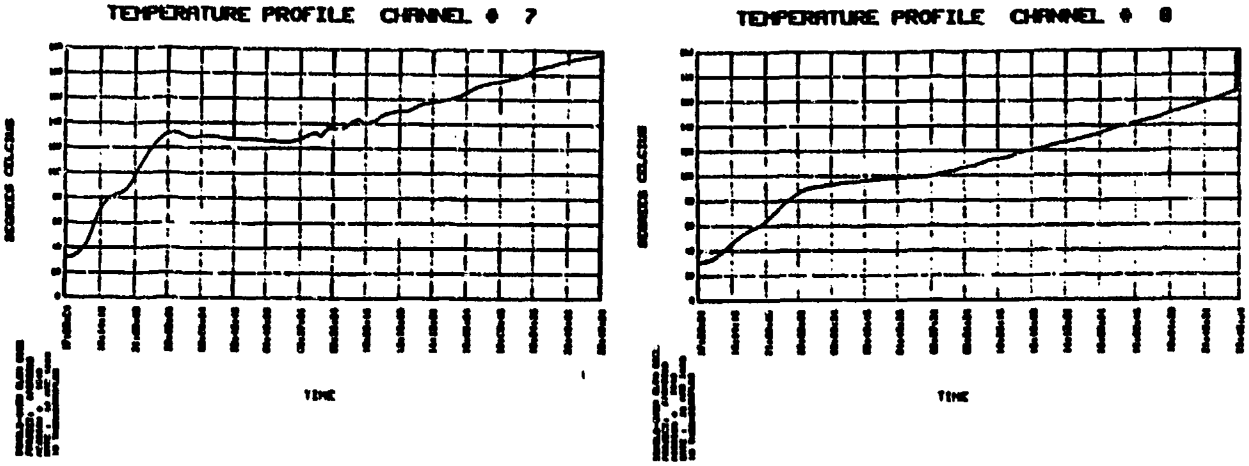


Figure 12a. Slow Cookoff Test Set Up



Figures 12b-g. TNTO IV Slow Cookoff Temperature Profiles



Figures 12h-i. TNTO IV Slow Cookoff Temperature Profiles (cont.)

The oven temperature was initially raised to 100°C at the approximate heating rate of 12.4°C/hr. The item was soaked at this condition for 6.5 hours. The oven temperature was then raised at a rate of 3.5°C/hr until reaction occurred. Equilibrium between the internal portion of the test item and the oven space was not achieved during the soak prior to final ramping; however, the internal heating rate had slowed considerably. Self heating of the item began near 134°C. Reaction occurred at an oven temperature of 160°C when the internal item temperature was 190°C. Nearly 3.5 hours passed between the time at which self-heating was observed and final reaction occurred (See Figure 13).

The item vented mildly from the nose and burned non-propulsively in place. The nose fuzewell liner was partially inverted and slightly crushed, tearing it from the bomb skin and forming a one-inch diameter vent hole. The tail fuzewell liner was also slightly inverted, allowing molten explosive to flow through the charging tube hole into the collection reservoir below the item. Prior to reaction, smoke was observed from the

Figure 13. Remnants of TNTO IV Slow Cookoff

reservoir beneath the nose of the item indicating some venting and exudation had occurred. After reaction, the test fixture and surrounding insulation were engulfed in flames. Large quantities of charred explosive residue were observed around the test stand after the test. The bomb case did not fragment or rupture but remained intact and in position throughout the test. The results of this test meet the requirements for Division 1.6 articles as specified by the United Nations Test Series 7.

Effects of Item Positioning On Sympathetic Detonation

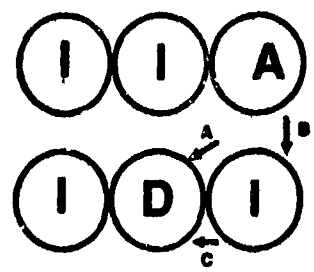
Experimental Results

The current Air Force general purpose bomb fill, tritonal (a mixture of TNT and aluminum powder) propagates the detonation of the donor bomb in both the adjacent and diagonal positions of the standard metal pallet. Tritonal shows a sensitivity to long duration (tens of microseconds) shock impulses with a peak pressure of about 10 kbars in the 8-inch diameter gap test. Items filled with a wax desensitized tritonal formulation developed by the

Air Force, AFX-1100 (References 9 and 16), do not sympathetically detonate in the adjacent position, but do propagate in the diagonal position of the standard metal pallet. AFX-1100 shows an insensitivity to long duration impulses with a peak pressure of about 43 kbars. A study was conducted by S. A. Aubert and J. G. Glenn of the Air Force Armament Laboratory (Reference 10) to determine experimentally the factors influencing propagation of the bomb in the diagonal position of the standard pallet. The results are summarized in Figure 14. As is shown, when the separation distance between the top and bottom rows of bombs is increased to 3.00 inches, propagation was eliminated.

SYMPATHETIC DETONATION TEST RESULTS

EXPLOSIVE: AFX-1100 (500-POUND BOMB)



A. DIAGONAL
B. VERTICAL
C. HORIZONTAL

TEST #	VERTICAL	DIAGONAL	HORIZONTAL	REACTION
1	5.25"	9"	.5"	NO PROPAGATION
2	3.25"	7.8"	.5"	NO PROPAGATION
3	.5"	5.25"	6."	PROPAGATION
4	3.00"	7"	.5"	NO PROPAGATION
5	1.63"	6.25"	.5"	PROPAGATION

Figure 14. Sympathetic Detonation Test Results

Hydrocode Predictions

E. A. Lundstrom of the Naval Weapons Center used the AFX-1100 equation of state parameters determined by J. C. Dallman of Los Alamos National Laboratories to study this problem using the MESA two-dimensional Eulerian hydrocode (References 11, 12, 20). Graphical representation of his calculations using inert acceptors are shown in Figure 15.

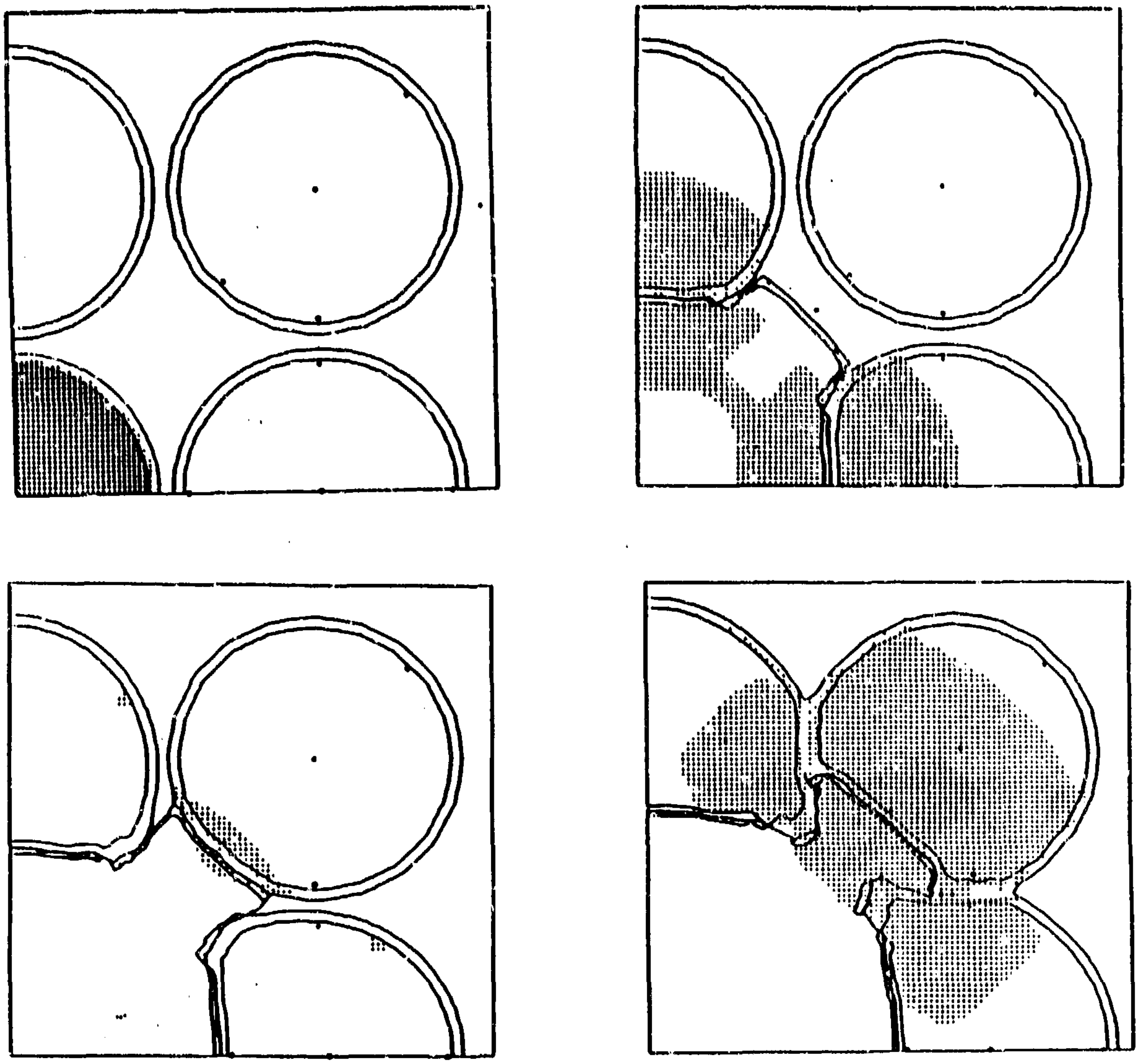


Figure 15a-d. Hydrocode Calculation of Symmetrical Pallet Configuration with Inert Acceptors

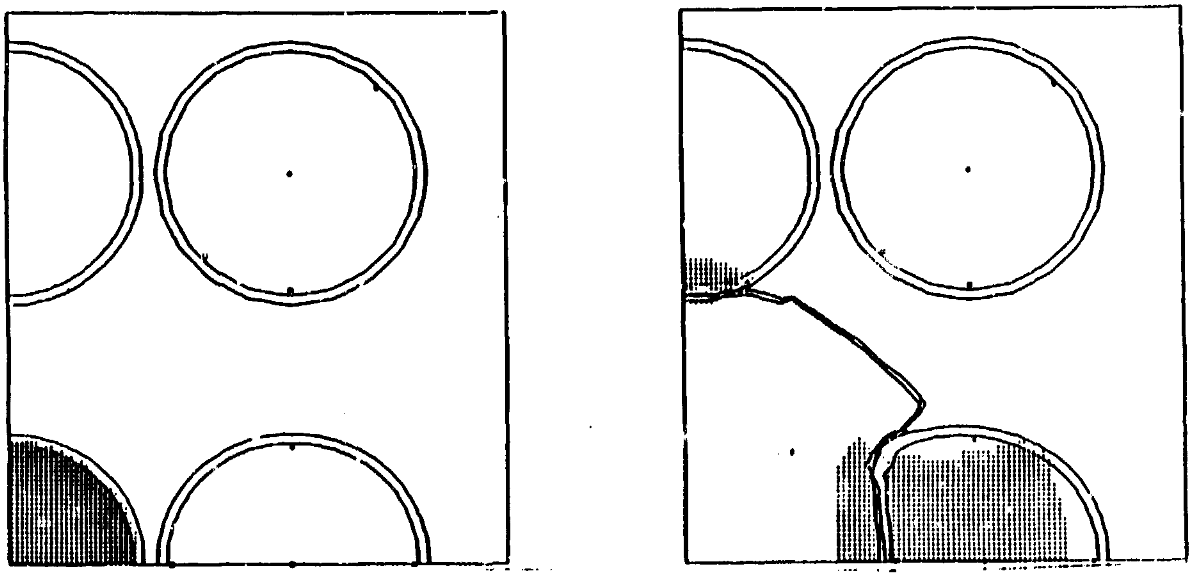
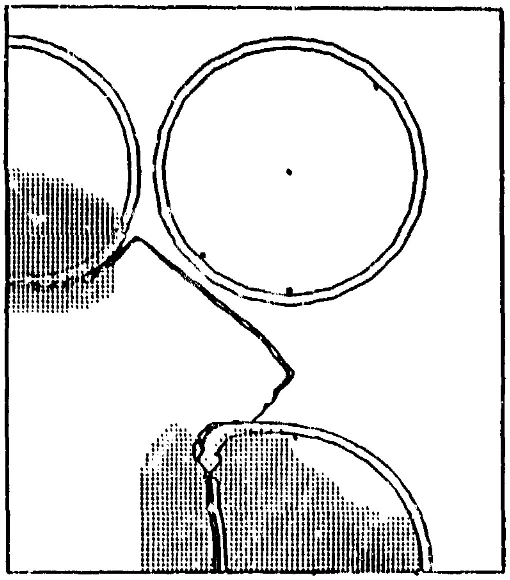


Figure 15e-f. Hydrocode Calculation of Non-Symmetrical Pallet Configuration with Inert Acceptors



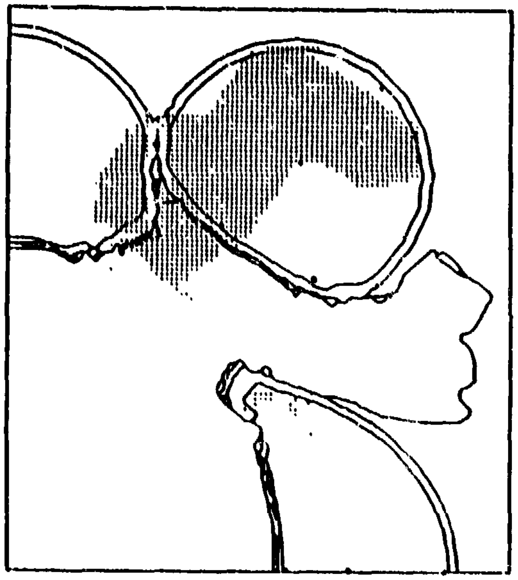


Figure 15g-h. Hydrocode Calculation of Non-Symmetrical Pallet Configuration with Inert Acceptors (cont.)

These were fairly coarse resolution calculations (2 elements per centimeter) with a 9-member three-by-three array of bombs implied by symmetry and the rigid boundaries along the left and bottom edges. However, they show the contrast between the environments of the diagonal bomb in two different geometrical configurations. At 0.5 inches of separation, the donor case has little space for expansion and the diagonal acceptor bomb is impacted with a relatively thick "flyer" plate over a fairly small portion of its circumference. The acceptor bomb is severely deformed and the confinement from the adjacent items allows no relief for the reaction products. At a vertical separation distance of 3.0 inches, the "flyer" plate from the donor becomes quite thin and, in reality, probably fragments before impacting the acceptor bomb. Its energy is less concentrated as it is released along a much larger portion of the circumference. Additionally, there is less confinement from the adjacent acceptors allowing some of the donor energy to release to the atmosphere.

The calculations to determine the response of live acceptor bombs have been completed and are shown graphically in Figure 16 provided by Lundstrom. The reactive calculations were performed using a Forest Fire Burn Model, calibrated with wedge test data sensitivity parameters approximating those for AFX-1100. With an initial symmetrical separation (Figure 16 a-d) distance of 0.5 inches, the acceptor bomb in the diagonal position transitions promptly to detonation upon impact. When spaced unsymmetrically with a vertical separation of 3.25 inches, an unreactive shockwave tranverses the item (Figure 16 e-l). Upon impacting the rear interior casewall, the wave is reflected and converges upon itself. Pressure increases at these interfaces; however, for this formulation the pressure change is not large enough to initiate a reactive detonation wave. This is consistent with the experimental results for AFX-1100. The response for a more sensitive formulation is shown in Figure 16 m-t. In this example, the diagonal item does transition to detonation after convergence of the reflected shockwave.

The calculations do not account for the desensitization of the acceptor explosive by the initial shockwave. Initiation via a reflected shockwave is questionable in reality since the resulting pressure is incapable of initiating the desensitized material (Reference 21). However, the calculation is still useful to complement experimental testing by determining margins of safety for the limited experimental data base. This is the fundamental value of all hydrocode calculations.

As is shown, a very slight modification of pallet designs including moderate alterations of spacing between items has a dramatic impact on the vulnerability of stored munitions.

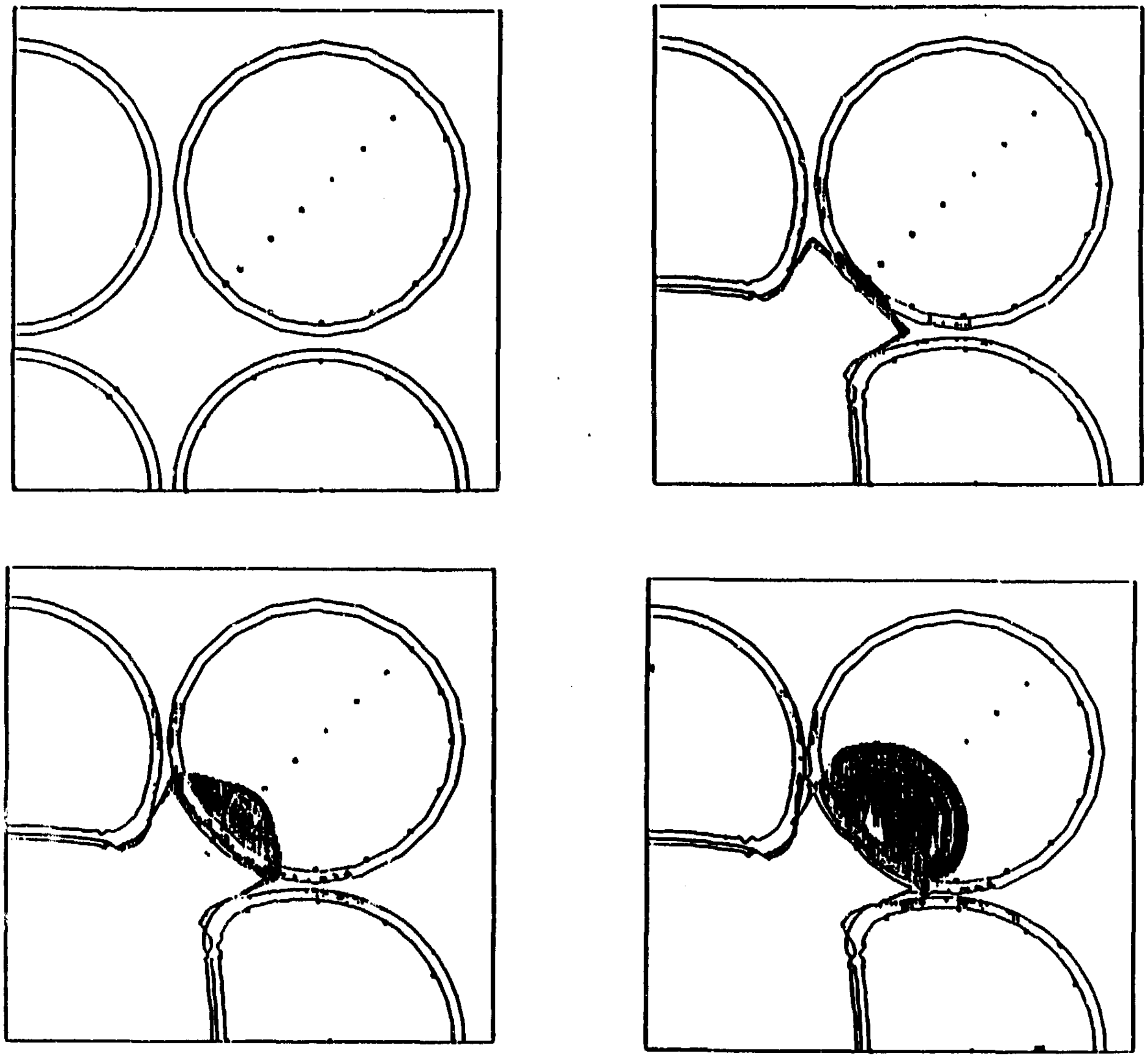
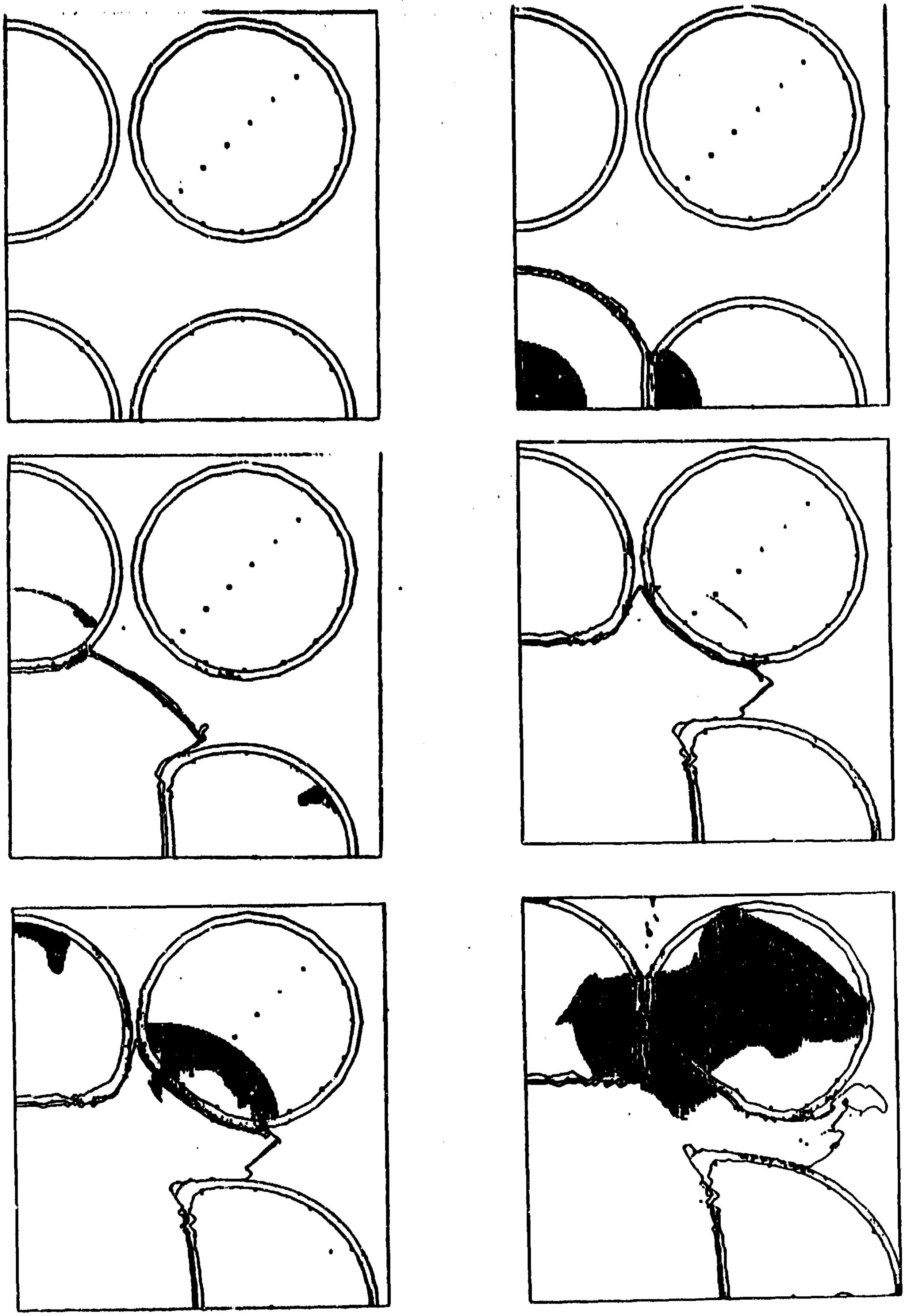
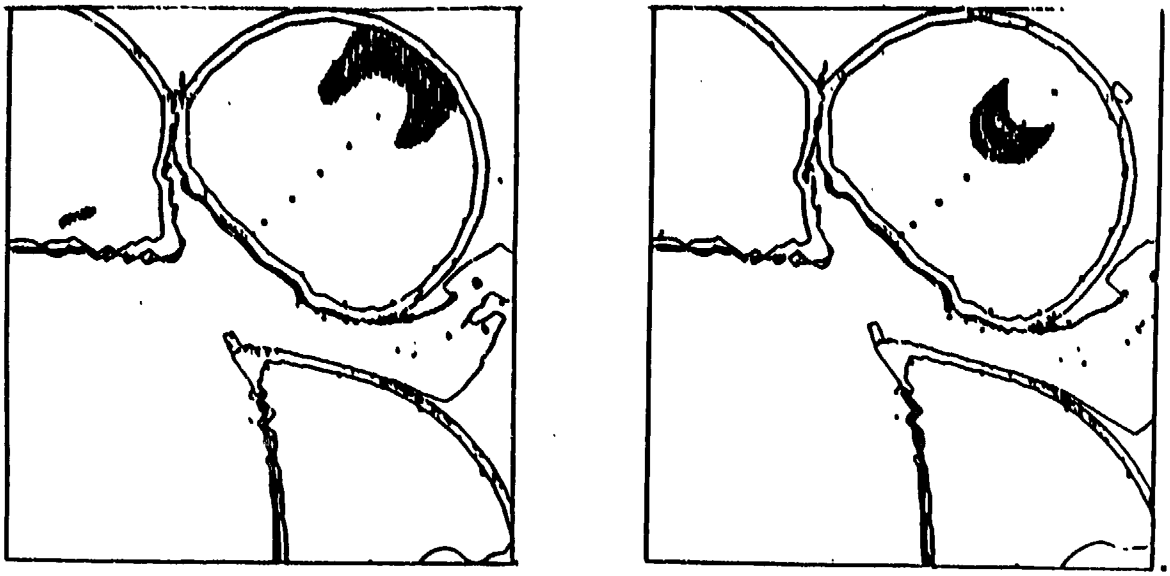


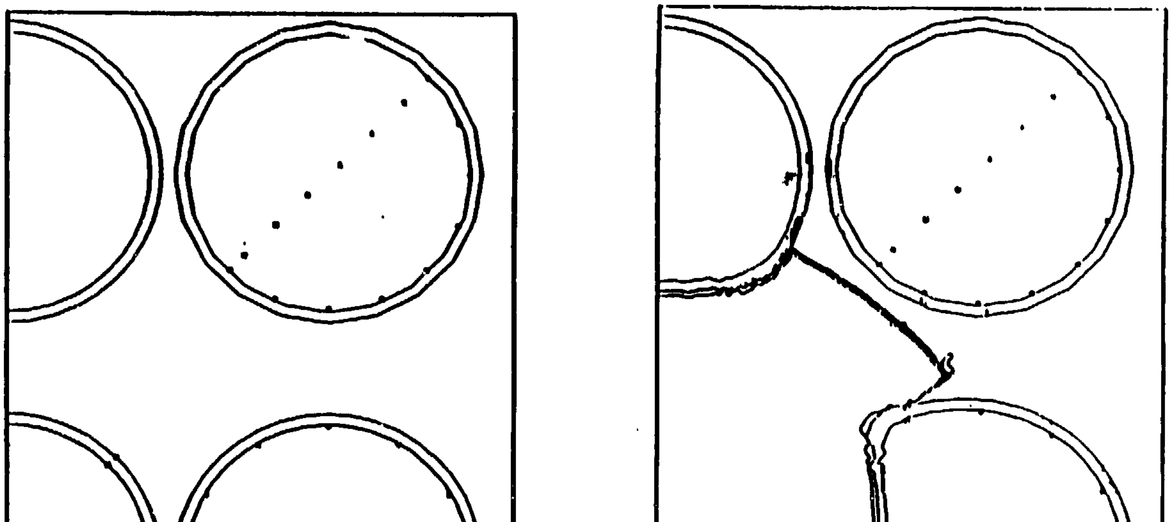
Figure 16a-d. Prompt Initiation of an AFX-1100-Type Explosive in the Symmetrical Configuration



Figures 16e-j. Response of AFX-1100-type Explosive in Unsymmetrical Configuration (No Propagation)



Figures 16k-l. Response of AFX-1100-type Explosive in Unsymmetrical Configuration (No Propagation) (cont.)



Figures 16m-p. Response of Relatively Sensitive Explosive In Unsymmetrical Pallet

31

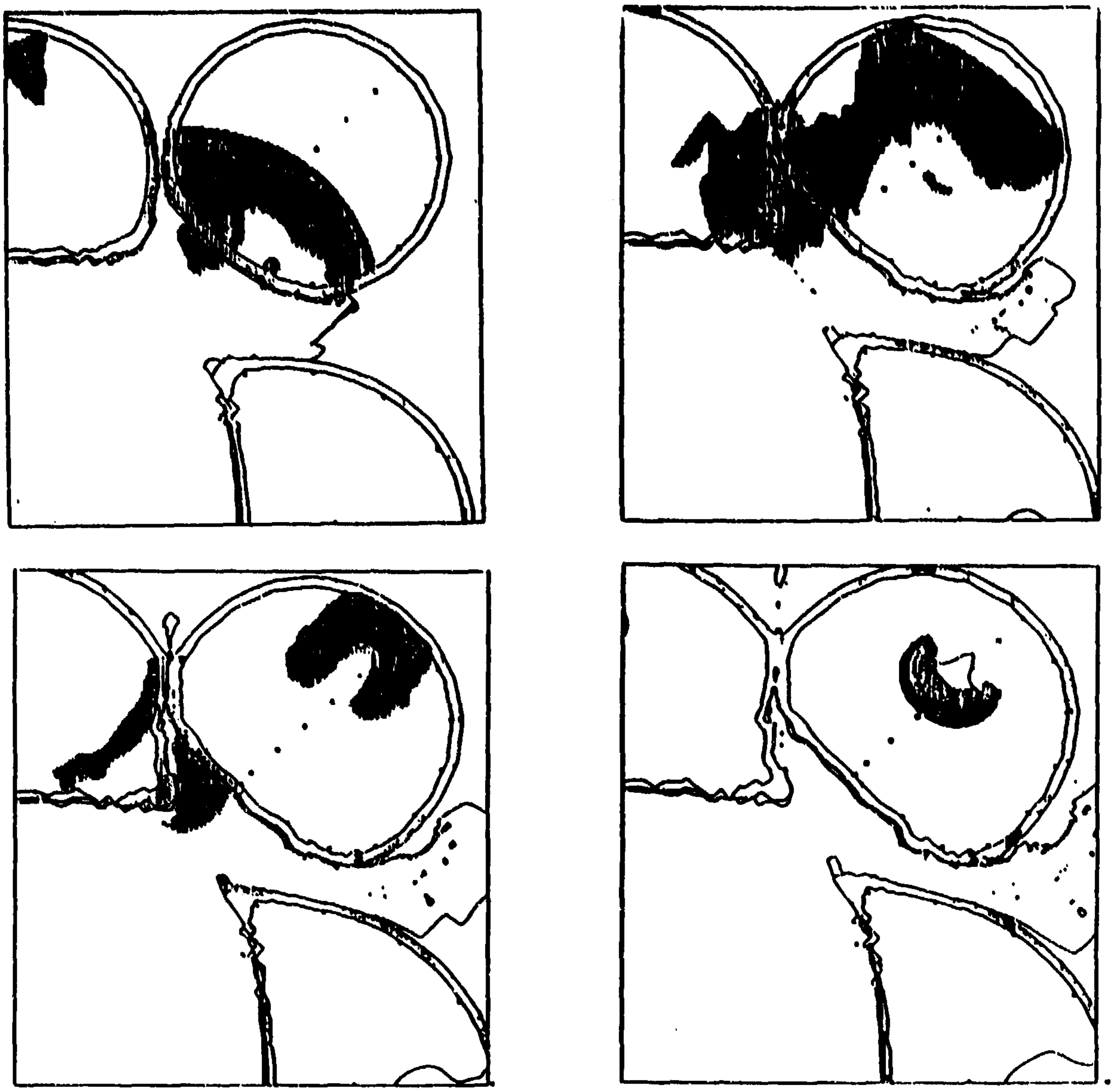


Figure 16q-t. **Response of Relatively Sensitive Explosive In Unsymmetrical Pallet**

Summary

The Air Force is responding to the challenge of developing safe explosives which continue to meet performance requirements. The approach of having concurrent in-house and contractual development processes increases the probability of success and the rate at which this success will be achieved.

The TNTO IV formulation has survived full-scale sympathetic detonation testing without propagating. This formulation has also achieved the 1.6 Hazard Classification criteria for slow cookoff in a single test. Next steps for this formulation include optimization of performance and sensitivity parameters as well as specification of the individual ingredients. Equation of state parameters of the final formulation will be determined and incorporated into modeling systems to predict full-scale behavior and provide margins of safety for the experimental results. The

EIDS substance tests for 1.6 Hazard Classification of the optimized formulation are scheduled for 1QFY91.

Sympathetic detonation is becoming better understood as full-scale testing results are being used to calibrate hydrocode models. The proper design of storage configurations and item separation distances is important for controlling sympathetic detonation.

The U S Air Force is committed to protecting its assets as well as those belonging to the communities and host nations in which its forces reside by providing safer munitions.

Acknowledgements

The authors wish to acknowledge the special contributions of Mr Joseph G. Glenn, Mr George A. Lambert, and Mrs Lois A. Walsh. The technical advice of Mr Larry R. Pitts, Mr Gary H. Parsons is also greatly appreciated. We are also indebted to Mr Eric Lundstrom for allowing us to include a discussion of his unpublished reactive hydrocode calculations.

REFERENCES

1. AFSC/AFLC Regulation 127-101. Hazard Classification of Explosives, 12 Sep 83.

2. DOD 6055.9-STD, Ammunitions and Explosives Safety Standards, Change No. 2, Oct 1989.

3. Recommendations on the Transport of Dangerous Goods (Tests and Criteria), United Nations, Feb 1989.

4. Ward, J. M. Hazard Class/Division 1.6 Test Protocol, DoD Explosives Safety Board, 1989.

5. Statement of Operational Need (SON) for Reducing the Risk of Munitions Operations, TAF-309-88, USAF Tactical Air Command, 22 May 1989.

6. Statement of Operational Need (SON), Format A (AFLC02-83) for Insensitive High Explosives in Air Munitions, USAF Logistics Command, 1983.

7. Parsons, G. H. and Surina, M. J. "Insensitive Munitions: New Dimension of System Performance" Program Manager Vol XVI, No 6 (November-December 1987).

8. MIL STD-1751 (USAF), Safety and Performance Tests for Qualification of Explosives, Aug 1982.

9. Parsons, G.H., Pitts, L.R., Summers, P.G., Glenn, J.G., "Suppression of Sympathetic Detonation In Stacks of 500-Pound Bombs." 23rd DDESB Explosive Safety Seminar, Aug 1988.

10. Private Communication with S.A. Aubert and J.G. Glenn, 1990.

11. Lundstrom E. A. "Analysis of High Explosives Research and Development (HERD) Group Bomb Stack Sympathetic Detonation Tests," NWC TM6723 July 1990.

12. Dallman, J. C. "Characterization of Air Force Explosive AFX-1100 II," Los Alamos Report LA-UR 88-4221.

13. Chiper, G. I., Bolkalder, R.P., and Grishter, V. Ya. "1,2,4-Triazol-3-One and Its Nitro and Amino Derivatives," Khim. Getero, Soed, Vol 2, No 1, pp 110-166, 1966.

14. Lee, K.Y., and Coburn, M.D. "3-Nitro-1,2,4,-triazol-5-one a Less Sensitive Explosive," Los Alamos National Laboratory Report No LA-10302-MS, February 1985.

15. Chapman, L.B. "NTO Development at Los Alamos," The 9th Symposium on Detonation (Sep 1987).

16. Aubert, S.A., Massey, S.J., Corley, J.D. "Desensitization of Tritonal with Wax Emulsions," AFATL-TR-88-32, July 1988.

17. Aubert, S.A., Parsons, G.H., Glenn, J.G., "Calibration and Correlation of a Modified Expanded Large Scale Gap Test with the Large Scale Gap Test and the 8-Inch Gap Test," AFATL-TR-89-46, August 1989.

18. Kennedy, J. E. "Gurney Energy of Explosives: Estimation of the Velocity and Impulse Imparted to Driven Metal," SC-RR-70-790, December 1970.

19. Corley, J.D. "Insensitive High Explosive Evaluation Techniques, " 22nd DDESB Explosives Safety Seminar, 1986.

20. Private Communication with E. A. Lundstrom of Naval Weapons Center, July 1990.

21. Private Communication with B. Craig, July 1990.

22. Aubert, S. A. "Development of TNTO Composite Explosives," AFATL-TR (unpublished).

23. Kennedy, J. E., "Explosive Output for Driving Metal," Behavior and Utilization of Explosives in Engineerings Design," (March 1972).

PYROTECHNICAL SAFETY OF AEROSPATIALE TACTICAL MISSILES - APPLICATION TO CONVENTIONAL WARHEAD

Alain GRAVE

AEROSPATIALE Division Engins Tactiques
2 rue Béranger,
92322 CHATILLON CEDEX, FRANCE

ABSTRACT : This paper begin with a qualitative review of some past safety tests done on various AEROSPATIALE in-service conventional warheads. The diversity of test configurations - fuel fire, bullet impact and sympathetic detonation - is shown, and, despite the difficulty of comparison with current standard tests, the situation is resumed. In a second part, the work on the second generation EXOCET anti-ship warhead, for which safety specifications were defined, is described. The use of PBX explosive loading permitted to satisfy the safety requirements. Finally, some aspects of current AEROSPATIALE studies and developments from a safety point of view, are given.

1. INTRODUCTION

Nearly all of the AEROSPATIALE Tactical Missiles in production have been tested by 12-meter drop, fuel fire, bullet impacts and sympathetic detonation. These tests were applied, sometimes on a complete missile, always on major pyrotechnical sub-assemblies, i.e. warhead and propellant. They were done in different configurations, according to each weapon system requirements. This paper is limited to conventional warheads, and drop tests are not considered.

Up to now, in all cases except one, the safety tests were "statement type", i.e. they were achieved a posteriori, as evaluation tests, on qualified equipments that were designed only for optimal terminal ballistic performances. In para. 2, some examples of these tests are described.

The above exception is the EXOCET anti-ship missile second generation warhead. Safety tests were done during feasibility and development phases, in accordance with the specified safety performance requirements. This is the subject of para. 3.

Finally, some aspects of current AEROSPATIALE studies and developments from a safety point of view, are described in para. 4.

2. EXAMPLES OF SAFETY TESTS PERFORMED ON WARHEADS

The tests described in this chapter do not represent the entire range of tests. They are simply aimed at illustrating the various test methods and the insensitivity levels obtained with the current warheads.

2.1. Fuel fire tests

The main characteristics for some of these tests are detailed in the table below :

Weapon system	Test date	Fuel volume	Fire dimensions	Fuel/ specimen height	Specimen configuration
EXOCET	04.74	1600 l	6 x 2 m^2	0.17 m	Missile mock-up in inclined container
HOT	10.72	10 l	1.5 x 0.5 m^2	0.4 m	Missile in tactical package
MILAN 2	09.83	10+30 l	"	"	"
MILAN 2	09.83	30 l	"	"	"
HOT 2	10.84	20 l	"	"	"

The EXOCET anti-ship warhead is characterized by a strong steel confinement and a composition-B cast explosive loading. The fuel fire test produced a violent pyrotechnical reaction after a few minutes.

For the HOT and MILAN anti-tank shaped charges, the confinement, on the contrary, is very moderate. With both the 1st generation RDX basis and 2nd generation HMX basis cast explosive loadings, the pyrotechnical reaction was limited to combustion of the explosives.

2.2. Bullet impact tests

This type of test was performed under various conditions, as shown by the table next page :

Weapon system	Date	Warhead configuration	Type of agression
EXOCET	04/74	In container	1 shot, using a 12.7 mm AP bullet
ROLAND	03/76	Bare warhead	1 burst of five 12,7 mm bullets (1 tracer + 2 incendiary + 2 AP)
HOT	10/72	Bare warhead	5 shots, 7.5 mm bullet (standard/tracer/standard/standard/tracer)
HOT 2	10/84	Warhead in tactical package	1 shot with standard 7.62 mm bullet 1 shot with 20 mm APT round 1 shot with 23 mm explosive round

As for the fire tests, only moderately confined charges (HOT-ROLAND) were measured, producing pyrotechnical reactions limited to combustion, using a RDX-TNT or HMX-TNT cast explosive loading.

Special attention was sometimes given to the initiating device, with certain firings aimed at reaching this device. Thus for example, the five consecutive firings on the same HOT warhead were performed in the chronological order shown in figure 1. No reaction was produced by these firings.

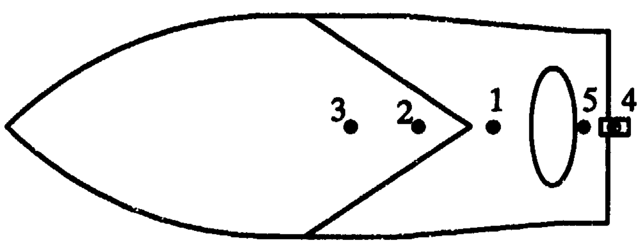


figure 1 : Bullet impacts on HOT warhead

For the highly confined warhead (EXOCET), a violent pyrotechnical reaction was produced with splinter projection (composition-B explosive). A series of specific tests showed that the reaction appeared once the bullet obtained sufficient velocity to just perforate the steel case of the warhead, and come into contact with the explosive loading.

2.3. Sympathetic detonation tests

All of the tests of this type performed on warheads currently in service resulted in propagation of the detonation of the initiated warhead (transmitter or donor) to the nearby warheads (receivers or acceptors). The example in figure 2 shows the test configuration used for the HOT and

MILAN missile rounds : logistic package, comprising four tactical packages, two of which contained live missile rounds.

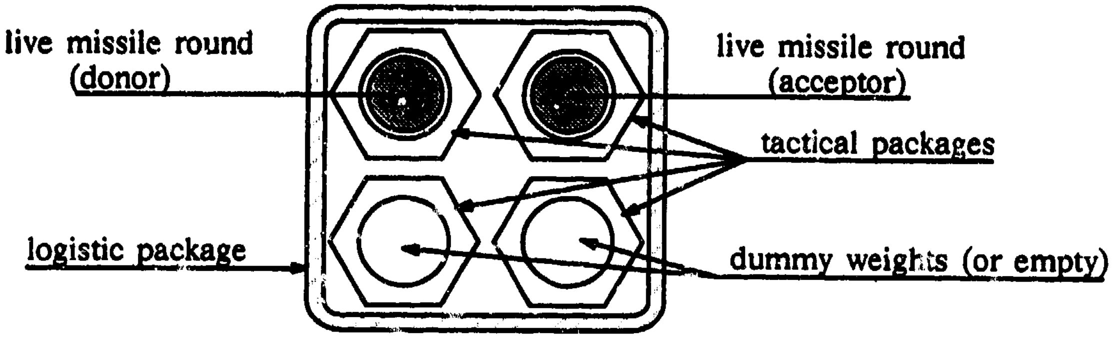


figure 2 : Sympathetic detonation test configuration for anti-tank missiles

This led to performing certain specific tests to ensure safety under both factory and operational conditions. These tests were aimed at studying the intermediate protections required and sufficient to avoid transmission of the detonation from one warhead to another. For instance, the test showed that a wood protection with a thickness of 4 cm inhibited transmission of the detonation between two ROLAND warheads. The same applies between two EXOCET warheads in container, using a 12.7 mm thick steel plate.

2.4. Conclusions on these tests

Despite the diversity of test configurations used in the past, and the difficulty in comparing these tests with current standard tests, the situation can be resumed as follows:

- The highly confined 1st generation warheads (EXOCET, etc.), with composition-B explosive loading, have a high degree of sensitivity and do not satisfy any of the three major safety test requirements.
- The moderately confined warheads, 1st and 2nd generation, using RDX or HMX basis cast explosive, could satisfy the safety requirements relative to two of the three safety tests : fuel fire and bullet impacts.

These observations led the French Ministry of Defence to issue us the contracts for research and development of the 2nd generation EXOCET warhead, covered in the next paragraph.

3. SECOND GENERATION EXOCET WARHEAD

The work on this warhead was performed in three phases: general research, feasibility and development under contract to the French Ministry of Defence. The technical specifications defined two major goals: safety level (fuel fire and bullet impact) and terminal efficiency performance level. The safety portion was carried out in collaboration with the SNPE.

3.1. General study phase

This phase took place between 1975 and 1978 and resulted in testing of three composite explosives (PBX) using plastic binder, proposed by the SNPE, comprising :

Explosive	HMX %	RDX %	Aluminium	Plastic binder %
A	70	0	18	12
B	0	84	0	16
C	86	0	0	14

During this phase, four fuel fire tests and two bullet impact tests were performed. The charges consisted of full-scale EXOCET bodies in which the explosive to be tested was polymerised. The tests were performed on the bare warhead with slightly varying parameters. However, all of the impact tests consisted of a single shot using a 12.7 mm AP bullet.

The encouraging results obtained from the very start of this phase made it possible to initiate the feasibility phase as of 1977.

At the end of this phase, the C-type explosive was selected, providing the best performance/safety compromise. The A-type explosive in particular, providing a higher performance level, was not selected due to its excessive degree of sensitivity.

3.2. Feasibility phase

This phase took place between 1977 and 1981 and was mainly aimed at optimizing terminal ballistic performance. The safety tests performed at the end of this phase reinforced the results obtained in the preceding phase, taking account of the changes in the definition of the warhead.

One fuel fire test and four bullet impact tests were performed during this phase with the following characteristics:

- For all the tests, the warhead was fitted, at the front and rear, with dummy weights representative of the weights of the EXOCET missile, in view of simulating the axial confinement of the warhead. This test specimen was not placed in a launch tube.
- For the fuel fire test, the fuel-specimen height was set at 47 cm.
- The bullet impact test was performed by a single shot using a 12.7 mm AP bullet. Certain charges were subjected to a second, and sometimes third, bullet impact when their condition after a firing so permitted.

3.3. Development phase

This phase took place between 1982 and 1985 and was completed by qualification tests of the EXOCET missile second generation warhead.

One fuel fire test and one bullet impact test were performed using the same methods as before.

The safety requirements detailed in the specifications were satisfied, i.e.:

- No violent pyrotechnical reaction with splinter projection produced by fuel fire.
- Increase of velocity threshold of 12.7 mm AP bullet producing violent pyrotechnical reaction (deflagration) : this velocity threshold was increased by more than 150 m/s with respect to that obtained with the first generation EXOCET warhead containing a composition-B loading.

The second generation EXOCET warhead has been in service in the French Navy since 1986.

4. CURRENT AND FUTURE WORK

In the field of anti-ship warheads, the ANS missile currently under development has benefitted from the work described in the preceding paragraph. Insensitivity has been improved by optimization of the HMX granulometric size.

The successful compromise between ballistic performance and insensitivity provided by the plastic-bonded explosives has led to initiating development of the warhead for the ASTER anti-aircraft missile using this type of explosive.

In the anti-tank field, the terminal efficiency remains the primary goal. However, the safety level of the TRIGAT-MR warhead has been evaluated as of the debugging phase by fuel fire and bullet impact tests per STANAG 4240 and 4241 standards.

The SNPE work on ONTA explosives are currently considered as the main research channel in view of obtaining a level 3 insensitivity, i.e. non-propagation by sympathetic detonation. In collaboration with the SNPE, a study has been initiated to evaluate a type B3017 composite (74% ONTA, 26% binder and miscellaneous) as an explosive loading for shaped charge. This composition provides a good energy level for this type of application. Planned in this study are three sympathetic detonation tests using a test configuration similar to that shown in figure 2. If successful, the perforation performance of the shaped charge will be evaluated.

The preceding study is general in nature. Currently, no specifications for conventional weapon systems under development by AEROSPATIALE contain safety requirements (except for ANS) issued by the French Ministry of Defence. We believe this situation should be changing soon, producing a decisive move forward for research relative to insensitive missiles in France.

SAFETY CONSIDERATIONS FOR CAST AND PRESSED WARHEAD DESIGNS

Jon S. Derickson, PE
Charles P. Hoes, PE, CSP
Hoes Engineering, Inc, Davis CA

ABSTRACT

The authors have performed safety assessments of several cast and pressed warhead designs. Each evaluation consisted of considerable research into the behavior of explosives as they relate to safety. Based upon research and discussions with explosive experts, necessary design criteria was developed to minimize or control the risk of accidental explosion and other hazards associated with the warheads.

This paper presents a discussion of the major hazards that were identified during the system safety analysis and safety assessment of several cast and pressed warhead designs. The discussions are intended to assist warhead designers and safety engineers in the identification and control of hazards during the development of new warhead designs. A bibliography is provided for further information on the hazards discussed.

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SAFETY CONSIDERATIONS FOR CAST AND PRESSED WARHEAD DESIGNS

Jon S. Derickson, PE
Charles P. Hoes, PE, CSP
Hoes Engineering, Inc, Davis CA

INTRODUCTION

Over the past five years, the authors have evaluated several cast and pressed warhead designs. Each evaluation consisted of a considerable amount of research into the behavior of explosives as they relate to safety. Based upon research and discussions with explosive experts, the warhead designs were evaluated to identify necessary design criteria to minimize or control the risk of accidental explosion and other hazards associated with the warheads.

Based upon the research and evaluations, it became evident that the number of new concerns identified during each subsequent analysis steadily decreased. Much of the information generated on previous analyses could easily be adapted to new warhead designs.

This paper discusses the general concerns that were identified and addressed. Discussions of control procedures are presented. Examples have been included for clarification.

SCOPE

This paper addresses many of the explosive safety concerns that should be addressed during the development of a new cast or pressed warhead design. The paper does not address safety and arming devices or other initiation systems beyond interface considerations.

TYPICAL WARHEAD DESIGN

A typical warhead consists of a main explosive charge that is enclosed in a shell. For the purposes of this paper, the main explosive material is either cast or pressed into its final configuration within the shell. The shell provides structural integrity and environmental protection for the explosive material. Depending on the type of warhead, there will be additional features or components necessary to perform its function. For example, a fragmentation warhead will have fragments, and a hard target penetrator or shaped charge warhead will have a shaped charge liner and cavity. Figure 1 illustrates a typical shaped charge warhead.

In addition to the main charge explosive, there is typically a booster and initiating explosive. The initiating explosive is contained within a safety and arming device. The booster explosive is generally a secondary explosive that may or may not be in direct contact with the main charge.

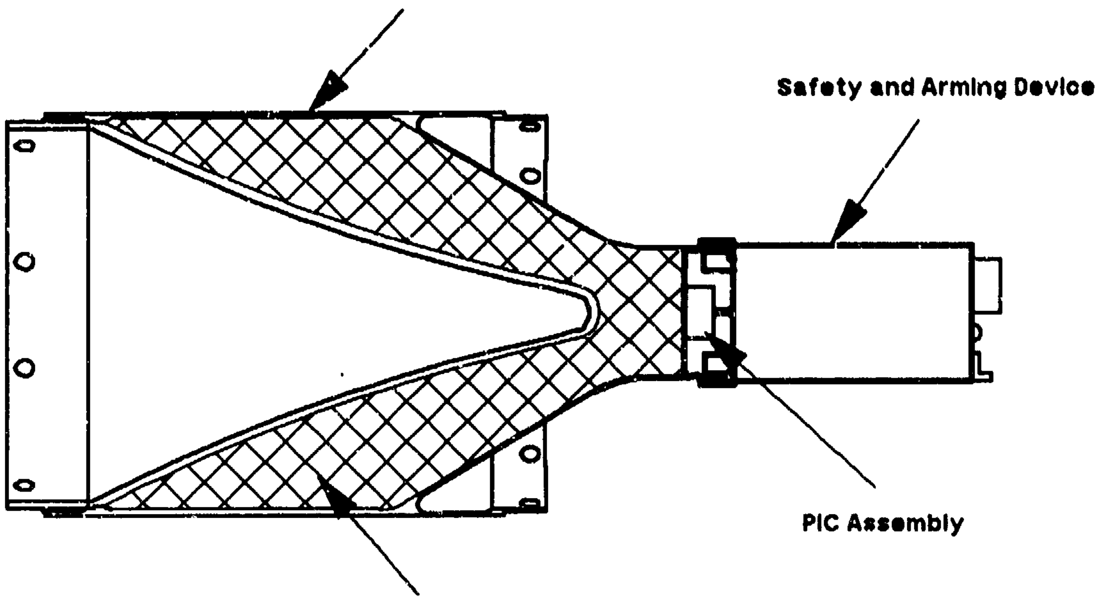


Figure 1. Typical Shaped Charge Warhead

PRELIMINARY HAZARD LIST

Not surprisingly, nearly all of the significant hazards associated with a warhead design either leads to or is a result of the deflagration or detonation of the explosive materials within the warhead. Table 1 provides a list of many of the common hazards associated with a typical warhead. Each of these hazards will be discussed in greater detail within this paper.

Table 1. Preliminary Hazard List

HAZARD	POTENTIAL CAUSE
Deflagration or Detonation	Direct Mechanical impact of explosives Electrostatic Discharge Increased Sensitivity; - Thermal expansion - Explosive enters joints - Inclusions in explosives - Age induced degradation - Incorrect explosive formulation - Bubbles or voids in explosive - Incorrect thermal conditioning Sharp edges in contact with the explosive Exposure to external heat Lightning induced electrical discharge Explosive dust or fumes Sympathetic Detonation Transportation vibration Friction ignition Fire
Toxic Materials	Seal failure Toxic materials used on exposed parts Explosive by-products
Flying Fragments	Normal during test
Blast overpressure	Normal during test
Heavy objects (Handling)	Weight exceeds allowable limits

HAZARDOUS CONDITIONS

Major identified hazards include explosion, fire, flying fragments, toxicity, and noise. Mechanical hazards such as pinch points, or crush points are considered minor as compared to the other hazards and have not been included in this paper.

In addition to the above listed hazards, there are several causes that could lead to an accidental explosion. These causes include material incompatibility, mechanical shock, spark ignition, electromagnetic radiation, friction, heat and pressure.

Both major hazards and potential causes of explosion are considered major hazardous conditions. Included in the discussion of the hazardous conditions is a brief description of controls that can be considered during the design and manufacture of explosive warheads to minimize the risk of mishaps during later life cycle phases.

MATERIAL INCOMPATIBILITY

> *Material incompatibility hazards can be controlled in design by selecting materials that are known to be compatible with the explosives. It is best to select those materials for which long term compatibility data is available. Material selection should include both materials used in the warhead, and materials used during manufacturing of the warhead.*

Material incompatibility is not generally a hazard by itself, but can often lead to hazardous conditions that could result in a mishap. For example, if incompatible materials increase the sensitivity of an explosive, a mishap could result if an unsuspecting handler moves the explosive in a manner not suitable for the more sensitive explosive. Hazardous conditions that could result from incompatible materials include increased sensitivity of the explosive, self initiation, reduced mechanical strength, and leakage of toxic, corrosive, and sensitive chemicals from the warhead assembly.

Material incompatibility induced changes can be slow to manifest themselves and can occur during long term storage. If the warheads absorb water, or are subjected to biological attack, they may change properties and become hazardous during storage or subsequent operations. Corrosion from the outside of the body could eventually penetrate and expose the explosive to environmental conditions and corrosion products. These effects must be considered during the design and selection of materials for the warhead.

The actual material interfaces between all materials within the warhead, including all coatings, lubricants, glues, cleaning solvents, or other materials used during manufacturing must be considered when selecting materials and developing processes for the warhead. All of the materials in the warhead must be shown to be compatible with one another during long term storage, including hot, cold, and humid storage environments. Compatibility must also exist between different phases or polymorphs of the explosive and material interfaces. Synergistic effects that might occur when three or more materials come into contact should be considered when determining material compatibility.

When relying upon materials compatibility data, the data must be specific to the exact materials used within the warhead. This includes verifying that the chemical composition of the materials being used are identical to the chemical composition of the materials that were tested to create the materials compatibility data. Very little data is available where three or more chemicals have been tested for synergistic effects. The interfaces of three or more chemicals should be kept to a minimum and the probability of synergistic reactions should be investigated.

When the warheads are to be stored in a sealed environment such as a launch tube, there is a potential for gases from adhesives or other materials to accumulate. Any such gases must be compatible with the explosives. Synergistic effects of different gases may also be an issue. This is a system level issue and should be addressed at the system level. Consideration should be given to allowing adhesives and paints to cure prior to placing the warhead into a sealed environment.

MECHANICAL SHOCK

Accidental explosions caused by impact of an explosive that meets insensitive munitions requirements is unlikely. However, special precautions are necessary to ensure that a design defect cannot increase the sensitivity of a qualified warhead design.

All explosives are shock sensitive. Therefore there is some risk of inadvertent ignition caused by impact of the explosive or item. The impact can be the result of dropping or hitting the explosive. For explosive items that have passed insensitive munitions requirements, mechanical shock impact is not generally a concern for normal environments. However, a mechanical shock impact hazard exists if some condition has increased the sensitivity of the explosive so that an impact that would normally be acceptable, could ignite the warhead. For example, many explosives become more shock sensitive when they are heated or confined under pressure.

Inclusions, grit, bubbles, contaminates, residual internal stresses, or variable average particle size introduced into the explosive material during manufacturing operations can increase the shock sensitivity of the explosive. Explosive cracking can increase a warhead's sensitivity to mechanical impact. Cracks can be introduced in all life cycle phases. Thermal extremes, vibrations, radiation or manufacturing defects could potentially introduce explosive cracking.

An effective quality control program can prevent the receipt of contaminated materials and can prevent the introduction of contaminates or manufacturing defects. It is important that manufacturing processes be performed that result in clean, uniform materials that do not have excessive, residual internal stresses or cracking of the explosive.

SPARK IGNITION

A warhead should be designed to shield all explosives from both mechanical and electrical sparks or electrostatic discharges. This is demonstrated by Electro-Static Discharge (ESD) and Electromagnetic Radiation (EMR) testing of the warhead during qualification. Sparks should never be present when explosive materials are exposed.

Spark ignition can be caused by mechanical or electrical sparks. Static electricity sensitivity of an explosive can be increased if it is in the form of dust, or if it is fractured or sensitized by factors such as contact with incompatible materials. Spark sensitivity can be controlled by designing and manufacturing the warhead to prevent cracks or fractures in the explosive material, preventing the presence of incompatible materials, and by providing conductive shielding around the warhead.

Many secondary explosives are not considered sensitive to electro-static discharge. However, beware of ESD sensitivity data. There are several different ESD sensitivity testing techniques. The values reported by the different tests can vary by orders of magnitude. In addition, most of the testing techniques rely on a small statistical sample size (10 trials). The number reported is the maximum energy level tested that did not produce a "reaction" in 10 trials. The explosive samples are typically in a powder form and may or may not be confined. Test results do not provide statistical probability of reaction an lower energy levels that those reported.

ELECTROMAGNETIC RADIATION

All explosive materials within the warhead should be enclosed within a continuous conducting container that shields the explosives from strong EMR fields. EMR testing should be conduced to verify the design. Quality assurance inspections should be developed to verify that parts are properly bonded. Long term affects of corrosion and incompatible materials should be considered to ensure that conductive shields do not fail over time.

Some explosive devices and materials are sensitive to initiation by electromagnetic radiation. This can be in the form of Radio Frequency (RF), X-ray, microwave or other radiation. RF radiation can produce a spark, or heat a conductor, if the field is sufficiently strong and an antenna circuit is present. Microwaves can heat the interior of explosives enough to cause auto-ignition.

FRICTION

Friction hazards can be introduced by manufacturing defects. These hazards will be controlled through proper design, processes, and quality control of the warhead assembly.

Explosives can be ignited by friction. The friction can be generated between the explosive and other objects, or between two pieces of explosive. Ignition can occur whenever the explosive is trapped, crushed and heated by friction. For example, friction ignition can occur if explosives are caught in threads that are screwed together, inside of holes that have pins inserted into them, or when explosives are trapped in metal interfaces that move relative to one another. Ignition can also occur at explosive interfaces where two explosive come together, or where a piece of explosive breaks off. Any of these conditions can lead to ignition of the warhead when it is exposed to shock or vibration environments that would normally be acceptable.

THERMAL

There are three basic safety concerns relating to thermal effects on the explosives. Temperature extremes can increase explosive sensitivity, differential thermal expansion can cause cracks and increase sensitivity, and extreme temperatures can cause ignition. Each of these conditions should be considered in design and controlled through design, processes, quality control, and by following proper handling and storage procedures.

Overheating is the main cause of accidental detonation of explosives. Overheating bulk explosive material can directly lead to ignition or explosion or it can indirectly lead to ignition or explosion by increasing the sensitivity of the explosive to the other types of ignition sources. Pressing or casting operations can be especially critical because of the necessity to work with heated, sensitive explosives.

Some explosives can change chemical properties as a result of being exposed to high temperatures. For example, the temperature at which spontaneous exothermic decomposition will occur in HMX is decreased if it is overheated during the pressing or casting operations. HMX has several possible polymorphs. The beta form is relatively stable and is used in explosive manufacturing. Beta HMX can convert to the less stable alpha HMX (solid to solid phase transition) when it is heated above 217°F for an extended period of time. It is difficult to determine that the conversion has taken place because there are no obvious indications of the change, such as a change in color or appearance.

The rate at which the Beta to Alpha solid to solid phase transformation occurs is dependent on the temperature of the HMX. For example, at the threshold temperature of the transformation, it may take several days or weeks to detect a phase transformation. An increase in temperature over the critical temperature is likely to accelerate the transformation rate. Therefore, the overheating of HMX during pressing or casting should be prevented. However if heating above the transition temperature is necessary, then monitoring of the temperature and the durations will become critical to ensure consistent sensitivity.

Most explosive materials react with hydrocarbons such as lubricants, oils, and plasticizers. The reaction often decreases the temperature at which the explosive will undergo spontaneous exothermic decomposition. Manufacturing processes and controls must prevent the contamination or contact of explosives with these hydrocarbon materials during manufacturing. The warhead design should be sealed to prevent the introduction of these materials if they should be involved in later sources of contamination such as having oil or hydraulic fluid spilled on the warhead.

Assembled warheads can be affected by exposure to external heat sources such as heaters, solar radiation, or contact with hot objects. This exposure can directly result in the ignition of the explosive materials, or indirectly by changing the chemical structure or composition of the explosives resulting in an increased sensitivity of the explosive to future events.

Differential thermal expansion of the explosive and its enclosure must be considered during design. As an example, LX-14 has nearly three times the coefficient of thermal expansion as compared with copper or aluminum. Elevated temperatures may compromise the structural integrity of the explosive enclosure. In addition, elevated temperature can result in the migration of explosives into warhead joints or mechanical interfaces. The migration can either occur from extrusion of the explosive into the interface or from exudation of liquid explosive into the joint. The likelihood of either extrusion or exudation will depend on the explosive and the design of the warhead.

Lowered temperatures may induce cracking in the explosive if it shrinks around a material that has a lower coefficient of thermal expansion. For example, a precision shaped charge with a copper liner may develop cracks when the explosive shrinks around the liner. Low temperatures may also cause the explosive charge to become loose within its enclosure. This could result in an increased risk of ignition by friction, or could result in other hazardous conditions.

EXPLOSIVE DENSITIES

Explosive densities must be controlled in the design of the warhead and the loading process. Means for ensuring consistency in loading densities and eliminating bubbles and voids must be included in the loading operations. Appropriate quality control inspections are necessary to verify that production warheads are the same as the warheads that were qualified.

Pressing operations under vacuum are less likely to produce air pockets, bubbles, or voids than casting operations. However, improper pressing cycles (temperature or dwell time) can result in improper overall explosive density. Depending on the characteristics of the specific explosive material, variations in explosive density could change the impact sensitivity of the warheads.

The configuration of each warhead, including pressing time and pressure history, must be the same as those of the samples used to qualify the warheads. It is recommended that the time/pressure history of each warhead be included as part of the quality control acceptance criteria for pressed charges. Pressing dies must also be inspected for damage, deformation and cleanliness prior to use. Quality control of explosive pressing can be enhanced by properly choosing material hardness, clearances, tapers and finishes.

Casting operations must include provisions to minimize the occurrence of entrained air, bubbles, and voids within the final explosive warhead. Bubbles and voids can increase the impact sensitivity of the warheads by increasing the risk of ignition through adiabatic heating of the gases in the void. In addition, it is conceivable that crystal fracturing on the surface of a void could release very fine explosive particles into the void.

BLAST OVERPRESSURE

Consequences of a high explosive shock wave must be controlled by range safety during testing and by allowing safe separation during training and operation of the weapon. Range safety data is usually obtained as part of the qualification program for a warhead subsystem.

A high explosive shock wave will be produced upon detonation of the warhead. Detonation will occur as a result of the use of the weapon and during static firing of the warhead. The high pressure shock wave can cause whole body injury to personnel, damage to structures and can cause serious hearing injury. Blast overpressures should be maintained to acceptable levels during controlled tests. Hearing protection will be required to prevent hearing damage.

Pressure waves can also be reflected to produce damaging effects that are greater than expected. Weather conditions can cause reflections and combining of pressure waves that will break windows and damage property at much greater distances than the pressure wave would have directly.

FLYING FRAGMENTS

Exposure of personnel to flying fragments during training and testing must be controlled by test procedures that include personnel protective structures, and/or adequate separation distances.

Flying fragments and debris are of major concern when the warhead is detonated whether during testing or accidental detonation. All flying fragments or debris from the warhead must be contained within a controlled area during testing. This can be accomplished by controlling the fragments or by allowing sufficient distance between the test site and any populated areas and providing protection for test personnel within the established surface area danger zone. Aircraft flying overhead should also be considered during training and testing.

HAZARDOUS MATERIALS AND COMPONENTS

An evaluation of the hazardous materials within a warhead, and possible by-products from a detonation must be evaluated for each new warhead design.

Recent studies have shown that many explosives do not produce highly toxic by-products by themselves. For example, LX-14 contains mostly organic compounds that contain carbon, oxygen, nitrogen, and hydrogen. The products that can reasonably be expected to result from the explosion of LX-14 include carbon dioxide, carbon monoxide, oxides of nitrogen, hydrocarbons, and some water vapor. However, because the warheads contain other materials that make up the shell and other features, the by-products of a warhead detonation can be highly toxic. Other products might include aluminum fumes and dust, and by-products of binders, adhesives, products from the initiators, adhesives, and any other materials.

The use of composites in warheads may also produce adverse health affects as a result of releasing small respirable fibers. Health studies of carbon fiber composites indicate that more single fibers are reduced when the composite is involved in an explosion. They also indicate that the fibers can cleave in a longitudinal direction resulting in an increase in respirable fibers under explosion conditions. Additional study is necessary to study the characteristics of carbon fiber composites under detonation conditions.

CONCLUSIONS

The discussions in this paper provide a "hazard list" to help identify many of the major concerns associated with cast and pressed explosive warheads. The bibliography provides a selected list of reference materials for further information on some of the issues discussed.

This is the first step in performing a hazard analysis for a warhead system. Once these hazards are identified, the real work begins. Each specific warhead design must be evaluated to ensure that all of the identified concerns are adequately addressed and controlled in the design of the warhead. The controls for the specific warhead should be integrated into an effective hazard tracking system and provided to the designers as design requirements. The requirements must be tracked to ensure they are included in the design and that new hazards are identified and resolved as the development of the warhead matures.

BIBLIOGRAPHY

AFR 127-100, Explosives Safety Standards, 24 December 1984

AMCP 706-290, Engineering Design Handbook for Warheads, July 1974

AMCR-385-100 Safety Manual, August 1985

BRL-TR-2635 Safety Practices and Training for Explosives (AD-A152 295)

DOD-STD-2105 Hazard Assessment Tests for Navy Non-Nuclear Ordnance, Sept 82

DOD 4145.26 Contractors Safety Requirements for Ammunition and Explosives, July 85

DoD 6055.9-STD, Department of Defense Ammunition and Explosives Safety Standards, 26 June 1986

DOE/EV/06194-3 Explosives Safety Manual, August 1985

MIL-T-248C, Trinitrotoluene (TNT), 30 March 1976

MIL-STD-889B, Dissimilar Metals, 7 July 1976

MIL-H-45444B, HMX, 27 February 1974

MIL-O-45445B, Octol, 14 March 1977

MIL-E-81111B, Explosive, Plastic-Bonded Molding Powder, 22 February 1973

NAVORD OD 44942 Part IV, Hazard Control for Explosive Ordnance Production

NAVSEA OD 30393 HERO Design Guide, Jan 1980

PATR 2700 Volume 8, Encyclopedia of Explosives and Related Items, 1975

PITR-3406-02 Dragon Generation II Test Report for Warhead Safety Tests for Warhead Qualification, 27 March 1987

TM 9-1300-214 (TO 11A-1-34), Military Explosives, November 1967

TM 9-1300-206, Ammunition and Explosives Standards, August 1973

UCRL-52997, LLNL Explosives Handbook, Properties of Chemical Explosives and Explosives Simulants, January 1985

Humphrey, J.R., "LX-14 A New High-Energy Plastic Bonded Explosive" November 1977

Rogers, R.N., "LASL Methods for Derivation of Predictive Models for Explosives Thermal Hazards and Lifetime" (LA-UR-77-1378), June 1977

Scribner, Kenneth J., "The effect of Thermal Aging on the Sensitivity of LX-14" May 1981.

Smith, Louis C., "On the Problem of Evaluating the Safety of an Explosive" LA-UR-77-1304, June 1977

VERY INSENSITIVE HIGH EXPLOSIVES WHICH RESIST THE SYMPATHETIC DETONATION

Bruno NOUGUEZ, Jean-Claude DERRIEN
Michel ANDRE and Georges DONZEL

S.N.P.E. - Centre de Recherches du Bouchet
BP 02 - 91710 VERT-LE-PETIT - FRANCE
(33-1) 64-99-12-34

ABSTRACT

Meeting the Insensitive Munitions requirements is a technical challenge and a strong multidisciplinary effort is needed. SNPE has been working for several years to develop insensitive high explosives, and now, several Cast Plastic Bonded Explosives which resist the fast cook-off, bullet impacts and the sympathetic detonation are available, along with their booster systems. The purpose of this paper is to give some information on the SNPE effort to demonstrate the feasibility of munitions which are functionally detonable but which resist the sympathetic detonation, using NTO based Cast Plastic Bonded Explosives.

1 - INTRODUCTION

According to the SNPE approach for the Insensitive Munitions and more specifically for insensitive high explosives, three levels of increasing insensitivity [7] are to be taken into account :

Level 1 : fire resistance
Level 2 : level 1 and bullet impact resistance
Level 3 : level 2 and no sympathetic detonation

A SNPE objective is to reach level 3 and to demonstrate the feasability of munitions which are functionally detonable and which resist the sympathetic detonation as well as classical stimuli such as the fuel fire and the bullet and fragments impacts.

Parts of this work are supported by STPE of the French Ministry of Defence.

The achievement of this objective, and particularly the problem of the sympathetic detonation, requires a multidisciplinary effort :

1) Development of very insensitive high explosives with sufficient performances.

2) Development of the insensitive boosters systems adapted to these explosives.

3) Analysis of the sympathetic detonation phenomenon and development of meaningful tests and predictive methods.

4) Research on design concepts for the insensitive munitions.

5) Concept assessments based on probative models which are representative of various munitions and are tested in "donor/acceptor" or stack trials.

6) Optimization of explosive compositions with their booster systems, concepts and processes associated to a specific munition as a function of the required performances.

Points 1 to 5 have been partly realized with significant positive results and are still in progress. Point 6 is to be undertaken on a case by case basis.

The purpose of this paper is to give some information on this effort through some examples which are relevant to points 1, 3 and 5.

2 - DEVELOPMENT OF VERY INSENSITIVE HIGH EXPLOSIVES

SNPE has been working for several years to develop insensitive high exlosives [1 to 8]. Most of our cast plastic bonded explosives are reaching level 2 but SNPE has a special ongoing effort on NTO based cast PBX [4, 5, 6, 8] to meet level 3, i.e the "no sympathetic detonation" level.

Two examples of NTO based cast PBX, representative of IHE at the level 3 are selected to illustrate our work, along with a classical and powerfull HMX based "level 2" PBX.

These compositions are described on table 1.

NAME	HMX	NTO	BINDER	LEVEL
ORA 86	86	0	14	2
B 2214	12	72	16	3
B 3017	0	74	26	3

TABLE 1 **: COMPOSITIONS (MASS PERCENTAGE)**

Their main performance characteristics are given on table 2 and their shock sensitivities on table 3.

More details on ORA 86 and B 2214 are given in reference 8, about their ability to endure the fast cook-off, the bullet impacts, the heavy fragment impact (M = 250 g, V up to 2300 m/s for the B 2214 without detonation) and the shaped charge shot.

B 2214 and B 3017 are good candidates for the next United Nations "1.6" classification (EIDS : Extremely Insensitive Detonating Substances) according to the test series 7 [12].

NAME	DENSITY	DETONATION VELOCITY (m/s)	DETONATION PRESSURE (GPa) (calculated)	GURNEY VELOCITY (m/s) (estimated)
ORA 86	1.71	8330	30	2750
B 2214	1.63	7440	22.5	2210
B 3017	1.74	7800	26.5	2450

TABLE 2 **: PERFORMANCE CHARACTERISTICS**

NAME	GAP TEST THRESHOLDS			
	LARGE SCALE GAP TEST (L S G T)		EXPANDED LARGE SCALE GAP TEST (E L S G T)	
	FRENCH CARDS (9/7 US CARDS)	PRESSURE (GPa)	PMMA THICKNESS (mm)	PRESSURE (GPa)
ORA 86	160	5.	90	3.5
B 2214	25	14.5	40	9.5
B 3017	65	9.5	<70	>5.5

TABLE 3 **: SHOCK SENSITIVITIES**

The detonation and vulnerability properties of these two NTO [illegible] PBX are not necessarily optimum for all the purposes. Adaptations are easy by modifying the relative amounts of NTO or HMX or by using additives such as AP or aluminium to obtain the required effects for a specific munition.

3 - <u>THE SYMPATHETIC DETONATION PHENOMENON : ANALYSIS AND FORECAST</u>

This analysis is somewhat difficult to develop in a few words. Nevertheless, it seems to us that, concerning the cast plastic bonded explosives such as manufactured by SNPE, the main phenomenon which can promote the sympathetic detonation of a stack of munitions is the shock induced by the impact of the case or of the case fragments issued from the neighbouring detonating munition.

The other aspects of the problem (air shocks, thermal effects) are to be taken into account in particular situations where air shock focusing or heat concentrations could occur.

The main problem thus seems to be the shock to detonation transition of the energetic materials (sometimes damaged). The significant tests used to assess the shock sensitivity of our explosives are :

- The GAP tests (LSGT and ELSGT)
- The flyer plate test [8]
- The wedge test [10]
- The French Navy "GERBAM" heavy fragment test [8] in a generic hardware.

The numerical predictive methods are also relevant to the shock to detonation transition. In a given configuration, we evaluate numerically the shock pressures that are running across the munitions with the help of computer codes (DYNA 2D/3D [11]). The shock pressures are then compared to the Gap tests threshold pressures which have been calibrated numerically and with piezoresistive pressure gauges. For specific PBX's, a direct diagnosis is possible by using reactive modeling rate laws [10].

This methodology has given reliable results for donor/acceptor tests and has been validated for munition stack tests.

4 - EXPERIMENTAL ASSESSMENTS

SNPE has identified several design concepts that could meet the insensitive munitions requirements at level 3, i.e the "no sympathetic detonation" level. These concepts are largely dependent on the mission, the nature and the size of the munitions.

The simplest concept is to use very insensitive high explosives with their specific insensitive booster systems.

In order to test our concepts and energetic materials in realistic sizes, we have designed cylindrical test devices, which are representative of generic munitions (figure 1).

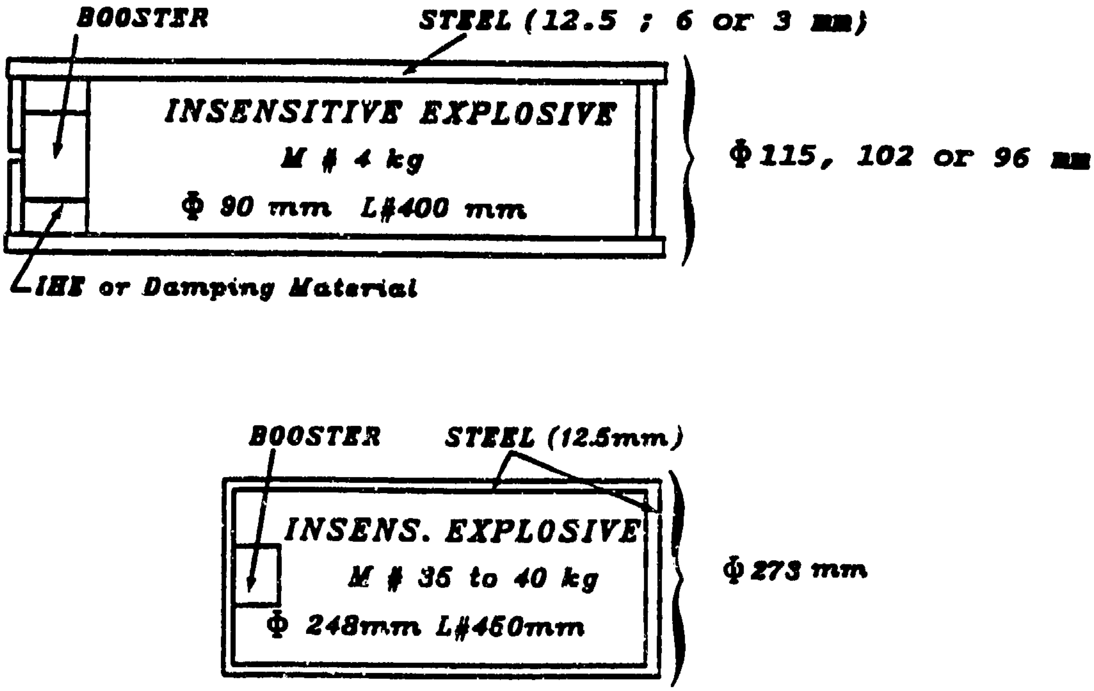


FIGURE 1 : SMALL AND LARGE DEVICES EXAMPLES

Experiments of sympathetic detonation are performed either on a donor/acceptor basis, used as a screening tool, or on stacks of nine live devices containing the promising insensitive high explosives fitted with their functional insensitive booster systems.The test configurations are described on figure 2 .

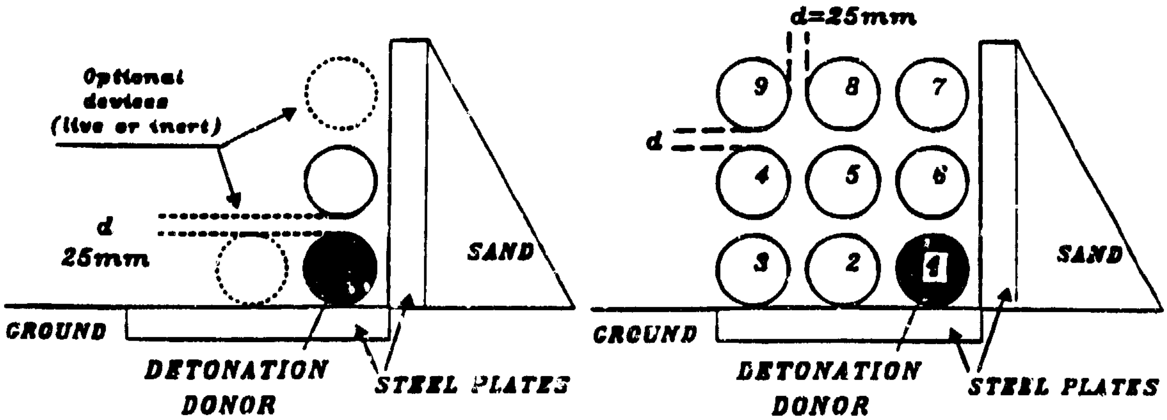


FIGURE 2 : DONOR/ACCEPTOR AND STACK OF LIVE DEVICES CONFIGURATIONS.

The tests are instrumented with blast pressure gauges, four high speed cameras (500 frames/sec., 2 x 1500 f/s, 30000 f/s) located on different angles of view, including a 50 meter high tower, and in-situ ionization pins.

With these instruments, the local observations and post-mortem recoveries, we are able to do a reliable diagnosis of the test.

5 - EXPERIMENTAL RESULTS

The results obtained with the previously described devices and configurations are :

Stack of 9 live small devices (Φ 115mm) :

In this case, the total mass of high explosives was about 40 kg.

- ORA 86 :

Full detonation of the stack within 250 microseconds, according to the high speed camera and ionization pins.

- B 2214 :

No sympathetic detonation. 8 devices were recovered, more or less damaged. Devices 2,5 and 6 were opened with signs of partial burning. The maximum projection distance was about 350m for device 3.
Devices 3,4,7,8 and 9 were reusable for an other test.

- B 3017 :

No sympathetic detonation. Same observations as for B 2214.

Using small scale devices with a case thickness of 6 or 3mm don't modify the no-sympathetic detonation result for B 2214 or B 3017. We have verified this fact with rows of one donor and two acceptors. The only differences are larger projection distances, up to 550m for the second acceptor, and an increased damage for the first acceptor.

Donor/acceptor configuration for the large devices (Φ 273 mm):

In this case, the total mass of high explosive was 72 kg.

- *B 2214 :*

No sympathetic detonation. The acceptor was completly destroyed with large pieces of metal. Partially burnt fragments of IHE were recovered on a large area (100 m radius circle) : deflagration or explosion of the acceptor.

Associated inert large devices containing various booster designs have allowed us to explain a previous sympathetic detonation of B 2214 in large devices, due to a wrong booster design.

Stack of 9 large devices (Φ 273mm)

In this case, the stack was constituted with 8 live large devices, whose total IHE mass was about 280kg, associated with an inert device (n°3). Specially designed yellow and red B 2214, using a small proportion of colouring matters in the binder, were used to fill devices 2,5 and 6 ("yellow" B 2214) and devices 4,7,8 and 9 ("red" B 2214).
The result of the test was : **no sympathetic detonation.**

Devices 2,5 and 6 were destroyed in large pieces with combustion or deflagration of the explosive. Few "yellow" B 2214 was recovered.

Devices 3,9 and 7 were recovered opened and empty at distances up to 500m."Red" B 2214 fragments were scattered on a large area (300m radius circle).

6 - CONCLUSIONS

Very insensitive, NTO based, high explosives are already available at SNPE. These IHE, associated with their specific insensitive boosters, are good candidates to meet the Insensitive Munitions requirements, for the future munition programs, as well as for retrofitting programs.

They resist fast cook-off, bullet and fragments impacts and sympathetic detonation in large calibers up to 270mm. They are "level 3" high explosives. For larger calibers, we are in a research and development phase, where special concept designs and compositions are to be assessed.

BIBLIOGRAPHY

1 - **P. DENEUVILLE, C. GAUDIN, Y. de LONGUEVILLE, J. MALA**
Comparison of TATB and Dingu explosive properties. Proceedings of the 7th International Symposium on Detonation. 16-19 june 1981. Anapolis USA.

2 - **C. GAUDIN, R. OUSSET, R. TEISSIER**
Explosifs peu vulnérables. Proceedings of the 13th International Annual COnference of ICT. 30 june 1982. Karsruhe FRG.

3 - **H. MOULARD, J.W. KURY, A. DELCLOS**
The effect of RDX particle size on the shock sensitivity of cast PBX formulations. Proceedings of the 8th International Symposium on Detonation. July 1985. Albuquerque USA.

4 - Utilisation du 5-oxo 3-nitro 1,2,4 triazole comme substance explosive et compositions pyrotechniques contenant du 5-oxo 3-nitro 1,2,4 triazole. French Patent n° 85-09-885 and European Patent n° 86-401282.8.

5 - **A. BECUWE, A. DELCLOS**
L'oxynitrotriazole et son utilisation en tant qu'explosif insensible. Proceedings of the 18th Internation Annual Conference of ICT. July 1987. Karlsruhe FRG.

6 - **A. BECUWE, A. DELCLOS**
Use of Oxynitrotriazole as a low sensitivity explosive. Proceedings of the International Symposium on Pyrotechnics and Explosives. October 1987. Beijing China.

7 - **A. FRECHE**
Low vulnerability cast plastic bonded explosives. ibid.

8 - **A. BECUWE, A. DELCLOS**
Use of Oxynitrotriazole to prepare an insensitive high explosive. Proceedings of the 9th International Symposium on Detonation. August 1989. Portland USA.

9 - A. FRECHE, R. KENT
Cast plastic bonded high explosives for insensitive munitions : SNPE contribution. Ninth International Seminar of Defense Technology. December 1989. Wah Cantt Pakistan.

10 - M. QUIDOT, J. GROUX
Reactive Modeling in shock initiation of heterogeneous explosives. Proceedings of the 9th International Symposium on Detonation. August 1989. Portland USA.

11 - J.O. HALLQUIST
User's Manual for DYNA2D, LLNL report 18756, Jan. 1984.

12 - Recommandations on the Transport of Dangerous Goods. Tests and criteria. 2nd Edition ST/SG/AC 10/11 rev.1. United Nations Publications, New York 1990.

FIRE RISK ASSESSMENT FOR CHEMICAL STOCKPILE DISPOSAL PROGRAM FACILITIES

Joseph Chang, Martin N. Fabrick, Vincent Ho, and Song T. Huang
The Ralph M. Parsons Company
100 W. Walnut St.
Pasadena, California 91124

and

David Douthat
US Army Engineer Division
Huntsville, Alabama 35807

Bernard Bindel
Program Manager for Chemical Demilitarization
Aberdeen Proving Ground, Md 21010

ABSTRACT

The U.S. stockpile of chemical munitions stored at various locations in the Continental United States (CONUS) is scheduled to be thermally demilitarized under the supervision of the U.S. Army Chemical Stockpile Disposal Program (CSDP). This paper describes a fire risk assessment (FRA) performed under the system hazard analysis (SHA) task for the initial CSDP facility. The fire risk methodology used in the assessment is adopted from the methodology developed for nuclear power plant fire risk assessment. The task of fire risk assessment consists of three phases: (1) preparation, (2) fire risk assessment, and (3) fire risk management. Design recommendations were formulated based on the findings of the FRA to reduce the fire-induced risk and to improve safety-system reliability. The FRA presented in this paper proved to be a very useful tool in supporting the facility fire protection system design. It is also proved to be an important portion of the system hazard analysis task to assess the potential of agent release and equipment damage from fire.

1. INTRODUCTION

1.1 BACKGROUND

The U.S. Department of Defense (DOD) has been directed by Congress in the DOD Authorization Act of 1986 (as amended by Public Law 100-456) to destroy the nation's stockpile of lethal unitary chemical warfare agents and munitions. The stockpile consists of nerve agents (GB and VX) and a blister agent (H/HD/HT, or mustard) in bulk storage containers, bombs, rockets, mines, projectiles, and mortar rounds stored at eight locations in the Continental United States (CONUS), in Europe, and at Johnston Atoll in the Pacific Ocean.

Because of the hazards associated with handling of these lethal unitary chemical warfare agents and munitions, Congress directed that the destruction be accomplished in such a manner as to provide: (1) maximum protection of the environment, the general public, and the personnel who will be involved in the demilitarization operations; (2) adequate and safe facilities designed solely for the destruction of the lethal chemical stockpile; and (3) cleanup, dismantling, and disposal of the facilities (i.e., decommissioning) when the disposal program is complete. Early in the CSDP, a System Safety Program Plan (SSPP) [Ref. 1] was developed to ensure that all of the project safety goals would be met in the various project stages, including design, construction, and testing. The system hazard analysis (SHA), is one of the key elements in the SSPP during the final design stage of the program.

A fire can either cause an accident or reduce the plant's margin of safety. A fire can damage equipment which is needed to safely operate the demilitarization processes and to prevent release of agent vapor from toxic areas during normal or abnormal operations. Apart from hardware failure, crucial equipment in the facility can also be damaged by fire, flooding, or other causes. Recent risk studies [Refs. 2 through 4] have concluded that fires can be important contributors to public health risk. The adverse effects of fire on plant safety are further demonstrated by the well-known cable-spreading-room fire at Browns Ferry Nuclear Power Plant [Ref. 5]. Therefore, fires present a substantial risk to the system safety; a fire risk assessment was performed for a CSDP facility as a part of the SHA to meet the SSPP requirement.

1.2 FIRE RISK ASSESSMENT

Investigation of fire risk requires the application of probabilistic risk assessment (PRA) technology to qualitatively and quantitatively assess the probability of fire occurrence rate, fire protection system (FPS) unavailability, and fire induced damage probability.

The key segments in the FRA are: assess fire frequency, evaluate fire damage probability, assign Risk Assessment Codes (RAC) to current design, and provide risk management recommendations. Event-tree/fault-tree methodology is applied to determine the probability of occurrence for the selected accident scenarios. Consequences of the accident scenarios are assessed via the loss of critical safety equipment and the estimate of agent release.

2. TECHNICAL APPROACH

The FRA adapts the general methodology that has been developed for fire risk assessments performed for nuclear power plants. The methodology combines engineering judgment, statistical evidence, fire phenomenology, and plant system analysis to systematically quantify the risk of fires to the operation in the facility.

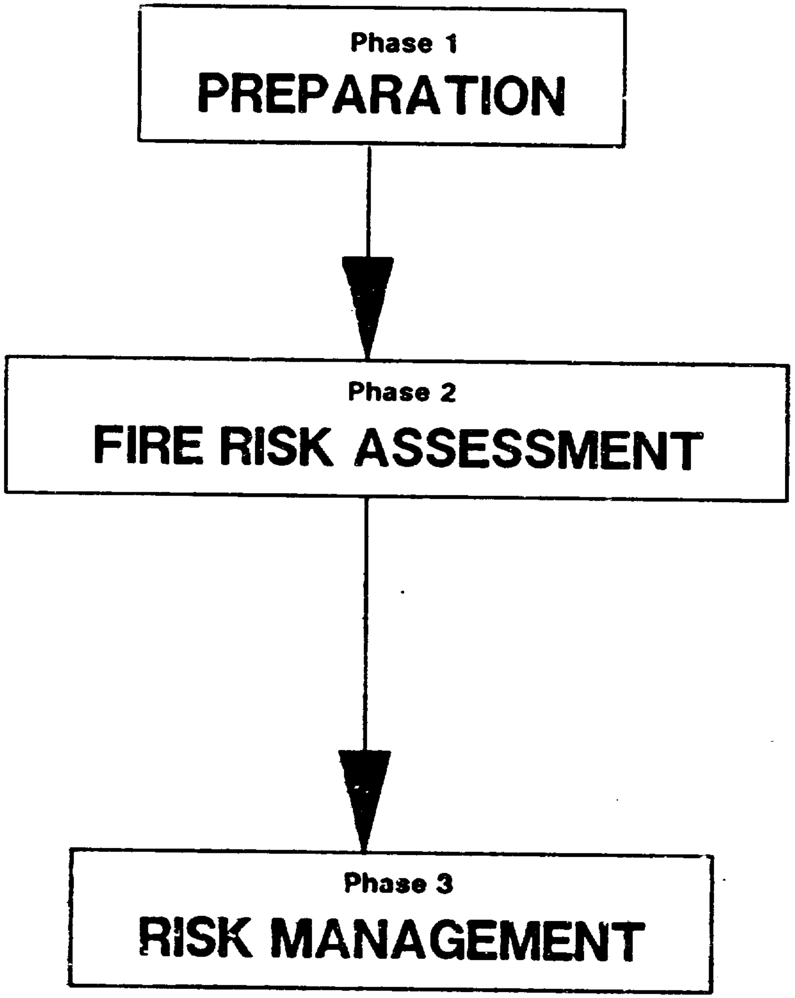
2.1 OVERALL PLAN OF APPROACH

The overall approach for the FRA work is illustrated in Figure 2-1. The figure identifies the three main phases of the analysis, each of which involves several work activities:

Phase 1: Preparation: (a) plant design familiarization, (b) identification of engineered safety functions (ESFs), and (c) database development.

Phase 2: Fire Risk Assessment: (a) identification of critical locations and components and credible fire scenarios, (b) estimation of fire frequency, (c) estimation of fire-growth times and competing fire-detection and suppression time, (d) assessment of FPS unavailability, (e) assessment of fire-induced damage probability, and (f) evaluation of total fire risk.

Phase 3: Fire Risk Management: (a) design confirmation, and (b) fire risk reduction recommendations.



Phase 1:

a. Design familiarization
b. Identification of engineered safety functions
c. Database development

Phase 2:

a. Identification of critical locations
b. Estimation of fire frequency
c. Estimation of fire growth and hazard times
d. Assessment of FPS unavailability
e. Assessment of fire-induced damage probability
f. Evaluation of total fire risk

Phase 3:

a. Design confirmation
b. Risk reduction recommendations

Figure 2-1 - Overall Approach of the FRA

2.2 PREPARATION

The occurrence of fires and their effects on the facility plant safety are very complex issues that require detailed design information. Documentation such as plant layout drawings, process flow diagrams (PFDs), piping and instrumentation diagrams (P&IDs), system descriptions, technical specifications, and other supporting engineering calculations was collected during the initial phase of the FRA. During this preparation phase, engineers from various disciplines - design, process instrumentation and fire protection - were consulted for correct interpretation of the drawings and processes.

Theoretically, an FRA should study all the potential contributors to the risk of agent release associated with fires anywhere in the facility. By screening out less important scenarios, however, the amount of work required can be greatly reduced without sacrificing significant confidence in the results. To accomplish this objective, a screening criterion is used to select only the fire scenarios that can damage engineered safety functions (ESF). An ESF is a safeguard designed to prevent agent from contaminating the nontoxic areas or to mitigate agent-release accidents. ESFs were identified from the PFDs, P&IDs, SHA [Ref. 6], and design criteria document. The identification of the ESFs sets forth the scope of the FRA and is an important step in the identification of critical locations analyzed in the following phases of the FRA.

2.3 FIRE RISK ASSESSMENT

A general methodology [Refs. 7 through 12] for the assessment of the risk associated with fires has been developed and applied in major FRAs [Refs. 13 through 16]. The methodology addresses many aspects of a fire incident (e.g., fire ignition, progression, detection and suppression, or characteristics of materials under fire conditions) as well as the plant safety functions and their behavior under accident conditions. Although the methodology was developed primarily for the evaluation of a nuclear power plant's fire risks, it can be applied to any complex facility.

2.3.1 Identification of Critical Locations and Components

A location is classified as critical when the occurrence of a fire there has the potential of creating an abnormal condition leading to the damage of the components that perform the ESFs (generally known as critical components) directly or indirectly. The critical locations are identified systematically by dividing the facility into fire areas. A fire area is defined as an area bounded by firewalls. Partitions separated from each other by non-fire-rated walls within a fire area are defined as a compartment. Compartments within a fire area are usually grouped into fire zones. The compartments within a fire zone are usually protected by the same FPS. If the FPS for a fire zone is lost, the fire-control capability is said to be lost in all compartments within the same zone. The critical locations analyzed were selected from these compartments based on the amount of hazardous material and combustibles available in the locations, the significance of the critical ESF equipment within the room, the consequences of losing this equipment, and the likelihood of fire initiation and propagation.

2.3.2 Definition of Fire Scenarios

Fire scenarios in each of the critical locations were postulated in order to conduct the risk analysis. These scenarios include different sizes of fires at the worst-case locations. A worst-case location is that where a fire can cause the most significant damage to the ESF equipment. Generally, a scenario includes the following information: the size of the fire, the location of the fire, the type of FPS, the equipment (target) being considered, and the progression of the fire event. The progression of a fire event is illustrated in Figure 2-2. Three events are included: (1) the automatic FPS is available, (2) fire is controlled successfully by automatic FPS, and (3) fire is controlled successfully by manual suppression. The first event models the reliability of the FPS, if present. The second event models the speed of the FPS, and the third event models the speed of the manual-suppression effort. The fire event will lead to a damage state by either of the following scenarios:

(1) The automatic FPS is fully functional as designed; however, the FPS cannot control the fire before the fire damages the ESF equipment.

(2) The automatic FPS is not functioning, or there is no automatic fire-suppression system installed in the compartment. Manual-suppression effort is not able to control the fire before damage occurs.

2.3.3 Fire Occurrence Frequency

Since fire occurrence data for facilities similar to the CSDP operation do not exist, available industrial fire experience and engineering judgment were used to approximate the frequency of occurrence of fires in the critical locations. A methodology that allows such an approach is formulated in References 7 and 17 through 21. The methodology integrates new evidence (including

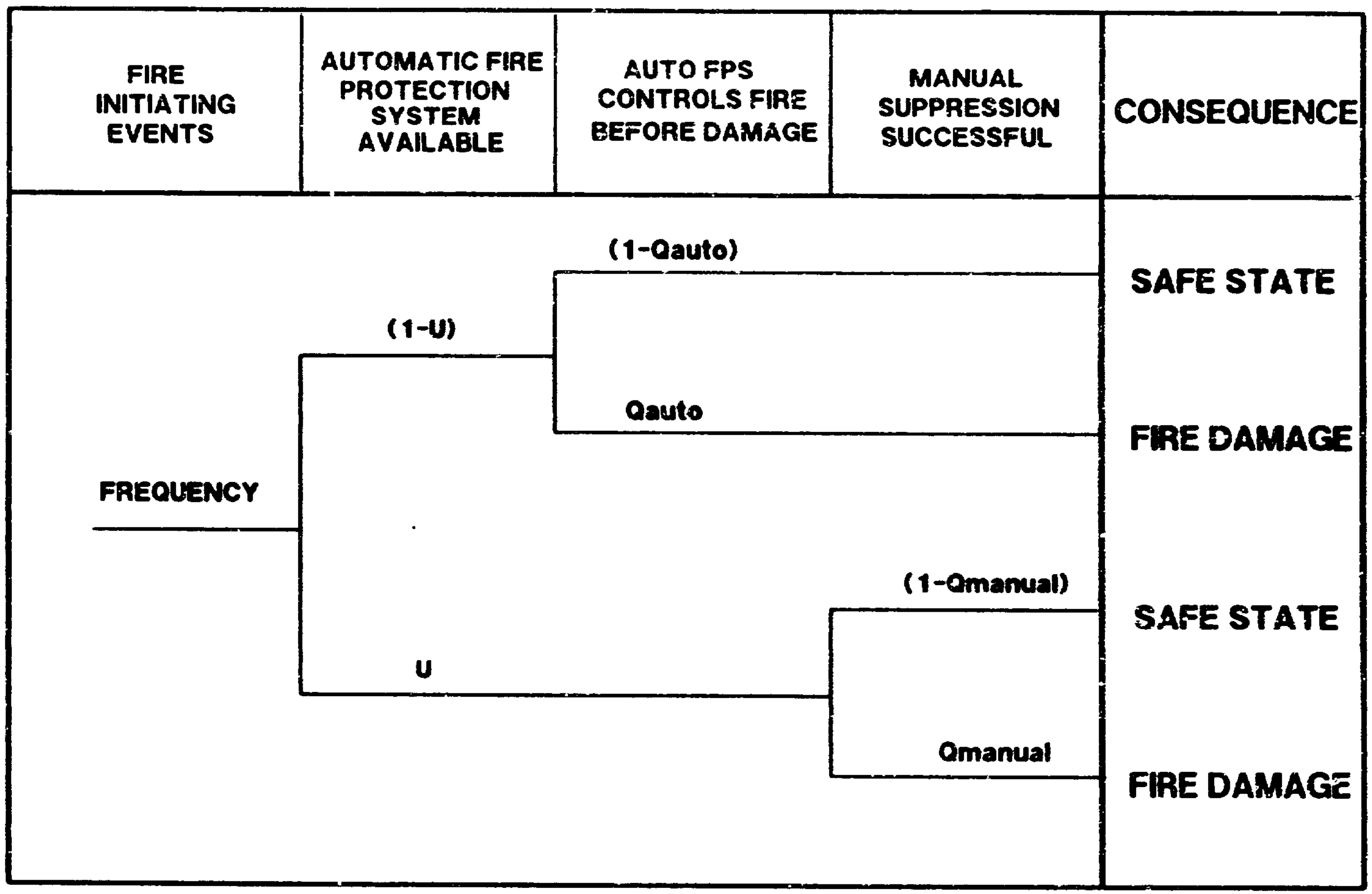


Figure 2-2 - Fire Event Tree Used in the FRA (Typical) imprecise or debatable evidence) into the state of knowledge of the frequency of fire occurrence. The central conceptual tool is Bayes' Theorem from the theory of probability. This theorem, the fundamental law of logical inference, is the ideal tool for quantitatively assessing the significance of various items and forms of information. Bayes' Theorem is expressed as follows:

$$K(a|E) = \frac{K_o(a) * L(E|a)}{\int_0^\infty K_o(a) * L(E|a)\, da} \qquad (2\text{-}1)$$

where

$K_o(a)$ = probability distribution of the frequency "a" prior to having evidence E (prior distribution).
$L(E|a)$ = likelihood function (probability of the evidence given a).
$K(a|E)$ = probability density function of a given evidence (the posterior distribution).

In the FRA, the frequency of fires is treated as a random variable, and its distribution expresses our current state of knowledge about the values of that frequency. The prior distributions developed in the knowledge process are generic. Since there are no historical data of fire occurrence at the new facility, the prior distribution of the frequency for each of the critical locations is almost noninformative, i.e., no significant prior knowledge was injected into the analysis. The evidence used in the analysis was derived from actual nuclear power plant fire incidents as reported to the American Nuclear Insurers (see Table 2-1). Bayes' Theorem was used to formally incorporate the experience into the knowledge of the frequencies.

Based on the form of data available, the evidence (Table 2-1) is best modeled as a Poisson process. Therefore, the likelihood function is

$$L(E|a) = e^{-a\,T} \frac{(a\,T)^r}{r\,!} \qquad (2\text{-}2)$$

where

a = frequency of occurrence used to model the process.
T = number of relevant years of operation.
r = number of fires.

Table 2-1 - Statistical Evidence of Fires in Light Water Reactors (As of June 1985) [Ref. 21]

Area	Number of Fires (r)	Number of Compartment Years (T)
Control Room	3	681.0
Cable Spreading Room	2	747.3
Diesel Generator Room	37	1600.0
Reactor Building	15	847.5
Turbine Building	21	654.2
Auxiliary Building	43	673.2
Electrical Switchgear Room	4	1346.4
Battery Room	4	1346.4

To facilitate the calculation, the gamma family of distributions, which is conjugate to the Poisson distributions, was chosen to represent the prior distribution. A gamma distribution is expressed as:

$$G(a) = \frac{b^{\alpha} * a^{\alpha-1} * e^{-b a}}{\Gamma(\alpha)} \qquad (2\text{-}3)$$

where α and b are the parameters of the distribution.

For the noninformative prior distribution, the greatest ignorance is represented by setting "A" and "b" to a value of zero. In the FRA, slightly more conservative prior distributions (α and $b > 0$) were used to give more weight to the values of "a" in the neighborhood of one per compartment-year. The distributions cover a wide range of values to express our vague prior knowledge. Since the gamma distributions are conjugate with respect to the Poisson distribution, the posterior distributions are also gamma distributions, with parameters $\alpha' = \alpha + r$ and $b' = b + T$.

To express the large uncertainties in applying the generic distributions obtained from nuclear power plant experience as the evidence for the facility operation, these distributions were further broadened to express the uncertainties in the application of the knowledge [Ref. 19]. The degree of broadening depends on the differences between the nuclear experience and the new facility designs.

2.3.4 Fire Growth Time and Competing Fire-Detection and Suppression Time

Figure 2-3 depicts a simplified view of the interactions in a compartment fire as modeled in the FRA. A fire starts and releases energy to other contents in the room. This energy causes the gas pressure in the flame zone to rise. The products of combustion, with temperature higher than that of the environment, are driven upward by buoyancy forces. A hot, turbulent plume is generated and begins to rise. The upward momentum of the plume depends on the distance between the fire source and the ceiling, the fire strength, and the thermal stratification of the room. Along the axis of the plume, relatively quiescent air at ambient temperature is entrained into the plume and mixes with the plume gases as they continue their ascent toward the ceiling. As a

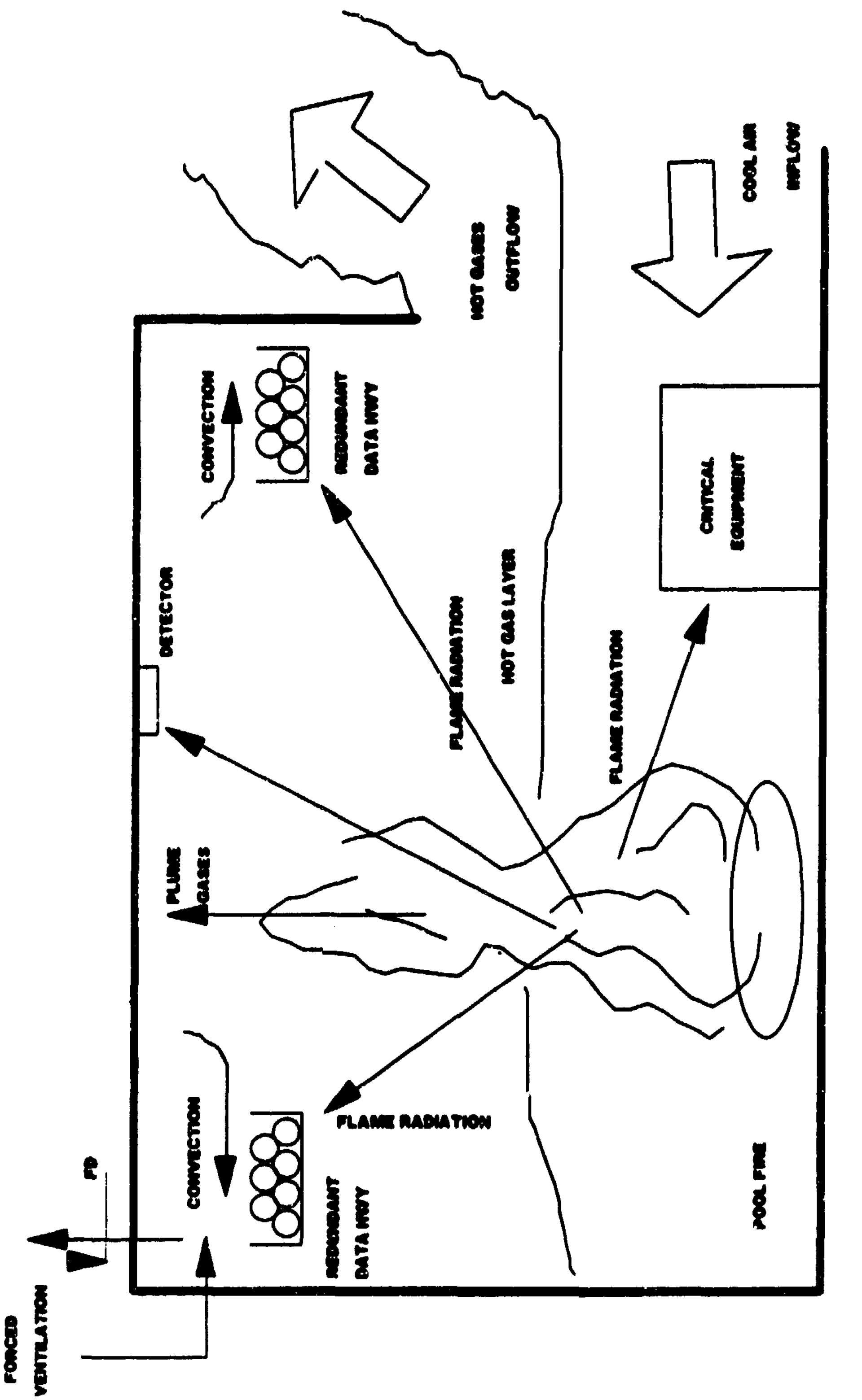


Figure 2-3 - Simplified Compartment Fire Model result of the air entrainment, the total upward mass flux in the plume continuously increases while its temperature decreases. When the plume gases impinge on the ceiling, they spread and form a relatively thin turbulent ceiling jet. As this hot jet moves radially outward, it transfers energy by convection, conduction, and radiation to the ceiling, causing its temperature to rise. This ceiling jet also sends fire signatures to the ceiling-mounted fire detectors and sprinkler nozzle heads.

When the ceiling jet is blocked by the room boundaries, it turns downward at the ceiling-wall juncture, thereby initiating a downward-directed wall jet. This wall jet is of higher temperature and lower density than the ambient air into which it is being driven. The wall jet, retarded by its relative negative buoyancy, turns upward and entrains an additional amount of cooler air from the lower region on its way up. Eventually, a relatively quiescent upper gas layer, called the hot gas layer, is formed below the continuing jet flow activity. Thus, stratified regions are formed as the fire grows, and the room is divided into several regions with distinct thermal boundaries. Objects within a hot gas layer will be subject to a similar degree of convective and radiative heat transfer.

Simple fire and heat transfer models and correlations were employed to predict the thermal environment as a function of time. The thermal response of various targets in the fire scenario was modeled to predict the amount of time required for a fire to damage or ignite critical equipment.

The fire growth, detection, and suppression processes are time-competing processes. As the fire heats up the equipment in the room, it also sends fire signatures to the fire detectors. The fire can cause damage before the detection system can respond, or before the suppression system can be actuated. These times can be summarized by two characteristic time factors, T_G and T_H, such that a component X can be defined to be damaged due to fire if $T_G < T_H$. The fire growth time, T_G, is defined as the time it takes for the fire to propagate to X and damage it. The hazard time, T_H, is defined as the total fire exposure time during which X can be damaged by the fire. The conditional frequency that X will be damaged, given that the fire occurs, can then be formulated as

$$Q_X = \text{Freq}\,(T_G < T_H \mid \text{Fire}) \qquad (2\text{-}4)$$

where Freq $(A|B)$ denotes the frequency of occurrence of event A conditioned on the occurrence of event B.

Equation 2-4 simply says that the damage frequency of X, given that a fire has occurred, is equal to the frequency of the event having growth time smaller than the hazard time; i.e., the time to damage the component in a given magnitude of a fire is shorter than the time it takes to detect and suppress the fire.

The expression (as defined in Eq. 2-4) is usually modeled as an exponential process [Refs. 8, 10, and 11], such that:

$$Q_X = e^{-T_G/T_H} \quad (2\text{-}5)$$

The probabilistic distribution of Q_X is obtained by combining the distributions of T_G and T_H using the exponential model. For each critical location, the fire growth time, T_G, is estimated using the computer code COMPBRN III [Ref. 12]. If a fire-protection system is available in the location, the hazard time, T_H, is determined by the reaction of fire-protection systems such that

$$T_H = T_D + T_S \quad (2\text{-}6)$$

where T_D is the detection time; which is defined to include not only the time to acknowledge the presence of the fire, but also the time interval following acknowledgment but prior to initiation of suppression efforts. T_S is the suppression time; i.e., the time required to extinguish the fire after the actuation of the suppression systems (which could be a manual or an automatic system).

2.3.5 Fire-Induced Damage Probability

As described in Figure 2-2, each fire initiating event can have two scenarios that lead to equipment damage in that location. The conditional probability of equipment damage, P_X, due to a particular event, is the sum of the probability of occurrence of the two scenarios; i.e.,

$$P_X = (1 - U) * Q_{auto} + U * Q_{manual} \quad (2\text{-}7)$$

where

- U = unavailability of the FPS.
- Q_{auto} = probability of fire-induced damage calculated by Eq. 2-5 when the location is guarded by automatic FPS and the FPS fails to control the fire before damage.

Q_{manual} = probability of fire-induced damage calculated by Eq. 2-5 when manual suppression fails to control fire before damage.

2.3.6 Total Fire Risk

The unconditional probability of equipment damage due to a particular fire initiating event is then the product of the fire occurrence frequency and the conditional probability as assessed from the event tree. The probability of equipment damage in a critical location is the sum of the unconditional probability of all events developed to model the credible damage scenarios in that location. The total fire risk is equal to the sum of unconditional probabilities for all critical locations in the facility.

2.4 RISK MANAGEMENT

Risk management provides design confirmation and recommendations to reduce fire risk, if necessary. The design can be confirmed by either of the following:

(1) The risk of fire occurrence is acceptable so that protective measures are not necessary.

(2) The existing fire protection capabilities are adequate to prevent agent release due to fires.

The FRA utilizes the Risk Assessment Code (RAC) system to evaluate the risk associated with individual critical areas. The RACs are based on a combination of probability and severity, as delineated and approved in the CSDP Safety System Program Plan [Ref. 1]. For locations where the fire risk (RAC number) was found to be unacceptable, recommendations are provided to reduce such risk. Figure 2-4 describes the various hazards and control measures in fire risk management. The control measures are used to break down the "fire triangle" so that combustion cannot be sustained. In general, the likelihood of component damage can be reduced by :

(1) Slowing down the fire growth rate, e.g., by reducing combustible loading in rooms, or by installing fire barriers.

(2) Speeding the fire detection and suppression capabilities. Different types of fire detectors may be used to provide a faster response time, or to reduce the false alarm rate. Installation of automatic fire

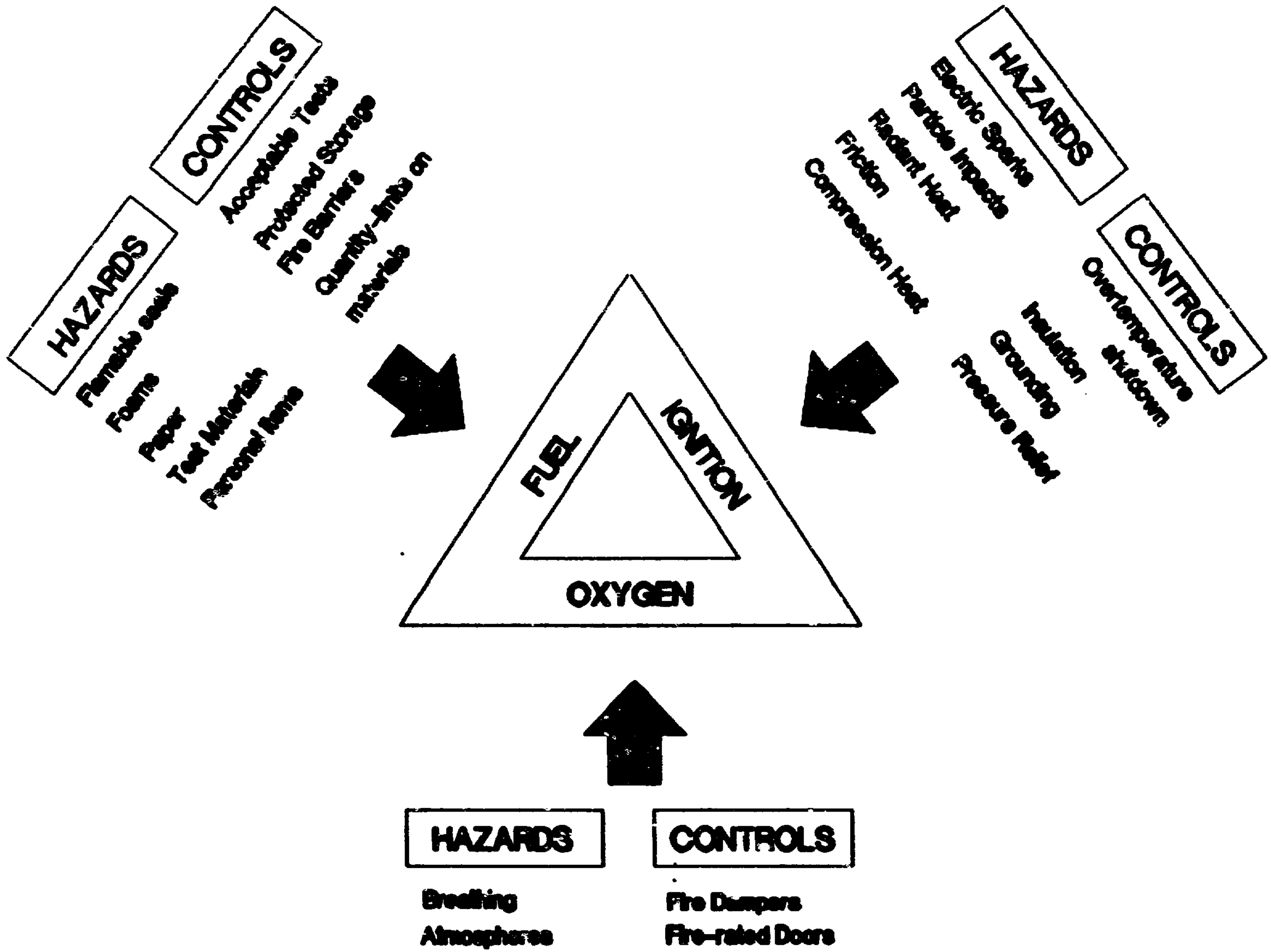


Figure 2–4 Hazards and Control Measures in Fire Risk Management

suppression systems may be necessary in locations where manual suppression capability is limited.

(3) The risk of common-cause failures due to fire can be reduced by increasing the redundancy of important equipment, and positioning the redundant components in independent areas so that single-mode and single-cause failure are virtually impossible.

3. FIRE RISK ASSESSMENT

3.1 SELECTION OF CRITICAL LOCATIONS AND COMPONENTS

There are two main objectives in selecting critical locations. The first objective is to ensure that all important locations are analyzed. This may lead to the consideration of a potentially large number of candidate locations. The second objective is to minimize the effort spent in quantifying the fire risk in unimportant locations. These two objectives are counteractive to each other and must be balanced in a meaningful FRA.

In order to account for all important locations and identify the critical locations systematically, the following information was obtained:

(1) The ESFs that are designed to safeguard against agent release from the demilitarization processes.
(2) The critical equipment that performs these ESFs.
(3) The locations of this critical equipment and its control and power cable routes.
(4) The fire areas that contain this critical equipment.

The critical locations were then selected based on the following criteria:

(1) The amount of critical equipment in a fire area.

(2) The presence of combustibles in the area.

(3) The potential of rapid fire growth, extinguishment delay, and equipment.

(4) Locations identified from previous studies (e.g., the SHA [Ref. 6]).

(5) The estimated frequency of fire occurrence and its consequences in these locations.

This screening process optimizes the effort in performing the FRA. However, the analysis does not indicate that other locations in the facility that are not in this list are absolutely free from fire risks. The critical locations chosen in the FRA are dominant to other areas in terms of the probability and consequences of fire occurrence.

The CSDP facility contains the basic process equipment and control systems necessary to disassemble, punch, and drain munitions and bulk items; to incinerate agent, other liquid, and solid waste; and to decontaminate munition bodies and other metal items. The facility also provides critical services to the personnel operating and maintaining the process equipment [Ref. 22]. ESFs are incorporated to safeguard these areas of operation by preventing propagation of agent from toxic areas to less-toxic or nontoxic areas. The functions identified as ESFs include the cascaded ventilation systems, containment protection, HVAC filtration, liquid agent removal, decontamination, control and power supply, and fire protection.

The ESFs, when needed, will be performed by the corresponding safety equipment. This safety equipment, coordinated with corresponding control and power supply units under both normal and off-normal conditions, is designed to prevent agent release to the nontoxic areas and to mitigate the consequences following agent-handling mishaps. Each of the ESFs may require one or more pieces of designated equipment to carry out its function. Table 3-1 shows the selected ESFs, critical components and their locations.

3.2 ESTIMATION OF FIRE OCCURRENCE FREQUENCY

The probability distributions for the fire-occurrence frequency at the critical locations were assessed by applying Bayes' Theorem. Data compiled from industrial plant experience (Table 2-1) are treated as evidence and modeled by the likelihood functions. The posterior distributions for the fire-occurrence frequency in each of the critical locations were developed using noninformative prior distributions. The posterior distributions were analyzed and modified with justification to closely reflect the difference between the analyzed facility design and the evidence.

3.3 AREA DESCRIPTION

An area description is based on reviewing the design drawings to identify the location of postulated ignition pilot fire, fuel elements, room openings, room dimensions, and locations of critical equipment. The area information is used for the COMPBRN III fire growth model.

3.4 FPS CHARACTERISTICS

Fire protection characteristics include the description of the fire-rated walls, the fire detection system, detector locations, zoning and spacing of the detection system, control panel type and location, and types of suppression systems. The information collected is used for the DETACT computer program to calculate the detector response time and the fire-suppression time.

3.5 FPS UNAVAILABILITY

The FPS unavailability refers to the FPS failure unavailable on demand. Fault-tree analysis is used to model the FPS. The analysis includes both the manual and automatic systems. The analysis includes the failure rate calculation of fire detection system, fire panels, and fire suppression system. The CAFTA computer workstation [Ref. 23] is used to perform the unavailability analysis. An example of an FPS fault tree is shown in Figure 3-1.

3.6 THERMAL-RESPONSE EVALUATION

The thermal response evaluation focuses mainly on the critical equipment fire-damage-time evaluation for a given fire. The thermal response of critical equipment is best estimated by the COMPBRN III computer code.

3.7 FIRE-HAZARD-TIME ASSESSMENT

Fire-hazard time is equal to the sum of the detector-response time and the fire-suppression time. The detector-response time is the time from the fire start to the time when detectors send signals to panels and/or fire warning systems. The length of detector response time depends on many factors: detector type, the type and size of fire, and the spacing of the detectors. The detector-response time is calculated by the DETACT computer code.

Table 3-1 - ESF, Critical Components and their Locations

Engineered Safety Functions	Critical Components	Location
1. Cascaded Ventilation System	Supply Air Blowers	Mechanical Equipment Room
		Air Handling Room
		Battery Room
		Switchgear Room
		Electrical Rooms
	Exhaust Air Blowers	HVAC Filter Areas
	Air Flow Isolation Dampers	Various Locations
	Instrument Air Compressors	Mechanical Equipment Room
2. Containment Protection	DPE Suits	Various Locations
	High Curb	Various Locations
	Sloped floor	Various Locations
	Enclosures	Various Locations
3. HVAC Filtration	Intake Filters	Mechanical Equipment Room
		Air Handling Room
		CON Filter Area
		Electrical Rooms
		Battery Room
		Switchgear Room
	Exhaust Filters	HVAC Filter Areas
	ACAMS	Monitor Houses
4. Liquid Agent Removal	Sumps	Various Locations
	Level alarms	Sumps
	Sump Pumps	Sumps
	Plant Air Compressors	Equipment Room
5. Decontamination	Decon Solution	Various Locations
6. Control and Power Supply	Instrument Cables	Various Locations
	Power Cables	Various Locations
	UPS Power Supply	Battery Room
7. Fire Protection	Fire Detectors	Various Locations
	Fire Control Panels	Various Locations
	Halon 1301	Halon Room
	Dry Chemical	Obs. Corridor 09-142
	Sprinkler System	UPA, CHB

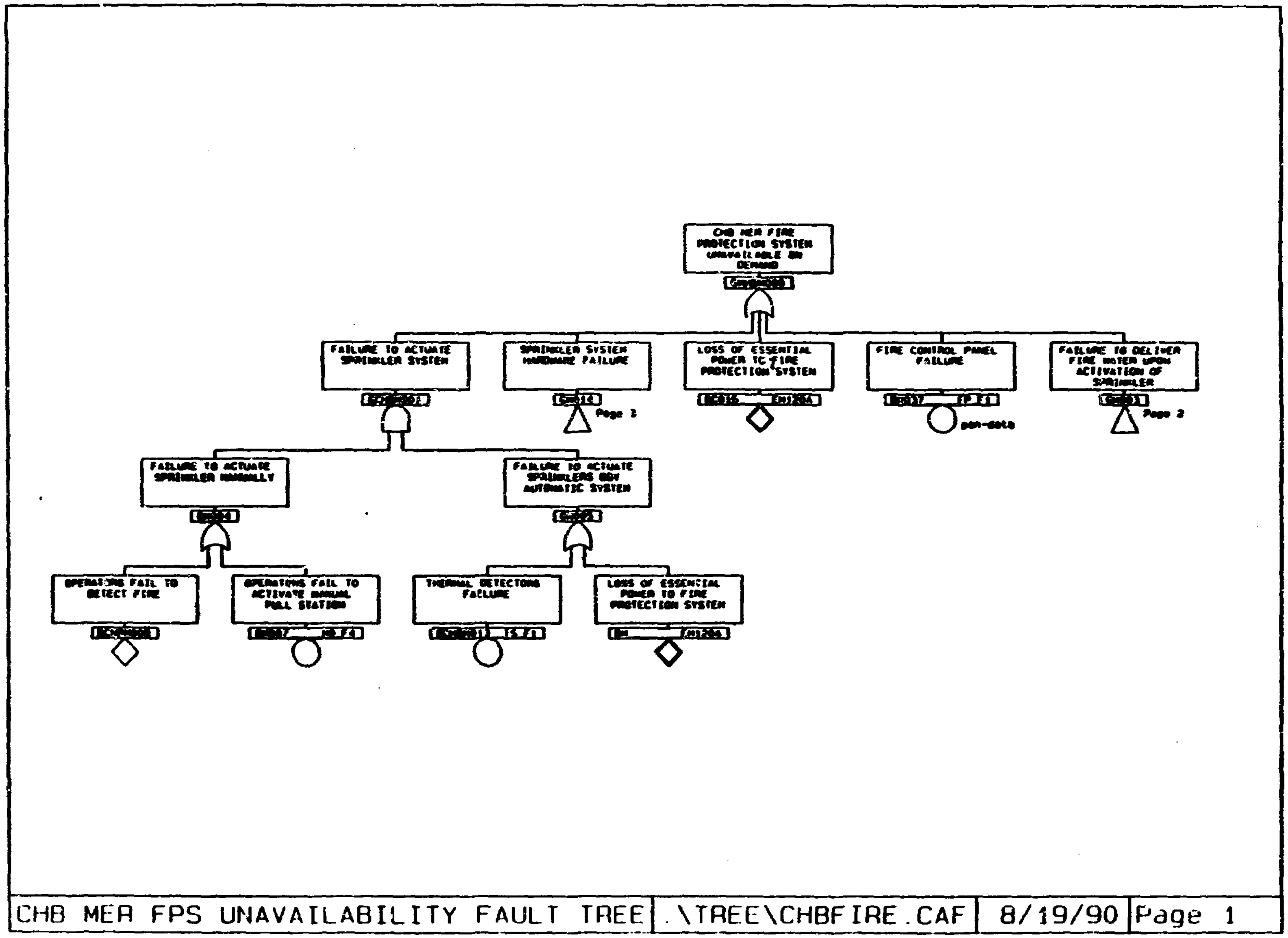


Figure 3-2 Fault Tree of a Fire Protection System

The fire-suppression time depends on the fire-suppression system design, the availability of the suppression system/equipment, the response of personnel, and accessibility of the area. Suppression time of the automatic FPS can be estimated by the available vendor data or engineering judgement. The manual suppression time will depend on the fire size, the experience of personnel, and availability of equipment. Engineering judgement is commonly used to estimate the manual suppression time.

3.8 FIRE-INDUCED-DAMAGE PROBABILITY

The fire-induced-damage probability, Q_x, of a piece of critical equipment x is calculated by Eq. 2-5. The calculated fire-induced-damage probability is the probability of either the automatic FPS or manual FPS depends on the area design.

3.9 UNCONDITIONAL FIRE RISK

The unconditional fire risk is the probability of fire damage to a piece of critical equipment based on all the fire scenarios in the area. The probability is the sum of the fire-induced-damage probability times the fire-occurrence frequency for the scenario. The total area fire risk is the sum of all critical equipment damage risks in the area. The total facility fire risk is the sum of all the area fire risks.

3.10 DISCUSSION AND INTERPRETATION

The fire risk calculations stated above show the parameters involved in the calculations, which in turn determine the fire risk of a critical equipment. The fire risk of the area is the sum of the fire risk of all the critical equipment in the area. If the fire risk is too high, risk management must be performed based on the variation of the crucial parameters. The fire risk analyst must interpret the results to FPS designers to develop an alternative FPS design. If the design change is not feasible, stringent operating procedures must be incorporated in the plant standing operating procedures to reduce the fire-occurrence frequency and to reduce the fire-suppression time.

4. CONCLUSION

The fire risk of a CSDP facility has been quantified by applying the FRA methodology described in Section 2. The methodology combines the use of state-of-the-art computer codes, engineering judgment, relevant industrial experience, and numerical analysis techniques to evaluate the unconditional probability of fire damages in various critical locations of the facility.

As discussed in Subsection 2.4, the results of the assessment confirm whether the design is within the acceptable safety margins by comparing the risk with the RACs. In locations where the fire risks are found to be unacceptable, design recommendations are provided to reduce such risk based on FRA and FPS designer discussion. These recommendations were developed primarily based on the dominant factors in the FRA to reduce the fire hazard time (detection and suppression), increase the fire growth time, prevent fire propagation, and reduce fire occurrence frequency. The fire risks of the facility were re-evaluated based on the FRA recommendations.

During the course of FRA, it was found that a small fire is as important as big fire. This is because small fires have high occurrency rates and they can damage critical equipment before or without actuating the FPS. The ESFs are engineering-designed components to protect the facility from agent release, major equipment damage, and personal injury.

The quantitative assessment of the recommended FRA provides a basis for fire-risk management. The results of assessed risk at different locations can be used as priority scales to determine where the risk management effort should be focused. This is a key concept of risk management.

5. REFERENCES

1. "System Safety Program Plan for the Chemical Stockpile Disposal Program," Task G-5A, Parsons, Dec. 1986.

2. "Indian Point Probabilistic Safety Study," Consolidated Edison Company of New York, Inc., and power Authority of the State of New York, May 1982.

3. "Probabilistic Risk Assessment, Big Rock Point Plant," Consumers Power Company, March 1981.

4. "Zion Probabilistic Safety Study," Commonwealth Edison, Chicago, September 1981.

5. Sawyer, R.G. and Elsner, J.A., "Cable Fires in Browns Ferry Nuclear Power Plant," Fire Journal, Vol. 70, 1976.

6. Chemical Stockpile Disposal Program, System Hazard Analysis for the First Seventeen Agent Release Accident Sequences, Task G- 5E, The Ralph M. Parsons Company, August 1989.

7. Apostolakis, G., and Kazarians, M., "The Frequency of Fires in Light Water Reactor Compartments," presented at the ANS/ENS Topical Meeting on Thermal Reactor Safety, Knoxville, Tennessee, April 7-11, 1980.

8. Siu, N., and Apostolakis, G., "Probabilistic Models for Cable Tray Fires," Reliability Engineering, 3(1982)213-227.

9. Siu, N., "Physical Models for Compartment Fires," Reliability Engineering, 3(1982)229-252 .

10. Apostolakis, G., Kazarians, M. and Bley D., "Methodology for Assessing the Risk from Cable Fires," Nuclear Safety, 23(1982)391-407 .

11. Kazarians, M., Siu, N., and Apostolakis, G., "Fire Risk Analysis for Nuclear Power Plants: Methodological Developments and Applications," Risk Analysis, 5(1985)33-51.

12. Ho, V., Siu, N., and Apostolakis, G., "COMPBRN III - A Fire Hazard Model for Risk Analysis," Fire Safety Journal, 13(1988)137-154.

13. Zion Probabilistic Safety Study, Commonwealth Edison, Chicago, September 1981.

14. Indian Point Probabilistic Safety Study, Consolidated Edison Company of New York, Inc., and Power Authority of the State of New York, May 1982.

15. Seabrook Station Probabilistic Safety Assessment, Public Company of New Hampshire, and Yankee Atomic Electric Company, December 1983.

16. Oconee Probabilistic Safety Study, Duke Power Company, June 1984.

17. Apostolakis, G., "Probabilistic and Risk Assessment: The Subjectivistic Viewpoint and Some Suggestions," Nuclear Safety, 20(1979)308-317.

18. Apostolakis, G., Kaplan S., Garrick, B.J., and Duphily, R.J., "Data Specialization for Plant Specific Risk Studies," Nuclear Engineering and Design, 56(1980)321-329.

19. Apostolakis, G., "Data Analysis in Risk Assessment," Nuclear Engineering and Design, 71(1982)375-381.

20. Apostolakis, G., "Expert Judgment in Probabilistic Safety Assessment," Accelerated Life Testing and Expert's Opinions in Reliability, pp. 116-131, CII Corso, Italy, 1988.

21. Mosleh, A., and Apostolakis, G., "The Assessment of Probability Distributions from Expert Opinions with an Application to Seismic Fragility Curves," Risk Analysis, 6(1986)447-461.

22. Chemical Stockpile Disposal Program, Facilities Project Development Brochure, Tooele Army Depot (TEAD) Mixed Munitions Plant, Task E-4, Final Report, The Ralph M. Parsons Company, May 1987.

23. CAFTA User's Manual, Version 2.0, Science Applications International Corporation, Nov. 1988.

TWENTY-FOURTH DOD EXPLOSIVES SAFETY SEMINAR

ADAM'S MARK HOTEL, ST. LOUIS, MISSOURI

28 - 30 AUGUST 1990

APE 1236 DEACTIVATION FURNACE UPGRADE TO MEET RCRA REQUIREMENTS

by

Mark M. Zaugg
Robert Anderson

Directorate for Ammunition Equipment
Tooele Army Depot

APE 1236 DEACTIVATION FURNACE UPGRADE TO MEET RCRA REQUIREMENTS

ABSTRACT

This paper is a comprehensive review of the current status of the upgrade of the APE 1236 furnaces and Explosive Waste Incinerators (EWI) to meet the RCRA regulations. It includes a description of the equipment and the purpose of each component. It also contains an overview of permitting issues and the outlook for burning munitions in an environment of changing regulations.

INTRODUCTION

In 1978 Congress passed environmental legislation known as the Resource Conservation and Recovery Act or RCRA. This law regulates the processing, handling, transportation, storage and disposal of hazardous waste. The APE 1236 furnaces are used to dispose of class 1.1, 1.2, and 1.3 munitions which are classified as hazardous waste. The furnace must therefore be permitted as a hazardous waste incinerator when these types of munitions are burned.

BACKGROUND

A project was initiated in 1987 to upgrade the APE 1236 furnaces to comply with RCRA standards for burning hazardous waste. The project included design, purchase, and installation of equipment which would bring the furnaces into compliance with RCRA hazardous waste incineration (HWI) regulations so a RCRA part B permit could be obtained. The part B permit defines the conditions under which the sites will be permitted to operate.

PROJECT STATUS

The original APE 1236 furnace consists of a rotary retort 20 feet long and 3 feet in diameter made up of 4 sections, each 5 feet in length. The two end sections are made of cast steel 2-3/4 inches in thickness and the two center sections are 3-1/2 inches in thickness. The sections have an internal spiral flight which is an integral part of the casting that pushes the material being burned through the furnace as the retort sections rotate. The flights vary in height with the highest section in the middle, tapering down toward both ends. The flights also separate munitions to prevent propagation between items on opposite sides of the flights, and help reduce the pressure waves caused by a detonation.

The upgrade of the furnaces required several major additions to the existing system. Under RCRA requirements the stack emissions must be sampled to demonstrate that 99.99% of the principal organic hazardous constituents (POHCs) are destroyed by the system. The system must monitor the stack emissions to verify compliance with the POHC limits on a continuous basis. The data from the continuous monitoring of CO and O2 is also used to control the system by reducing or stopping feed if preset limits are reached. A system to control the feed rate to the furnace is required which will prevent exceeding the feed rates set in the Part B permit and which will stop feed to the incinerator should an upset condition or equipment failure occur. The particulate discharge to the atmosphere can not exceed .08 grains per cubic foot. The equipment includes a shroud over the retort and feed conveyors to contain fugitive emissions so there are no uncontrolled discharges to the atmosphere. The control system compares all sensor generated data with established limits and controls temperatures, pressures and feed rates to maintain compliance with the permit conditions.

To comply with the requirement for destruction of hazardous constituents an afterburner was added as a secondary combustion chamber to complete combustion. This system has the capability to elevate the temperature of the exhaust gas from 450o F to 2000o F. The minimum residence time in the afterburner is 1 second at 1800o F. The operating temperature of the system to achieve complete combustion will generally be 1200o F to 1400o F except when higher temperatures are needed to destroy more problematic organics. At these temperature all hazardous material should be destroyed to the 99.99% or higher level.

To reduce the exhaust gas temperatures, protect the baghouse and prevent fires caused by the elevated temperatures two air-to-air heat exchangers or gas coolers were installed in the system. The largest of these units can cool the exhaust gas from 2000o F to 850o F. The second unit cools the air from 850o F to 350o F. Additional cooling occurs in the ducting between equipment so that the temperature entering the baghouse is between 250o F and 300o F.

The existing APE 1236 furnace includes a baghouse and cyclone. The cyclone is used to remove large particles. The baghouse, which is either a 100 or 144 bag unit, provides fine particle filtration of the exhaust gas. These pieces of equipment are used to comply with the requirement for particulate discharge to the atmosphere.

The ducting connecting the baghouse to the exhaust stack includes a bypass. The bypass is used during start up to allow the system to reach the preset operating temperature before the exhaust gas is sent through the baghouse. This is required to prevent condensation on the baghouse which reduces the efficiency and effectiveness of the filters.

The draft fan was increased from a 30 hp to a 50 hp unit capable of producing 6700 scfm at 30 inches of water column. The fan size was increased to account for the additional pressure losses in the system resulting from the afterburner, gas coolers and shrouding around the furnace and feed end conveyor.

A Beckman gas monitoring unit was purchased which measures the level of CO and O2 in the stack emissions. The CO level is used as an indicator of complete combustion. CO is used due to the extreme difficulty in measuring the actual level of hazardous material in the exhaust. The allowable limit for CO is 100 parts per million measured as a 1 hour rolling average updated every minute. The previous 59 readings are added to the current reading, averaged and value used to determine the CO level. The O2 is used to indicate if dilution air is being added to the system. The CO level is corrected to 7% O2 dry measurement.

A stack velocity measurement device is included in the controls to record the velocity of the exhaust gas up the stack. This equipment measures pressure and temperature and provides to the computer the data needed to calculate the stack gas velocity.

To prevent exceeding the feed rates for a particular munition a waste feed rate monitoring system was installed in the control room. This is a unit incorporating an explosion proof scale upon which every item to be fed to the furnace is placed. The item or items are weighed and compared to a data table which contains the permissible weight of that item per unit of time. If the weight is equal to or less than the allowable limit the item is loaded to the feed conveyor. If the limit is exceeded the operator must remove units until the weight is below the allowable limit. If a problem with the operation of the system occurs, such as failure of a component or exceeding the emission limits, the feed conveyor stops and the waste feed rate monitor prevents feeding of additional items to the furnace until the problem is corrected.

A dual conveyor arrangement was installed in the system at the direction of the EPA. In discussions with the EPA the decision was made that emptying the feed conveyor in an upset condition before correcting the problem was environmentally unacceptable. On the other hand, it was considered to unsafe to stop the conveyor with munitions on it since munitions may be stopped at the entrance to the incinerator feed chute where they could be heated to the point of burning or detonating outside the confinement of the retort sections. The dual conveyor arrangement allows stopping feed to the furnace except for the items which are on the short conveyor. The short conveyor will continue to run and load these items into the furnace to prevent an unsafe situation.

The retort and feed conveyors are shrouded to control fugitive emissions which occur when the pressure inside the furnace goes positive. This happens when a munition detonates or the feed rate exceeds the capacity of the furnace. The shrouds capture these emissions until the balance in the retort is restored and the emissions can be pulled back into the furnace.

The last major component installed in the upgraded system is a new control system. The control system consists of a Honeywell PLC which controls operation of the equipment, an IBM computer which houses the data base for the munitions, records the data from the system sensors and provides an interface to the data recording devices, which are a strip chart recorder and printer. A color monitor allows the operator to interface with the computer and visually observe the condition of the system during operation.

The control system provides both automatic and manual start up capability as well as local start up of components for maintenance. The lights on the control panel indicate the current status of system components and alarm lights if a problem should occur. By observing the control panel, the operator has the ability to determine the status of the system and detect any problems that may exist.

A typical operation would be as follows. The operator enters the munition identification code for the item to be processed. The code is compared to the information stored in the data base and a screen shows the operator which item has been identified and the operating parameters for that item. The operator then verifies that the correct munition has been selected. The operator then pushes the green system start button and the PLC automatically starts the equipment in the programmed sequence. Information such as temperatures, rotation speed, pressures and other system information is sent to the controlling devices. The system continues through start up until all preset operating conditions are met and the operator is then permitted to start feed to the furnace. At the end of the day the operator simply pushes the stop button and the system is shut down in the programmed sequence.

Problems with the project include defining the munitions which will be included in the data base. Each site processes some but rarely all of the approved feed list items and many sites have a unique item or two. In addition, the regulations are constantly being updated. What may have achieved compliance when the project started may not meet existing standards when the system is put into operation. For example, regulations determining what constitutes a hazardous waste are being constantly changed and class 1.4 munitions which were not classified as hazardous waste may soon be. The particulate standards have been revised and a new limit will soon go into effect.

States are allowed to set their own standards and the standards and interpretation of standards are not consistent state to state. For example, some states allow the upgrade without an approved permit while other states will not allow construction without a permit in place. All this creates a climate in which determining exact design requirements is very difficult. The decision was made early in the project to make all systems the same initially and to make modifications as required by particular site problems.

The final issue is the part B permit. This permit, which allows the furnace to be used as a hazardous waste incinerator, is issued to the site by the state or federal EPA depending on who has primacy. The permit sets forth the conditions which must be met to comply with environmental regulations. The Code of Federal Regulations or CFR 40, which is the controlling document for hazardous waste, also includes "omnibus authority". This permits the regulators to implement any policy which they feel is necessary to protect the health and safety of the environment. This is in effect an open ended authority to develop any policies and regulations, in addition to those specifically listed in RCRA, which the regulator feels are necessary.

Much of the permit focuses on records for the material which is processed in the furnace. Much of the data needed for the record keeping requirements is logged by the control system and will be used to demonstrate compliance with the permit standards. This data includes operating parameters, feed rates and logging any upset conditions which occur.

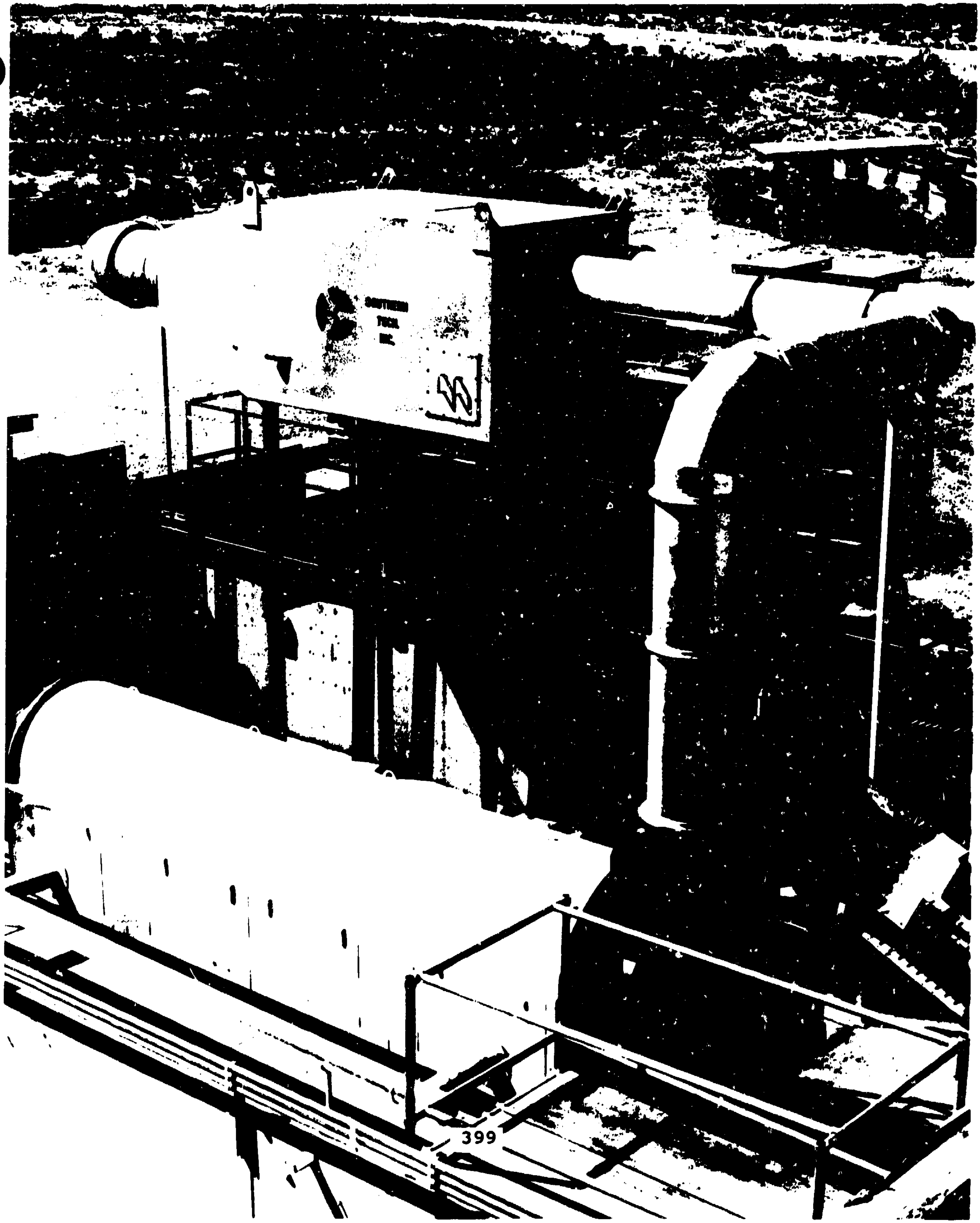
Trial burns to measure the level of pollution during furnace operation are being scheduled for the sites . The trial burn is used to demonstrate that the furnace can achieve the destruction of hazardous waste and protect the environment. The data obtained during the trial burn will be used by the state to determine and set forth the permit conditions under which the furnace must be operated.

In conclusion, the upgrade is currently proceeding on 9 sites with the specification for 4 additional sites being prepared and other sites are under review. The project has gone well in most cases. There have been some design changes which are being incorporated at all sites. The equipment has been operated successfully at Tooele, Iowa, and Lake City. There is still some work to be done to complete the systems and pass a trail burn. Several sites should be complete in the near future. Compliance with environmental regulations is a priority and this system upgrade will bring the furnaces in line with the standards in effect today.

Incineration of munitions appears to be the acceptable method of the future. Open burn / open detonation is being more severely restricted all the time and may soon be outlawed. In this light the furnaces will provide the only approved method of disposing of munitions.

Difficulties will occur in complying with regulations. The regulations will become more restrictive and harder to achieve. There will be an increase in the types of items which will be regulated and the record keeping to needed to satisfy the regulators that environmental laws are being observed. There will be an increase in the requirements to demonstrate that burning munitions is environmentally safe. Waste characterization will be an increasing burden as the restricted items list grows. The characterization of munitions is very time consuming and expensive. It took nearly 8 years to characterize the explosives and propellants now listed in the permit applications. No serious work has been done on characterizing the metal components of munitions. This may well become the next major problem facing the sites which incinerate munitions due to the difficulty in defining the exact make up of the metal components.

It appears that future disposal of munitions will produce many challenges and provide opportunity to develop new methods and technology for safe and environmentally sound disposal of these items.

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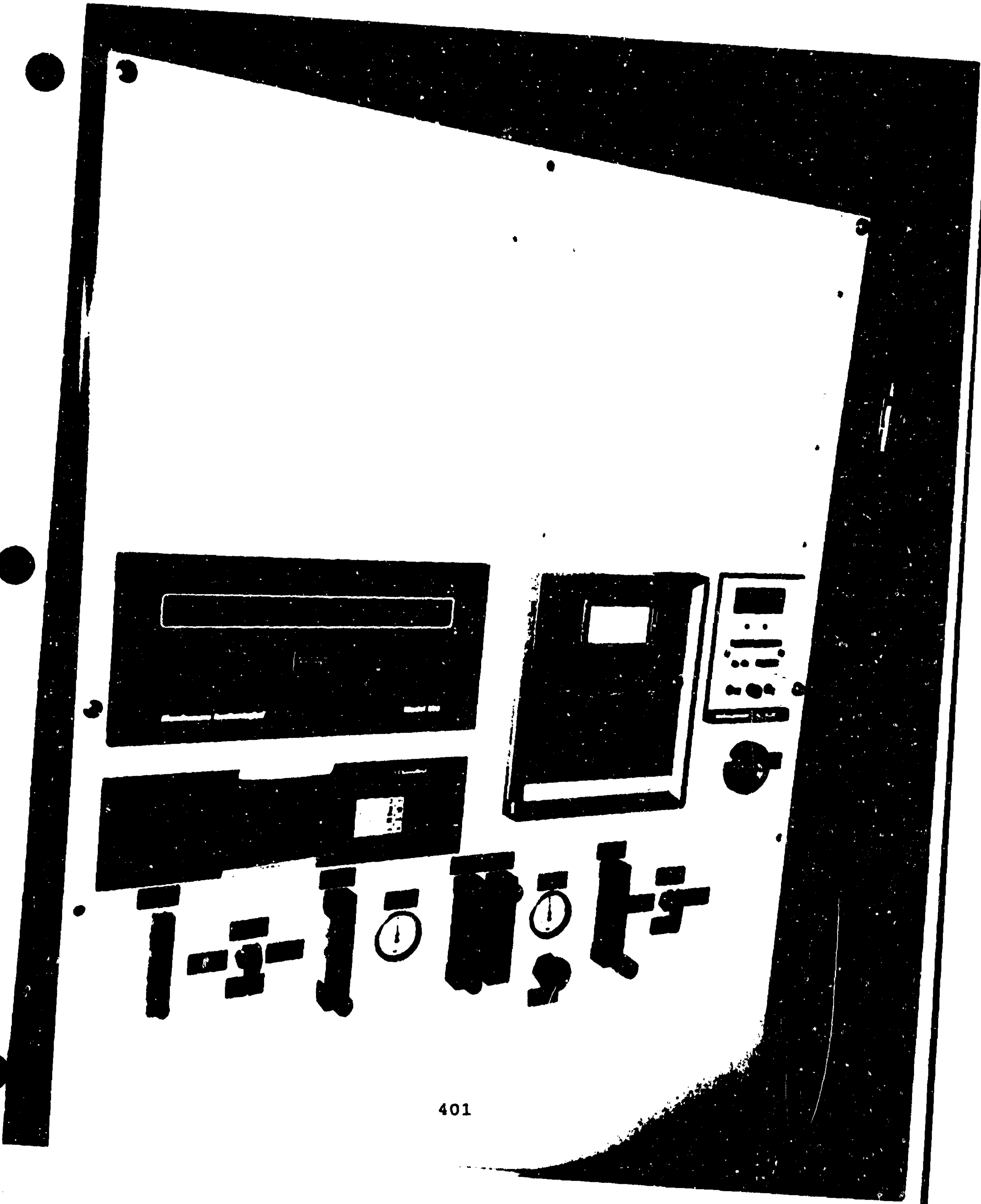

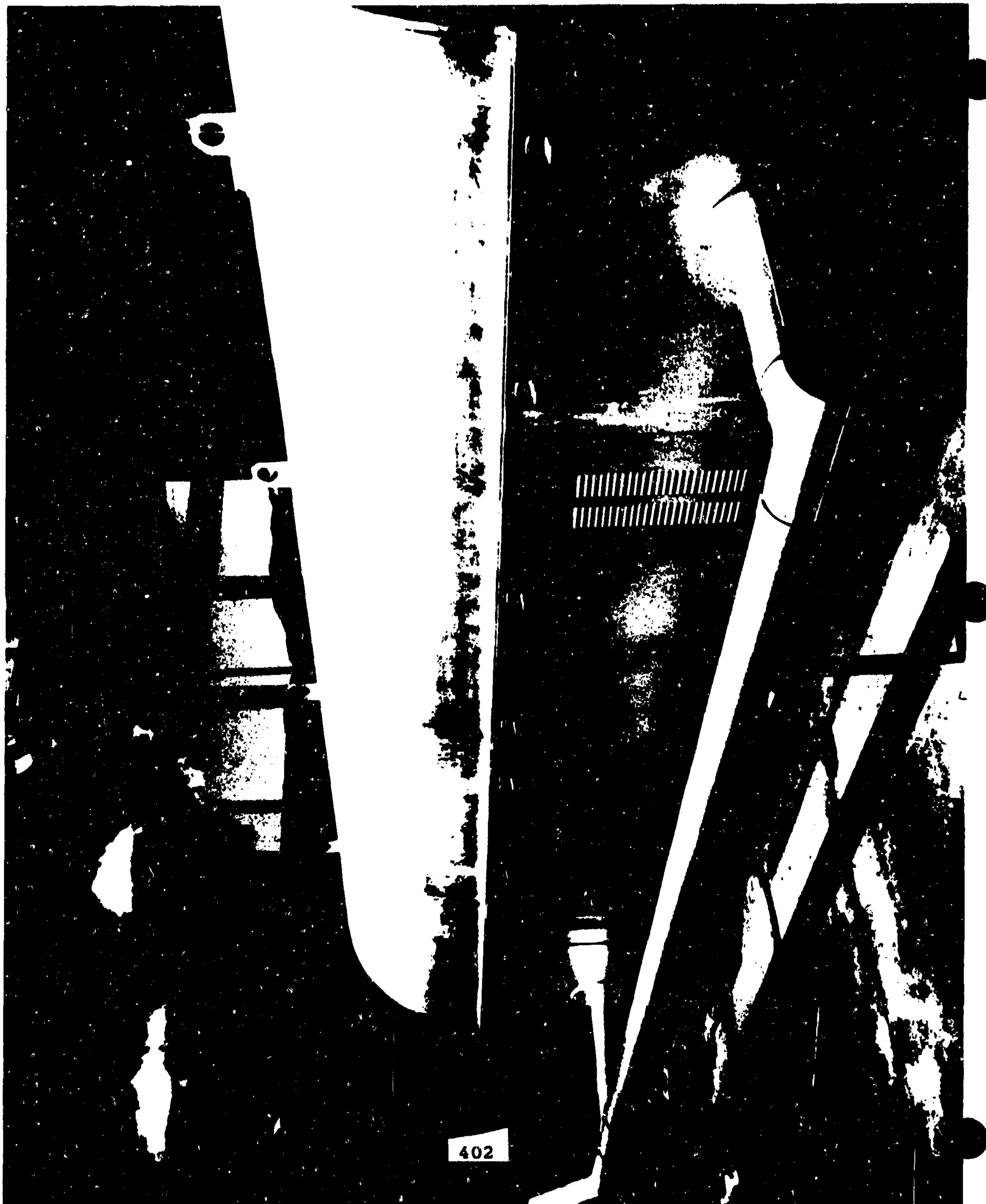
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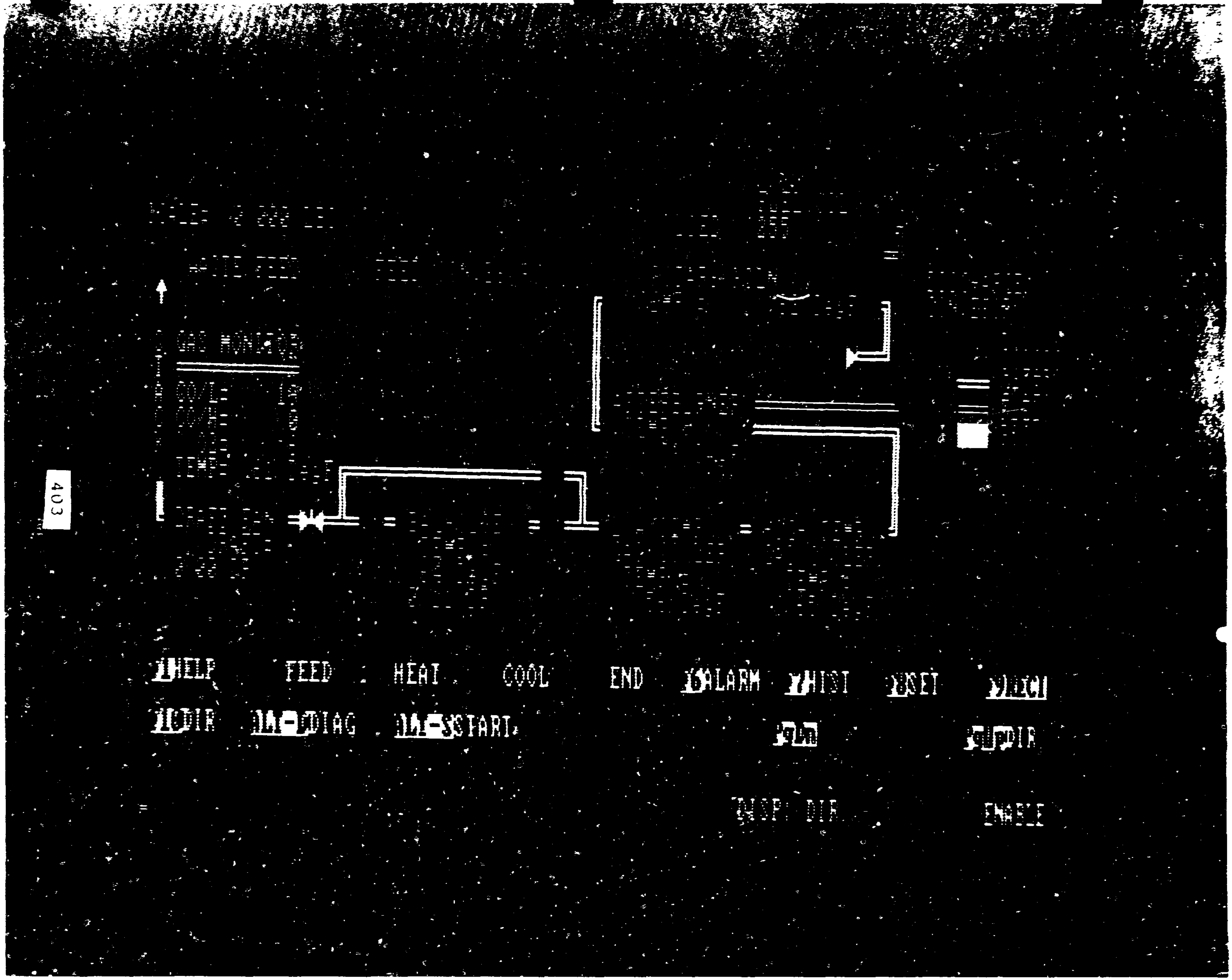
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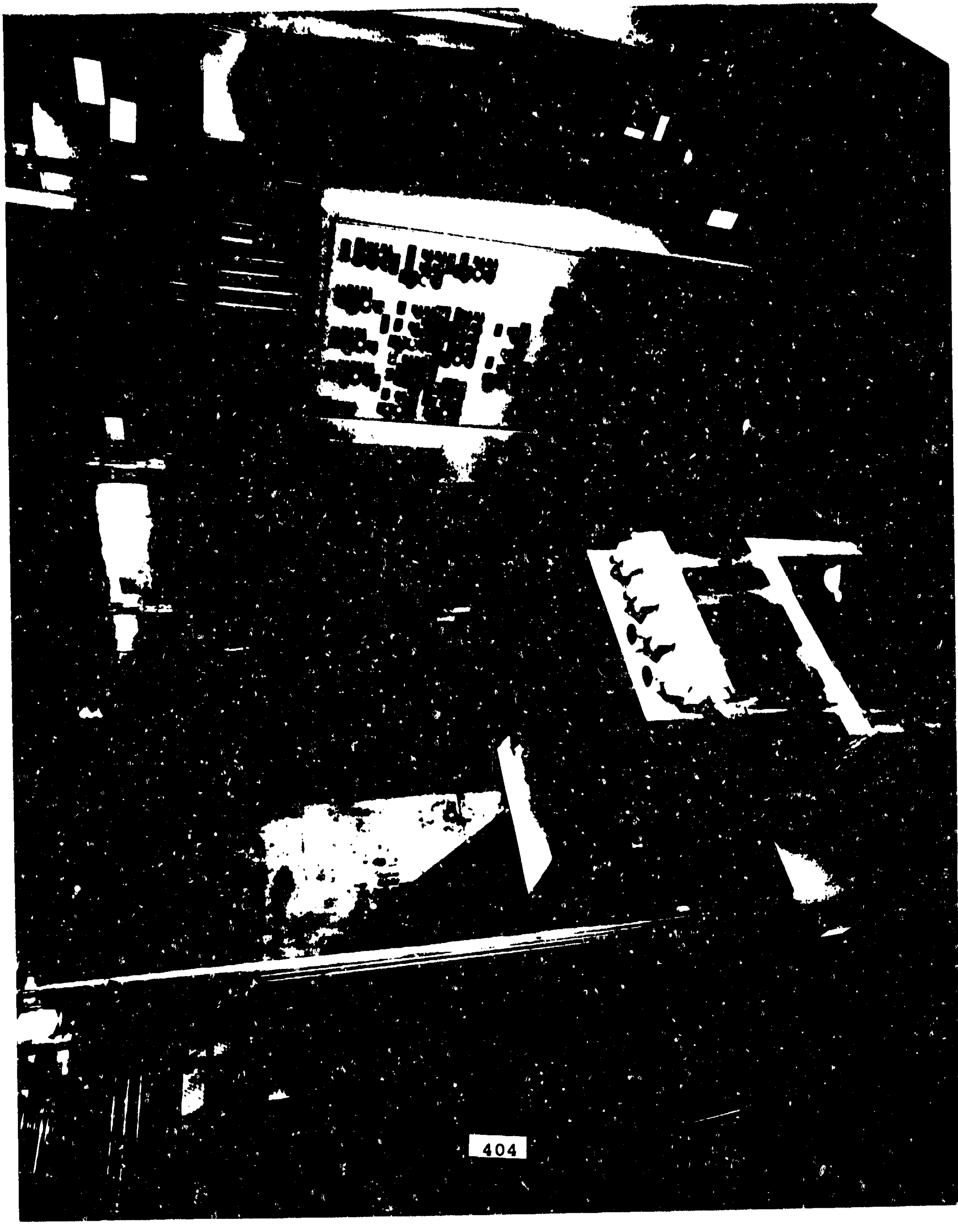


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TEST & EVALUATION OF VARIOUS DESIGNS OF BURNING TRAYS FOR OPEN BURNING OF PROPELLANTS AND EXPLOSIVES

DANIEL B. HILL
MARTIN BARTH
Ammunition Equipment Directorate
Tooele Army Depot

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ABSTRACT

Several designs of burning trays have been tested to evaluate adequacy for use in open burning of explosives and/or propellants. Purpose of the test program is to develop a standard design of burning trays to be used in lieu of burning waste or obsolete explosives and propellants on the ground. Eight different designs of trays and liners had been tested at the time of preparation of this paper.

TEST & EVALUATION OF VARIOUS DESIGNS OF BURNING TRAYS FOR OPEN BURNING OF PROPELLANTS AND EXPLOSIVES

INTRODUCTION

In response to a requirement to eliminate open burning of waste and obsolete propellants and explosives on ground surfaces as has been historic practice at DOD installations manufacturing and/or storing those materials, a project was initiated through AMCCOM's Ammunition Peculiar Equipment (APE) program to evaluate a variety of burning tray designs. Eight different designs were tested by burning TNT and/or M26 propellant. The designs included different steel tray configurations, and various types of liners; e.g., clay, firebrick, and castable refractories.

The Ammunition Equipment Directorate (AED) at Tooele Army Depot, Utah, and the U.S. Army Defense Ammunition Center and School (USADACS) at Savanna Depot Activity, Illinois, collaborated on the designs; and the AED fabricated the trays and conducted the testing. The design and test program has been lengthy, with tests being conducted in mid 1985, June 1986, and in mid 1989. The tests are reported in AED Reports 03-86[1], 10-86[2], and 20-89[3]

Summary of Testing

Eight different designs of trays, including different combinations of trays and liners, were fabricated and tested at Tooele. A summary of tray and liner designs is given in Table 1 which also includes a summary of material burned to test the trays. In addition to the controlled testing conducted by AED, some disposal operations were conducted by Tooele's Ammunition Mission Division in which six burns of approximately 300 pounds each burn were made in each of two burn trays; the fire brick lined tray and the 4' x 8' castable refractory lined tray.

The propellant used in the first tests (Table 1) was a granular, multiperforated M26 double based recoilless rifle propellant. The TNT used in most of the tests was a flaked product of TNT washout operations, although a somewhat chunky, or cubed, configuration of TNT was used in some of the tests.

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[1] Barth, Martin, Evaluation of Open Burning Trays, March 1986

[2] Nordquist, Tyrone, Evaluation of Lined Open Burning Trays, September 1986

[3] Barth, Martin, Evaluation of Heavy Pan and Refractory Lined Burning Trays, November 1989

TABLE 1-SUMMARY OF TRAY DESIGNS

TRAY TYPES	LINER TYPES	MATERIAL/QUANTITY BURNED
Rectangular Box 4'W x 16'L x 1'D 1/4" thk A285 Grade C Steel	None	M26 Propellant, 2 tests @ 610 lbs ea Flaked TNT, 1 test @ 733 lb 1 test @ 255 lb *Dunnage, 25 ft^3 w/185 lb wet TNT 30 ft^3 w/155 lb wet propellant
Double-walled Rectangular Box Water-Jacketed 4'W x 16'L x 1'D	None	Flaked TNT, 1 test @ 83 lb 1 test @ 170 lb 1 test @ 255 lb
Rectangular Box 4'W x 8'L x 1'D 1/4" thick 1018 CR steel	Local soil mixed w/water, formed into 3" thick lining on bottom and at sides	Flaked TNT, 1 test @ 275 lb
Rectangular Box 4'W x 8'L x 1'D 1/4" thick 1018 CR steel	Local soil, dry, poured into tray to form 3" lining at bottom, tapered up sides	Flaked TNT, 2 tests @ 275 lb ea
Rectangular Box 4'W x 8'L x 1'D 1/4" thick 1018 CR steel	Fire bricks, 4 1/2" thick, on bottom and at sides	Flaked TNT, 1 test @ 220 lb 1 test @ 275 lb
Rectangular Box 4'W x 8'L x 1'D 1/4" thick 1018 CR steel	Castable refractory, 4 1/2" thick on bottom and at sides	Flaked TNT, 4 tests @ 275 lb ea
Rectangular Pan 8'W x 20'L x 1' D 30° sloping sides 1" thick pressure vessel steel	None	Cubed TNT, 2 tests @ 900 lb ea
Rectangular Box 5'W x 17'L x 1'D	Castable refractory	Cubed TNT, 2 tests @ 900 lb ea

*Dunnage Grate specially-designed to fit inside rectangular burn tray

TESTING

Preparations for all the tests were basically common in that in all cases the explosive or propellant was poured into the burn tray and leveled to a 1", 2", or 3" depth with a wooden screed. Thermocouples were attached to each tray at several locations to monitor temperatures. Each test burn was initiated with a rocket igniter and dry excelsior.

Unlined Steel Tray-This tray was a simple rectangular box with dimensions 4 ft. W x 16 ft. L x 1 ft. D. (Fig. 1). The tray was supported by 4" x 4" I-beams and attached at both ends with sliding tie down assemblies to allow for axial expansion and contraction. The tray was fabricated from 1/4" thick ASTM A285 Grade C steel. This tray had no liner material. It was tested with M26 propellant in 3" depths (2 tests at 610 lbs ea.), and TNT in 1" and 3" depths (255 and 733 lbs respectively). The propellant burned so rapidly (9 and 12 seconds) that high metal temperatures were not a factor and the tray was not damaged. The TNT, however, burned much more slowly (14 and 37 minutes) , producing significantly higher temperatures for a longer period of time. The extreme heating then cooling created by the moving combustion zone caused extensive warpage and melting of the tray (Fig. 2).

A dunnage grate, fabricated of 1" X 11 guage stainless steel square tubing (Fig. 3), was designed to fit into the rectangular tray and to be used to burn mixtures of either wet explosives or wet propellant with dunnage (wood, cardboard scrap). Tests were conducted with 185 lbs flaked TNT, 20% wt H_2O and 30 ft^3 dunnage; and 155 lbs M26, 20% wt H_2O and 25 ft_3 dunnage. The burn times ranged from 1 to 1 1/2 hours. The dunnage grate performed well, sustaining no damage.

Waterjacketed Tray-This tray consisted of an outer shell and an inner trough supported by 2" square tubing (Fig. 4). The tray was designed to hold approximately 60 gallons of water between the shell and trough. Vents were cut into the upper outer shell walls. The tray was tested with flaked TNT in 1", 2", and 3" depths (83, 170 and 255 lbs respectively). Burn times were 6, 13 1/2 and 13 1/2 minutes. The tray design performed well for burning TNT, and should do as well for propellant. The water jacket worked well in moderating tray wall temperatures, but the tray was also slower to cool down after burning. The only damage sustained by the tray was mild warpage of the upper edge around the vent openings, which were above and furthest removed from the water jacket. No steam or boiling of cooling water was observed during the tests; however, there may be a potential problem of water being contaminated with explosive or propellant.

Steel Tray, Wet Local Soil-The basic tray was a rectangular steel box 4 ft. W x 8 ft. L x 1 ft. D, fabricated from 1/4" thick cold rolled steel plate. The tray was lined with a mix of local soil and water which was poured into a form, making a 3" thick lining on the bottom and at the side walls of the tray (Fig. 5). The tray was tested once with flaked TNT, 3" deep (275 lbs). The burn time was 9 1/2 minutes. Although the poured soil lining proved to be a fair insulator, preventing extreme heat at the steel walls, some minor warpage was observed. The use of local soil as a liner, however, is impractical because the lining cracks badly on drying, creating pockets for contamination by explosive.

Steel Tray, Dry Local Soil-Again, the basic tray was a rectangular steel box 4 ft. W x 8 ft. L x 1 ft. D, fabricated from 1/4" thick cold rolled steel plate. This tray was lined with a dry local soil which was poured into the tray to a depth of 3" on the bottom with the side walls tapering up to the top edge of the tray (Fig. 6). The tray was tested with flaked TNT at depths of 3" (2 tests at 275 lbs ea). Burn times were 6 and 8 minutes. The soil lining worked well as an insulator, preventing damaging temperatures from reaching the steel side walls; however, saturation of explosive into the soil was observed to be to a depth of one quarter inch after only two tests.

Steel Tray, Fire Brick Lined-The basic tray was lined with a standard commercial fire brick forming a lining 4 1\2" thick on the bottom and at the sides of the tray (Fig. 7). Stainless steel refractory anchors were welded to the steel tray sides and bottom to provide better holding and to minimize cracking of the bricks. The tray was tested once with flaked TNT 3" deep (220 lbs), and once with 3 1/2" depth (275 lbs). The first burn lasted 16 minutes, while the second lasted 9 minutes. No tray warpage was observed; however, the refractory mortar between the bricks showed signs of cracking, casting doubt on its'longevity. The fire brick provided good insulation for the steel tray, but also retained the residual heat for long periods of time.

Steel Tray (small), Refractory Lined-The basic tray was lined with a castable refractory recommended for use to 2550° F. The refractory was poured to a thickness of 4 1/2" on the bottom and the sides of the tray (Fig. 8). Stainless steel refractory anchors were also used. The tray was tested 4 times with flaked TNT 3" deep (275 lbs each test). Burn times ranged from 7 to 12 minutes. The refractory lining appeared to be the most durable of the four linings tested in the small steel tray (4' x 8' x 1'); and the most feasible for installation. It provided excellent insulation for the metal tray and dissipated heat rapidly. No tray warpage nor deterioration of the refractory was observed.

Heavy Steel Rectangular Pan-The heavy pan tray measured 8' W x 20' L x 1'D overall, and was fabricated from 1" thick steel. All four sides sloped inwardly 30° (Fig. 9). The tray was supported on an I-beam frame with sliding gussets to support the tray and to allow for expansion. The tray weighed approximately 7000 lbs. It was unlined. TNT in chunky form (referred to as cubed) was burned in both tests with this pan. The TNT was spread to a depth of 4 1/2" (900 lbs each test). Burn times ranged from 8 to 10 minutes. The two tests had no adverse impact on the tray. Further testing is needed to evaluate this tray design. The tray has since been shipped to Sierra Army Depot and will be used to burn rocket propellants. Data will be collected from those burns.

Steel Tray (large) Refractory Lined-This tray was a simple rectangular box 5 ft. W x 17 ft. L x 1 ft. D, fabricated from

1/4" thick mild steel. The tray was lined with a castable refractory suitable for service to 2900 F (Fig. 10). The refractory was reinforced with stainless steel needles. Rod type alloy anchors were installed to hold the liner to the tray. Two tests were conducted with 4 1/2" depth of cubed TNT. The burn times ranged from nearly 7 minutes to 11 minutes. Although the steel tray sustained no damage, the refractory sustained significant damage in the form of spalling. Some pieces up to 15 in^2 in area and 1/4" thick came off; and some cracking was observed.

Temperature Data

In all tests, a minimum of ten thermocouples were attached at various location to the exterior of the steel burning tray. Obviously, given the number of designs tested and the multiple tests conducted on each, there is too much data to present in this paper. However, some examples of temperature curves are presented in Figures 12 through 15. Figure 11 illustrates thermocouple locations on three tray designs. In Fig. 12, the curves reflect the instantaneous climb to peak temperatures resulting from burning the M26 propellant, and then the relatively slow dissipation of heat in the 1/4" thick steel tray. Fig. 13, however, shows the slower climb to much higher temperatures resulting from burning TNT; and the retention of heat in the tray. The heavy steel tray temperatures, Fig. 14, show a significant reduction in the peaks measured at the exterior of the 1" thick tray walls from those seen in Fig. 13 for the 1/4" tray. It is not yet known how much of that difference can be attributed to the different TNT configurations (small flaked TNT in the 1/4" tray, thicker cubed TNT in the 1" tray). Fig. 15 gives the temperature curves for the large refractory-lined tray. The curves show the effectiveness of the refractory lining in reducing heat transfer to the steel tray.

OBSERVATIONS

The minimal testing done with the M26 propellant gave encouraging results in that the combustion occurred so rapidly that the temperatures throughout the metal trays never got high enough to be damaging. Considerable work needs to be done with other propellants and in other forms in order to adequatelly evaluate tray designs.

The slower burning TNT resulted in significantly higher temperatures throughout the various tray designs, causing warpage which, in some cases, was unacceptable. Similar results would be expected with other types of explosives. Some of the liner materials were effective in dissipating the heat transfer to the metal tray. Problems were encountered, or can be expected, with the various liners in cracking and/or spalling, leaving pockets for explosive or propellant residues. Further, life expectancy is suspect, given the extreme cyclic nature of the operations.

When burning the M26 propellant, much propellant was ejected from the tray. Similar problems can be expected with other granular propellants. Methods for controlling this ejection must be developed.

Tray covers were fabricated for some of the trays tested; however, an adequate means of securing them to the tray was not considered. Covers are important to prevent rain from entering the tray and washing explosive contamination onto the ground, or to prevent water from getting into cracks of liner materials (if used) and causing steam explosions, which were observed during the testing.

The thick steel pan-type tray tested appears to be very effective in that the thickness (1") worked well in dissipating the heat, with no warpage observed during testing. Further, the thicker material gave excellent structural rigidity to the tray design. This tray is currently being used on a production basis in rocket propellant disposal operations at Sierra Army Depot, California.

CONCLUSIONS

Use of liner materials appears to be a questionable design. All materials tested cracked to some extent. Some were effective in dissipating heat and protecting the basic steel tray, but the effectiveness is probably negated by short life expectancy and potential problems associated with explosive contamination within the cracks.

The thick steel tray appears most promising as a design, and should be tested further with propellants and explosives of different types.

Size of burning trays are probably restricted because of practicality; i.e., effective use of standard material sizes, cost-effective fabrication techniques, and in-field handling. Therefore, quantities of explosives or propellants that can be burned in any tray are limited to relatively small amounts. The simple economics are that disposal costs are going to be higher.

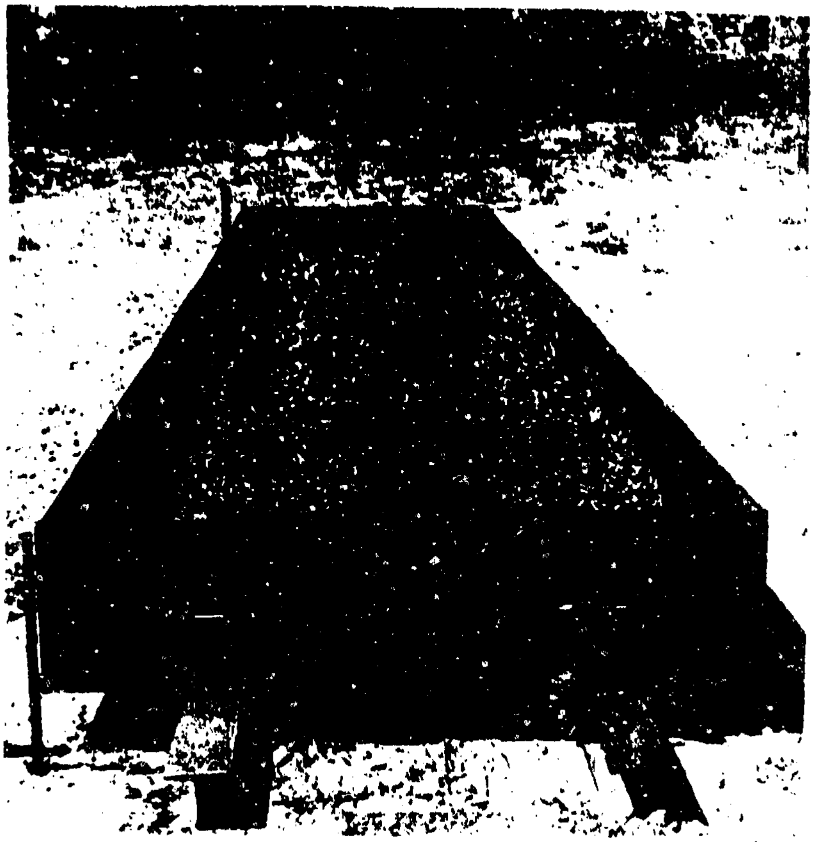


FIGURE 1

FIGURE 2

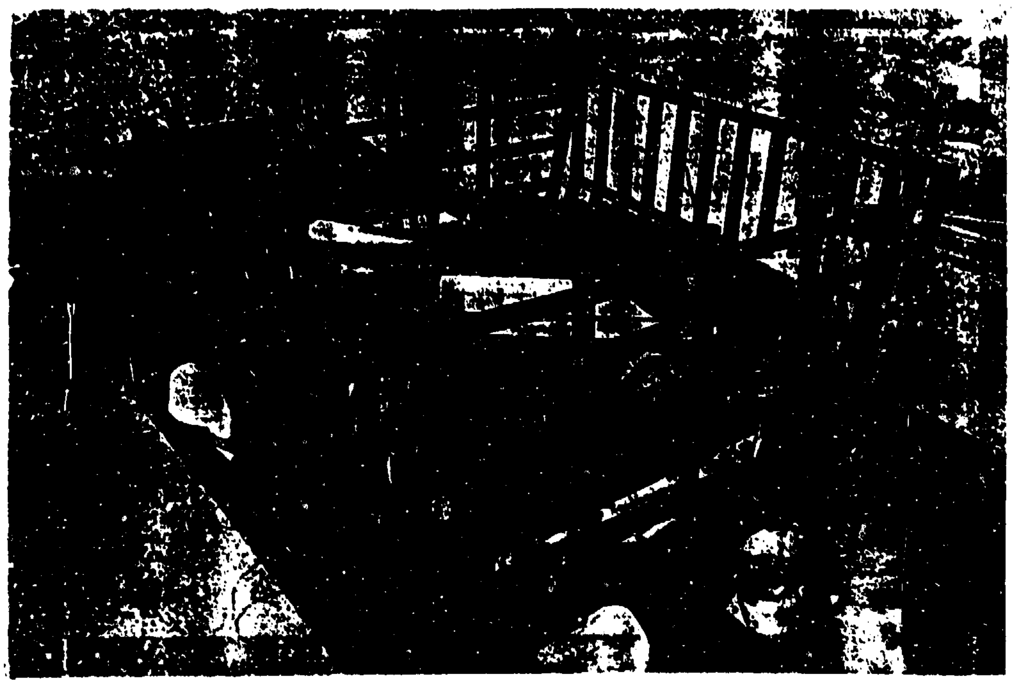
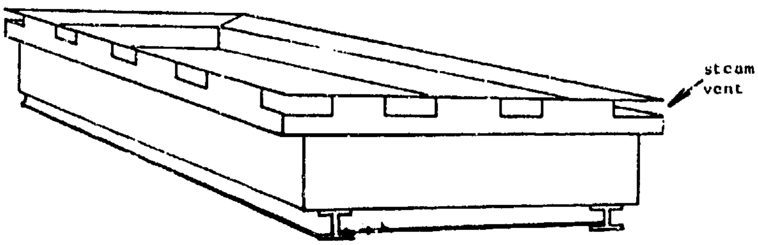
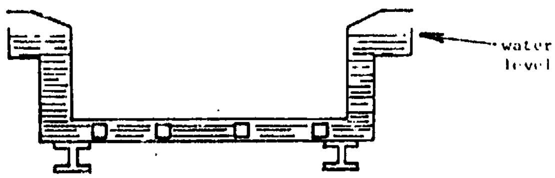


FIGURE 3



Water Jacketed Tray



Cross Section

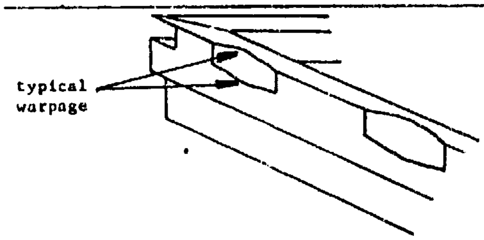
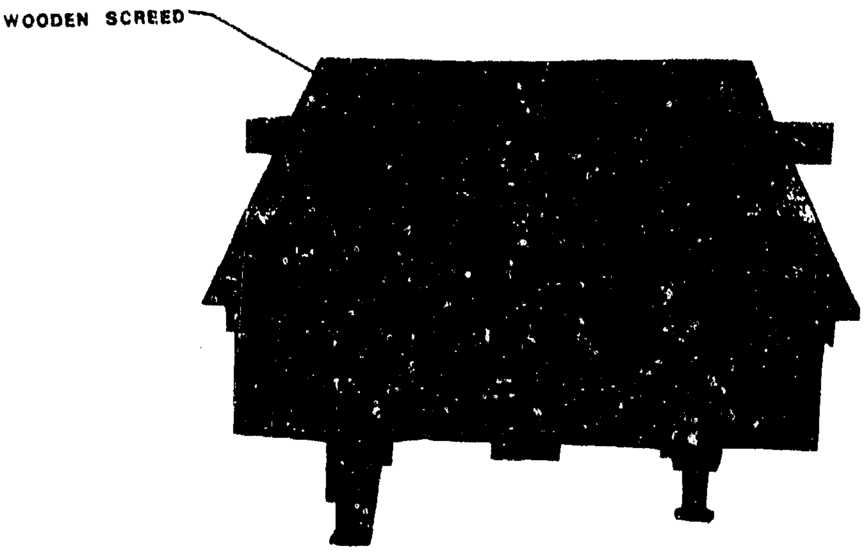
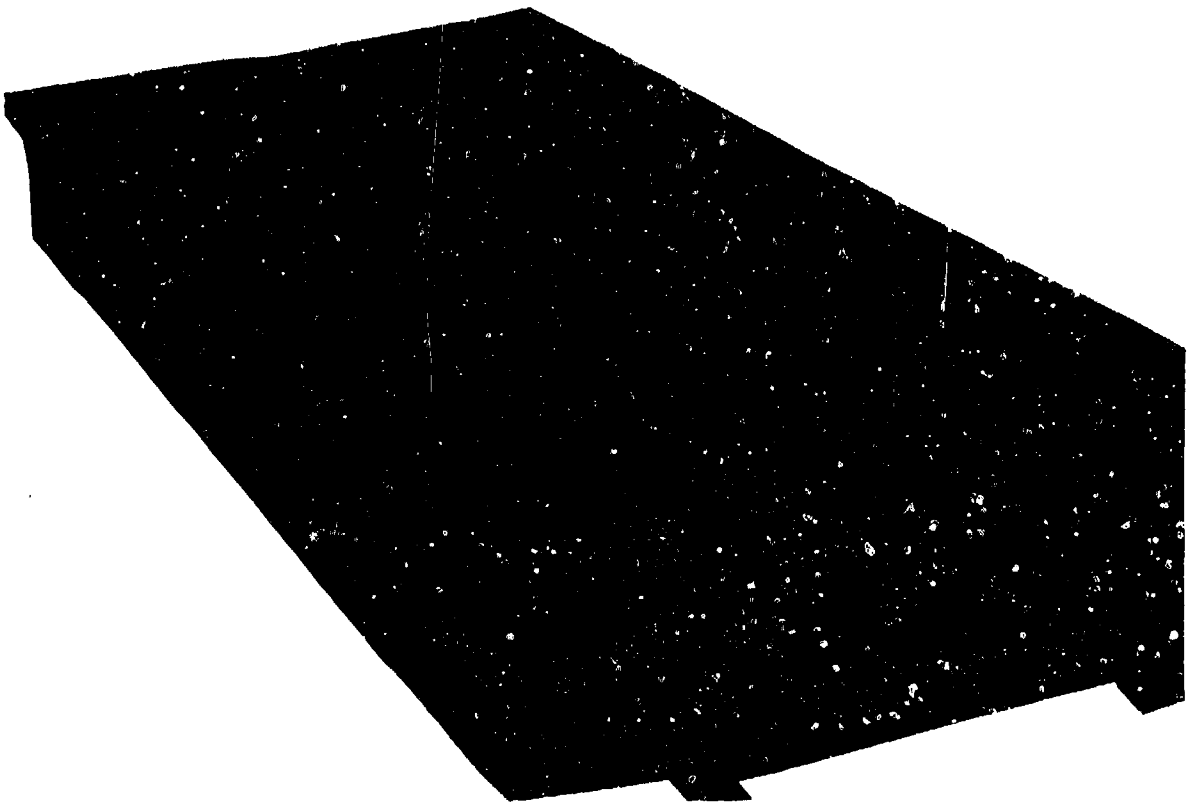


FIGURE 4



Soil Lined Tray (poured)

FIGURE 5

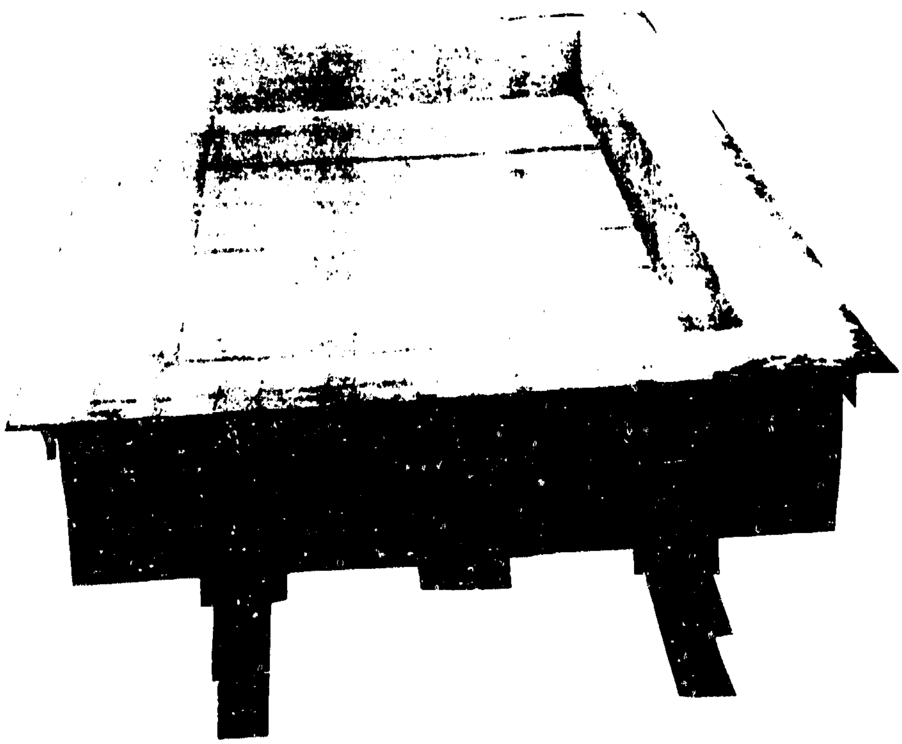


Soil Lined Tray (dry)

FIGURE 6

Brick Lined Tray

FIGURE 7



Refractory Lined Tray

FIGURE 8

FIGURE 9

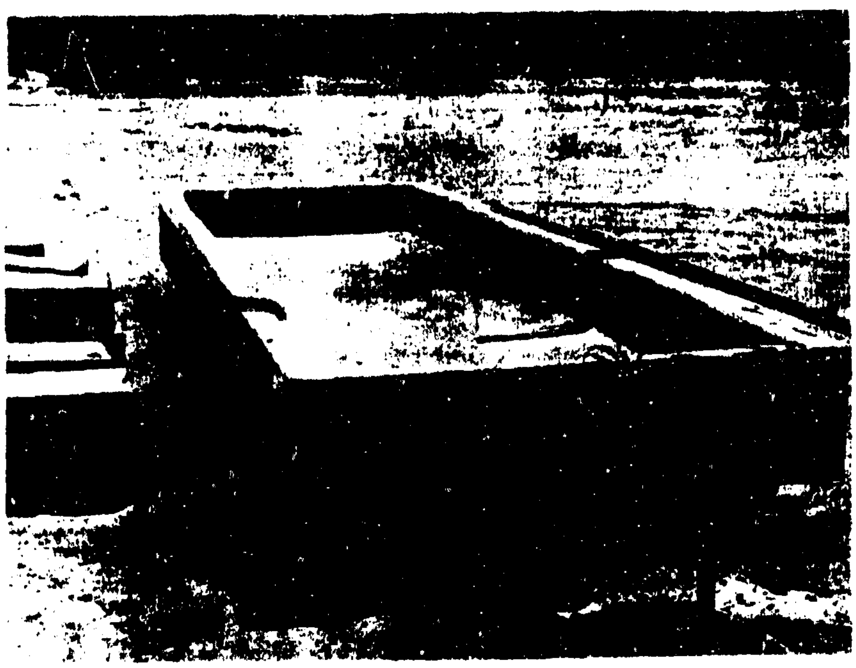
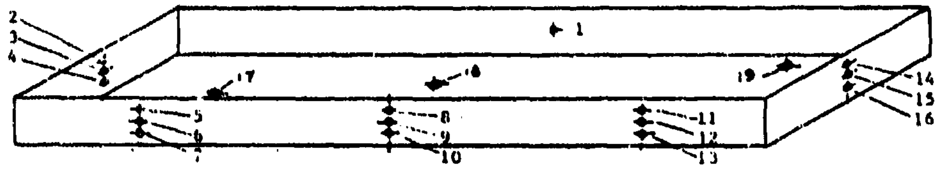
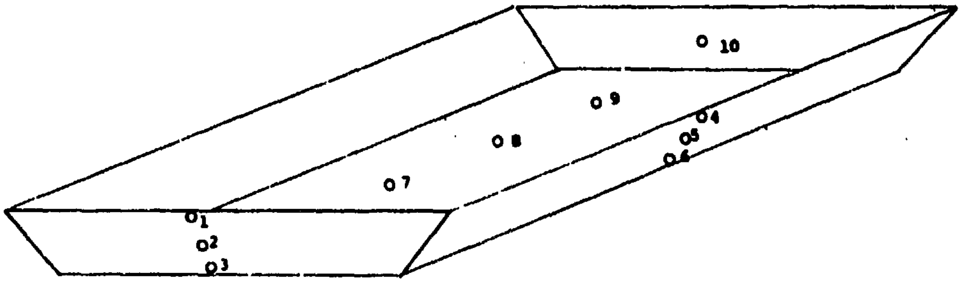


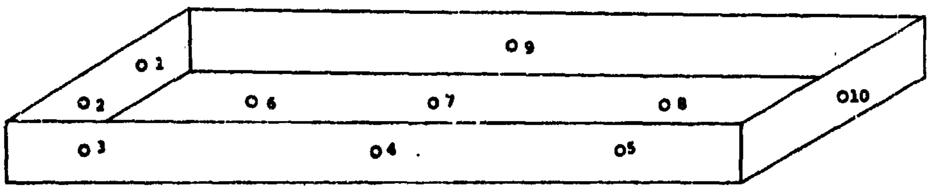
FIGURE 10



UNLINED STEEL TRAY



HEAVY STEEL PAN



LARGE REFRACTORY-LINED TRAY

FIGURE 11. THERMOCOUPLE LOCATIONS

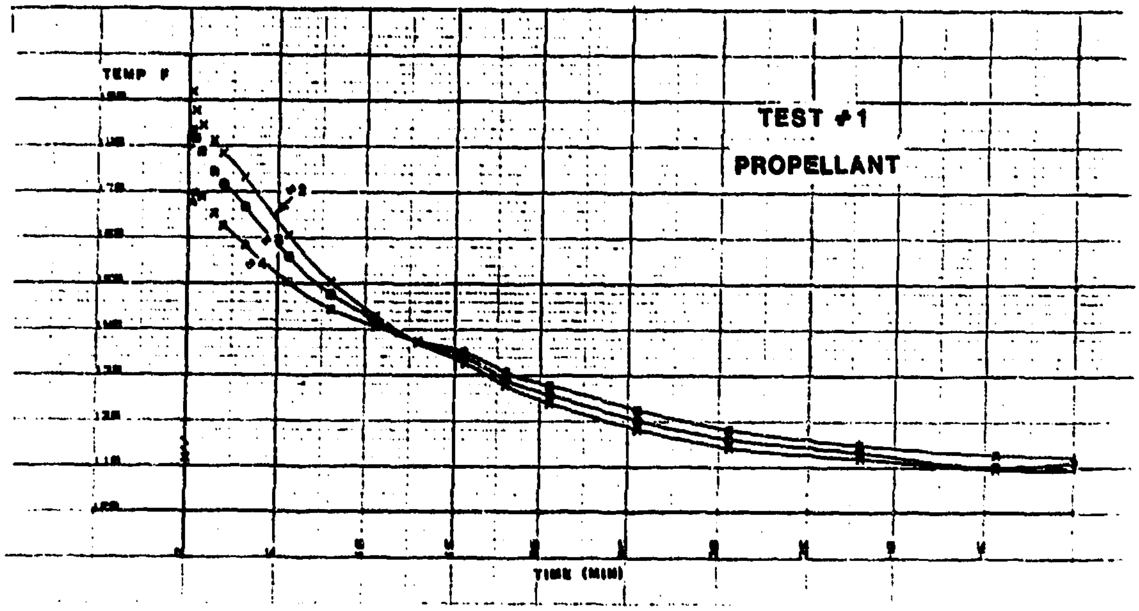


FIGURE 12. UNLINED STEEL TRAY

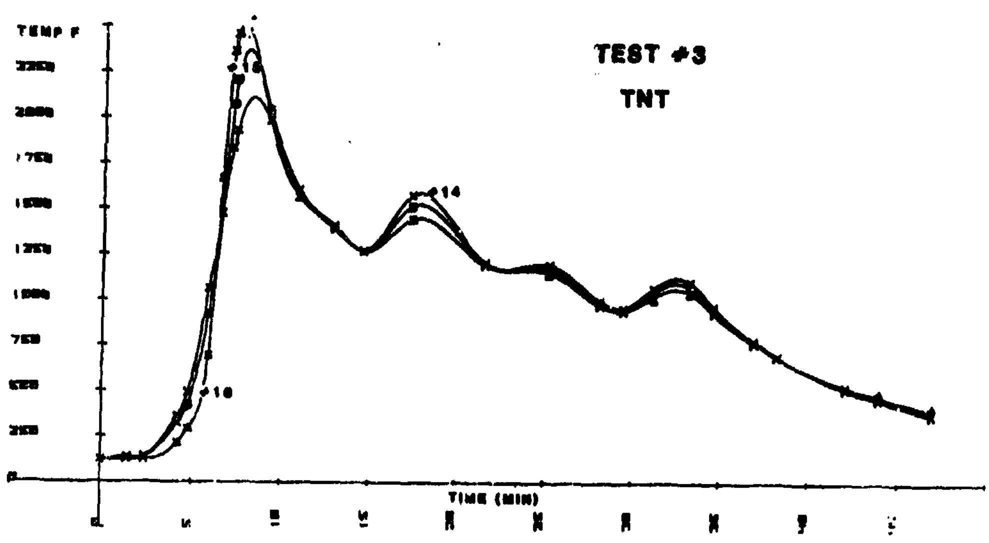


FIGURE 13. UNLINED STEEL TRAY

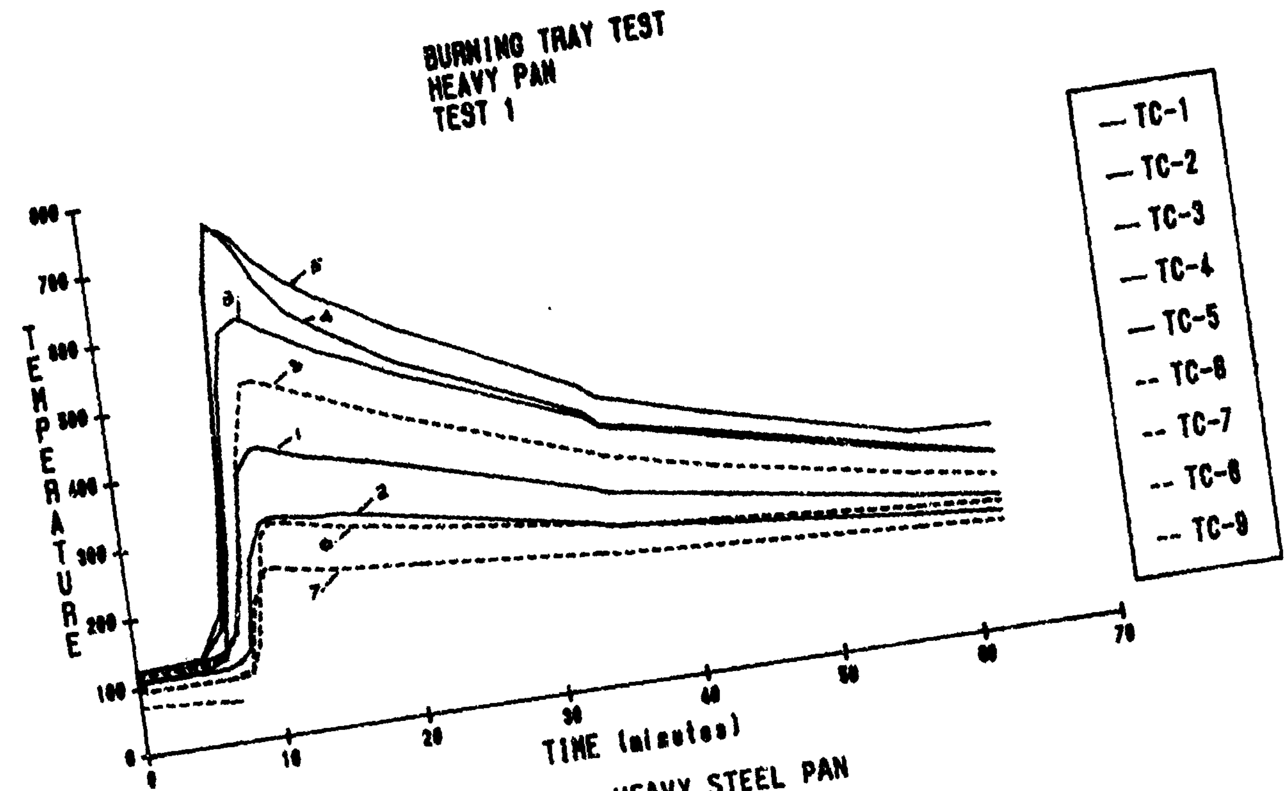


FIGURE 14. HEAVY STEEL PAN

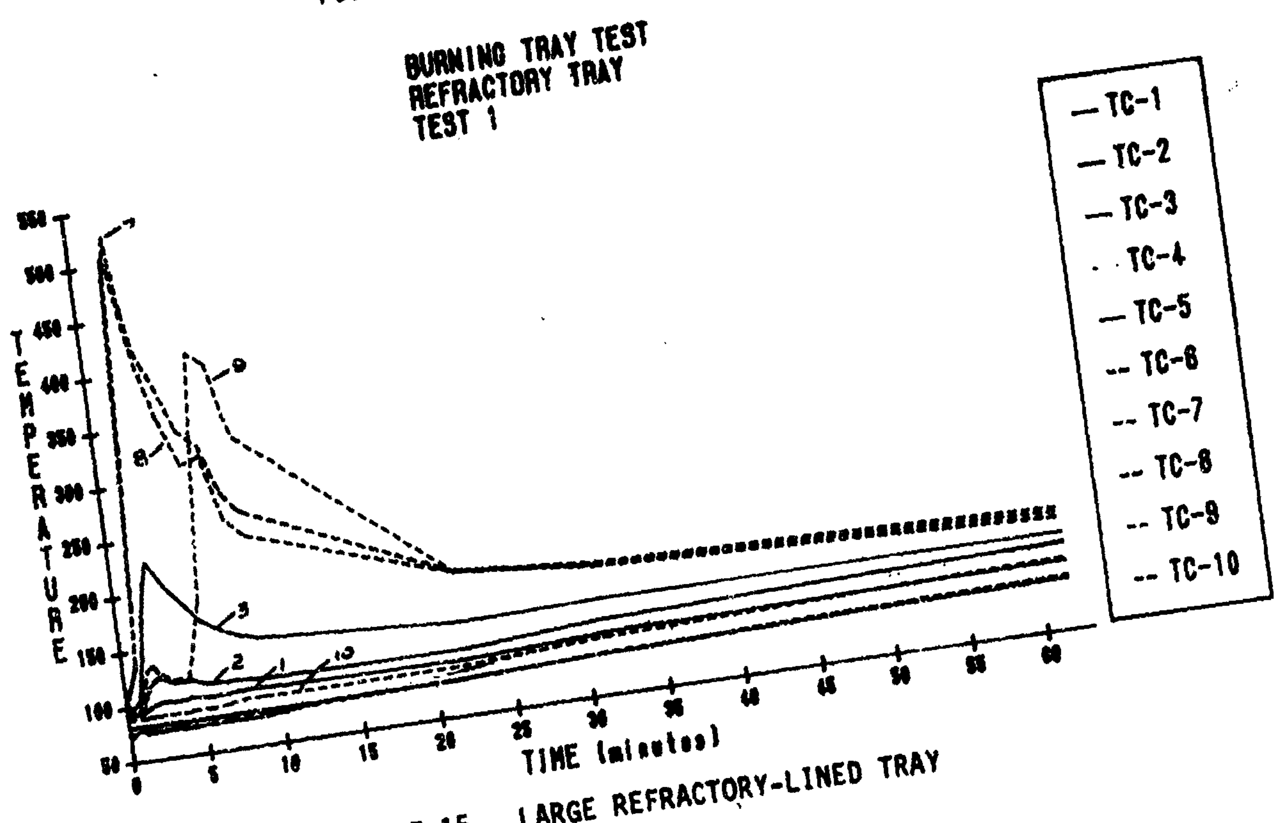


FIGURE 15. LARGE REFRACTORY-LINED TRAY

DEMILITARIZATION OF WHITE PHOSPHORUS MUNITIONS

Darrell R. Rainey
Industrial Operations Directorate
Crane Army Ammunition Activity, Crane, Indiana

Mark M. Zaugg
Ammunition Equipment Directorate
Tooele Army Depot, Tooele, Utah

Presented at the
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28-30 August 1990
Adam's Mark Hotel, St Louis, MO

ABSTRACT

This paper highlights one of the first resource recovery projects undertaken by the U.S. Army to meet the intent of the Resource Conservation and Recovery Act, which was the development and successful operation of a White Phosphorus to Phosphoric Acid Conversion Plant for disposal of white phosphorus filled munitions. Background for the plant development is presented, along with an operational history of the plant, and a description of the plant and how it operates.

INTRODUCTION

In August 1980, a moratorium on open burning of smoke munitions was issued by the Office of the Surgeon General of the Army, leaving the Army, as the single manager for conventional ammunition, the difficult problem of developing environmentally safe procedures for demilitarizing chemical smoke munitions.

BACKGROUND

Tests conducted by the Ammunition Equipment Directorate (AED), Tooele Army Depot, Tooele, Utah, showed that white phosphorus (WP) filled munitions could be burned in the Ammunition Peculiar Equipment (APE) 1236 Deactivation Furnace if the explosive components were removed and a hole was punched in the sidewall of the munitions. Since phosphoric acid is manufactured commercially by burning WP and scrubbing the resulting phosphorus pentoxide, AED engineers proposed adding a scrubbing system onto the furnace to produce acid from the burning of WP filled munitions. It was also proposed to make the scrubbing system mobile so that it could be transported to installations storing significant quantities of WP filled munitions and installed on their existing deactivation furnaces.

PROJECT ESTABLISHMENT

The Defense Ammunition Directorate, U.S. Armament, Munitions, and Chemical Command (AMCCOM), Rock Island, Illinois, evaluated the AED proposal against a proposal to recover WP from WP filled munitions, and determined that in either case, an incineration plant would be needed to decontaminate the emptied metal grenade and projectile bodies, and to dispose of WP contaminated water resulting from WP recovery operations. As a result AMCCOM funded AED in 1981 to develop a pilot process plant to incinerate white phosphorus (WP) filled munitions and convert the resulting phosphorus pentoxide to a saleable phosphoric acid. This project represented one of the first projects in the U.S. Army that was responsive to the constraints and intent of the Environmental Protection Agency (EPA) and the Resource Conservation and Recovery Act (RCRA). The resulting process involved the marriage of industrial acid conversion technology and processes to modified APE, and provided the capability of handling the wide variety of WP filled munitions, from grenades to 155 mm projectiles.

The original intent was to develop a White Phosphorus to Phosphoric Acid Conversion (WP/PAC) Plant that would be portable and could be transported to five locations where the majority of the WP munitions were stored. The five locations were: Ft. Wingate Depot Activity, Gallup, New Mexico; McAlester Army Ammunition Plant, McAlester, Oklahoma; Crane Army Ammunition Activity, Crane, Indiana; Letterkenny Army Depot, Chambersburg, Pennsylvania; and Hawthorne Army Ammunition Plant, Hawthorne, Nevada.

PILOT MODEL PLANT AT FWDA

The pilot model WP/PAC plant was assembled and tested at Ft. Wingate Depot Activity (FWDA). By early 1984, the plant had successfully processed 2,342 short tons of WP filled munitions, producing over 2.2 million pounds of 75% phosphoric acid and 1.9 million pounds of scrap steel from the munitions, both of which were sold on the open market.

PRODUCTION PLANT AT CAAA

Crane Army Ammunition Activity (CAAA), with the next largest inventory of WP munitions, and with its ammunition processing capabilities and expertise, was selected to be the next site for the WP/PAC Plant. Based on the operational experience gained at Ft. Wingate, it was determined that several upgrades to the system would be required to improve the operation of the system, increase the system availability and efficiency, and more fully automate the plant operational controls. All of this made the idea of portability less practical. Subsequently, the decision was made to locate the WP/PAC permanently at Crane AAA, and ship all WP munitions there to be processed for disposal. Upon completion of processing all WP assets at FWDA, the plant was decontaminated, disassembled, and moved to Crane AAA, where, through the efforts of AMCCOM headquarters, TEAD, and CAAA personnel, the plant was reassembled, and substantial modifications and improvements were made to the pilot plant equipment used at FWDA.

DESCRIPTION OF WP/PAC PLANT SYSTEM AND OPERATION

The WP/PAC Plant is designed to operate 24 hours a day, seven days a week. The operations to demilitarize WP munitions involve initial downloading of explosive components, such as fuzes, bursters, and propelling charges, from the munitions. The WP filled munitions, now without any explosive or propellant components, are delivered to the WP/PAC Plant where they are fed into a hydraulic press which punches a hole into the side wall of the munitions exposing the WP filler. The size of the hole to be punched and the frequency at which munitions are fed into the furnace are adjusted to establish a feed rate of WP into the furnace of approximately eight pounds per minute. After punching, the munitions are pushed into the feed chute of a modified APE 1236 Deactivation Furnace where they are gravity fed into the rotary kiln. In the kiln, the heat from the furnace burner and burning WP melts and then vaporizes the WP inside the munitions. As the WP vapors expand, they exit the munitions through the punched hole where they burn or oxidize to form phosphorus pentoxide.

The negative pressure, maintained in the entire system by two 75 horsepower draft fans mounted in series at the end of the system, draws the phosphorus pentoxide through a cocurrent/countercurrent flow hydrator where approximately 70% of the phosphorus pentoxide is removed from the gas stream by concentrated acid sprayed into the hydrator. The concentrated acid flows by gravity to a collection tank. Concentrated acid from the collection tank is cooled and recycled to the hydrator. As the concentration of the acid reaches the preset concentration of phosphoric acid (75%), a side stream of acid is diverted to the acid storage tank.

The remaining gas stream passes through a variable throat venturi where a pressure drop of 70 inches wc is maintained across the venturi. Two spray nozzles located at the venturi inlet provide dilute acid for the separator scrubbing process. From the venturi, the gas stream enters the separator tangentially at the bottom and exits out the top. Two mist eliminator pads are sequentially located in the top of the separator and are wetted by sprays of dilute acid. The dilute acid is collected in and recycled to the demister pads from a dilute acid tank. The gas stream then passes from the separator through two 75 horsepower draft fans mentioned above and through a final demister vessel containing two Brinks mist eliminator 'candles' in series downstream from the blowers. The demisters remove aerosol particles from the gas stream prior to exiting the stack. The demisters operate at a 99.9% plus efficiency.

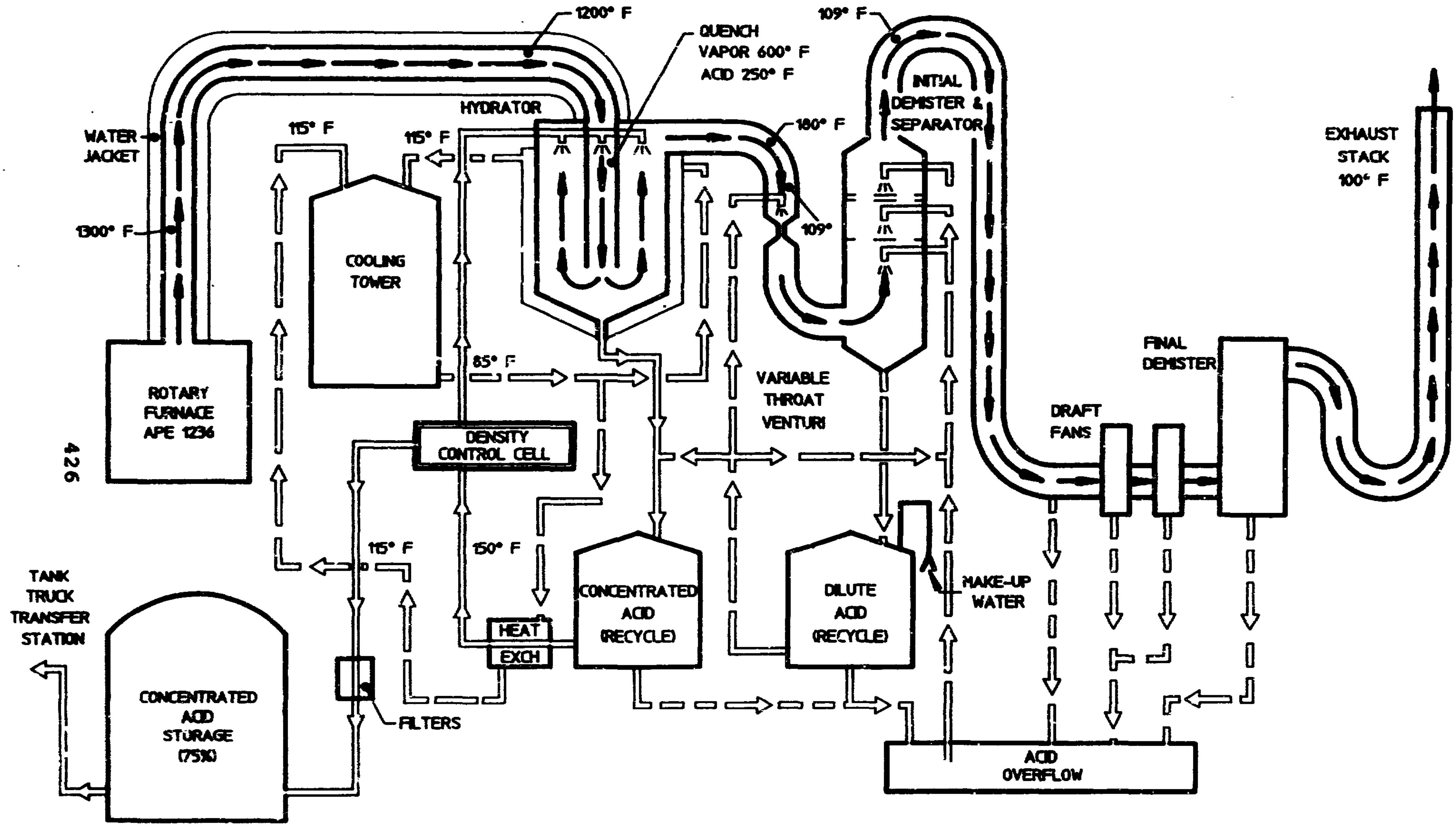
All plant functions are continually monitored, recorded, and controlled from a central location by two Allen-Bradley automated controllers. The product acid is filtered for removal of suspended solids above one micron in size, and is then stored on site waiting transfer to a tanker truck. The storage capacity at the site is 16,300 gallons (108 tons). Revenue from the acid sales to private industry are returned to AMCCOM headquarters, as is the revenue from the brass rotating bands, expended steel munitions bodies, and empty wooden boxes.

SUMMARY OF THE WP/PAC PLANT OPERATIONS

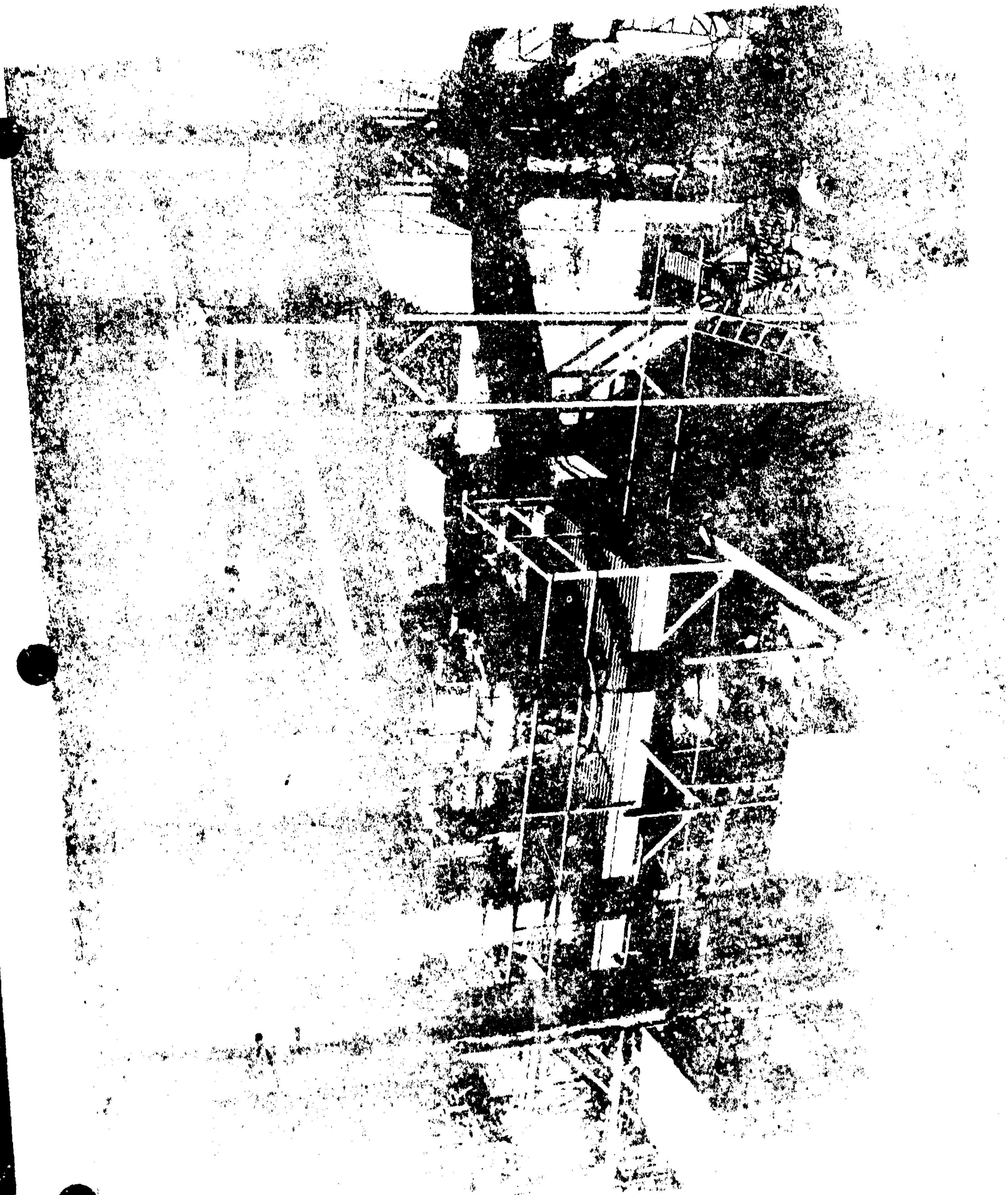
Since the plant officially began full scale operations at CAAA on 6 February 1989, acid sales have returned in excess of $1 million to AMCCOM. Over $300,000 has also been returned on the sale of more than 10 million pounds of scrap metal. As of August 1990, 199,159 3.5" rocket warheads, 198,101 4.2" mortars, 494,480 90 mm projectiles and 60,000 105 mm projectiles have been processed, which represents 2,992,000 lbs of WP. The plant operational availability, originally estimated at 85%, consistently operates in excess of 90% as a result of the modifications made to the original pilot plant equipment and controls.

The WP/PAC plant has the capability to process up to 11,520 pounds of WP daily thereby producing over 48,000 pounds of 75% concentration phosphoric acid in a 24 hour period. By the end of the program, almost 5 million pounds of WP will be processed and over 20 million pounds of phosphoric acid will have been produced and sold on contract. This represents the demilitarization of approximately 20,000 short tons of WP munitions.

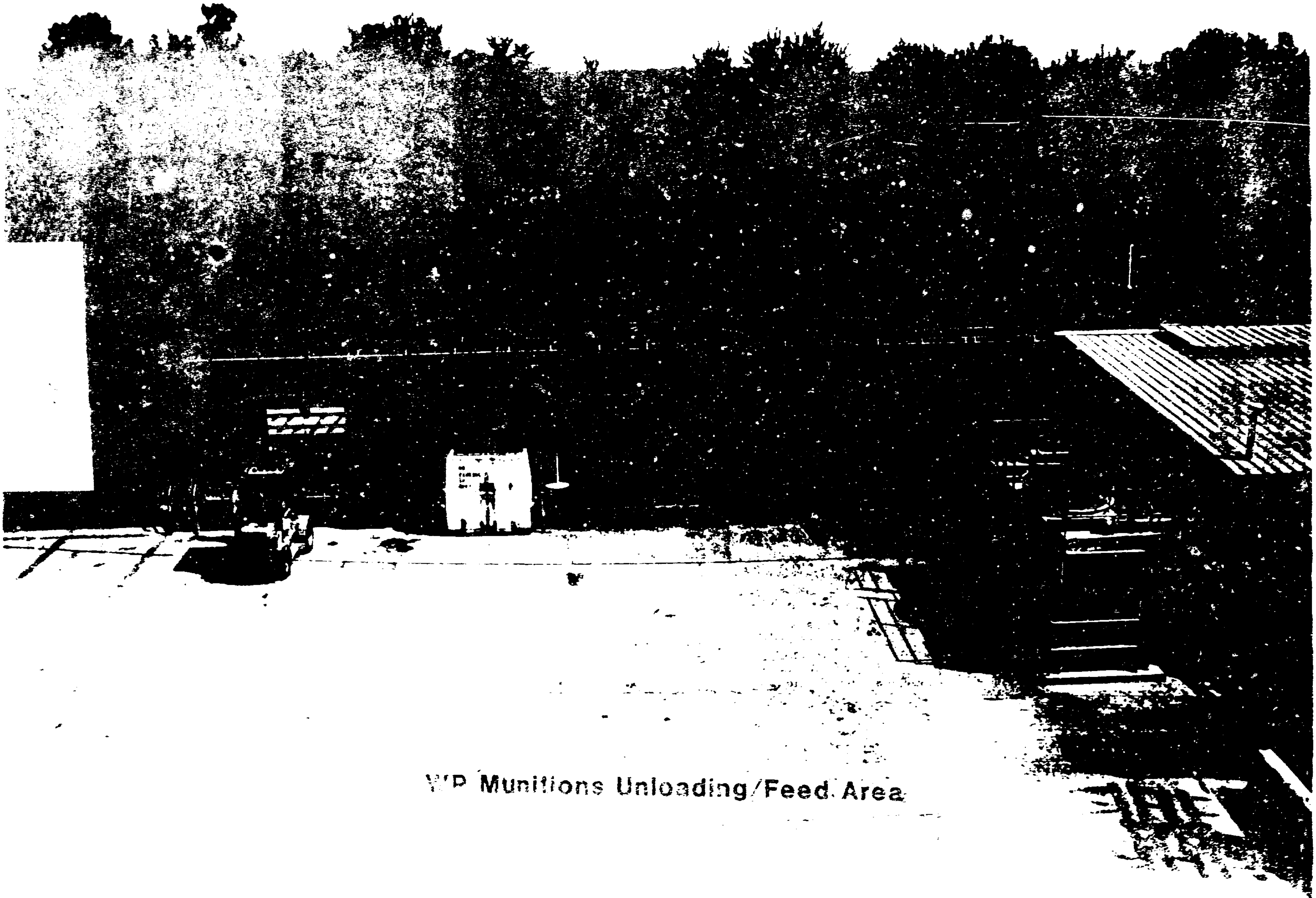
Because of the heightened awareness of environmental issues nationwide, and the increased technology utilized in development of new ammunition items, the Department of Defense (DoD) services will need to continue to develop demilitarization processes of this nature. The WP/PAC plant represents a unique blend of state-of-the-art and state-of-the-industry technology, and existing demilitarization methods, while maintaining the highest environmental quality.



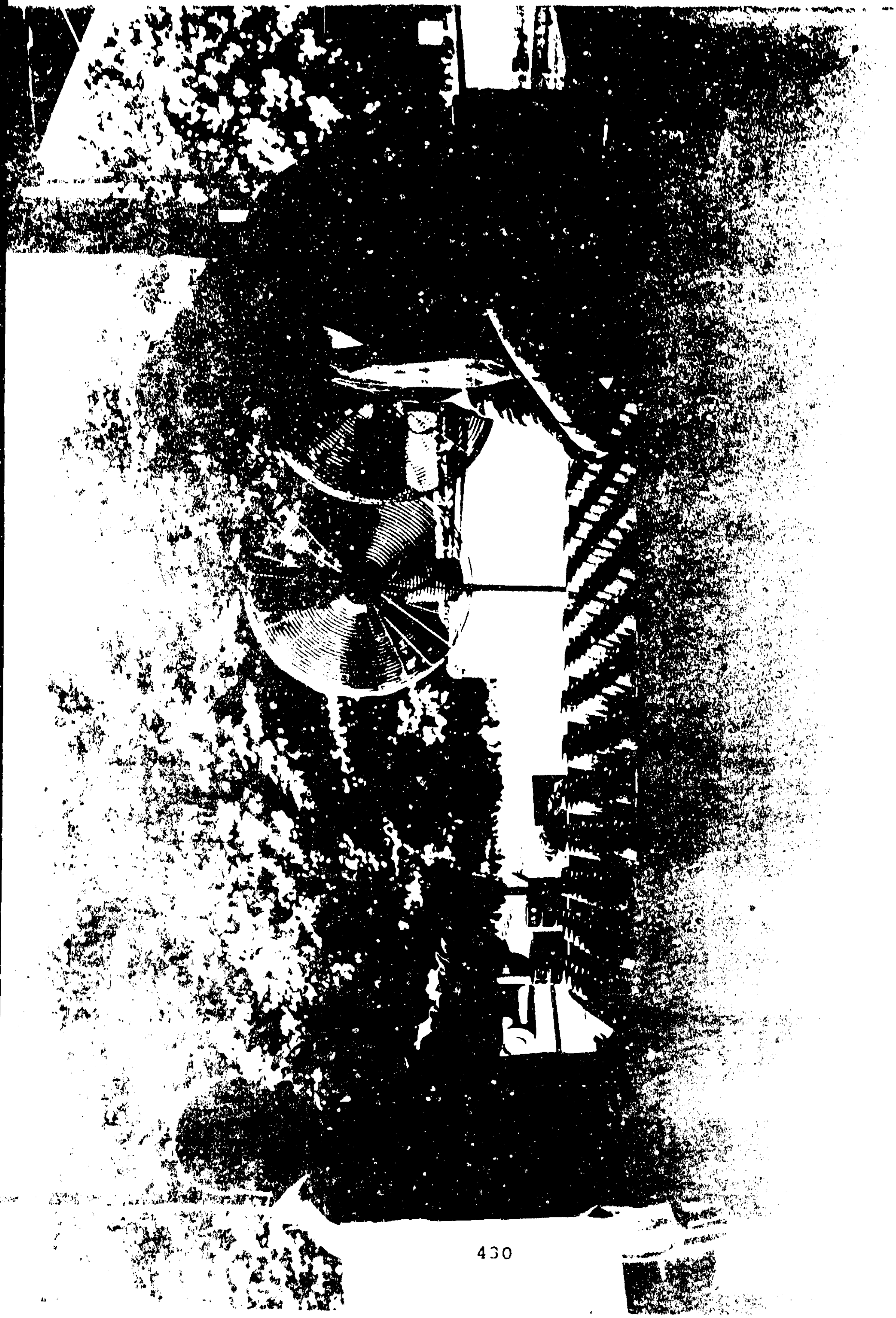
SIMPLIFIED WP TO PHOSPHORIC ACID CONVERSION PLANT
FLOW DIAGRAM

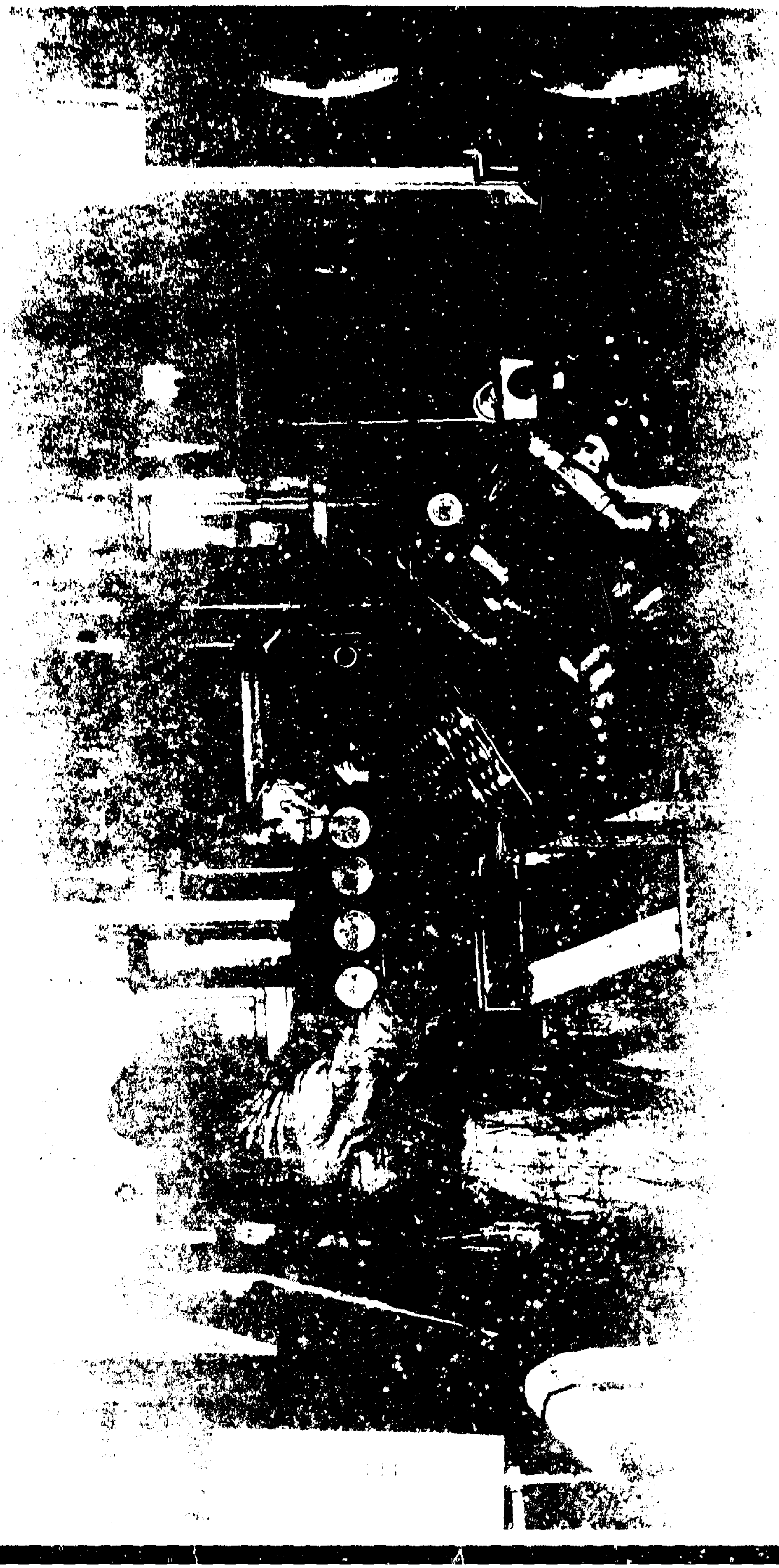


Overall View of WP/PAC Plant at Crane AAA



WP Munitions Unloading/Feed Area





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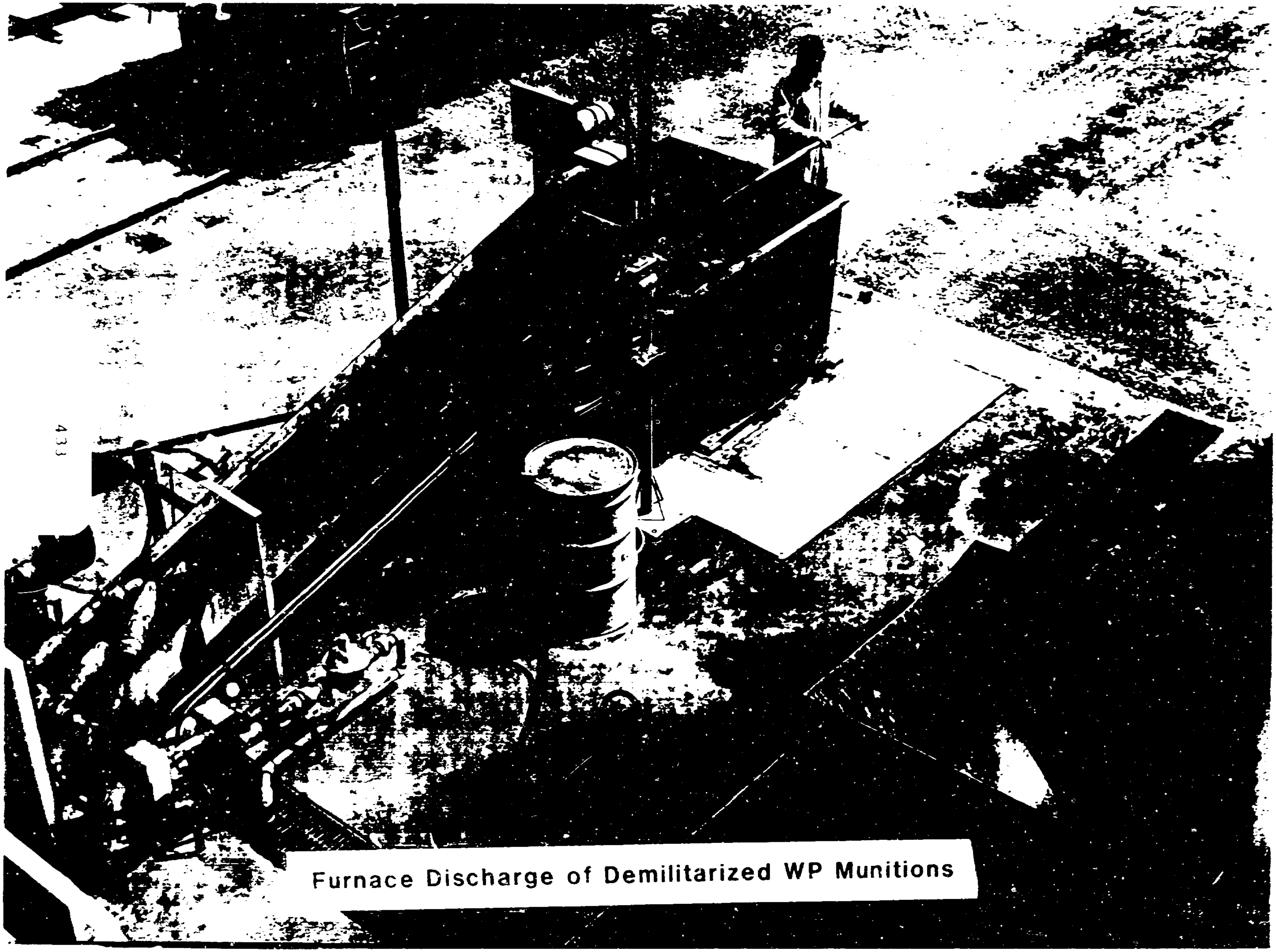
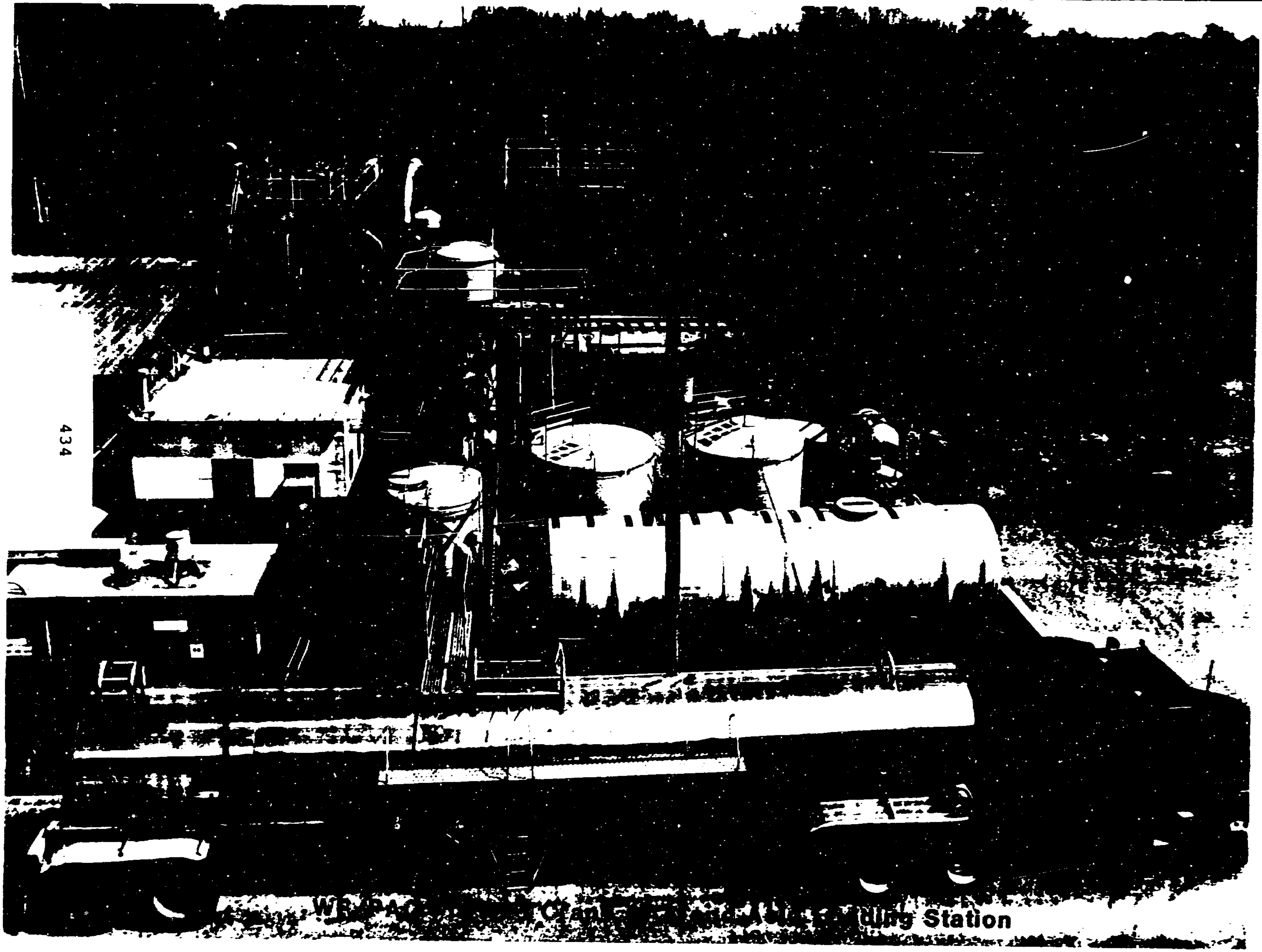
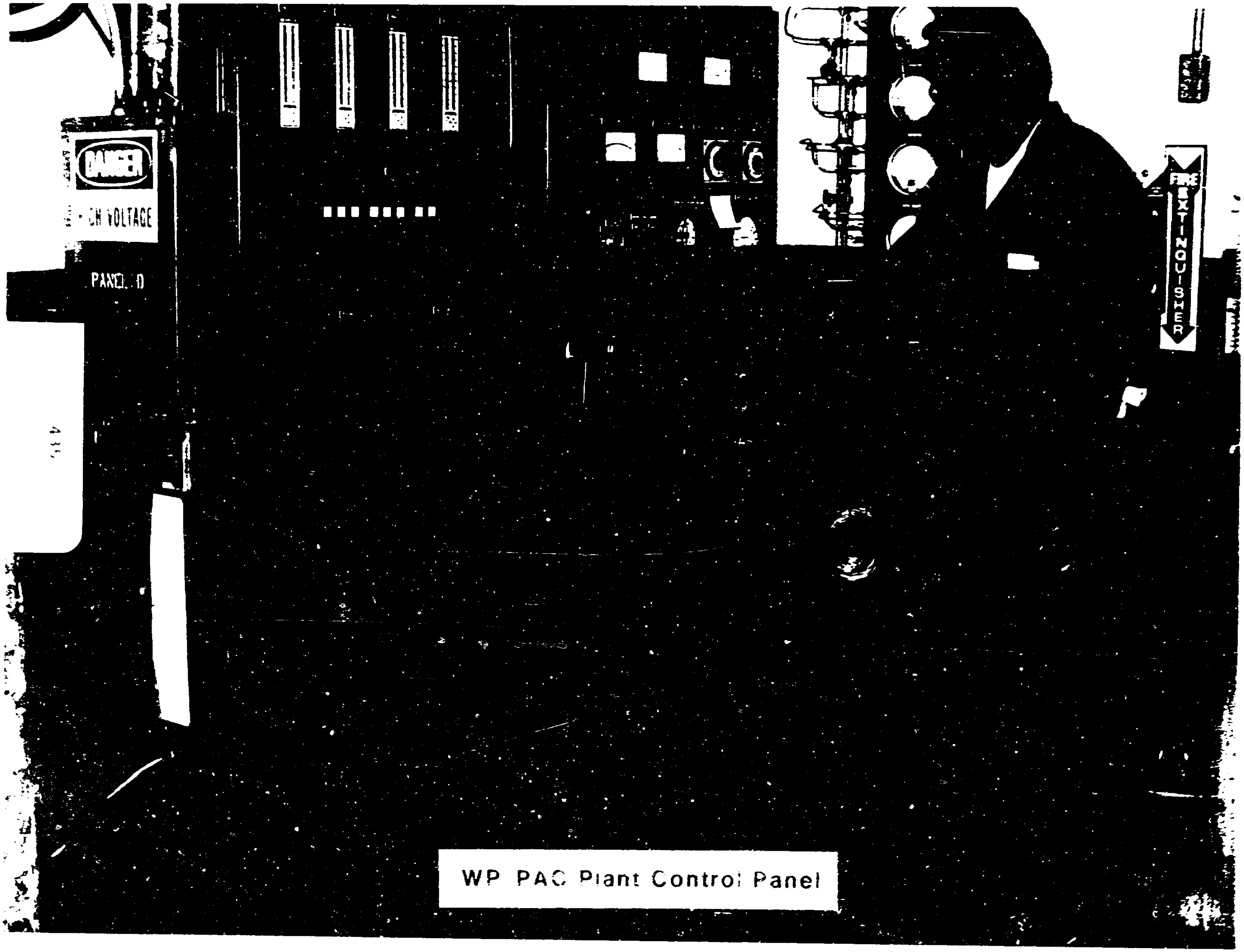
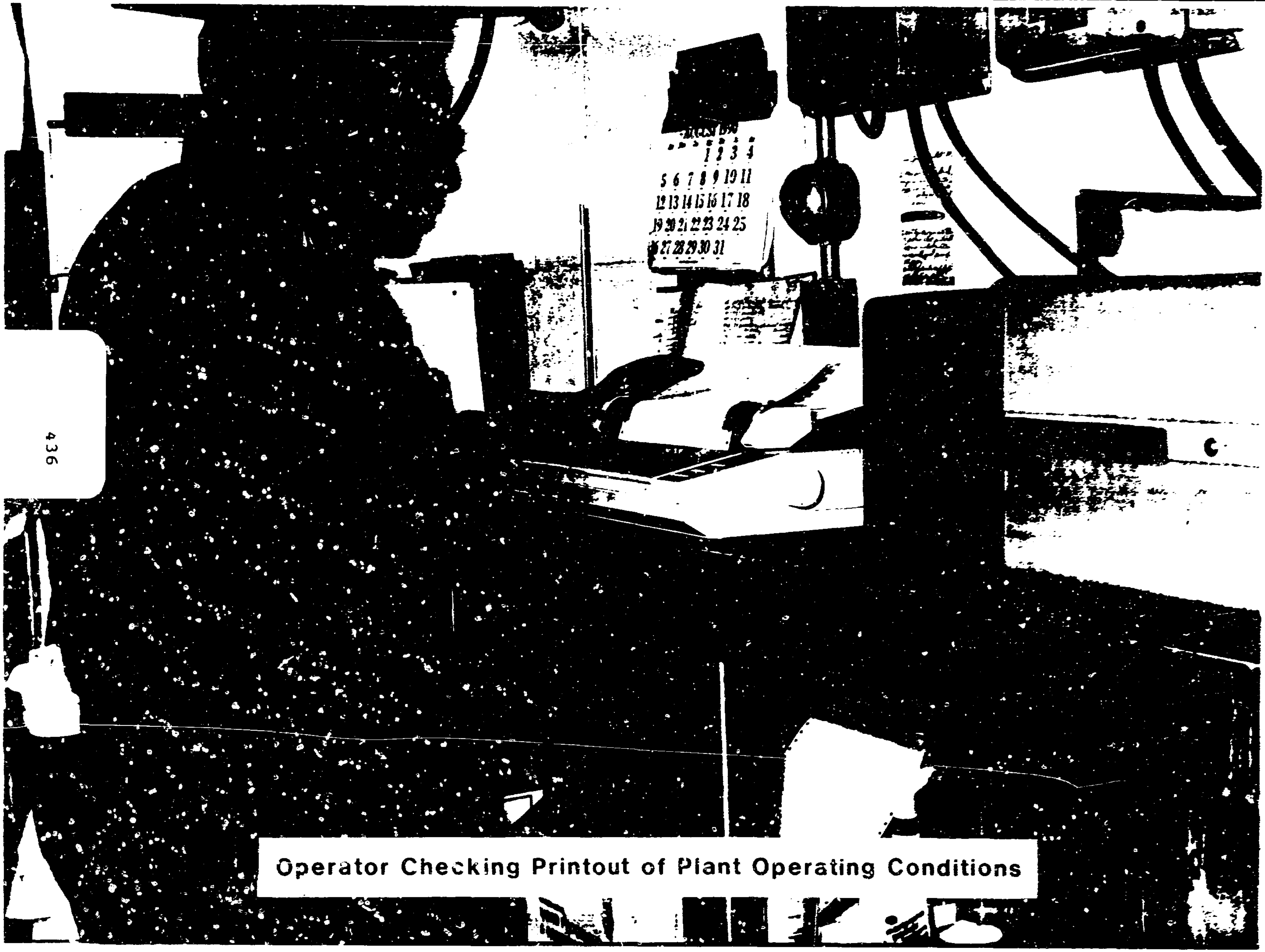


Furnace Discharge of Demilitarized WP Munitions


Station



WP PAC Plant Control Panel



Operator Checking Printout of Plant Operating Conditions

WP/PAC Plant Operator Changing Acid Filter Bag

PROPAGATION AND FIRE TESTS CONDUCTED ON A SECONDARY STEEL CONTAINER DESIGNED FOR MOVEMENT OF CHEMICAL AGENT ARTILLERY PROJECTILES

DANIEL B. HILL
Ammunition Equipment Directorate
Tocele Army Depot, Utah

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TWENTY-FOURTH DOD EXPLOSIVES SAFETY SEMINAR
Dept. Of Defense Explosives Safety Board
St. Louis, Missouri
28-30 August 1990

ABSTRACT

A Secondary Steel Container (SSC) has been developed to hold two pallets of 8" projectiles or three pallets of 155mm projectiles for use in the movement of chemical agent munitions. To answer questions on the impact that the container might have on the maximum credible event from the detonation of one projectile in the pallets, propagation tests were conducted. Two fire cookoff tests were also conducted to evaluate the time that fire fighters would have to extinguish a fire involving SSCs in MILVANS subjected to a large fuel fire resulting from an accident.

PROPAGATION AND FIRE TESTS CONDUCTED ON A SECONDARY STEEL CONTAINER DESIGNED FOR MOVEMENT OF CHEMICAL AGENT ARTILLERY PROJECTILES

INTRODUCTION

In response to a requirement for retrograde movement of lethal chemical agent artillery projectiles from the Federal Republic of Germany, the Army developed a steel overpack container that will provide secondary containment of agent (in liquid or vapor state) that may leak from the projectiles during transport. The overpack is further designed such that several of them can be transported in a MILVAN shipping container. This paper describes two test programs conducted to evaluate: (1) the potential for propagation of detonation of projectiles within the overpack, thus affecting maximum credible event calculations; and (2) time to cookoff of projectiles, should the MILVAN be involved in an accident resulting in an engulfing fire, thus impacting fire response planning for the move.

The U.S. Army Defense Ammunition Center & School (USADACS), located at Savanna Army Depot Activity in Savanna, Illinois, designed the steel container which is now called the Secondary Steel Container (SSC). The container is designed to provide a vapor tight containment for explosively-loaded chemical ammunition in accordance with requirements of Amendment 25 to the International Maritime Dangerous Goods (IMDG) Code. The container will hold two pallets (six projectiles each) of 8 inch artillery projectiles, or three pallets (eight projectiles each) of 155mm projectiles.

At the request of a DA-level Chemical Retrograde Task Force, the Ammunition Equipment Directorate (AED) at Tooele Army Depot, Utah conducted several tests during the period 4 October 1989 through 1 March 1990. This paper is later divided into two sections for purpose of describing each test separately. The tests are reported in AED Test Reports 17-89[1] and 04-90[2].

Propagation Test Summary

The projectiles are normally stored and/or transported in standard wooden pallets, burstered and without fuze. In such configuration, the palletized projectiles are U.N. Hazard

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[1] Hill, Daniel B., Tests to Determine Extent of Propagation or Damage When 8" or 155mm Chemical Agent Sinulant Filled Projectile Detonates Within Standard Pallet and in Pallet Overpack, 19 October 1989

[2] Hill, Daniel B., Secondary Steel Container Fire Tests, 30 March 1990

Class/Division 1.2 non-mass detonating munitions, indicating that in event of accidental detonation of one projectile within the pallet, propagation to adjacent projectiles will not occur. With development of the overpack container, it became necessary to determine if the containment might cause detonation of additional projectiles, thereby changing the hazard classification. The data was desired specifically for 8" M426 GB or VX projectiles and 155mm M121A1 GB or VX projectiles.

Tests were conducted on the two different sizes of projectiles during the period 4-10 October 1989 to determine if propagation would occur within the overpack container. An additional objective was to determine how many projectiles might be expected to leak their liquid agent fill. The tests were conducted using a liquid agent simulant. Three detonation tests were conducted for each size projectile:

°Single 8" projectile was detonated
°Donor in 2 std pallets of 8" projectiles was detonated
°Donor in 2 pallets of 8" projectiles within overpack was detonated

°Single 155mm projectile was detonated
°Donor in 3 std pallets of 155mm projectiles was detonated
°Donor in 3 pallets of 155mm projectiles within overpack was detonated

No propagation occurred in any of the tests. In the overpacked 8" projectile test, four projectiles incurred sufficient damage to leak their liquid fill. In the overpacked 155mm test, seven projectiles leaked.

Fire Test Summary

A movement planning scenario envisions an accident resulting in a large fuel fire that engulfs a MILVAN loaded with SSC which are filled with projectiles. Assuming that projectiles will eventually begin to cookoff in such a fire, it was desired to know how much time a fire response team may have to fight the fire before the first projectile detonates; therefore, tests were conducted on 6 February and 1 March 1990 which subjected SSCs to fuel fires. The test SSC were each loaded with three explosive filled 155mm projectiles and 21 inert projectiles. All were filled with ethylene glycol/water mix to simulate chemical agent. The SSCs were placed into CONEX containers to represent a MILVAN shipping container. Each assembly was suspended over a pan of fuel which was then ignited.

In the first test, the fire lasted approximately 44 minutes and, although no projectiles cooked off or detonated, the test appeared to demonstrate that a reasonable amount of time would be available to safely fight the fire. In the second test, one projectile burster cooked off in one hour ten minutes and a with 14.5 lbs of ethylene glycol/water (50/50 wt) to simulate the density property of chemical agent GB. Assembled and filled projectile weight is approximately 195 lbs. Palletized weight (6 rds/pallet) was approximately 1253 lbs.

155mm projectiles that had been modified from the M107 HE configuration to M121A1 chemical configuration were also used for these tests. The modified M107 was assembled with the M71 burster, which contains 2.45 lbs of composition B4; the supplementary charge containing 0.30 lbs of TNT; the appropriate cardboard spacer and steel support cup; and a lifting plug. The projectile cavity was filled with 6.5 lbs of liquid simulant. Assembled and filled projectile weight was approximately 99 lbs. Palletized weight (8 rds/pallet) was approximately 831 lbs.

All components were painted to assist identification in fragment collection after the tests. The 8" projectiles and all their components were painted one color while the 155mm were painted a distinctively different color. The donor projectile for each test was configured as follows:

1. The detector-type lifting plug was removed and a 1/8" hole drilled to accept an ionization probe. The detection screw was removed so the EBW detonator could be inserted into the approximately 36 grams of composition C4 that was packed into the lifting plug cavity.

2. The cardboard spacers were packed with composition C4 (approx 66 gm in the 8", 49 gm in the 155mm). The spacer, w/C4, was then emplaced atop the supplementary charge in the projectile.

SSC Preparation

The SSC for each test were painted different colors and were painted differently from the projectiles. After installation of the pallets of projectiles into the SSC, wood blocking and bracing was installed to preclude shifting or moving of the pallets within the SSC.

Test Setup

In both single projectile tests, the projectile was elevated above the witness plate, using wooden blocks, to a height approximating the elevation of the palletized projectiles within the SSC. In both Phase 1 tests, the pallets of projectiles were also elevated above the witness plate.

In the Phase 2 tests, the SSC, with projectiles and wood bracing already installed, were positioned in location at the test site. The EBW detonator was then inserted through the inspection hole, and the ionization probe inserted through the specially-drilled hole into the composition C4 in the lifting plug. The electrical wires were fed through the sampling hole in the top of the SSC. The SSC cover plate was then bolted in place, following specified torquing instructions.

Prior to each test, a spherical charge of approximately one lb. of composition C4 was detonated to validate the pressure transducer array. A fragment search was conducted at the conclusion of the tests. Fragments found in each 200 ft. cell within each of three 5° search sectors were reported as were major pieces of debris or unexploded components found outside the search sectors.

Results

8" Projectile Tests

Single Projectile Baseline Test-Pressure data is given in Table 1. Fragment dispersion for within and outside the search sectors was plotted and no fragments were found beyond 600 ft. from the detonation.

Standard Pallet Baseline Test-Pressure data is given in Table 1. Although no propagation occurred and all explosive components from acceptors were recovered, the damage was significantly more widespread in this test than was seen later in the overpack test. Five M83 bursters and eight supplementary charges were ejected from their projectiles; some as far away as 600 ft. One projectile was thrown 400 ft. Eight projectiles leaked their liquid fill.

Overpacked Pallet Test-Pressure data is given in Table 1. No propagation occurred and all explosive components from acceptors (two supplementary charges) were recovered. Four projectiles leaked their liquid fill. Two leaked significantly from around their burster cases; these were thrown 200 ft. Two were seepage-type leakers from around the joint between fuze adapter and projectile body. One was thrown 75 ft. and the other was thrown 50 ft. Deformation around the projectile nose caused the burster case press fit to break loose, allowing the liquid to leak. Damage to projectiles was not nearly as severe as was seen in the pallet baseline test; i.e., no projectile bodies were cracked although some were severely dented, only two projectiles lost their fuze adapters, and all others even retained their lifting plugs. The SSC split open at the rear and top joints with the top and the door being blown completely off.

TABLE 1-BLAST PRESSURE DATA FOR 8" PROJECTILE TESTS

TEST	BLAST LINE	TRANSDUCER STATION	R ft.	P_{so} psi	t_a ms	t_o ms
SINGLE ROUND	A	1	15	15.73	83.6	31.6
		2	22	11.73	131.4	34.6
		3	40	7.64	288.0	7.96
	B	4	15	13.61	81.4	32.4
		5	22	10.96	133.2	32.6
		6	40	5.73	244.0	14.6
STANDARD PALLET	A	1	15	11.92	86.08	34.4
		2	22	5.78	142.8	42.2
		3	40	3.34	297.6	52.5
	B	4	15	11.41	83.0	33.2
		5	22	7.68	137.6	39.8
		6	40	3.94	290.8	86.0
OVERPACKED PALLET	A	1	15	5.44	140.4	51.8
		2	22	3.62	198.0	46.8
		3	40	2.28	352.6	49.2
	B	4	15	4.89	141.4	59.5
		5	22	3.91	200.6	86.2
		6	40	2.00	358.4	72.4

R = Horizontal distance from center of donor round to transducer station, feet
P_{so} = Peak positive incident pressure, pounds per square inch
t_a = Time of arrival of blast wave, milliseconds
t_o = Duration of positive phase, milliseconds

155mm Projectile Tests

Single Projectile Baseline Test-Pressure data is given in Table 2. Fragment dispersion for within and outside the search sectors was plotted and no fragments were found beyond 600 ft. from the detonation. The blast pressure at transducer 5 in Blast Line B is abnormally low, however, it's likely that some ground-level obstruction (rock or dirt mound) deflected the blast wave.

Standard Pallet Baseline Test-Pressure data is given in Table 2. No propagation occurred and no explosive components were released or ejected from any acceptors. Transducer 5 recorded an abnormally high pressure which is unexplained. There was no extensive damage to any of the acceptors; i.e., none were broken or cracked, however seven rounds leaked their liquid fill. One projectile was thrown approximately 600 ft. The leakage results from deformation of the projectile nose causing the burster case press-fit to break loose.

Overpacked Pallet Test-Pressure data is given in Table 2. No propagation occurred and no explosive components were ejected from acceptors. Blast pressure readings appear normal. Seven projectiles were leakers. Two leakers were thrown 175 ft., one 150 ft., one 100 ft., and three were thrown 50 ft. All leakers were seepage-type leakers with no significant loss of liquid; and no projectiles were severely damaged. The SSC did not blow apart as was seen in the 8" test. The door blew off, landing approximately 500 ft. away.

TABLE 2-BLAST PRESSURE DATA FOR 155mm PROJECTILE TESTS

TEST	BLAST LINE	TRANSDUCER STATION	R ft.	P_{so} psi	t_a ms	t_o ms
SINGLE ROUND	A	1	15	8.42	96.0	2.4
		2	22	4.10	153.8	1.8
		3	40	2.34	313.8	38.0
	B	4	15	8.61	94.8	25.4
		5	22	1.78	173.6	16.4
		6	40	3.04	308.8	62.8
STANDARD PALLET	A	1	15	6.36	104.8	29.5
		2	22	3.31	163.6	26.0
		3	40	1.87	322.8	77.2
	B	4	15	6.20	103.2	28.4
		5	22	8.30	157.6	39.5
		6	40	1.71	322.0	36.0
OVERPACKED PALLET	A	1	15	2.71	135.4	43.4
		2	22	1.87	195.2	41.4
		3	40	0.76	352.8	48.0
	B	4	15	1.97	123.4	65.2
		5	22	1.49	189.4	71.5
		6	40	0.75	348.6	36.7

R = Horizontal distance from center of donor round to transducer station, feet
P_{so} = Peak positive incident pressure, pounds per square inch
t_a = Time of arrival of blast wave, milliseconds
t_o = Duration of positive phase, milliseconds

second burster cooked off in one hour seventeen minutes. The third live projectile did not function.

DESCRIPTION OF SSC

The SSC is a front-loading, skid-mounted steel container with the following approximate overall dimensions: 33¼" wide x 42¾" long x 47¾" high. See Figure 1. Its interior dimensions will accommodate two pallets of 8" projectiles or three pallets of 155mm projectiles, with appropriate wood blocking/bracing to prevent shifting of the pallets within the SSC.

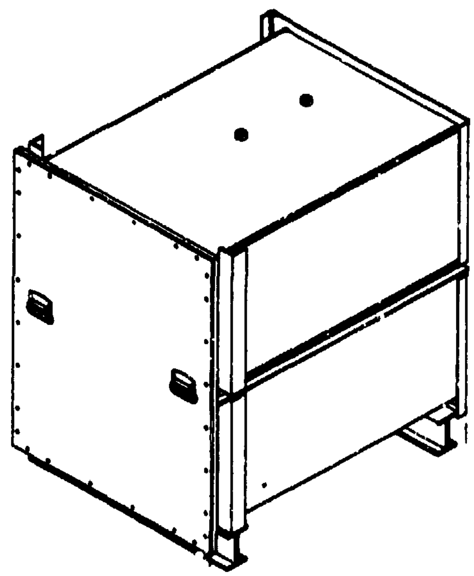


FIGURE 1. SECONDARY STEEL CONTAINER

The SSC is constructed essentially of 3/16" thick medium carbon steel plate, forming a box that is mounted on two standard 5" flange beams that provide side access for forklift. The front of the container is a 5/8" thick flange plate to which a 1/4" thick closure door is bolted with 28 3/8" socket head capscrews that thread into the flange plate. A 3/16" thick butyl rubber gasket is glued to the closure door and provides the vapor-tight seal for the container. The closure door has two handles welded to it for manual handling. Threaded fittings at the top of the container permit attachment of an air monitoring device and a valve to allow air to be drawn into the container while monitoring. The SSC weighs approximately 800 lbs.

PROPAGATION TESTS

These tests were conducted in two phases for each of the two test munitions. Phase 1 was a baseline test in which two 8" or three 155mm standard pallets were placed side by side and a donor round in one pallet was detonated to obtain baseline damage and pressure data to be used for comparison with data from Phase 2. In Phase 2, two 8" or three 155mm standard pallets were placed within the Secondary Steel Container and a donor round in one pallet was detonated to assess any propagation effect caused by the SSC.

Prior to each Phase 1 test, a single round (for each size munition) was detonated to obtain pressure baseline data for comparison with Phase 1 data.

Objectives of the tests included:

1. Obtain "baseline" data for projectiles in standard pallets, to include measurement of blast pressure (to aid in determining if explosive propagation occurred), visual assessment of damage to other rounds within the donor pallet, and visual assessment of damage to rounds within acceptor pallets; specifically to determine the number of (and which) projectiles suffered sufficient damage to release simulant.

2. Determine if Secondary Steel Container affected or altered the results achieved in Phase 1 tests.

3. Determine fragment dispersion.

Blast pressures were determined by measuring peak positive incident overpressures with low-impedance piezoelectric pressure transducers placed at ground surface along two air blast instrumentation lines at 90 degrees to each other. In all tests, the donor round was placed at the intersection of these two blast lines. A 1¼" thick steel witness plate provided a base for all tests. The donor round was initiated by an Exploding Bridgewire (EBW) firing circuit from a control center approximately 700 ft. away. High-speed cameras and real-time video documented the tests.

Munitions Preparation

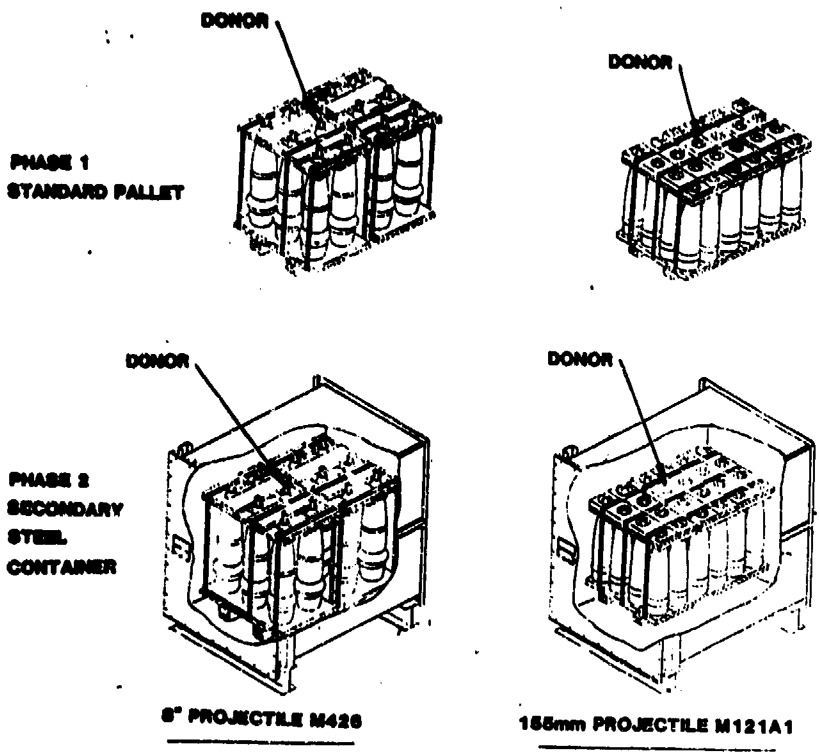
The chemical agent version of the 8" projectile is the M426. The high-explosive version is the M106. M106 projectiles modified to the M426 configuration were used for these tests. The modified M106 was assembled with the M83 burster, which contains 7 lbs of composition B4; the supplementary charge containing 0.30 lbs of TNT; the appropriate cardboard spacer and support; and a lifting plug. The projectile cavity was filled

Conclusions

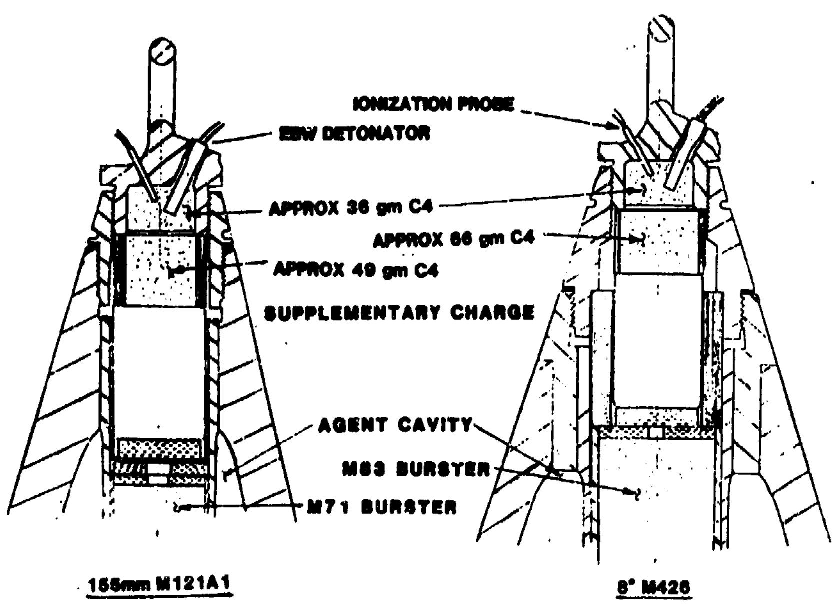
<u>8" Projectile Tests</u>-No significant anomalies were seen in the pressure data; i.e., the blast pressures seemed to decay normally as the pressure wave expanded outward across the transducers. The measured pressures also decreased with each test as would be expected, given the confinement of surrounding projectiles and the container. The lesser damage to acceptor projectiles in the overpacked pallet test might be explained by the instantaneous increase in air volume in the container, caused by the donor detonation, creating an air cushion between projectiles which minimized mechanical damage to them. The SSC also contained fragments, resulting in fewer being dispersed than seen in the standard pallet test.

<u>155mm Projectile Tests</u>-With exception of anomalous readings at transducer 5 in the standard pallet and the overpacked pallet tests, the blast pressures appeared normal. As described above, mechanical damage to projectiles was minimal, and there was very little fragmentation.

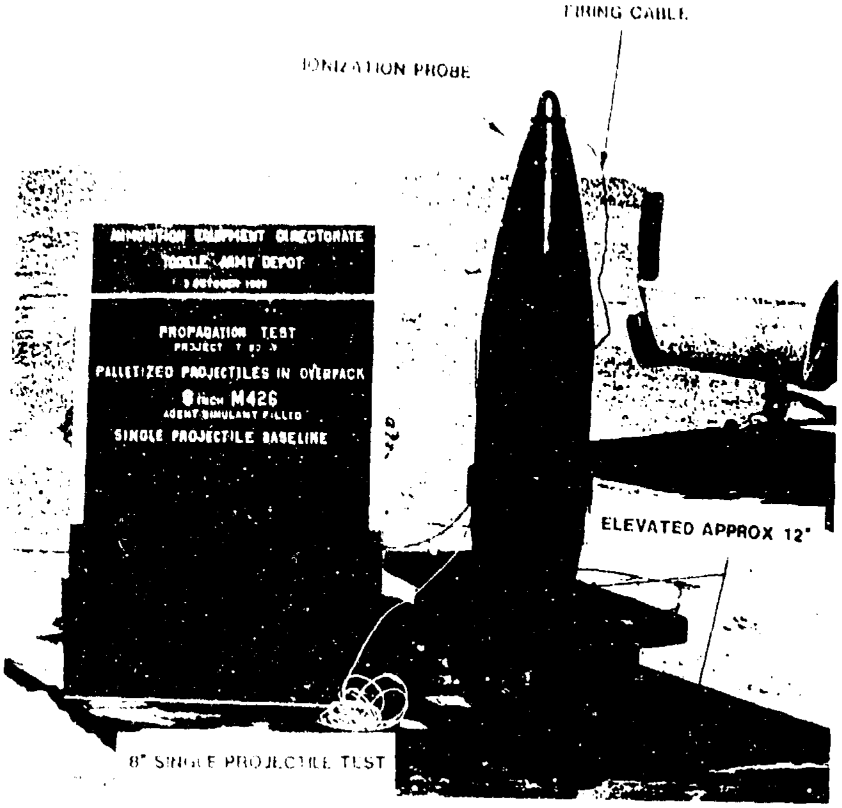
The following five pages of photos illustrate the test setups and results. Discussion of the Fire Tests continues after the photos.



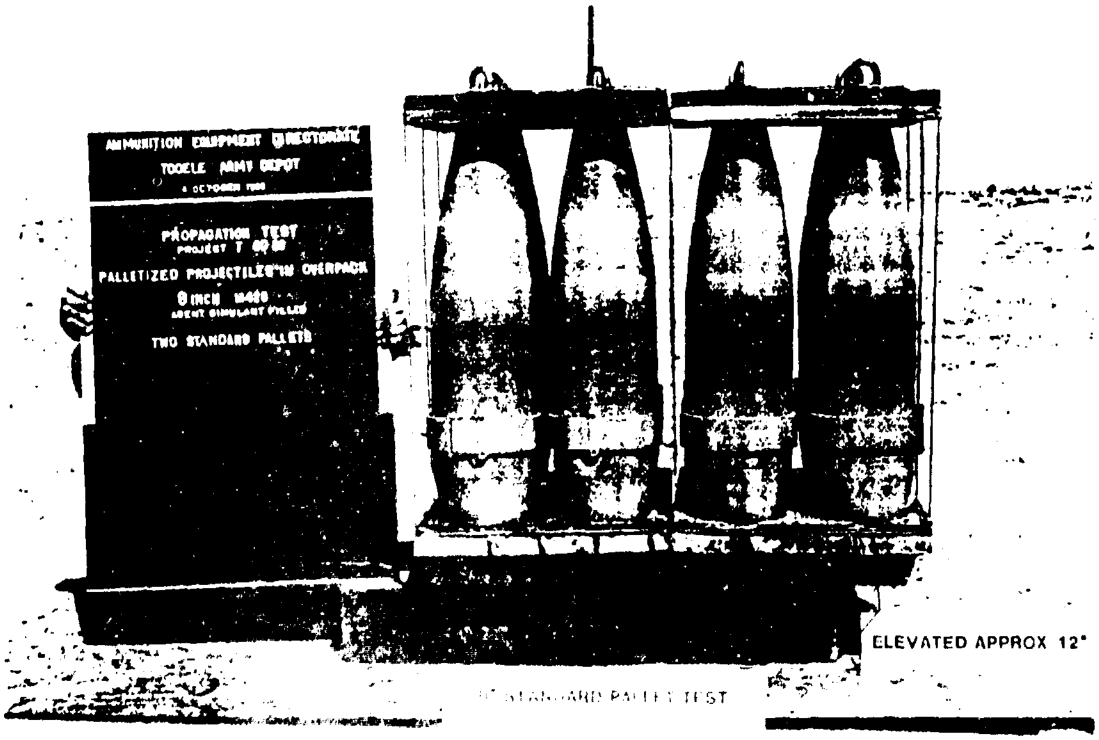
TEST CONFIGURATIONS



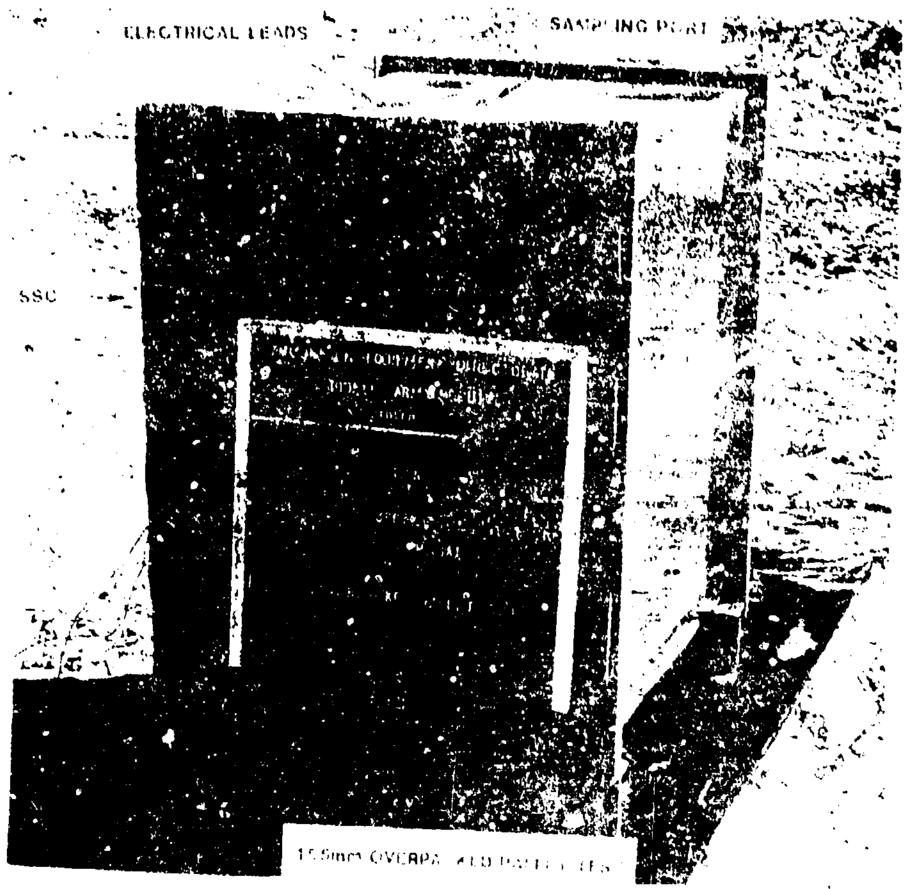
PREPARATION OF DONOR PROJECTILE

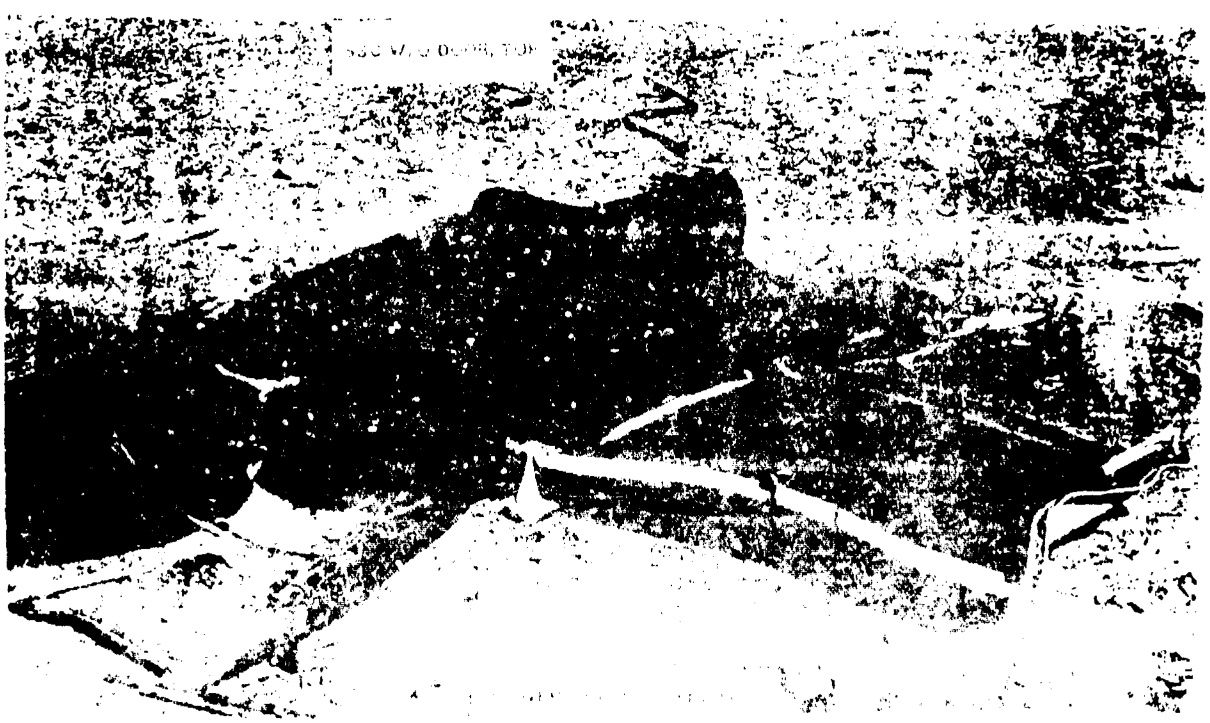


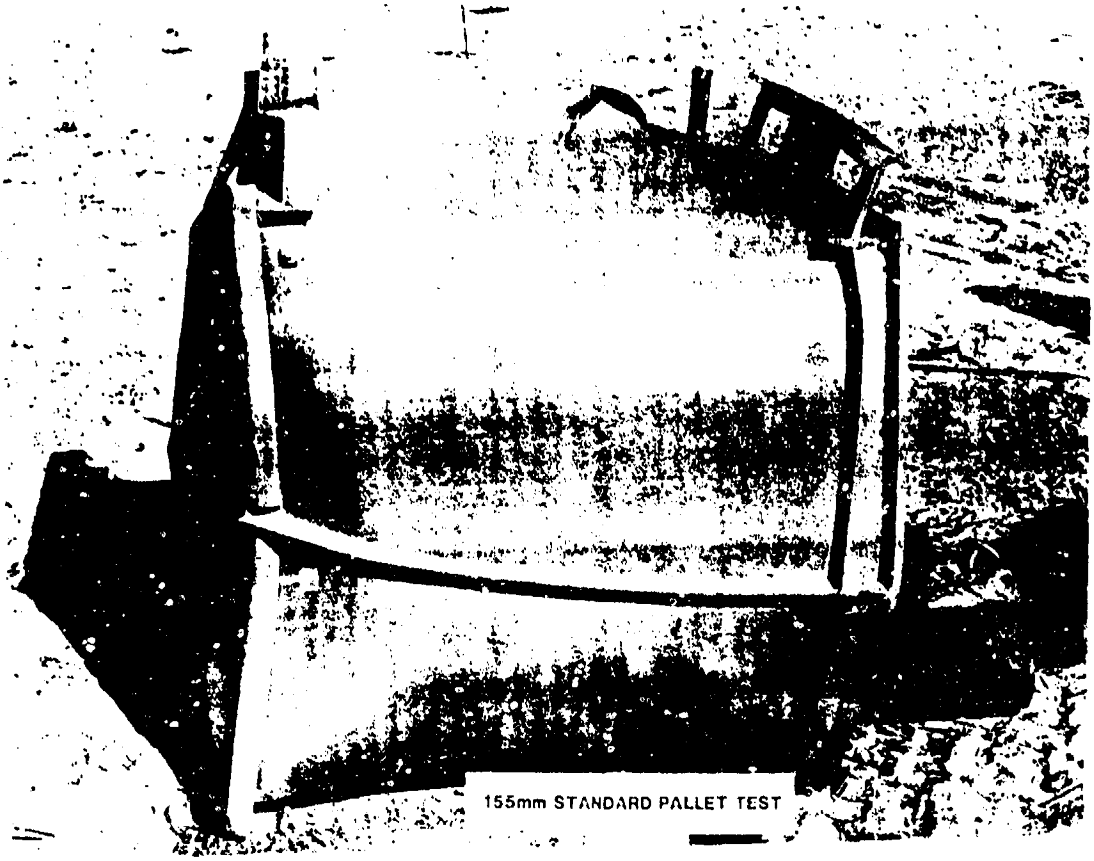
8" SINGLE PROJECTILE TEST

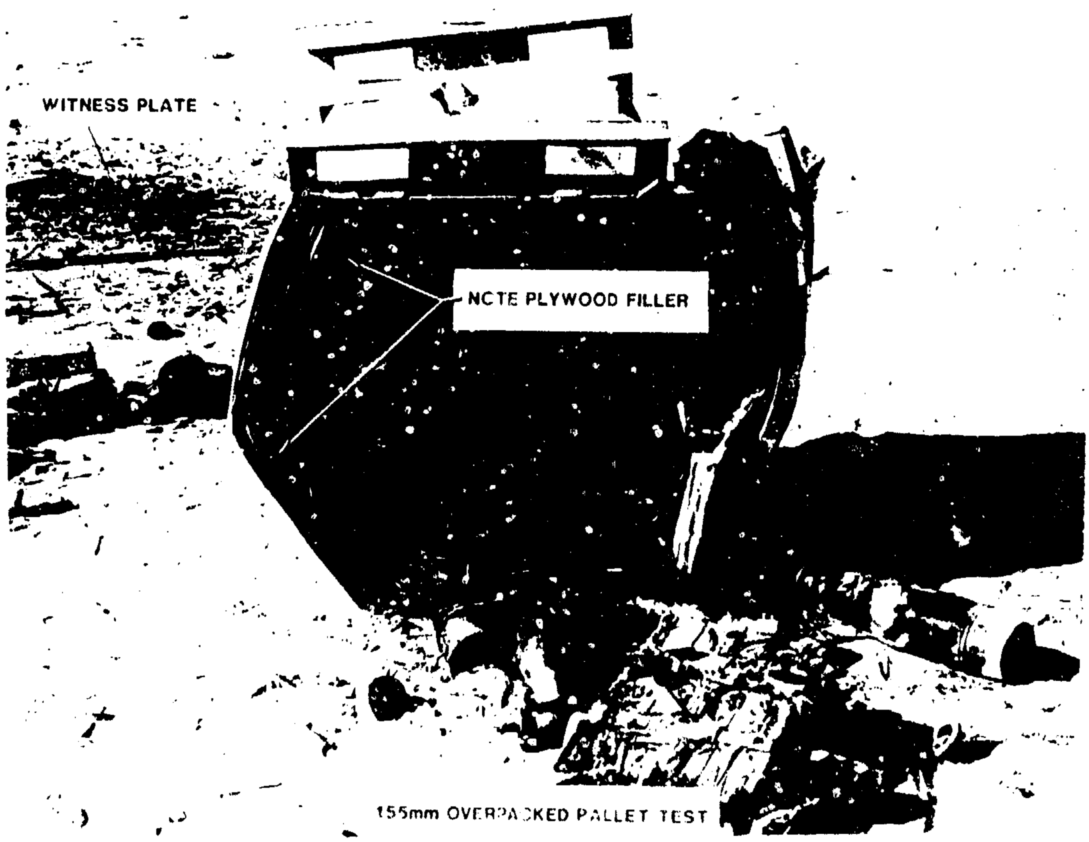


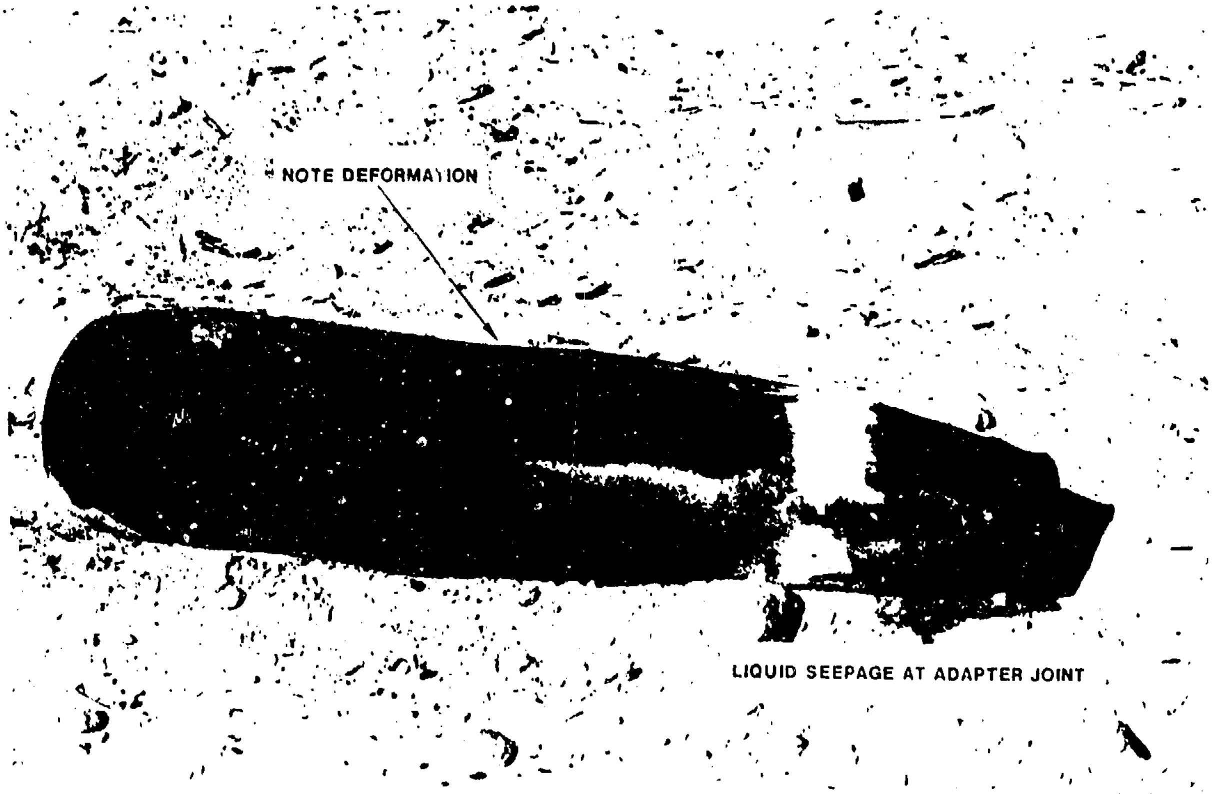
8" STANDARD PALLET TEST

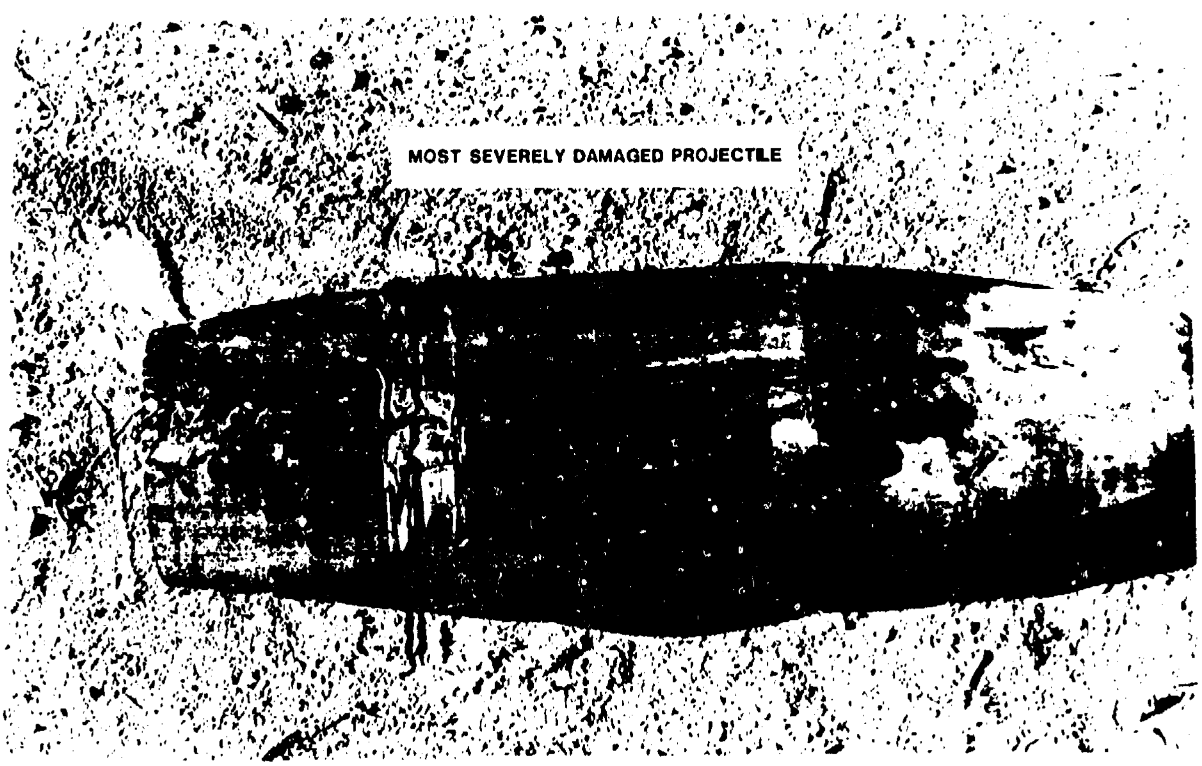

ELECTRICAL LEADS
SAMPLING PORT
SSC




155mm STANDARD PALLET TEST


WITNESS PLATE
NOTE PLYWOOD FILLER
155mm OVERPACKED PALLET TEST


NOTE DEFORMATION
LIQUID SEEPAGE AT ADAPTER JOINT


MOST SEVERELY DAMAGED PROJECTILE

FIRE TESTS

Two tests were conducted, on 6 February and 1 March 1990, which subjected SSCs to fuel fires with the objective of determining length of time to "cookoff" of explosively loaded 155mm projectiles within the container. The test SSC were each loaded with three explosive filled 155mm projectiles and 21 inert projectiles. All were filled with ethylene glycol/water to simulate chemical agent. The SSCs were placed into CONEX containers which represented a MILVAN shipping container. Each assembly was suspended over a pan of fuel (first test JP-5, second test diesel fuel) which was then ignited. Thermocouples recorded time/temperature histories, including the temperatures at the tops of the three bursters in the live projectiles.

In actual loading, the SSC are intended to be installed in the MILVAN with the SSC door facing outward, toward the MILVAN sidewall. For each of these tests, a fixture was fabricated to closely approximate the configuration of one SSC at the rear corner of a MILVAN.

The 155mm M121A1 (with liquid agent simulant) was selected as the test munition instead of the 8" because of its' thinner wall and the fact that, within the SSC, it is slightly closer to the container wall, suggesting shorter time to cook-off. Three pallets of projectiles (24 total) were placed into the SSC. Three projectiles were explosively loaded with a composition B-filled M71 burster. Two outside projectiles were approximately 3/8" from the SSC sidewall (one was adjacent to a plywood sheet which was fill material placed between the SSC door and the pallet of projectiles). The other live projectile was placed near the center of the SSC. All wood blocking/bracing specified by the SSC loading drawing was used (plywood sheets were at the side opposite the live projectiles).

The SSC was then placed into a corner of a standard Conex shipping container (representative of a MILVAN container). The door side of the SSC was approximately 4" from one wall of the container. The positioning was determined by wooden side blocking required by the MILVAN loading drawing. One side wall of the SSC (adjacent to two of the live projectiles) was approximately 24" from the other Conex wall. The Conex corner was then partitioned with floor to ceiling panels against the back and other side walls of the SSC, creating an enclosure for the SSC with an air volume roughly equivalent to the unit volume that will exist in the MILVAN, which is approximately 69 ft^3 of free air. The partition panels were insulated to prevent loss of heat from within the enclosure and to prevent entry of heat into the SSC through two walls (i.e., suggestive of surrounding SSC). The floor of the enclosure was lined with hardwood material to simulate the MILVAN flooring.

All projectiles were filled with an ethylene glycol/water mix to simulate liquid agent. Three projectiles were assembled with an explosive burster and a supplementary charge. The others had a plaster of paris-filled simulant burster and supplementary charge. The projectiles were appropriately palletized in wooden pallets and banded.

The corner of the Conex assembly was positioned above a burn tray filled with fuel. For the first test, the tray was initially filled with approximately 220 gallons of JP-5 fuel. Some literature indicated a burn rate of 0.1 in/min for JP-5 fuel. Using this rate, it was anticipated that 8.5" fuel depth should permit 85 minutes burn time. For the second test, the tray was filled with 275 gallons of diesel fuel. As a precaution against spilling fuel on the ground in event the burn tray was punctured by a detonation of the projectile(s), the burn tray was positioned within a larger, thick-walled pan.

The fuel was ignited by emplacing a small combustible container of gasoline in the fuel and igniting the gasoline with an M206 Countermeasure Flare which was ignited by electric squib.

Instrumentation for both tests consisted of several chromel/alumel thermocouples located throughout the Conex and the SSC. Thermocouples were also attached to the live projectiles. The thermocouple data was collected by a Fluke Datalogger. The tests were documented by video.

Results

Test One

At the start of the test, the ambient temperature was 42° F and the wind was blowing at 13 knots, impacting on the test fixture side adjacent to the SSC door. Subsequent readings were 7 knots, from the same direction. The temperature remained constant throughout the test, dropping only to 41° F at the end.

The fire burned approximately 44 minutes, significantly less time than expected because of the wind. Although the flames reached to the top of the Conex container, the wind generally swept the flames away from one side, affecting heat transfer through that side and through the SSC door. The measured flame temperature averaged 1300-1500° F. Note that the flame temperature was measured by a thermocouple inserted into the flame at one corner of the fuel pan and its readings fluctuated widely because the flame was affected by the wind.

No detonation occurred. Bursters 1, 2 & 3 reached maximum temperatures of 220, 180 & 200° F, respectively; but at approximately 1 hour 9 minutes after the fire died out, having continued to absorb heat from surrounding projectile bodies and the SSC. Table 3 gives the burster temperatures at the time the fire died down and the apparent average rate of temperature climb at that time.

TABLE 3-BURSTER TEMPERATURES
(at time fire died down)

BURSTER NO.	°F	°C	RATE OF TEMP CLIMB, °F/min
1	122.9	50.5	9°/min
2	91.1	32.8	3°/min
3	132.4	55.8	3°/min

Burster 3 exhibited sign of near melting in that it was lightly stuck to the bottom of the support cup. The TNT supplementary charge atop Burster 2 experienced some melting; i.e., the light gage aluminum closure disc was completely melted away and the explosive was melted down approximately 1/8". Burster 1 wasn't examined because the projectile couldn't be disassembled. Liquid temperatures in Projectiles 1 & 3 were essentially the same as the respective bursters and exhibited the same temperature rise rates. The liquid temperature data for Projectile 2 was lost due to thermocouple malfunction. Much of the projectile body temperature data was also lost due to malfunctioning thermocouples; however, maximum temperatures, recorded well after the fire died out, were 215° F on the exterior of Projectile 3, and 187° F on the base of Projectile 1.

Unfortunately, the thermocouple measuring the air temperature inside the SSC failed and no data was obtained. The thermocouples measuring door and wall exterior temperatures recorded maximums of 493 and 921° f, respectively. These temperatures were measured just before the fire died down and were in a relatively steep rate of climb. The floor temperature (inside the SSC) was at about 225° F when the fire died but continued to climb to a peak of 665° F 33-34 minutes later. The interior sidewall temperature peaked at 637° F about halfway through the burn; and the door interior wall temperature reached 371° F. There was some charring of the wood blocking/bracing but no significant combustion. The butyl rubber gasket was largely melted away although there were segments that were relatively intact.

Air temperatures inside the Conex were measured at several locations. Air temperatures rose very quickly to 400° F, within about 4 minutes after ignition. Air Temperature 1 reached 1000° F in approximately 27 minutes and Air Temperature 2 reached 1000° F in about 41 minutes, shortly before the fire died out. The floor temperature was measured at the surface of the wood floor, beneath the SSC. The temperature curve exhibited an abrupt change in rise rate at about 12-13 minutes after ignition and the wood floor could be seen burning at about 20 minutes. The wood floor was eventually totally consumed by fire.

Test Two

The second test was conducted in the afternoon of 1 March. The ambient temperature was 51° F and there was just a slight breeze blowing, 0-5 knots from the west. The temperature remained relatively constant throughout the test, dropping to 48° F by end of test. A light rain fell during much of the test. Although the breeze was light, the fire did not fully engulf one side of the test fixture as completely as desired. The flame temperature averaged 1100-1300° F.

At one hour ten minutes after ignition of the diesel fuel, just as the fire was starting to die down, a significant explosion occurred. Seven minutes later, at one hour seventeen minutes, a second, less devastating explosion occurred; and four minutes after that, at one hour twenty-one minutes, a flash, without sound, was seen on the TV monitors.

Upon subsequent inspection it was determined that only projectiles 2 and 3 had functioned. Projectile 3, located to the rear of the SSC, was the first to detonate. The flash seen on the TV monitor was probably caused by liquid fill venting from one of the projectiles, possibly from the unexploded projectile 1. None of the other projectiles were damaged at all. A steel burster case with empty aluminum burster tube within was found outside the earthen enclosure. It could not be determined with certainty which projectile it came from. The condition of the functioned projectiles (i.e., flared mouths, bodies not cracked or broken, nose closure missing), and the partially intact nature of the burster case suggest low-order detonation with the burster partially ejected. Video of the test reveals that the first detonation caused considerable damage to the test fixture, opening up the SSC and destroying the Conex.

A review of the video reveals that at about 25 minutes into the burn, the wood floor within the enclosure started burning and within a few minutes flame could be seen at the top corner of the Conex. The Conex floor and one air temperature curve reflect a drastic increase in temperature. SSC Temperatures show a quick rise in the SSC door temperatures (inside & outside), indicative of the fact that the flame engulfed that side of the Conex more than the other. SSC air temperature curve reflects a relatively normal rise as does the SSC exterior side wall temperature. The SSC floor and interior wall temperatures show a dramatic rise, initially corresponding to the rise in Conex floor temperature and then probably sustained by combustion of wood within the SSC. The Projectile #1 temperatures do not have a curve for the burster top, which was lost when dumping data from the datalogger to the computer; however, the liquid cavity temperature shows the same sharp rise seen in the subsequent curves for Projectiles 2 &

3. The exterior temperatures for the projectile bodies seem to follow the rise in the SSC floor temperature (resulting from combustion of wood within the SSC), which eventually catches up to the SSC air temperature. The interior temperatures, however, (liquid cavity and burster top) appear to have reached a critical temperature just prior to 2000 seconds where an exothermic degradation process begins in both the explosive and the ethylene glycol fill which drives those temperatures to 1500° F before leveling off. The reaction continues at a much slower rate until detonation.

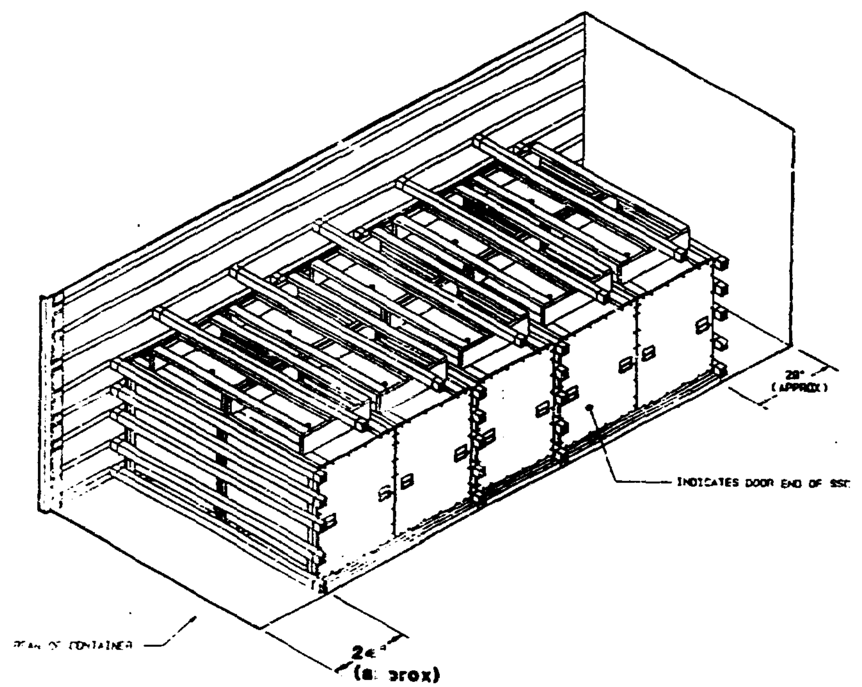
Conclusions

The two fire tests indicate that a reasonable amount of time is available to fire response personnel to fight a fire in the accident scenario described in the Introduction to this report, assuming that a response team can be on the scene within just a few minutes of ignition of such a fire. The SSC, with good structural integrity, appears to provide excellent protection for the projectiles from short-term exposure to fire, even under worst case conditions. Further, the blocking and bracing of the SSC within the MILVAN should generally ensure that the SSC will not be exposed directly to fire, providing the initial delay of heat transfer to the SSC.

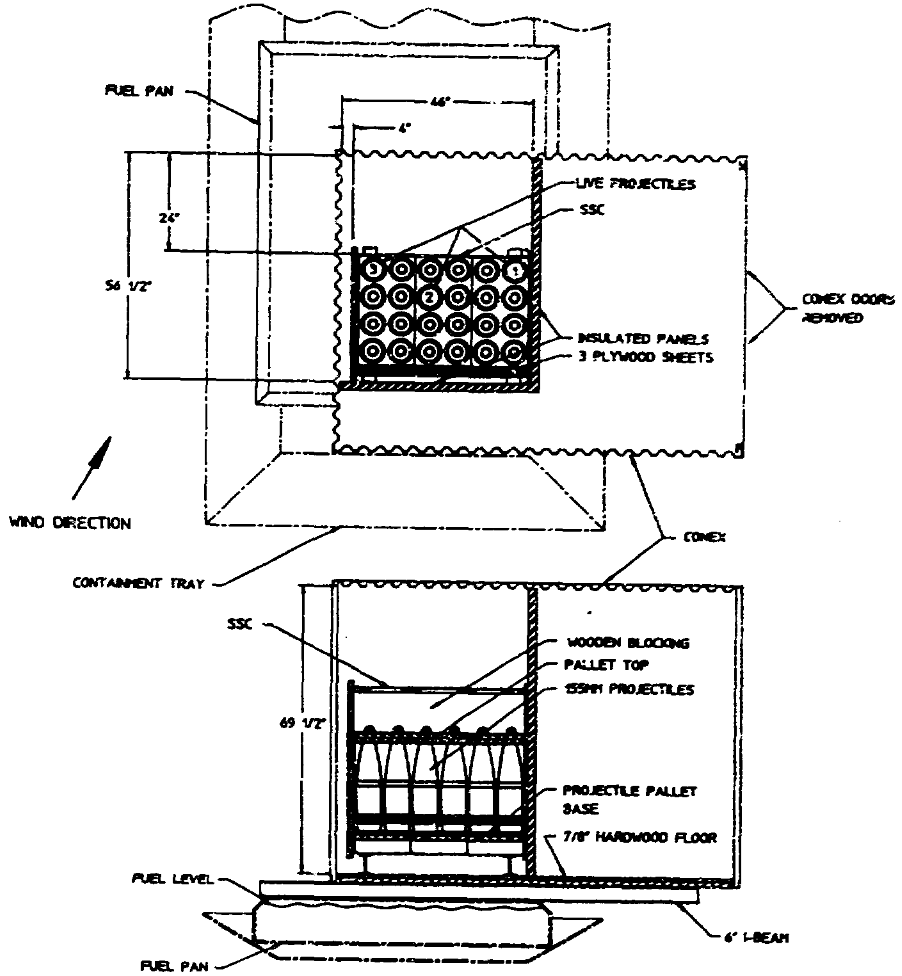
In both tests, the temperatures of the projectiles (both inside and outside) were near or below 150° F for the first 30 minutes, indicating relatively slow heat transfer through the SSC into the projectiles. Once the Conex wooden floor started burning at about 25 minutes in Test 2, however, temperatures within the SSC started to climb sharply. The Conex wooden floor in Test 1 rose to ignition temperature in about 15 minutes but did not actually begin to combust until 45-50 minutes after ignition of the fire. The conclusion here is that early combustion of the wooden floor in Test 2 was the driving mechanism that led to the detonations of the projectiles. Consideration may be given to treating the MILVAN wooden floors with fire retardant materials to gain further delay in combustion of the floor.

Thermocouple data from the two tests are not entirely consistent, largely because of the different wind conditions in each test which caused the fire to engulf the two critical sides of the Conex differently in each test. However trends in rise rates in the two tests are reasonably consistent, especially for the first 25 minutes.

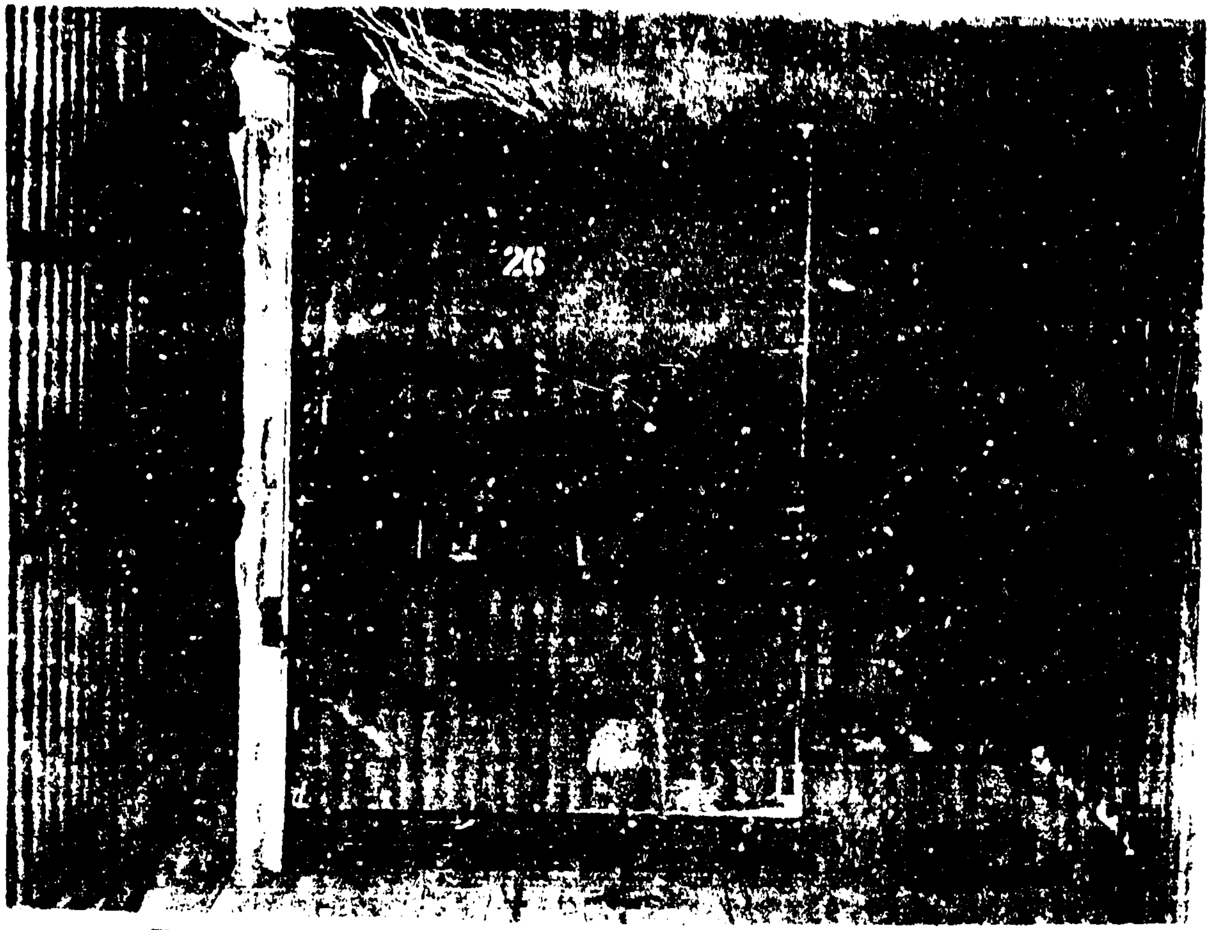
The next several pages illustrate setup and results for the two fire tests.

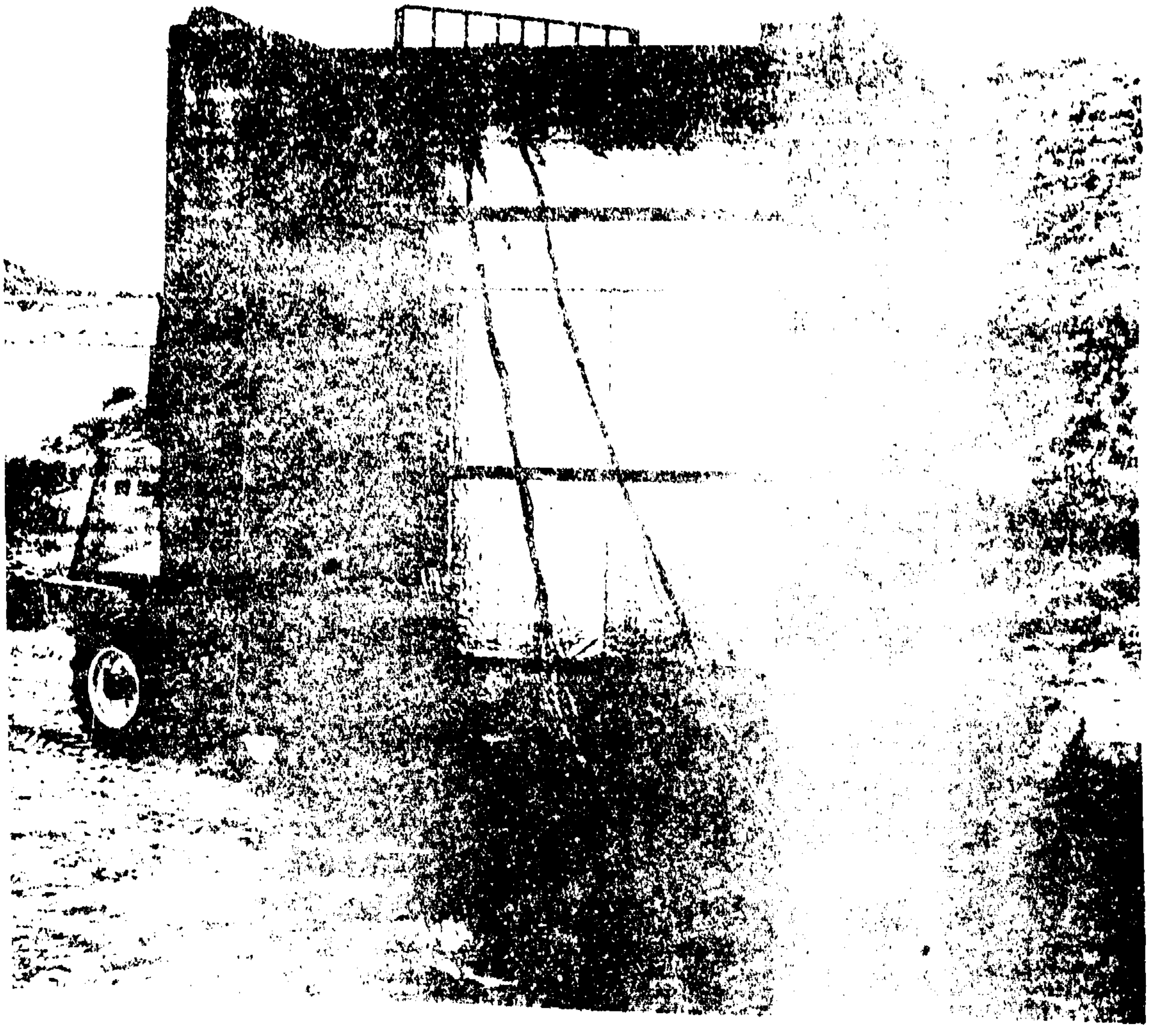


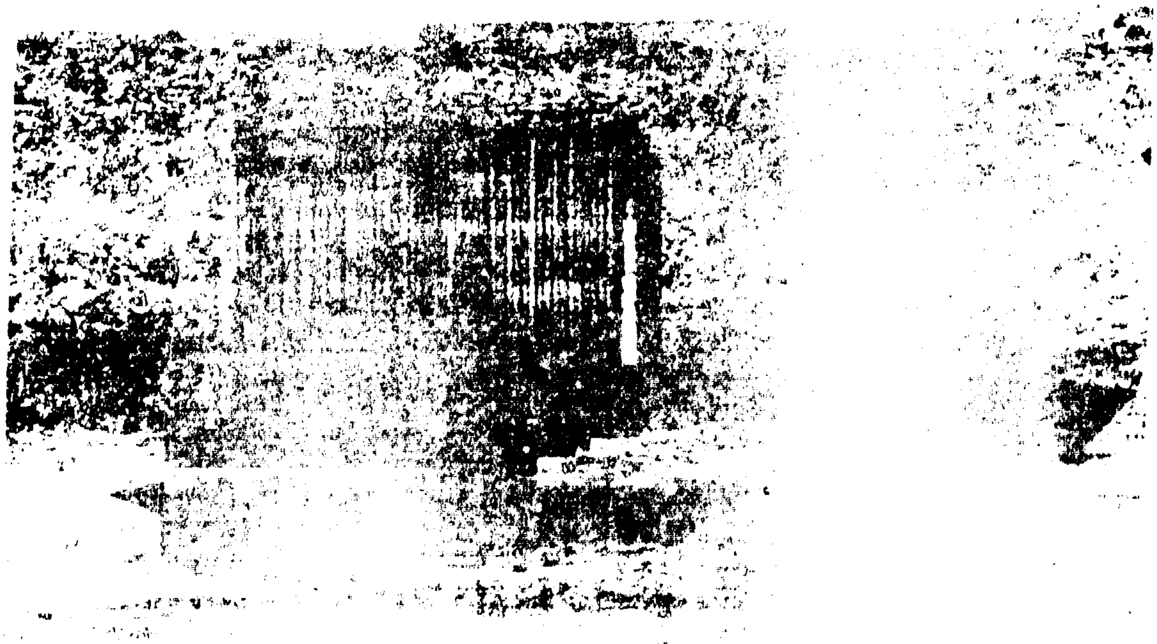
CUTAWAY-; LVAN WITH SSC

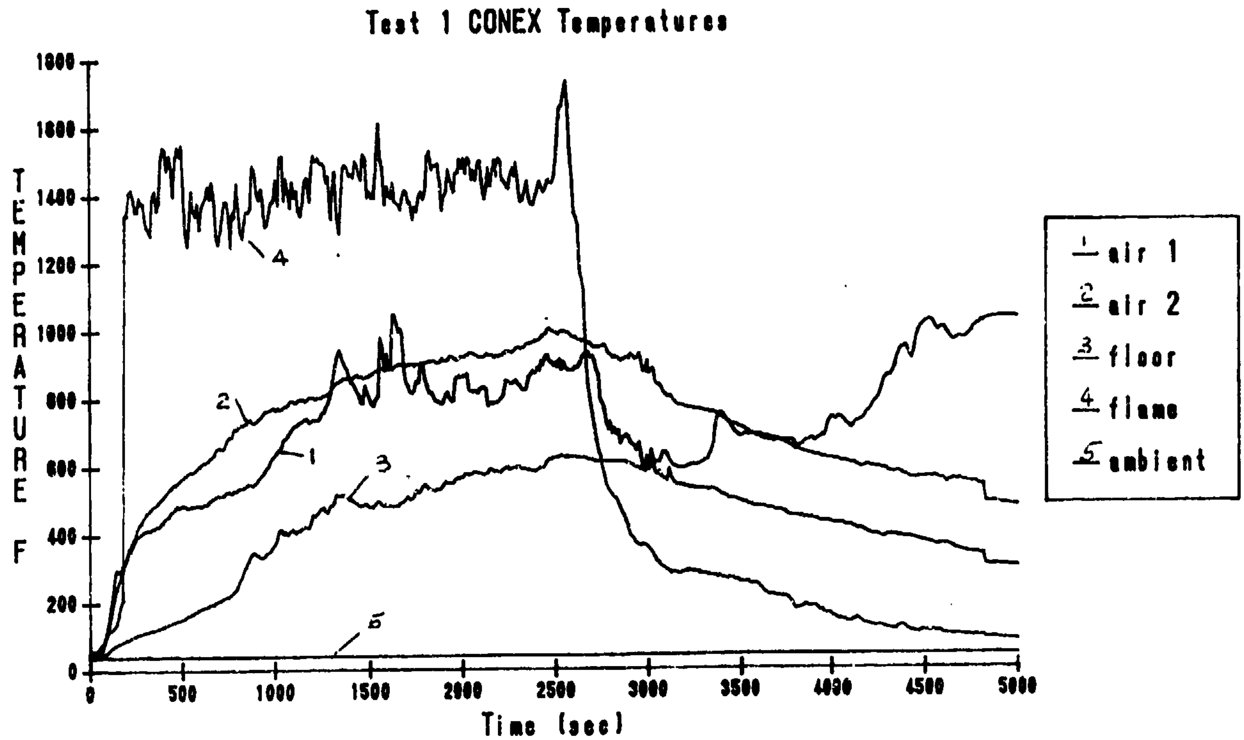


TEST SETUP


26



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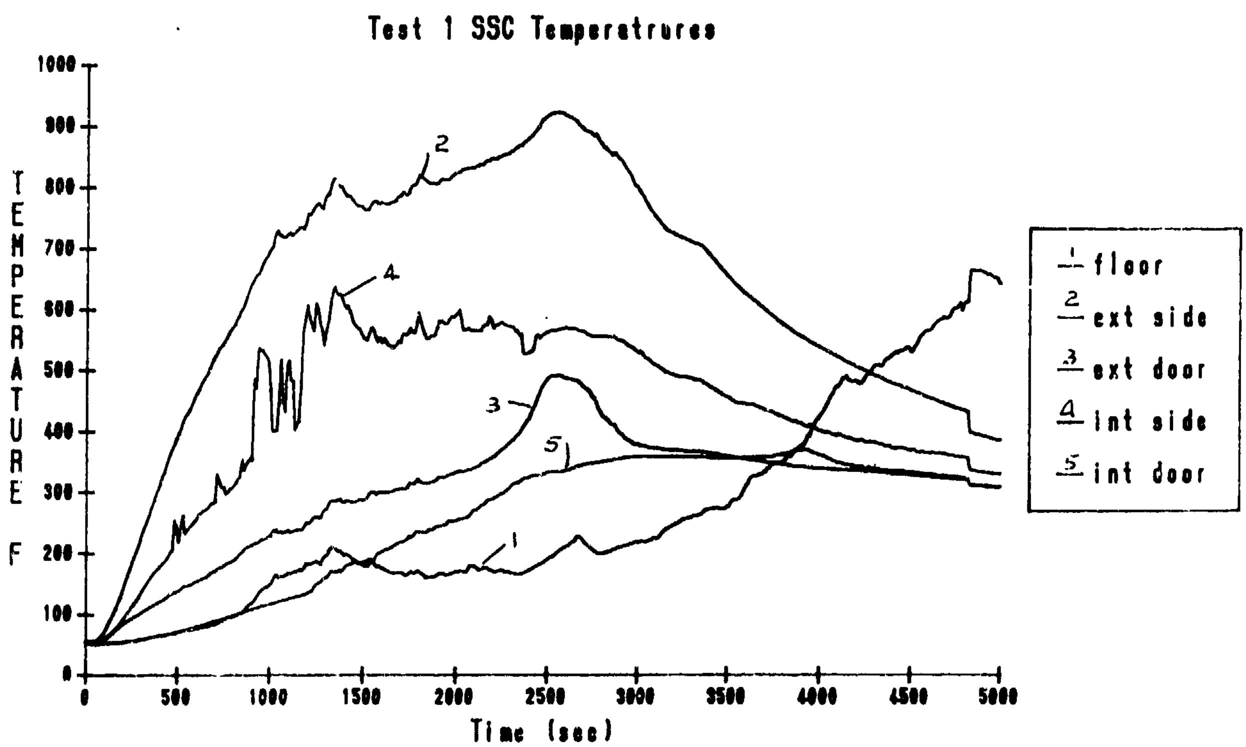
TEMPERATURE F
Time (sec)
1 air 1
2 air 2
3 floor
4 flame
5 ambient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TEMPERATURE F
Time (sec)
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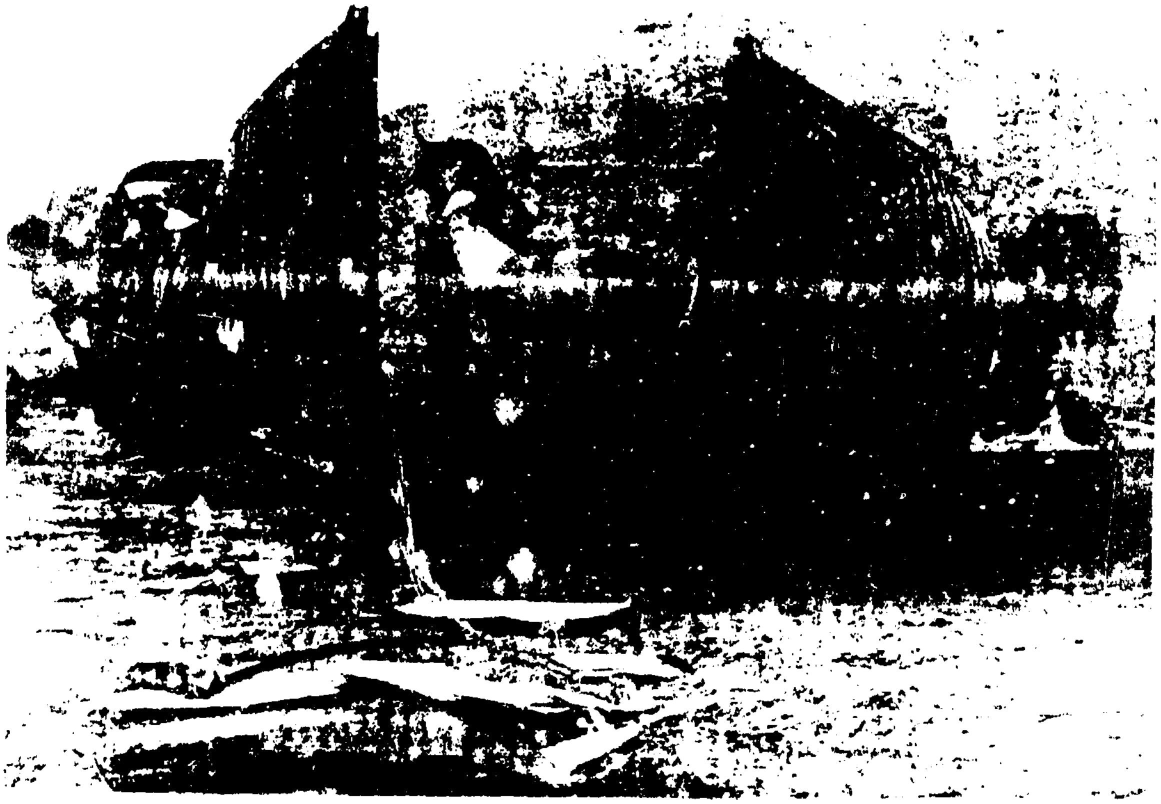
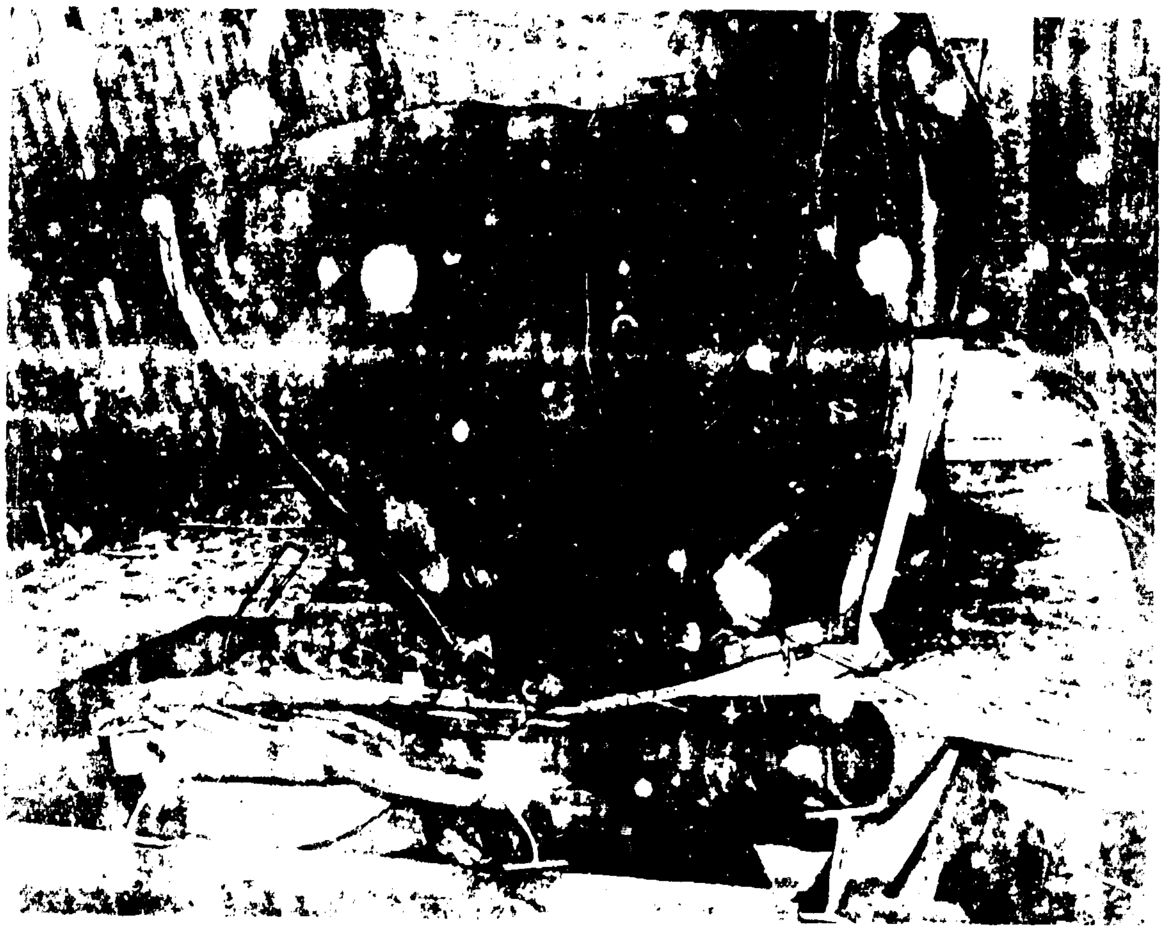
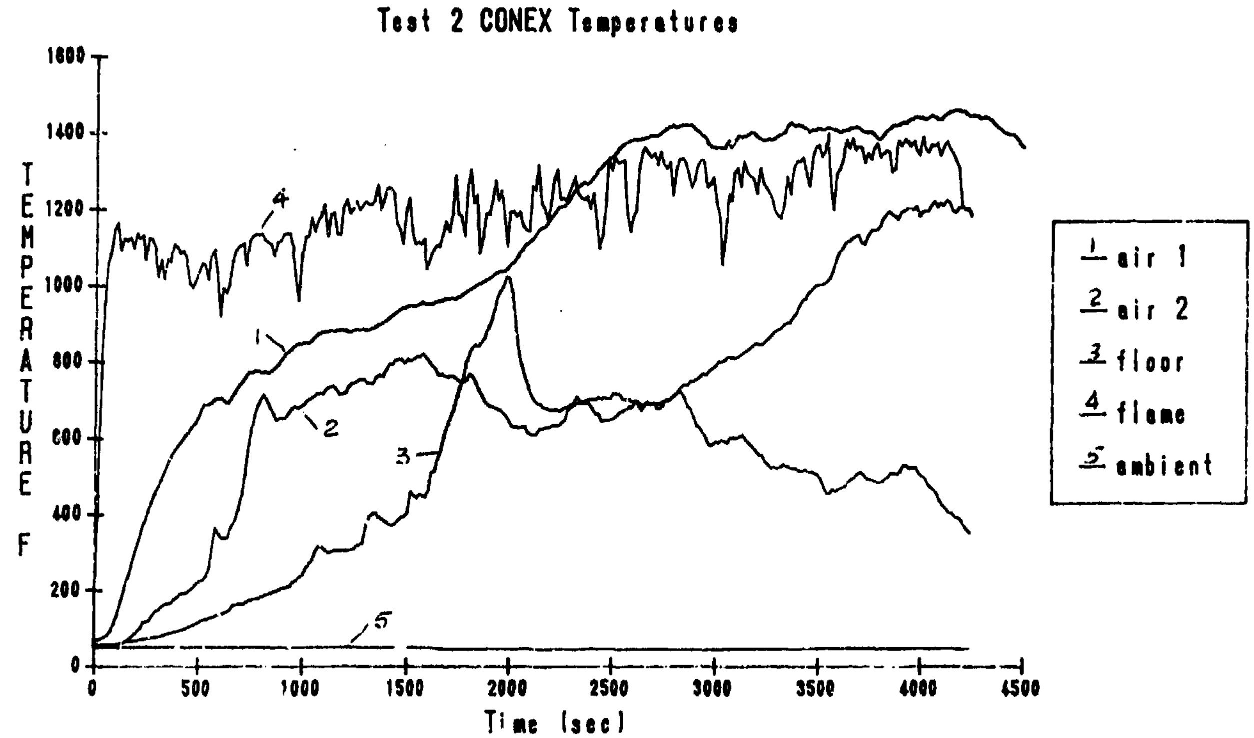
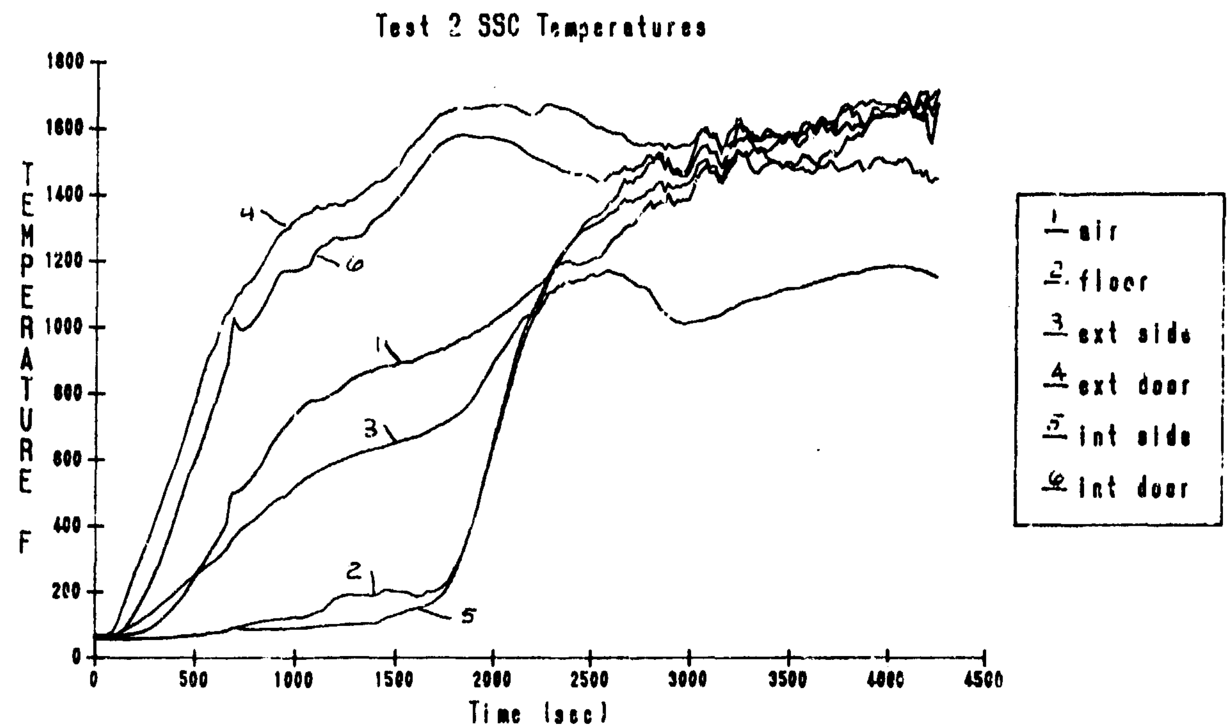
3 ext door
4 int side
5 int door






Test 2 CONEX Temperatures
TEMPERATURE F
Time (sec)
1 air 1
2 air 2
3 floor
4 flame
5 ambient


Test 2 SSC Temperatures
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REFLECTED BLAST MEASUREMENTS NEAR PANCAKE CHARGES

by

Edward D. Esparza
Southwest Research Institute
San Antonio, Texas

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ABSTRACT

Normally and obliquely reflected pressure and impulse data from pancake (cylindrical disk) charges were recently measured on two limited tests series as part of two experimental investigations. Composition B charges weighing 3.0 lb were detonated over a rigid, reflecting flat surface at scaled distances of 0.17 to 1.47 ft/lb$^{1/3}$. Pressure transducers and impulse plugs were mounted flush with the flat surface directly below the free-air charge detonations and at a few radial distances from the normal position along the flat surface. The peak reflected pressures and scaled impulses are presented as a function of normal scaled distances and angle of obliquity. Some comparisons are made with previous test data from pancake charges of slightly different aspect ratio, and with data and curves for spherical charges. The results confirm that at small scaled distances from a free-air charge detonation, geometry of the charge has a very significant effect on the reflected blast loads and their spatial distribution. From the limited data, approximate reflected pressure and impulse curves are presented for characterizing the blast loads from a cylindrical disk near a flat surface.

INTRODUCTION

Background

Experimental characterization of blast waves from high explosive detonations in free-air dates back to World War II. As reported by Kennedy [1], in the earliest work the investigators unknowingly used explosive charges of different shapes to conduct their free-air experiments and developed smooth TNT curves for peak overpressure and positive impulse. At the scaled distances tested of $Z > 5.0$ ft/lb$^{1/3}$, the difference in these parameters due to the shape of the explosive was not detected probably because of the scatter of this early data due in part to the geometry of the blast transducers used. Stoner and Bleakney [2] also reported results of free-air experiments conducted with charges of various shapes at scaled distances of $Z > 10$ ft/lb$^{1/3}$ and also did not recognize that the geometry of the explosive charge could affect the blast wave.

After World War II, Pentolite was established as a standard explosive in most free-air experiments because it gave reproducible data when detonated in small quantities. To avoid effects of charge shape, cast spheres were used exclusively. Goodman [3] compiled large numbers of measurements of side-on and normally reflected blast parameters which included the first comprehensive set of reflected pressure and impulse measurements made by Hoffman and Mills [4] with piezoelectric transducers flush mounted in a concrete wall. Later, O.T. Johnson, et al [5], devised a simple plug technique for measuring impulse in normally reflected blast waves. The plug technique allowed measurements of reflected impulse with good accuracy to very small scaled distances [6]. Jack [7], using improved pressure transducers, extended further the range of reflected pressure-time measurements making a few measurements at scaled distances as small as 0.5 ft/lb$^{1/3}$. Baker [8] provides an excellent historical summary up to 1970 and presents much of the data from these various investigations. Later measurements made by Esparza of normally reflected pressures and impulses at scaled distances as small as 0.3 ft/lb$^{1/3}$ from spherical charges are reported in References 9 and 10. Reference 11 has additional normally reflected data for scaled distances greater than 0.84 ft/lb$^{1/3}$. More recently, Huffington and Ewing [12] report on reflected impulse measurements near spherical charges at scaled distances of 0.15 to 0.5 ft/lb$^{1/3}$. Some reflected pressure measurements at scaled distances of 0.3 and 0.5 ft/lb$^{1/3}$ were also recorded on three exploratory tests.

Measurement of blast parameters from other than free-air detonations also dates back to World War II [1]. Extensive experimentation has been done by many investigators with ground bursts. For example, Kingery [13] compiled and analyzed data from many large hemispherical TNT charges detonated on the ground. Ground bursts experiments were first used by Adams, et al [14] to investigate blast parameters from explosive charges of different shapes. The scaled distances in their tests were greater than 9 ft/lb$^{1/3}$. Other investigators followed with experiments using non-spherical charge geometries such as cylinders, cubes, cones, pancakes, etc., detonated in free-air or on the ground [15-18]. Generally, side-on pressure measurements were reported and scale distances were greater than 5 ft/lb$^{1/3}$. Measurements of side-on overpressures at smaller scaled distances for cylindrical charges detonated on the ground surface are reported in References 19 ($Z \geq 3$ ft/lb$^{1/3}$) and 20 ($Z \geq 1.25$ ft/lb$^{1/3}$).

Reflected pressure and impulse measurements from non-spherical charges at scaled distances as close as $Z = 0.3$ ft/lb$^{1/3}$ were made by Esparza, as also reported in References 9 and 10. With an increase in interest to predict damage and response of armor or structural materials to close-in blasts, a series of investigations was recently completed [21-23]. As part of two of these investigations, normally and obliquely reflected pressures and impulses were measured at scaled distances ranging from 0.17 to 1.47 ft/lb$^{1/3}$ from disk (pancake) charges with a length-to-diameter ratio of 0.55. This paper presents a brief description of the limited number of experiments conducted with the pancake charges and the results obtained. More detailed descriptions of the tests and tabulations of all the data can be obtained in References 21 and 23. The peak reflected pressures and scaled impulses measured are presented in this paper as a function of scaled distance and angle of obliquity. Some comparisons are made with previous test data of cylindrical disks of slightly different aspect ratio from Reference 9, and with several test data and curves for spherical charges.

<u>Scaling</u>

Scaling of blast wave properties is a common practice used to generalize blast data from high explosives. Scaling or model laws are used to predict the properties of blast waves from large-scale explosions based on tests at a much smaller scale. The most common scaling law is the one formulated independently by Hopkinson [24] and Cranz [25]. This law states that self-similar blast waves are produced at the same scaled distance when two explosives of similar geometry and of the same explosive material, but of different size, are detonated in the same atmosphere. The Hopkinson-Cranz or cube-root scaling law has become so universally used that high explosive blast data are almost always presented in terms of the scaled parameters generated by this law. A more complete discussion of this law is given by Baker [8].

For explosive charges of different geometry a modified cube-root scaling law was developed in Reference 10. In a functional format the reflected blast pressure $P_{r\alpha}$ and impulse $i_{r\alpha}$ are defined as

$$P_{r_\alpha} = f_1\left(\frac{R}{r}, r_l, \alpha, \frac{R}{W^{1/3}}\right) \tag{1}$$

$$\frac{i_{r_\alpha}}{W^{1/3}} = f_2\left(\frac{R}{r}, r_l, \alpha, \frac{R}{W^{1/3}}\right) \tag{2}$$

where

R = standoff distance

r = characteristic dimension of the charge

r_i = shape factor for explosive charge

α = angle of obliquity

W = explosive charge weight

For model and prototype experiments using charges of similar geometry these two equations reduce to

$$P_{r_\alpha} = f_1\left(\alpha, \frac{R}{W^{1/3}}\right) \tag{3}$$

$$\frac{i_{r_\alpha}}{W^{1/3}} = f_2\left(\alpha, \frac{R}{W^{1/3}}\right) \tag{4}$$

The data from the pancake charges is presented in graphical form using these three parameters. When comparisons are made to disks of a different aspect ratio or to spherical data, different curves are denoted for each geometry.

DESCRIPTION OF EXPERIMENTS

Two limited series of experiments were conducted at the Southwest Research Institute (SwRI) explosives range to measure reflected pressure and impulse from cylindrical disks of Composition B. The first series was part of a project conducted by SwRI for the FMC Corporation [21]. The work done related to the development of an Explosive Shock Test for evaluating armor materials and welded joints [26, 27]. As part of this effort, a test fixture (table) was designed and built for testing the armor plates and welded joints. This table was adapted for making the required measurements at a scaled distance of 1.47 $ft/lb^{1/3}$. The transducer holder plate for the first series of tests consisted of a 6-inch thick plate of common grade A36 steel supported by a 2-inch thick support table, 58 inches square, on four 10-inch OD by 1.0-inch wall thick round tube legs of the same material. A sketch of the fixture is shown in Figure 1. This figure also defines the normal distance R between the charge and the target plate, and the angle of obliquity α for a measurement location on the plate a radial or ground distance R_G from the normal location. The fixture was modified slightly for the second test series. Since much higher pressures were expected at the smaller scaled distances, a cover plate, 1 x 24 x 24 inches, of high strength steel (200,000 psi) was bolted on top of the 6-inch, transducer holder plate. Transducer and plug holes were machined on the expendable cover plate and through the 6-inch plate.

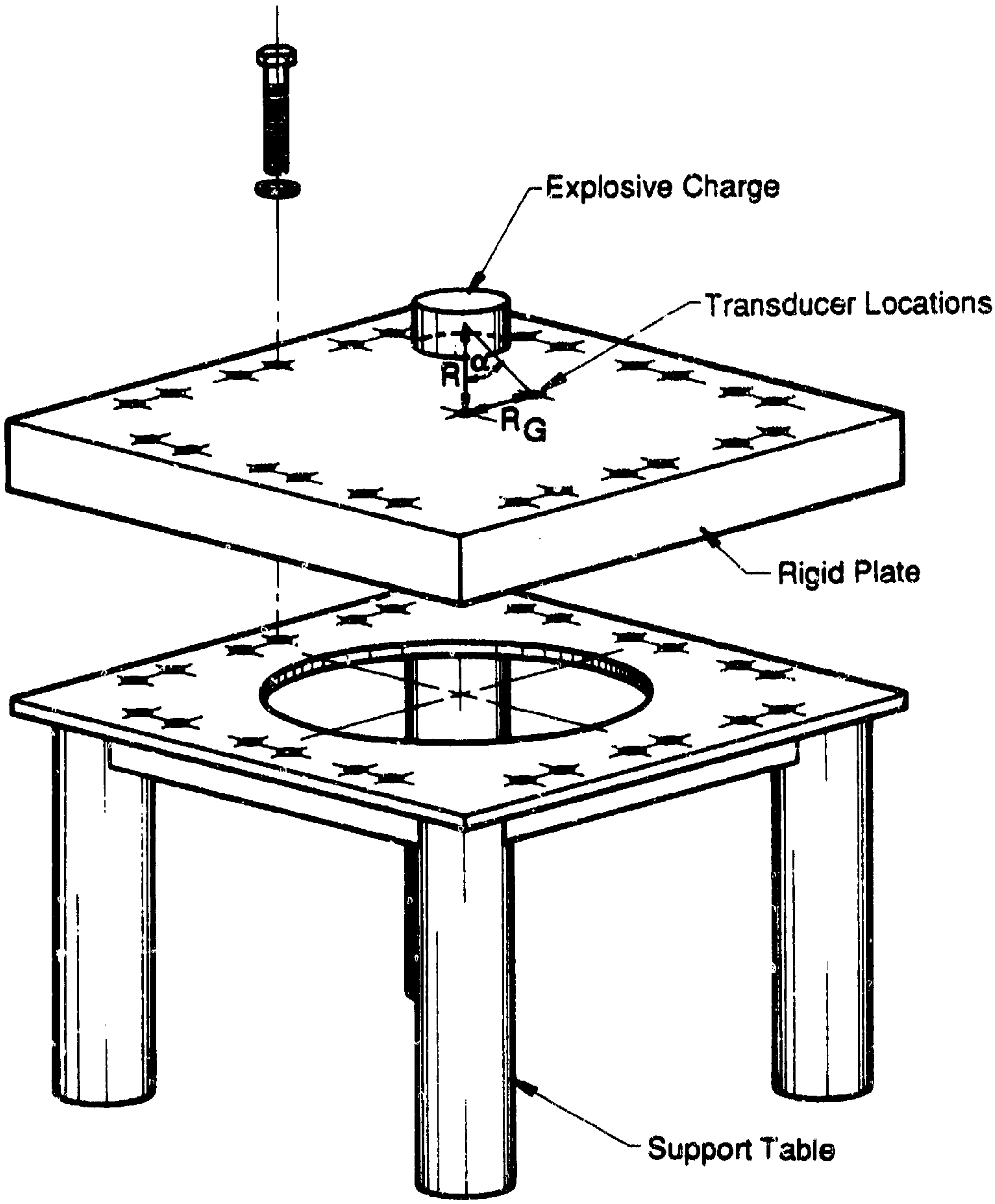


Figure 1. Test Apparatus For Reflected Blast Measurements

A summary of the limited number of experiments conducted is presented in Table 1. The first limited series of tests consisted of four experiments all at a scaled distance of 1.47 $ft/lb^{1/3}$ with transducer locations at angles of obliquity of 0°, 19.3°, and 33.8°. The pressure-time histories recorded were made using piezoelectric pressure transducers manufactured by PCB Piezotronics, Models 109A02 and 102A03. Transducers of the same type have been used successfully to obtain the blast data in many projects including those in References 10, 11, 28, and 29. Due to the interest in defining loads from detonations in close proximity to a target, the second limited series of five tests was designed to characterize pressure and impulse loads of a cylindrical disk charge at much smaller scaled distances. Of particular interest were distances sufficiently close so as to simulate the effects of surface mines, and detonations of stowed ammunition or reactive armor packages. Normal and oblique reflected measurements were attempted at scaled distances ranging from 0.17 to 0.67 $ft/lb^{1/3}$ [23]. The severity of the environment at these close distances to an explosive charge makes reflected blast pressure measurements an extremely difficult problem. Consequently, only a few data points can be found in the literature, even for spherical charges [7, 9, 10, 12]. For a cylindrical disk (or pancake) charge even less data [9] are found at these small scaled distances since this geometric shape enhances the reflected pressure output of an explosive on transducers located at small angles of incidence.

Two different measurement techniques were used in obtaining the reflected pressure data presented in this paper for the second series of tests. At angles of incidence sufficiently large such that the reflected pressure was estimated to be less than 20,000 psi, piezoelectric gages Model 102A03 made by PCB Piezotronics were used as in some of the first series measurements. At locations where higher pressures were expected, pressure bars made from Vascomax 350 steel, similar to those used in References 9 and 10, were used. Each of these transducers consisted of a high strength steel bar having a yield strength of 350,000 psi on which a pair of strain gages was mounted diametrically opposed to sense the longitudinal strain associated with an elastic wave

Table 1. Summary of Experiments

Series	Scaled Distance ($ft/lb^{1/3}$)	Pressure Data Location (degrees)	Impulse Data Location (degrees)	No. of Tests
1	1.47	0°, 19.3°, 33.8°	0°, 19.3°, 33.8°	4
2	0.67	0°, 9.5°, 18.4°, 26.6°	9.5°, 26.6°	2
2	0.50	0°, 12.5°, 24°	12.5°	1
2	0.33	18.4°, 33.7°, 45°	0°, 18.4°, 45°	1
2	0.17	33.7°, 53.1°		1

propagated through the bar. The bars had the strain gages 8 inches below the sensing end which was mounted flush with the reflecting surface and held in place by a silicon rubber insert. These inserts were soft enough to allow the elastic wave to travel down the bar without distortion, and snug enough to hold them in place for the test and protect the strain gages from the detonation products. The bars were 40 inches long, thus long enough to record a pressure pulse of 325 µsec before the reflection pulse from the far end of the bar arrived at the strain gages.

The PCB pressure transducers used in both series of tests were connected to PCB Model 494A06 units for power and amplification. The strain gages for the pressure bars were connected to Vishay Model 2310 signal conditioners/amplifiers. The blast pressure-time histories were recorded on magnetic tape using an Ampex Model 2230, Wideband II, FM tape recorder. The data were processed after each test in sets of four channels using two Nicolet Model 2090 transient recorders for digitizing. The digital data were transferred from the transient recorders to a DEC 11/23 computer and stored on hard disk and diskettes. Final data processing and plotting were then accomplished from the diskettes with either a DEC 11/70 or an Apple McIntosh II computer. Figure 2 shows a block diagram of the pressure data record/reduction system. Samples of data traces recorded with both types of pressure transducers are shown in Figure 3.

Two different impulse measurement techniques were used to obtain the data presented here. For the first series of tests, all impulse data were from the integration of the pressure-time histories recorded from the piezoelectric transducers. For the second series of tests, a few of the impulse data points were from the integration of pressure-time histories from the piezoelectric transducers. None of the pressure bar transducer data were integrated. The majority of the data in the second test series were obtained using the impulse plug technique in a similar manner to that reported by Johnson, et al [5]. This same technique has been used in many investigations including those in References 6, 9, 10 and 12. This technique consists of using small right circular cylinders of suitable mass, flush mounted on the reflecting surface, which are impacted by the blast pressure and allowed to move without restrictions. The velocity of each plug is determined over a short distance of travel. For vertically moving plugs, the velocity is corrected for gravitational effects. Using the impulse-momentum theorem the reflected specific impulse $i_{r\alpha}$ loading each plug can be calculated knowing the mass of the plug, the exposed area, and the plug velocity. The plugs used were 0.490 inches in diameter, and the holes on the transducer plate were 0.500 inches to minimize the blow-by of explosion products but allow enough clearance for elastic deformation of each plug without binding during the test.

Two methods were used to record the plug velocity. The first was the use of a high speed camera to film the motion of the plug against a scaled backdrop. Through knowledge of the camera framing rate and the scaled grid patterns on the backdrop which indicate the displacement of each plug, the plug velocity can be computed. The high speed camera was the primary means of

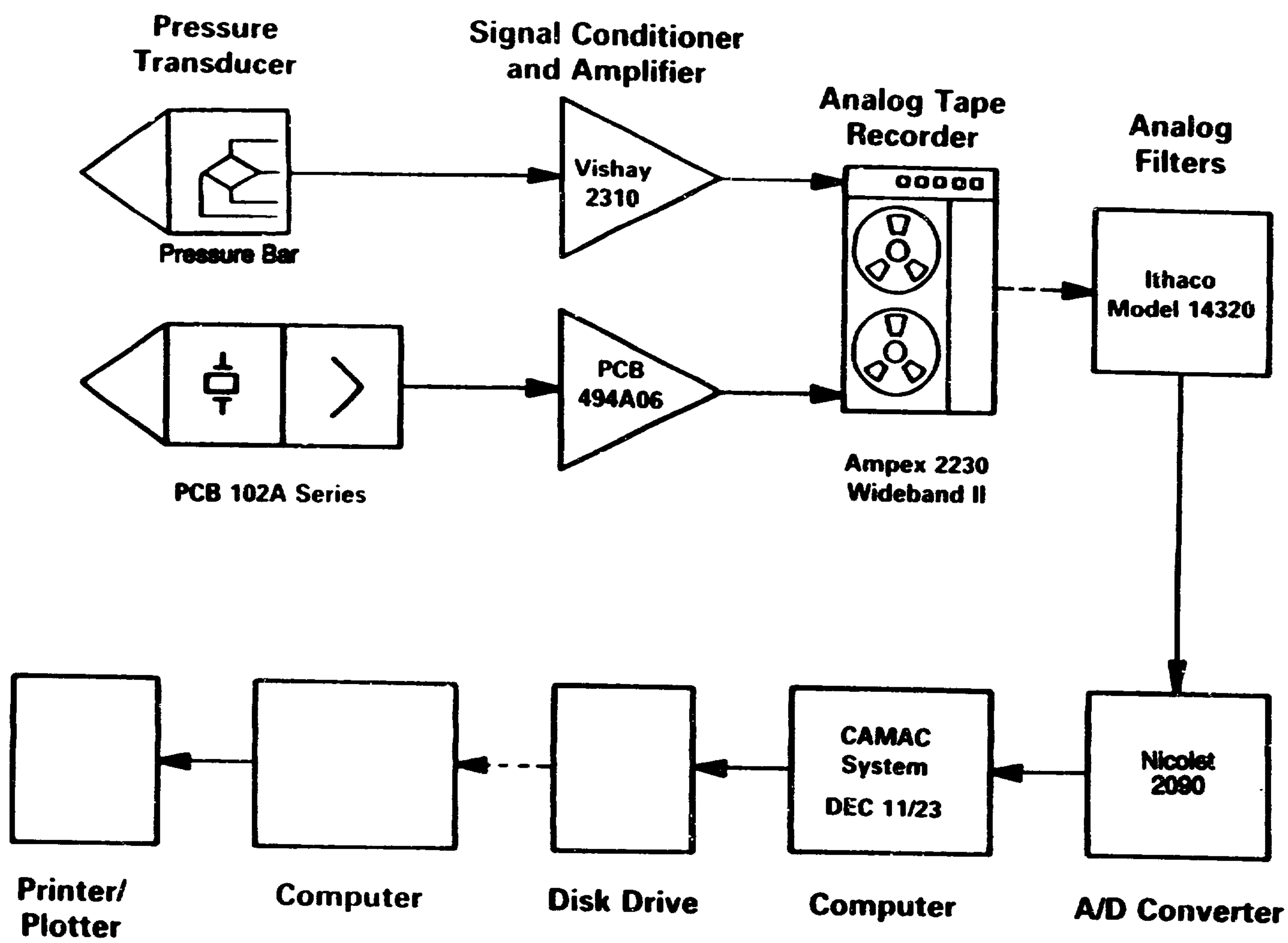
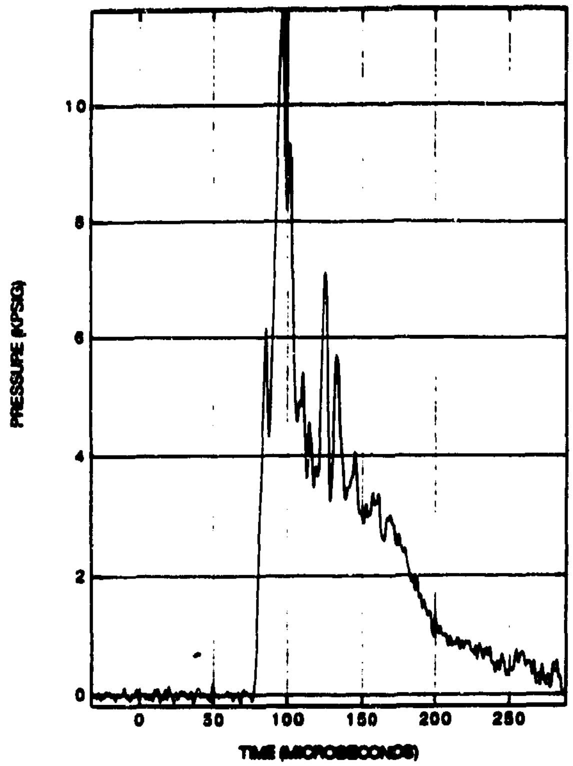
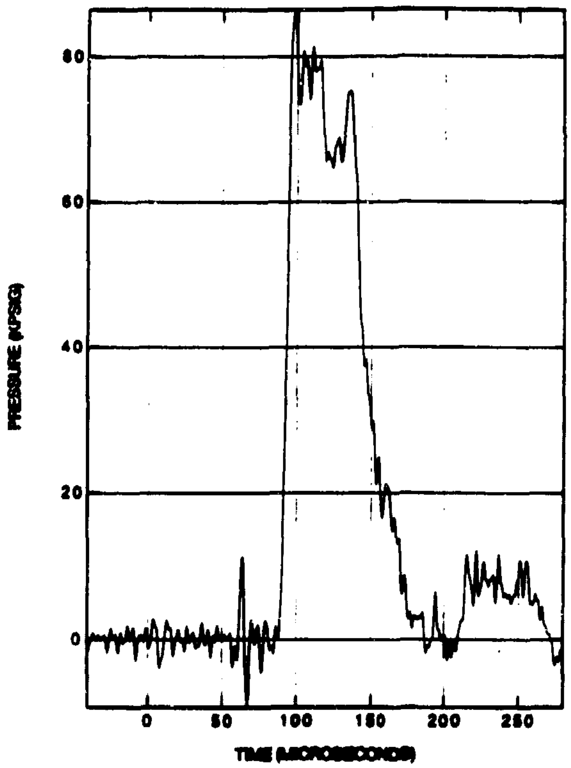


Figure 2. Data Recording and Processing System



(a) Piezoelectric transducer at $Z = 0.67$ ft/lb$^{1/3}$ and $\alpha = 26.6°$



(b) Pressure Bar Transducer at $Z = 0.5$ ft/lb$^{1/3}$ and $\alpha = 12.5°$

Figure 3. Reflected Pressure Measurements from Disk Charges at Small Scaled Distances

determining plug velocity. This method requires sufficient lighting for proper exposure, and motion film analysis after the test. One of the problems with this technique is that the field of view is sometimes obscured at the wrong time by the fireball or the explosive products. To overcome some of these problems a second system was tried to obtain plug velocities. This consisted of a 1-inch diameter PVC tube about 16 inches long placed concentrically underneath the transducer plate which allowed plug travel without interference. Even for the cases where the plug was expected to begin to tumble, the PVC tubes were not expected to provide much frictional resistance. At two stations a known distance apart on each tube a set of fiber-optic light detector and bright incandescent light source was mounted. As the plug travels through the tube, signals from the detectors were recorded on magnetic tape at the time that each end of the plug passed by the detector. This second method had very limited success and consequently the impulse data reported here is primarily that determined with the high-speed camera.

Measurements of reflected pressure and impulse were made on nine experiments using pancake (cylindrical disk) charges with an aspect ratio (length-to-diameter) of 0.55. This charge geometry and aspect ratio were selected to generate an increase in the blast loading over a large area on a target plate when compared to a spherical charge of the same weight at the same standoff distance (same scaled distance) [21]. The pancake charges for all tests were nominal 3.0 lb castings of Composition B, 4 7/8 - 5 inches in diameter and 2 3/4 inches in thickness. Note that the instrumentation layout in the test fixture was such that except for the normally reflected location at the center of the plate, more than one measurement could be made at a specific angle of obliquity. Consequently more than one data point were obtained at some angles of obliquity even though only one test was conducted at a particular scaled distance. Also, not every test used all the transducer locations available.

RESULTS AND DISCUSSION

Reflected Pressures

Several normally and obliquely reflected measurements were made in the nine close proximity blast tests listed in Table 1. The unscaled data for these nine tests are tabulated in Table 2. As indicated in Table 1, normally reflected pressure was measured at three scaled distances and the individual data points are listed in Table 2. These peak pressures are plotted in Figure 4 as a function of scaled distance. The data are plotted as individual points to show the limited number of measurements made and the spread of the data for the one scaled distance with more than one measurement. Also shown in Figure 4 are normally reflected pressures for pancakes of a slightly different aspect ratio from Reference 9. The TNT curves for spherical charges from "Structures to Resist the Effects of Accidental Explosions, Volume II, Blast, Fragment, and Shock

Table 2. Reflected Pressure and Impulse Data From 3 lb, Composition B Disk Charges

R Standoff Distance (ft)	R_G Radial Distance (ft)	$P_{r\alpha}$ Reflected Pressure (psi)	$I_{r\alpha}$ Reflected Impulse (psi-ms)
2.115	0.0	19,600	550
"	0.0	20,100	550
"	0.0	22,300	-
"	0.0	18,800	560
"	0.75	11,000	360
"	0.75	4,600	330
"	0.75	12,600	370
"	0.75	7,500	-
"	1.42	880	170
"	1.42	750	-
"	1.42	1090	125
"	1.42	670	-
"	1.42	1030	-
"	1.42	900	-
1.0	0.0	123,000	-
"	0.167	103,000	3,760
"	0.167	-	2,550
"	0.167	-	3,100
"	0.333	31,600	-
"	0.500	8450	410
"	0.500	12,000	550
0.75	0.0	206,000	-
"	0.167	88,000	4,110
"	0.333	25,500	-
0.50	0.0	-	10,040
"	0.167	128,000	2,200
"	0.333	23,500	-
"	0.500	10,700	370
"	0.500	13,700	340
0.25	0.167	268,000	-
"	0.333	15,800	-

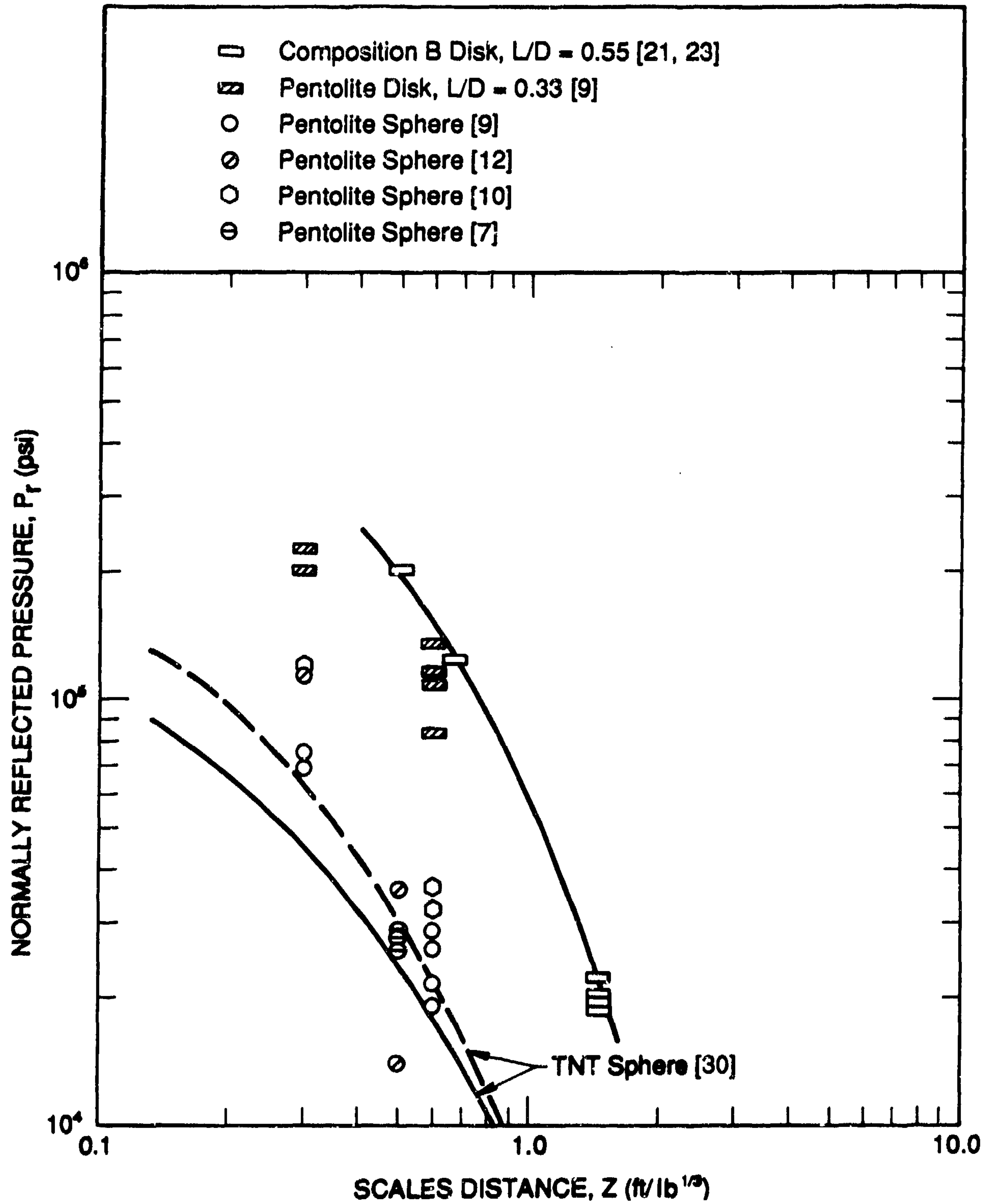


Figure 4. Comparison of Normally Reflected Pressures for Pancake and Spherical Charges Detonated in Free-Air

Loads" [30], which is part of an upgrade to Reference 31, are included in Figure 4. According to Reference 30, the dashed curve denotes extrapolation of the curve to the charge surface or an upper limit of experimental data and variation in theoretical predictions. In addition, individual data points from spherical charges from References 7,9, 10 and 12 are included for comparison.

The pancake or disk data shown in Figure 4 for an L/D ratio of 0.55, though limited in quantity, appears to be self-consistent as a function of scaled distance. It is also not too out-of-line with the older data from Reference 9 for disk charges of slightly different aspect ratio. Comparing to the spherical data and TNT curves it is obvious that normally reflected pressures from the disk charges are significantly greater at the same small scaled distances. From both sets of data and the number of data points shown it is obvious that a very limited number of measurements of normally reflected peak pressure at scaled distances less than 1.0 lb/ft^3 have been made. Furthermore, the limited spherical data shown indicates that the normally reflected pressure TNT curves from Reference 30 are not well defined experimentally at small scaled distances and considerable uncertainty would exist in predictions made with these curves.

The spatial distribution of the reflected pressures on the rigid test plate from the nine pancake tests (L/D = 0.55) as a function of angle of obliquity is presented in Figure 5. Note that as shown in Figure 1, the angle of incidence α is related to the transducer location by the $\tan \alpha = R_\alpha/R$. Therefore, either α or R_α/R could be used for plotting these data. Also shown in this figure are the data from Reference 9 for pancakes with L/D = 0.33. For clarity only the value of the mean peak pressure of one to six data points is plotted for each measurement location. The data are plotted as functions of the angle of obliquity (degrees) and scaled distance ($ft/lb^{1/3}$) as dictated by the scaling relationship of Equation 3. Constant scaled distance curves have been "eye-fit" through these data points to better show the trends of the data, solid curves for the new data [21, 23] and dashed curves for the previous data [9]. Although the aspect ratios are slightly different, the general trends of the data are similar for all the disk data. For each scaled distance, the reflected pressure at the normal location ($\alpha = 0°$) is the highest and decreases with the angle of incidence. And as the scaled distance increases, the reflected pressures decrease at similar angles of incidence.

In Figure 6 approximate curves combining the data for disks with L/D = 0.55 [21, 23] and L/D = 0.33 [9] are presented for 5 scaled distances, and are compared with spherical charge data from References 9, 10, and 12 and spherical charge curves from Reference 11 which fitted the data from References 9 and 10 for scaled distances of 0.3 and 0.6 $ft/lb^{1/3}$. The data from Huffington and Ewing [12] are the most recent and were compared in their report to SwRI data from Reference 10. In one of their three exploratory tests in which normally reflected pressures were recorded at Z = 0.3 $ft/lb^{1/3}$, the data trace recorded by the BRL showed a peak pressure of 116,000 psi; but because of gage damage it was not clear if the true peak pressure was recorded [12]. However, that value compares well with the 120,000 psi measured by Esparza of SwRI and reported in

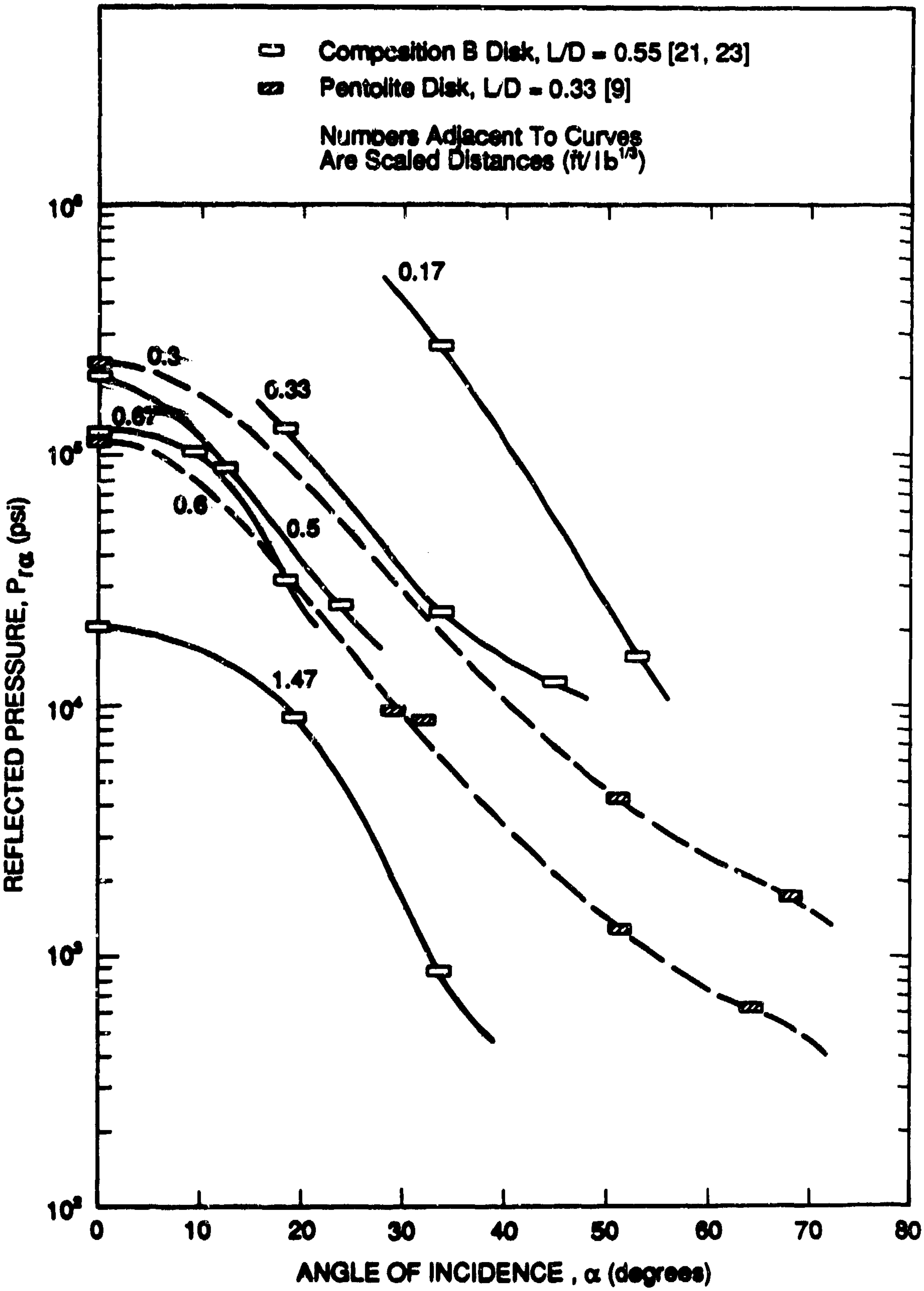


Figure 5. Spatial Distribution of Peak Reflected Pressure

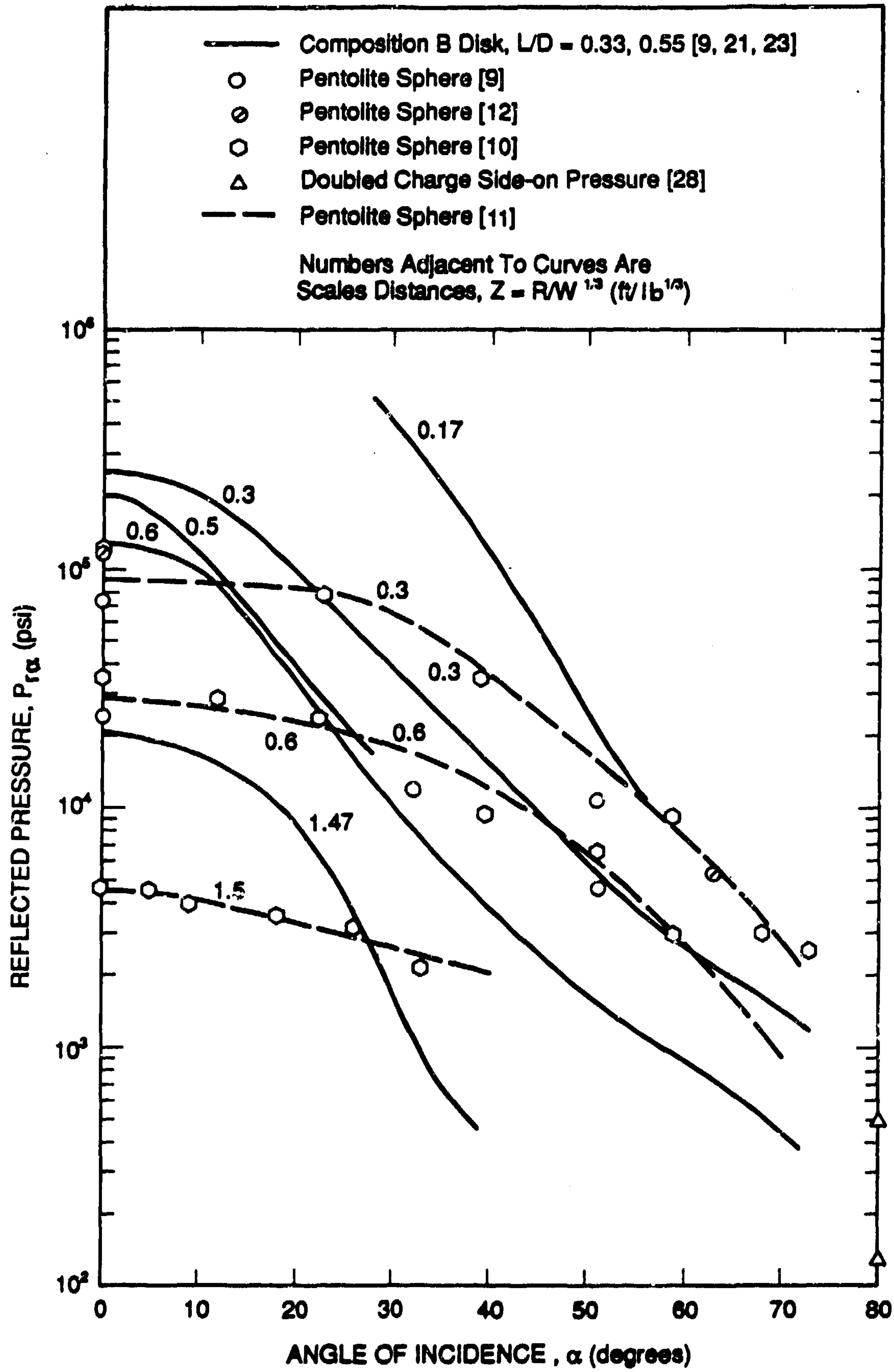


Figure 6. Comparison of Reflected Pressure for Pancake and Spherical Charges Detonated in Free-Air

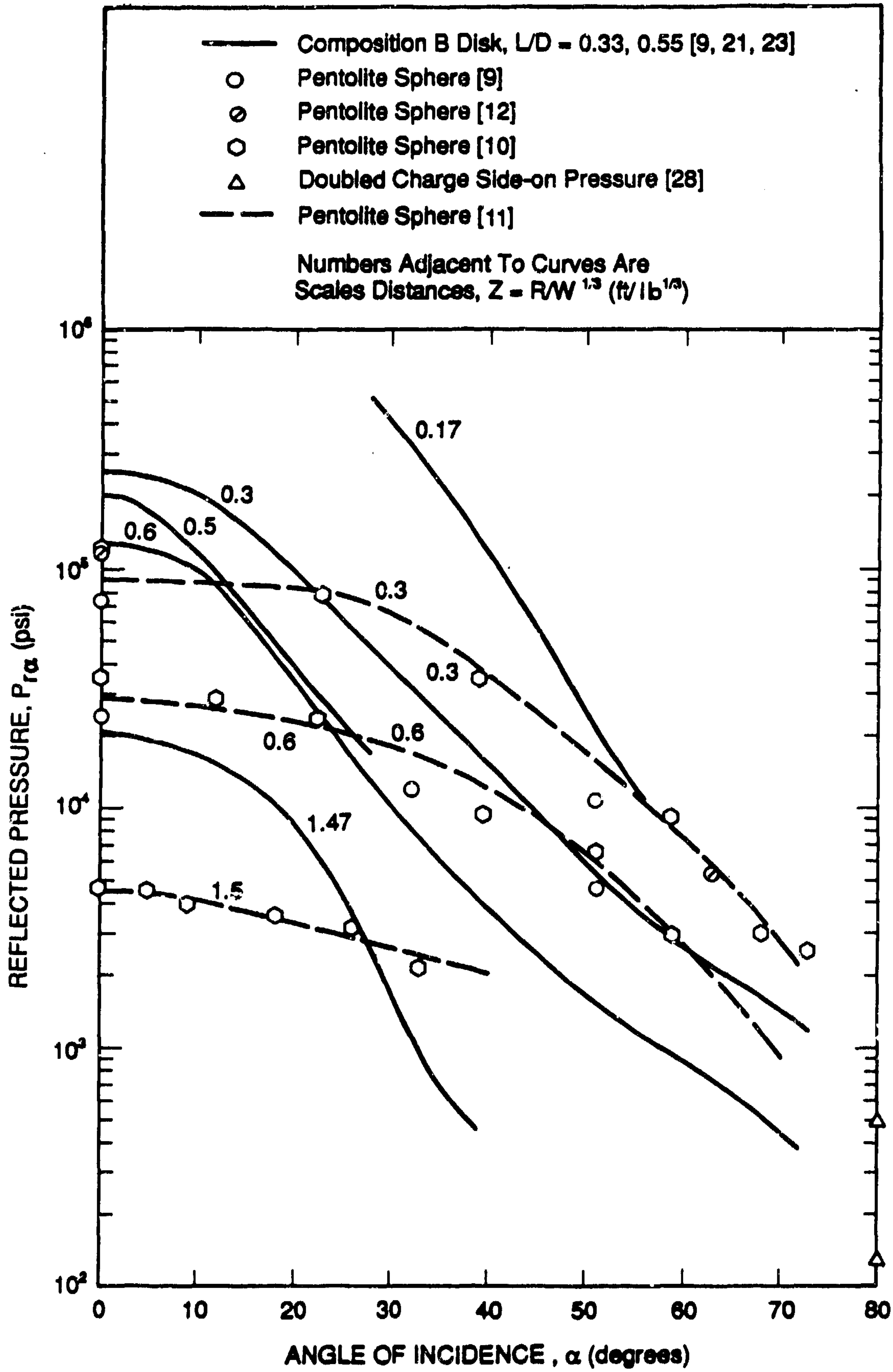


Figure 6. Comparison of Reflected Pressure for Pancake and Spherical Charges Detonated in Free-Air

Reference 10. Furthermore, at the same scaled distance but at an angle of incidence of $\alpha = 63.4°$ ($R_G/R = 2.0$), Reference 12 shows a measured peak pressure of 5,200 psi, and interpolation of the SwRI data from Reference 10 would have resulted in a prediction of 5,500 psi at that measurement location. The Pentolite curves for spherical charges shown in Figure 6 were developed by SwRI from the data in References 9 and 10, and were first published in Reference 11. A comparison of the disk and spherical charge curves at similar small scaled distances clearly shows the expected result of higher reflected pressures at small angles of incidence (at α of 0° to approximately 22° to 27°) and a sharper drop-off in pressure from the normal ($\alpha = 0°$) location for the disk charges. At larger incident angles the reflected pressures from the spherical charges become greater than the corresponding disk charge data. At angles approaching the limit of $\alpha = 90°$ (large R_G/R), one would expect the pressure data for both charge geometries to approach the incident pressure of a doubled charge weight burst in free-air. For Z = 0.3 and 0.6 ft/lb$^{1/3}$, these doubled charge side-on pressure values at $\alpha = 80°$ for a spherical charge are also shown in Figure 6.

In Figure 7 additional comparisons are made with the TNT curves from Reference 30 for scaled distances of 0.3 and 0.6 ft/lb$^{1/3}$. No curve is available for Z = 1.5 ft/lb$^{1/3}$. At angles of incidence greater than about 45° these two curves are essentially the same as the Pentolite curves developed from the data in References 9 and 10. However, at angles less than 45° there is obvious divergence as the angle approaches the normally reflected location ($\alpha = 0°$). Thus, it appears that the TNT curves for reflected pressures from Reference 30 would predict lower reflected pressures at $\alpha <$ 45° than those measured by SwRI [9, 10] and the BRL [12] at small scaled distances.

Reflected Impulses

As indicated in Table 1, normally reflected impulse was obtained at two scaled distances in the nine close proximity blast tests [21, 23]. The average scaled impulse for each scaled distance is plotted in Figure 8 along with previous data for C-4 disks with L/D = 0.33 from Reference 9 and for Pentolite spheres from References 6, 7, 9, 11, and 12. Also shown in Figure 8 is the TNT sphere curve from the revised tri-service manual, Reference 30. The average impulse values are plotted due to the large number of data points available for different charge sizes at the same scaled distances.

The new disk charge data for an L/D = 0.55 [21, 23], although limited to two scaled distances, is obviously of greater magnitude at corresponding scaled distances than the spherical data [6, 7, 9, 11, 12]. It is also of similar magnitude as the earlier disk data from charges with L/D = 0.33 [9]. This figure also shows that considerably more normally reflected impulse data are available from spherical charges at small scaled distances than normally reflected pressure which is plotted in Figure 4. Consequently, as shown in Figure 8, the TNT curve from Reference 30 is much better defined for impulse than for pressure close-in to a spherical charge.

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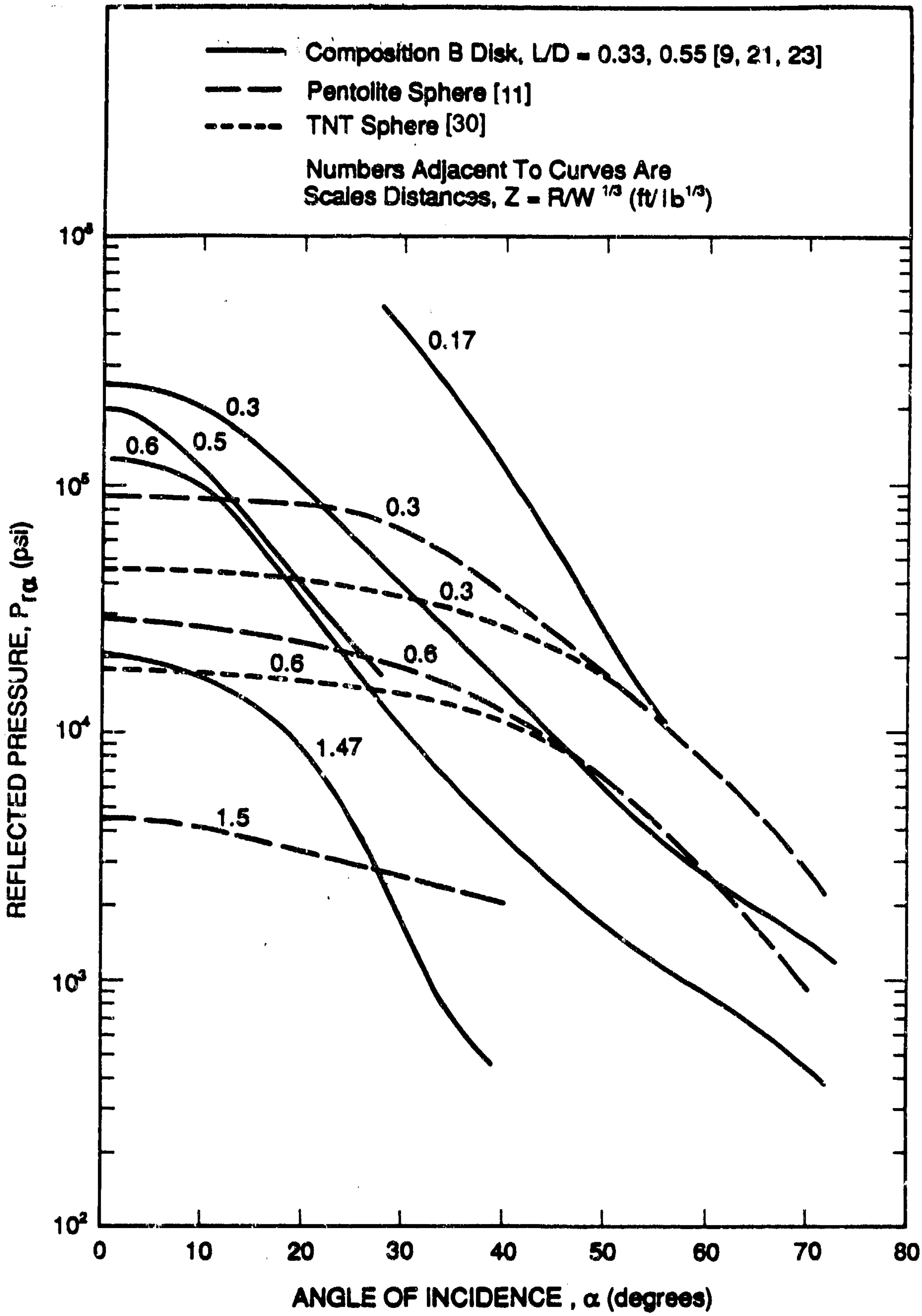


Figure 7. Comparison of Reflected Pressures for Pancake Charges Detonated in Free-Air With Spherical Charge Curves

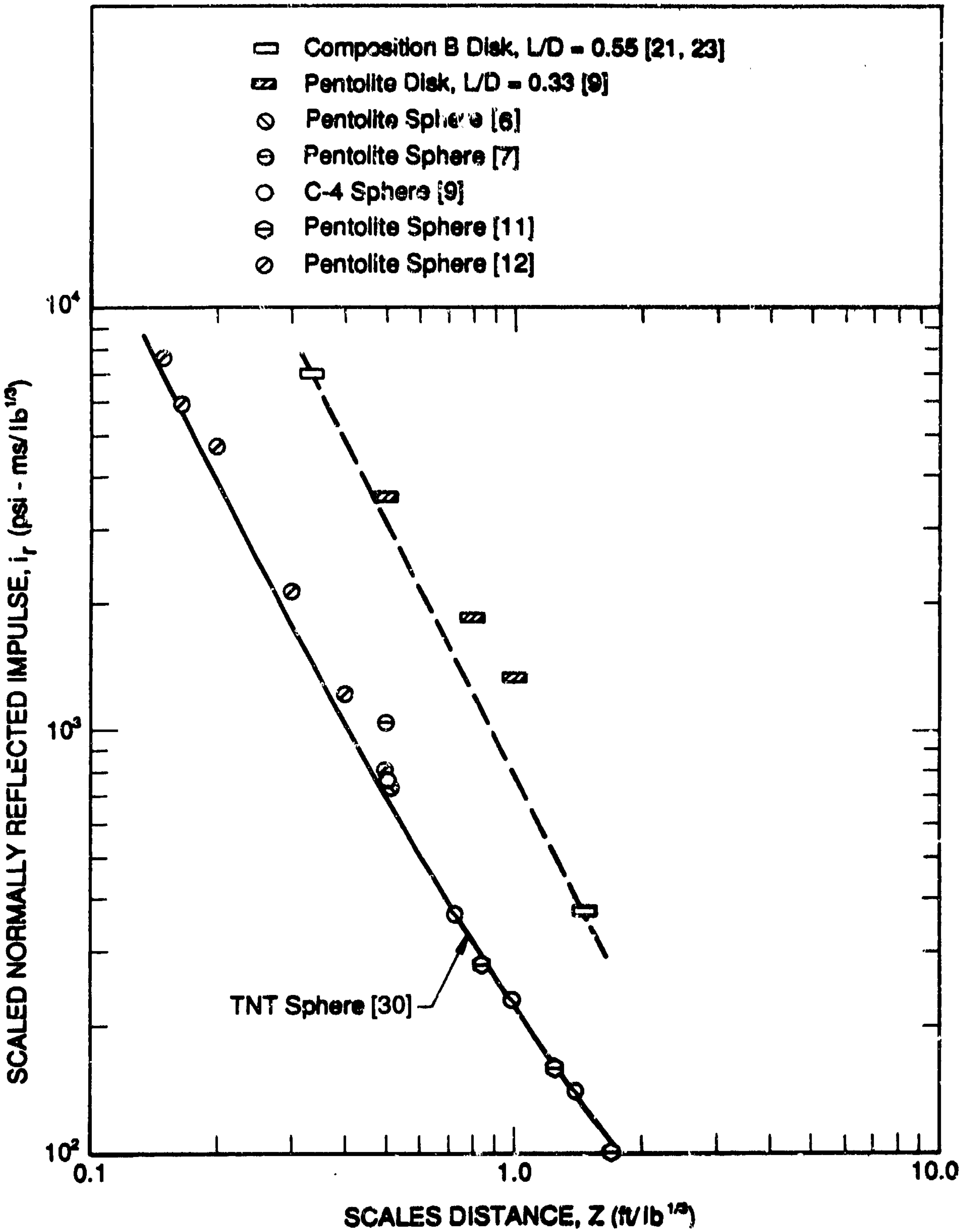


Figure 8. Comparison of Normally Reflected Scaled Impulses for Pancake and Spherical Charges Detonated in Free-Air

The spatial distribution of the scaled reflected impulses measured on the rigid plates from the nine tests in Table 1 as a function of the angle of obliquity is presented in Figure 9. Also plotted in this figure are the earlier disk charge data from Reference 9 for charges with an L/D = 0.33. For clarity the average scaled impulse at each measurement location is plotted. The scaled impulse data are shown as a function of scaled distance and angle of obliquity as dictated by the scaling law of Equation 4. As previously done with the pressure data, trend curves have been drawn through each set of data taken at the same scaled distance. Although the aspect ratios are slightly different, and the measurement locations covered different angles of incidence, the general trends of all the disk charge data are similar. The scaled impulse amplitude systematically decreases with an increasing scaled distance at a constant angle of incidence, and decreases with an increasing angle of incidence at a constant scaled distance.

In Figure 10, approximate curves for three scaled distances were developed from the disk charge data presented in Figure 9 that could be compared to experimental spherical charge curves fitted to data from References 9 and 10. The one set of data from Reference 12 at Z = 0.3 ft/lb$^{1/3}$ and $\alpha = 0°$ is also shown in this figure. As with the reflected pressure data, the scaled reflected impulse for the disk charges is higher at small angles of incidence with a sharper drop-off in reflected impulse than spherical charges from the normal location ($\alpha = 0°$). At larger angles of incidence the scaled impulse for a sphere become greater than for a disk charge located at the same scaled distance. Also shown in Figure 10 is the TNT sphere curve from Reference 28 for Z = 0.3 ft/lb$^{1/3}$ (a TNT curve for the other two scaled distances would have to had been obtained by interpolation leading to inaccuracies). The TNT sphere curve is almost the same as the empirical Pentolite sphere curve which indicates good experimental definition even at this small scaled distance.

SUMMARY

Experimental reflected pressure and impulse data for disk (pancake) charges of Composition B at small scaled distances from two recent programs [21, 23] have been presented in this paper. Nine experiments were conducted with cylindrical disk charges of a nominal weight of 3 pounds at scaled distances of 0.17, 0.33, 0.50, 0.67 and 1.47 ft/lb$^{1/3}$. A limited number of peak reflected pressure measurements were made at normal and oblique transducer locations using piezoelectric pressure transducers and strain-gaged pressure bars. Except for the smallest scaled distance, a limited number of reflected impulse data were also obtained at similar locations primarily using the impulse plug technique. A few of the impulse data points were obtained by integrating complete pressure-time histories from the piezoelectric pressure transducers.

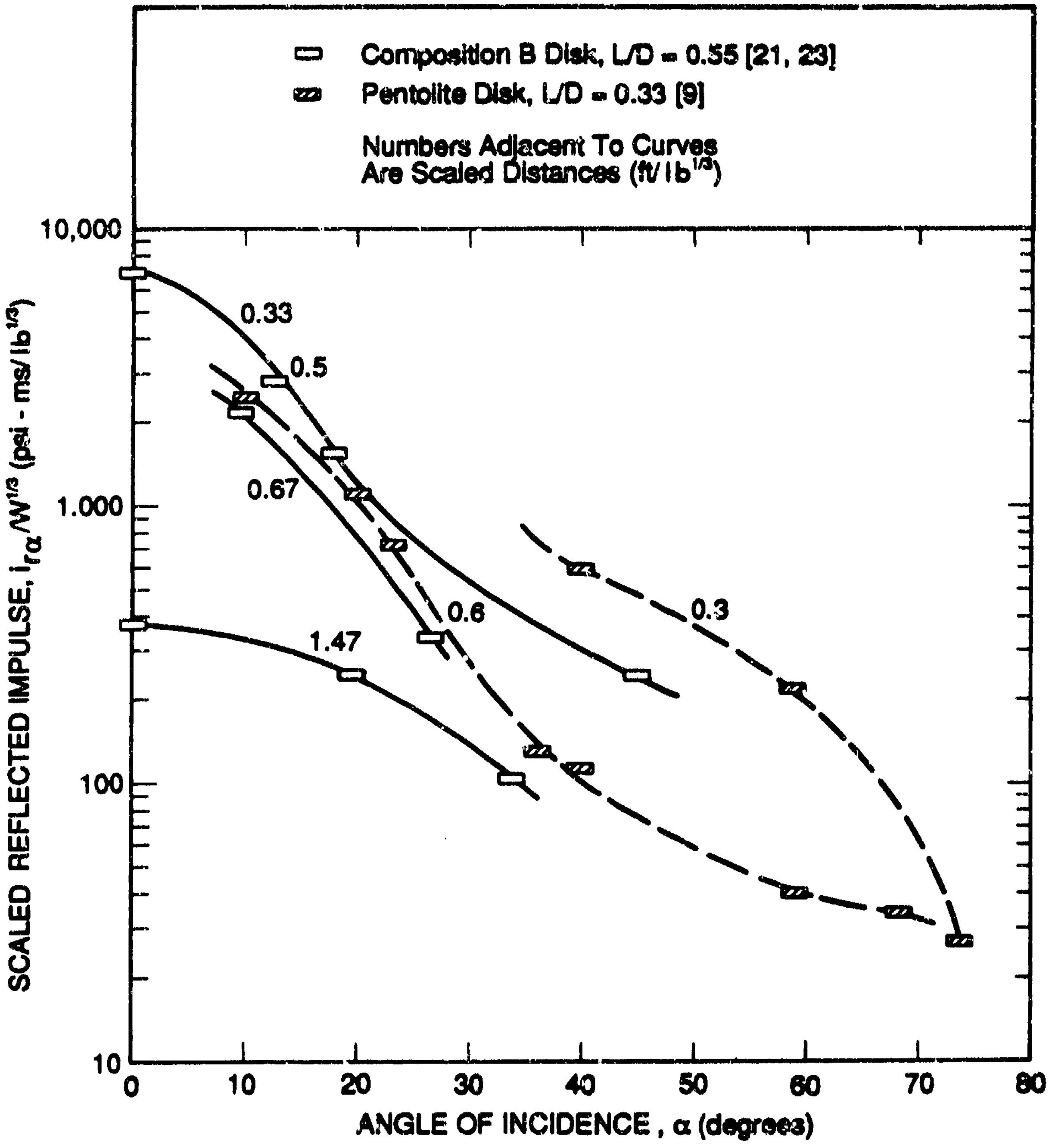


Figure 9. Spatial Distribution of Reflected Scaled Impulse

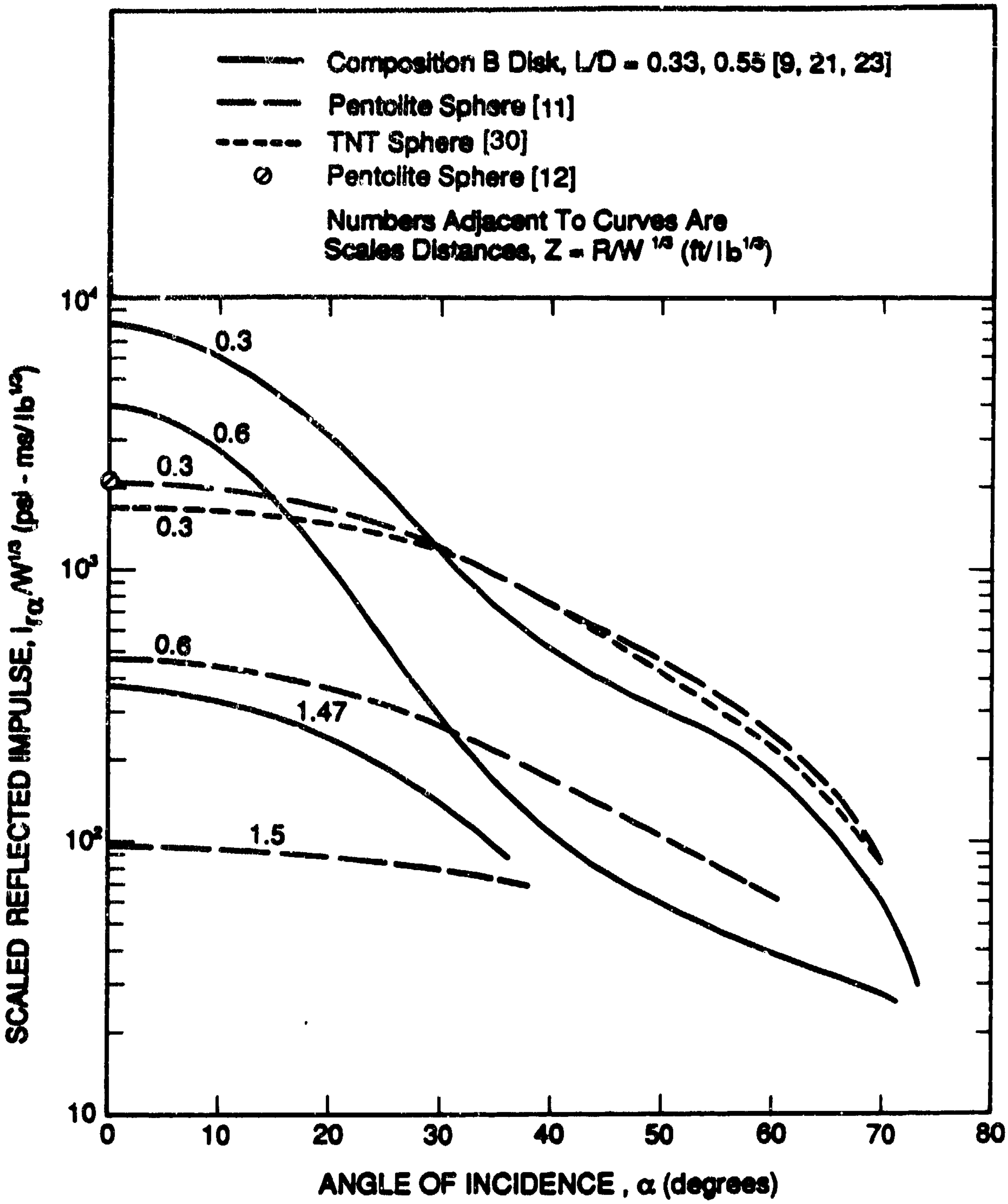


Figure 10. Comparison of Reflected Scaled Impulse for Pancake Charges with Spherical Charge Curves

Comparisons with some previous data from disk charges of a slightly different aspect ratio are made as well as with spherical charge data and curves. The reflected peak pressures from the recent disk charge tests were similar to those from the earlier disk charge data at analogous scaled distances and angles of incidence. Normally reflected pressures from the disk charges are significantly higher than for spherical charges at the same small scaled distances. Obliquely reflected pressures from disk charges decrease faster than from sphere charges at increasing angles of incidence from the normal (perpendicular) location on a rigid reflecting surface. At small scaled distances of 0.17 to 1.5 $ft/lb^{1/3}$, the decrease in pressure with angle of incidence is such that beyond a certain angle of incidence the obliquely reflected peak pressures from the disk charges become less than from comparable spherical charges. Similar behavior was observed for the scaled normally and obliquely reflected impulse data from disk charges at scaled distances of 0.3 to 1.5 $ft/lb^{1/3}$.

The reflected pressure curves derived from the spherical charge data used to compare with the disk charge data indicate that predictions made with the standard TNT curves [28] for reflected pressure would have significant uncertainty at small scaled distances less than 3.0 $ft/lb^{1/3}$. These standard curves may under predict considerably the reflected pressures from spherical charges at the normal location and at small angles of incidence (< 30°).

Direct measurement of the very high, normally reflected pressure on a rigid plane from a free-air detonation at scaled distances less than 1.0 $ft/lb^{1/3}$ is extremely difficult and very few measurements have been made. At these scaled distances, impulse measurement using the impulse plug technique is easier and a few more investigations have been made. Measurement of obliquely reflected pressure at small scaled distances have also been few, even though the pressures are easier to measure because they are of lower amplitude than at the normal location. At oblique locations the plug technique to obtain impulse is less reliable because, since the plug is loaded obliquely, binding and severe tumbling can create problems. At these locations, impulse can be obtained better from the pressure-time histories of piezoelectric transducers. As a result of these difficulties and the few investigations, only a small data base of reflected pressures and impulses at small distances from spherical charges exists, making prediction curves less well defined than at larger scaled distances. For charges of other geometries, such as a disk, even less data are found in the literature and the data presented in this paper are an important addition to the very limited free-air burst data available. The approximate curves presented characterizing the spatial distribution of reflected pressure and impulse from a disk at scaled distances less than 1.5 $ft/lb^{1/3}$ should be useful for estimating blast loads from disk charges. These curves can also be used to calibrate numerical codes.

Obviously, considerable more data are needed to better characterize close-in blast loads and increase their confidence level not only from disk charges, but also from spherical charges and other common high explosive geometries. In addition, the applicability of Hopkinson's law [24] at very small scaled distances needs to be verified. Such experimentation is highly recommended as is the development of pressure transducers and techniques that can better handle the extremely high reflected pressures and accelerations encountered very near any high explosive charge.

ACKNOWLEDGEMENTS

The new experimental data presented in this paper were obtained by SwRI on two projects performed for the FMC Corporation. Ms. Carolyn Krebs and Mr. Jim Drotleff were the FMC technical monitors, and Mr. Scott Mullin was the SwRI project manager. The author appreciates the support provided by SwRI for the preparation and presentation of this paper and the contributions of the SwRI project team in conducting the tests.

REFERENCES

1. Kennedy, W.D., "Explosions and Explosives in Air," in **Effects of Impact and Explosion**, M.T. White (ed.), Summary Technical Report of Div. 2, NDRC, Vol. I, Washington, DC, AD 221 586, 1946.
2. Stoner, R.A. and Bleakney, W., "The Attenuation of Spherical Shock Waves in Air," **Journal of Applied Physics**, Vol. 19, No. 7, 1948.
3. Goodman, H.J., "Compiled Free Air Blast Data on Bare Spherical Pentolite," BRL Report 1092, Aberdeen Proving Ground, MD, February 1960.
4. Hoffman, A.J. and Mills, S.N., "Air Blast Measurements About Explosive Charges at Side-on and Normal Incidence," BRL Report 988, Aberdeen Proving Ground, MD, 1956.
5. Johnson, O.T., Patterson, J.D.,II, and Olson, W.C., "A Simple Mechanical Method for Measuring the Reflected Impulse of Air Blast Waves," BRL Memorandum Report No. 1088, Aberdeen Proving Ground, MD, July 1957.
6. Dewey, J.M., Johnson, O.T., and Patterson, J.D., II, "Mechanical Impulse Measurements Close to Explosive Charges, " BRL Report No. 1182, Aberdeen Proving Ground, MD, November 1962.
7. Jack, W.H., Jr., "Measurements of Normally Reflected Shock Waves from Explosive Charges," BRL Memorandum Report No. 1499, Aberdeen Proving Ground, MD, AD 422886, July 1963.
8. Baker, W.E., **Explosions in Air**, University of Texas Press, Austin, TX, 1973.
9. Wenzel, A.B. and Esparza, E.D., "Measurements of Pressures and Impulses at Close Distances from Explosive Charges Buried and in Air," Final Report on Contract No. DAAK 02-71-C-0393 with U.S. Army MERDC, Ft. Belvoir, VA, August 1972.

10. Kulesz, J.J., Esparza, E.D., and Wenzel, A.B., "Blast Measurements at Close Standoff Distances for Various Explosive Geometries," **Minutes of the 18th Explosives Safety Seminar**, Vol. I, San Antonio, TX, Department of Defense Explosives Safety Board, September 1978.

11. Hokanson, J.C., Esparza, E.D., Wenzel, A.B., and Price, P.D., "Blast Effects of Simultaneous Multiple-Charge Detonations," Contractor Report ARLCD-CR-78032, Dover, NJ, October 1978.

12. Huffington, N.J. and Ewing, W.O., "Reflected Impulse Near Spherical Charges," Technical Report BRL-TR-2678, Aberdeen Proving Ground, MD, September 1985.

13. Kingery, C.N., "Air Blast Parameters Versus Distance for Hemispherical TNT Surface Bursts," BRL Report No. 1344, Aberdeen Proving Ground, MD, September 1966.

14. Adams, C.L., Sarmousakis, J.N., and Sperraza, J., "Comparison of the Blast from Explosive Charges of Different Shapes," BRL Report No. 681, Aberdeen Proving Ground, MD, January 1949.

15. Makino, R.C. and Goodman, H.J., "Air Blast Data on Bare Explosive of Different Shapes and Compositions," BRL Memorandum Report No. 1015, Aberdeen Proving Ground, MD, 1956.

16. Wisotski, J. and Snyer, W.H., "Characteristics of Blast Waves Obtained from Cylindrical High Explosive Charges," University of Denver, Denver Research Institute, November 1965.

17. Plooster, M.N., "Blast Front Pressure from Cylindrical Charges of High Explosives," Naval Weapons Center Technical Memorandum No. 3631, Navy Contract No. N00123-76-C-0166, Denver Research Institute, September 1978.

18. Reisler, R.C., "Explosive Yield Criteria," **Minutes of 14th Explosives Safety Seminar**, New Orleans, Department of Defense Explosives Safety Board, November 1972.

19. Reisler, R.E., Giglio-tos, L., and Teel, G.D., "Air Blast Parameters from Pentolite Cylinders Detonated on the Ground," BRL Memorandum Report No. 2471, Aberdeen Proving Ground, MD, 1975.

20. Guerke, G. and Scheklinski-Glueck, G., "Blast Parameters from Cylindrical Charges Detonated on the Surface of the Ground," **Minutes of the 20th Explosives Safety Seminar**, Vol. I, Norfolk, VA, 1982; and **Proceedings I, Eighth International Symposium on Military Applications of Blast Simulation**, Spiez, Switzerland, 1983.

21. Mullin, S.A., Esparza, E.D., and Garza, L.R., "Explosive Shock Test: Fixture Design, Operational Procedures, Test Results," Final Report, Southwest Research Institute No. 06-1882, FMC Corporation, December 1987.

22. Mullin, S.A. and Esparza, E.D., "Explosive Shock Testing: Materials Evaluation," Final Report, Southwest Research Institute No. 06-2403-001, FMC Corporation, January 1989.

23. Mullin, S.A., Friesenhahn, G.J., and Esparza, E.D., "Explosive Shock Testing: Close Proximity Blast Measurements," Final Report, Southwest Research Institute No. 06-2403-002, FMC Corporation, April 1989.

24. Hopkinson, B., **British Ordnance Board Minutes 13565**, 1915.

25. Cranz, C., **Lehrbuch der Ballistic**, Springer-Verlag, Berlin, 1926.

26. MIL-STD-1946, **Welding of Aluminum Armor**, April 8, 1986.

27. Dorsch, T.J., "Test Plan Number 10237, Test Report, Phase 1: Weldment Explosive Shock Test," PA 984-515-210, FMC Ordnance Division Engineering, San Jose, CA, January 1986.

28. Esparza, E.D., "Airblast Measurements and Equivalency for Spherical Charges at Small Scaled Distances," **Minutes of the 22nd Explosives Safety Seminar**, Vol. I, Department of Defense Explosives Safety Board, Anaheim, CA, August 1986.

29. Baker, Q.A., Spivey, K.H., Baker, W.E., and Esparza, E.D., "Blast Loading from Arrays of Parallel Line Charges," **Proceedings of the 4th International Symposium on the Interaction of Non-nuclear Munition with Structures**, Vol. I, USAF Engineering and Services Lab, Panama City Beach, FL, April 1989.

30. "Structures to Resist the Effects of Accidental Explosions, Volume II, Blast, Fragment, and Shock Loads," Special Publication ARLCD-SP-84001, U.S. Army Research, Development, and Engineering Center, Dover, NJ, December 1986.

31. **Structures to Resist the Effects of Accidental Explosions**, Department of the Army Technical Manual TM-5-1300, Department of the Navy Publication NAVFAC P-397, Department of the Air Force Manual AFM 88-22, Department of the Army, the Navy and the Air Force, June 1969.

DEVELOPMENT OF A NON-PROPAGATING, **SIFCON** EXPLOSIVES STORAGE CABINET

by
Bruce Schneider

New Mexico Engineering Research Institute
University of New Mexico
Albuquerque, New Mexico 87131

ABSTRACT

Sandia National Laboratories, Albuquerque (SNL) is currently designing an Explosive Components Facility (ECF). An integral part of the ECF will be on-site storage of explosives in six earth covered service magazines. Each magazine will contain a non-propagating Explosives Storage Cabinet (ESC) system made up of twenty modular units. The inside dimensions of the modular units are 42 inches wide, 42 inches high, and 36 inches deep. In addition to the storage of explosives, a primary purpose of the cabinet system is to prevent a sympathetic detonation of the explosives stored in the surrounding units as a result of an accidental detonation of up to 5.0 pounds of explosives (TNT equivalent) stored in a "donor" unit in the cabinet.

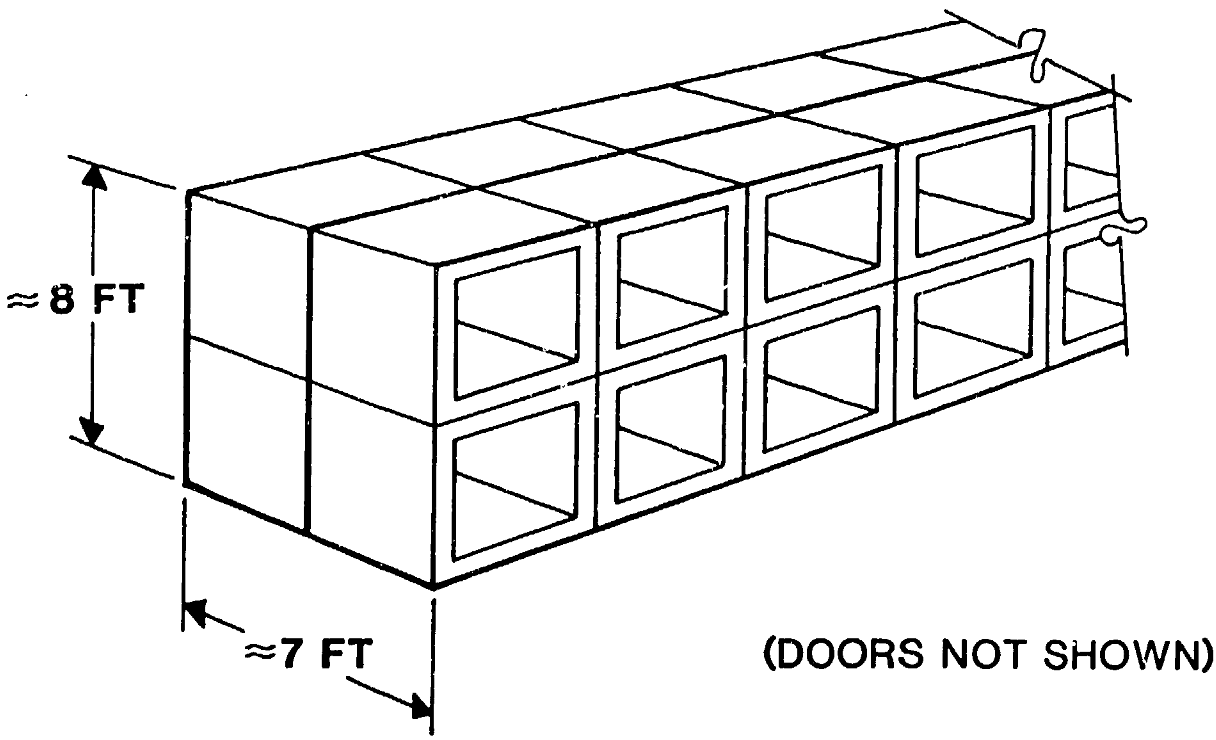
A new material being developed at the New Mexico Engineering Research Institute (NMERI) known as SIFCON (Slurry Infiltrated Fiber CONcrete), had been shown to be highly resistant to back spall from blast loadings, and penetration by high-velocity ballistic projectiles and fragments. These, and other characteristics unique to SIFCON, such as very high strength and ductility, appeared to make it an excellent candidate material for the modular units of the ESC.

In 1989 Sandia National Laboratories, Albuquerque (SNL) contracted with NMERI to develop a SIFCON modular unit for the ESC. This paper is a brief summary of the work undertaken in the program which included the design, fabrication, and explosive testing of the modular units. Of special interest was the exceptional performance of the SIFCON units in resisting the effects of the test explosions, and preventing sympathetic detonations of primary type explosives stored in the adjacent units of the cabinet.

INTRODUCTION

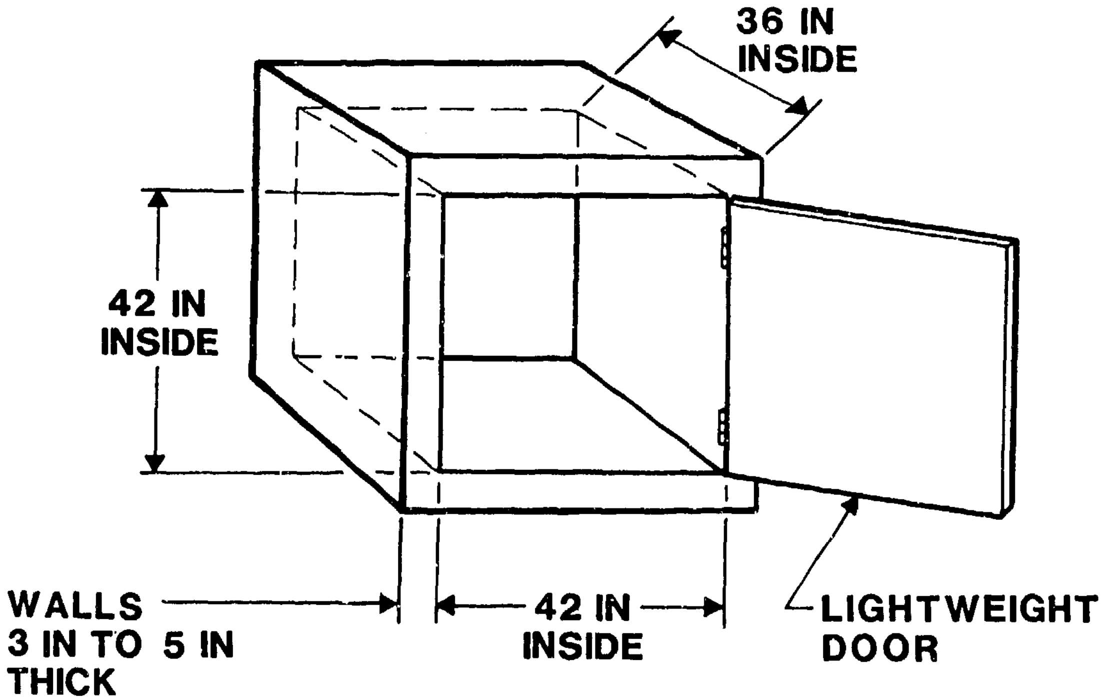
BACKGROUND

Sandia National Laboratories, Albuquerque (SNL) is currently designing an Explosive Components Facility (ECF) which will integrate, centralize, and extend many of the explosive, neutron generation, and weapons testing programs currently in progress at SNL. An integral part of the ECF will be on-site storage of explosives in six earth covered service magazines. Each magazine will contain approximately 480 square feet of interior floor area and will be of reinforced concrete construction. Each magazine will contain two rows of non-propagating Explosives Storage Cabinets (ESC) which will be installed back-to-back as shown in Figure 1.



Explosives Storage Cabinet (ESC)
Figure 1.

As shown in Figure 2, the inside dimensions of the modular units are 42 inches wide, 42 inches high, and 36 inches deep. The unit will be enclosed on five sides (sides, top, bottom and back) with a heavy, solid wall. A lightweight door mounted on one side will make up the sixth side (front) of the unit.



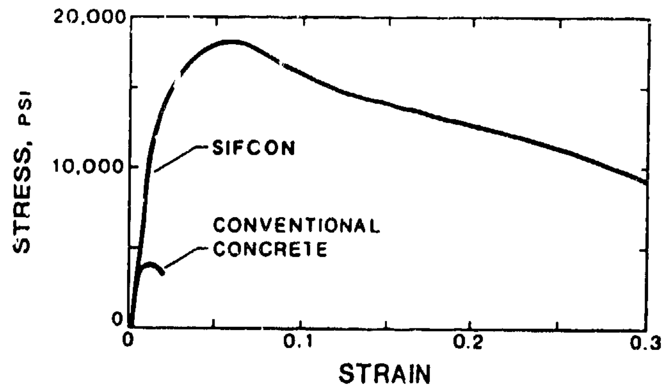
Modular Storage Unit
Figure 2.

In addition to the storage of explosives, a primary purpose of the cabinet system is to prevent a sympathetic detonation of the explosives stored in the surrounding units as a result of an accidental detonation of up to 5.0 pounds of explosives (TNT equivalent) stored in a "donor" unit in the cabinet. The basic design criteria allows for the complete destruction of the donor unit during the accidental explosion, and a level of damage to adjacent, "acceptor" units that does not cause explosives stored in them to detonate.

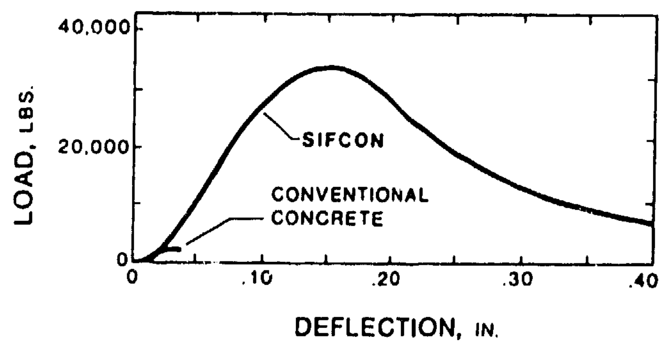
A NEW MATERIAL

A new material being developed at the New Mexico Engineering Research Institute (NMERI) known as SIFCON (Slurry Infiltrated Fiber CONcrete), had been shown to be highly resistant to back spall from blast loadings, and penetration by high-velocity ballistic projectiles and fragments. These, and other characteristics unique to SIFCON appeared to make it an excellent candidate material for the modular units of the ESC.

SIFCON is a composite material utilizing short steel fibers in a Portland cement based matrix. It differs from conventional steel fiber reinforced concrete (SFRC) in which the steel fibers are added directly to a typical concrete mix in the ratio of 0.5 to 1.5 percent by volume. SIFCON, on the other hand, starts with a bed of preplaced steel fibers in the range of 5 to 20 percent by volume. The fiber bed is then infiltrated with a low viscosity, cementitious slurry. The resulting composite material possesses a very high compressive strength as well as toughness and ductility. This is graphically illustrated in Figure 3a. A similar pattern of high strength and ductility is also true for the flexural properties of SIFCON as illustrated in Figure 3b.



COMPRESSIVE
(a)



FLEXURE
(b)

Typical Material Properties for SIFCON
Figure 3.

THE SIFCON ESC DEVELOPMENT PROGRAM

In 1989 Sandia National Laboratories, Albuquerque (SNL) contracted with NMERI to conduct a three-phase program to develop a SIFCON modular units of the ESC. The first phase of the program developed a baseline design for the modular unit. Using the baseline design, two prototype units were fabricated and tested by NMERI using the specified amount of explosives. The test results indicated that the basic design concept would easily meet the design criteria and the program advanced to Phase II.

The second phase involved refining the baseline design, fabricating five modular units, assembling them into a cabinet system, and conducting a verification test of the system. The test results showed that the SIFCON units prevented a sympathetic detonation of the explosives stored in the surrounding units.

The third phase will consist of preparing the Engineering Drawings and Technical Specifications for the modular unit and the cabinet system.

SCOPE OF PAPER

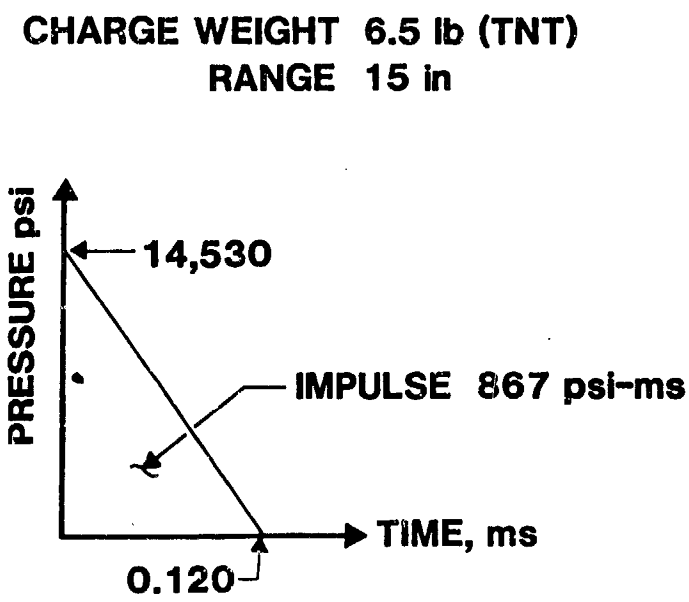
This paper is a brief summary of the first two phases of the SIFCON ESC development program. A complete presentation of the program including a detailed discussion of the results of each of the tests is given in the reports referenced at the end of the paper. The paper first discusses the process used to develop the preliminary design. This is followed by a summary of the fabrication procedures of the SIFCON ESC unit and the test set-up for Phase I. Also included is a discussion of the Phase I test results. The paper continues with a presentation of the design modifications and the test set-up for Phase II. The paper concludes with a summary of the results observed in the Phase II test.

BASELINE DESIGN

In reviewing the following design procedures for the SIFCON ESC, it must be remembered that only empirical results from a few testing programs were available to guide the designer. As a result it was not possible to "design" the SIFCON ESC in the conventional manner currently used for reinforced concrete or steel. Instead, the baseline design was prepared using what little information was available, combined with a large amount of experience and engineering judgment.

DESIGN LOADS

The first step in the design process was to determine the loads on the structural elements of the unit resulting from the detonation of explosives inside. A PC-based program called "BLASTINW" developed by the US Army Corps of Engineers, Waterways Experiment Station (WES) was used. The program calculated the pressure-time and impulse-time histories on the interior surfaces of the modular unit resulting from an explosive detonation inside. A copy of the baseline design calculations was presented in the Program Plan for Phase I, (Reference 1). Using the information generated by the program, a simplified pressure-time history, as shown in Figure 4, was developed for use in the engineering design.



Baseline Design Loading Diagram
Figure 4.

WALL THICKNESS SELECTION

Using the simplified loading condition determined above, combined with estimated ductility and dynamic strength factors for the material, the resulting bending, shear and axial forces acting on the structural elements of the unit were calculated. From these forces, the required wall thickness and SIFCON strength were determined.

One problem encountered in determining the wall thickness was a lack of knowledge about how the wall of the donor unit would interact with the wall of the acceptor unit. The fact that the donor unit could suffer severe damaged or even be completely destroyed, while the acceptor unit could suffer some unknown amount of limited damage, made this a very complex analysis. Limitations on the resources of this phase of the project prevented NMERI from conducting the detailed research and analysis required to obtain this information.

Another major factor contributing to the difficulty in designing the wall thickness was selecting ductility ratios and dynamic strength factors for the SIFCON material. At the time of the design, information on these two properties was virtually non-existent for SIFCON. In previous NMERI testing programs using explosives on SIFCON structures, the components had never actually failed or come apart in a manner similar to that expected for the cabinet units.

The wall thickness for the preliminary design was eventually selected by considering the capacity of two walls together. The rationale was that both the wall of the donor unit, and the wall of the acceptor unit would resist the effects of the detonation. In addition, much of the energy generated by the explosion would be expended in the destruction of the donor unit with a smaller amount being applied to the wall of the acceptor unit. An impedance mismatch between the units using a layer of air, foam or wood was specified in the preliminary design to help reduce the load being applied to the acceptor unit.

An economic constraint was also applied to the selection of the wall thickness. A quick cost analysis indicated that the wall thickness of the units needed to be 4 inches or less in order for a SIFCON system to be competitive with reinforced concrete or steel.

Using the design method noted above, combined with the economic constraint and a good deal of judgment based on past experience with SIFCON, a wall thickness of 3 inches was chosen. It was reasoned that if the 3-inch thickness survived the test it could always be reduced during the next phase of the development program and more economy gained. It was also believed that if using the 3-inch thickness resulted in a major failure of the system, and the results indicated a thickness of 4 or more inches was required, it would probably not be economical to pursue the development of the concept further. Consequently, the 3-inch thickness appeared to be a reasonable place to start.

CONSTRUCTION CONSIDERATIONS

As in all systems using SIFCON, the designer also considered the construction techniques to be used. The structural analysis indicated that flexure was the dominate failure mechanism for the units. This naturally suggested that the fiber orientation should be generally in the plane of each of the five walls. To accomplish this, the fibers would need to be installed with the plane of all the walls in the horizontal position. This requirement prevented the module from being cast, open end down, as a single unit. Instead, it suggested that the walls be cast as individual panels and assembled together into the module.

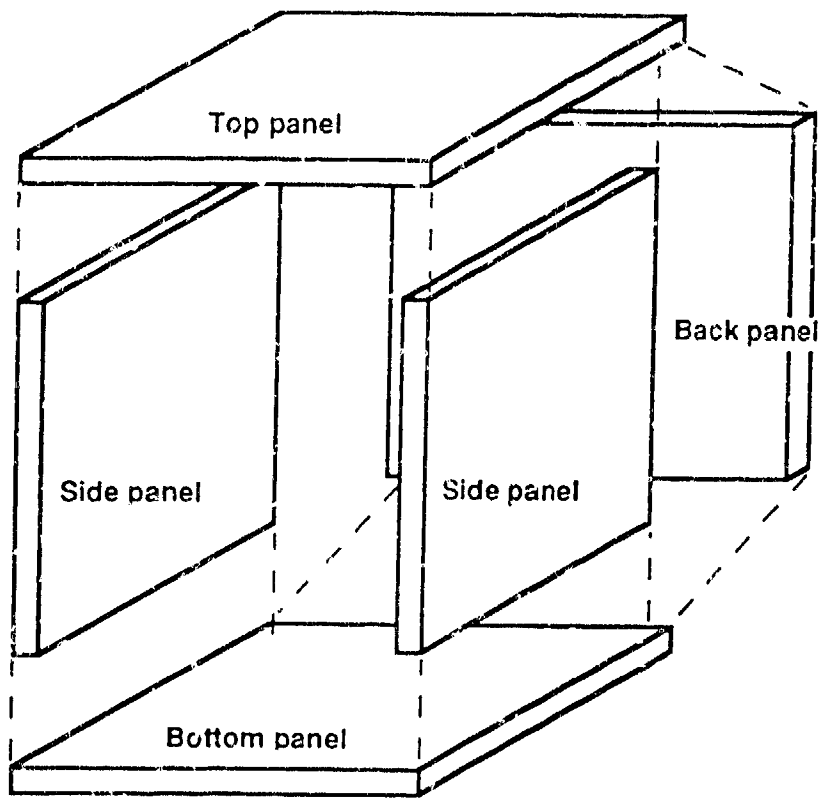
Upon further consideration, it became apparent that this method of construction actually had many advantages over the system cast as a single unit. First, the formwork for the component method was less complicated. A steel frame, required around the edges of each wall panel so they could be welded together into the modular unit, would also serve as the edge formwork. The only other formwork needed would be a simple plywood base for the back of the panel. On the other hand, the fabrication, installation, and removal of the inner and outer formwork for a single cast module would be much more complicated and time consuming than for the individual flat panels.

Second, the viscosity and open time of the slurry would need to be less precise for casting the individual components because it only had to infiltrate 3 inches through the fiber bed instead of 39 inches if the module was cast as a single unit. Therefore, using the flat panel concept would significantly increase the probability of a fabricator being able to consistently produce high quality units.

Third, if a problem, such as an equipment break-down, were to occur when placing the slurry in the individual components, only the defective wall panel would be lost, and it could be easily and economically recast. In contrast, if a problem developed while casting the single unit, the entire module would probably be lost and have to be replaced at considerable expense and time.

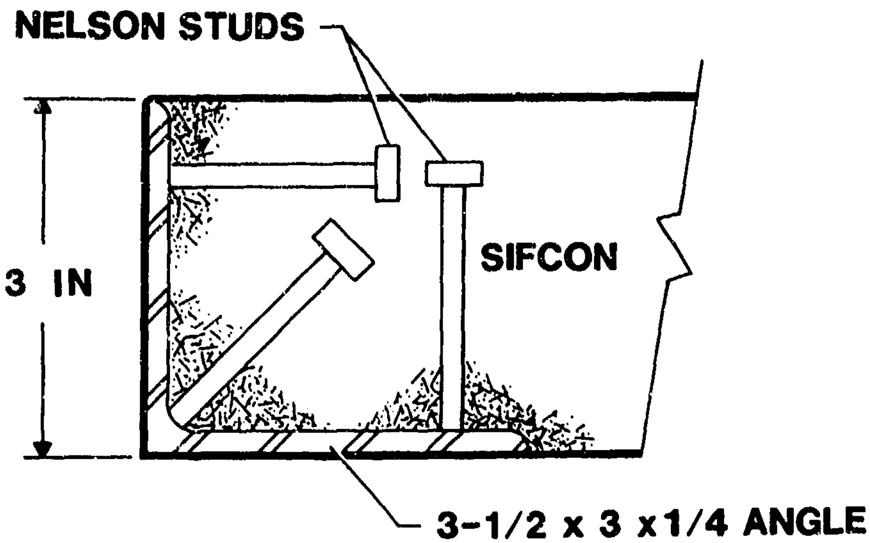
STRUCTURAL DETAILS

The modular unit was designed to be fabricated using five individual panels as shown in Figure 5. Because of symmetry, only three different sizes of panels were required: one size for the top and bottom, one size for the sides, and one size for the back. A rectangular frame made from a 3-1/2" x 3" x 1/4" steel angle was placed around the perimeter of each panel as shown in Figure 6. The steel frame was anchored to the SIFCON slab with

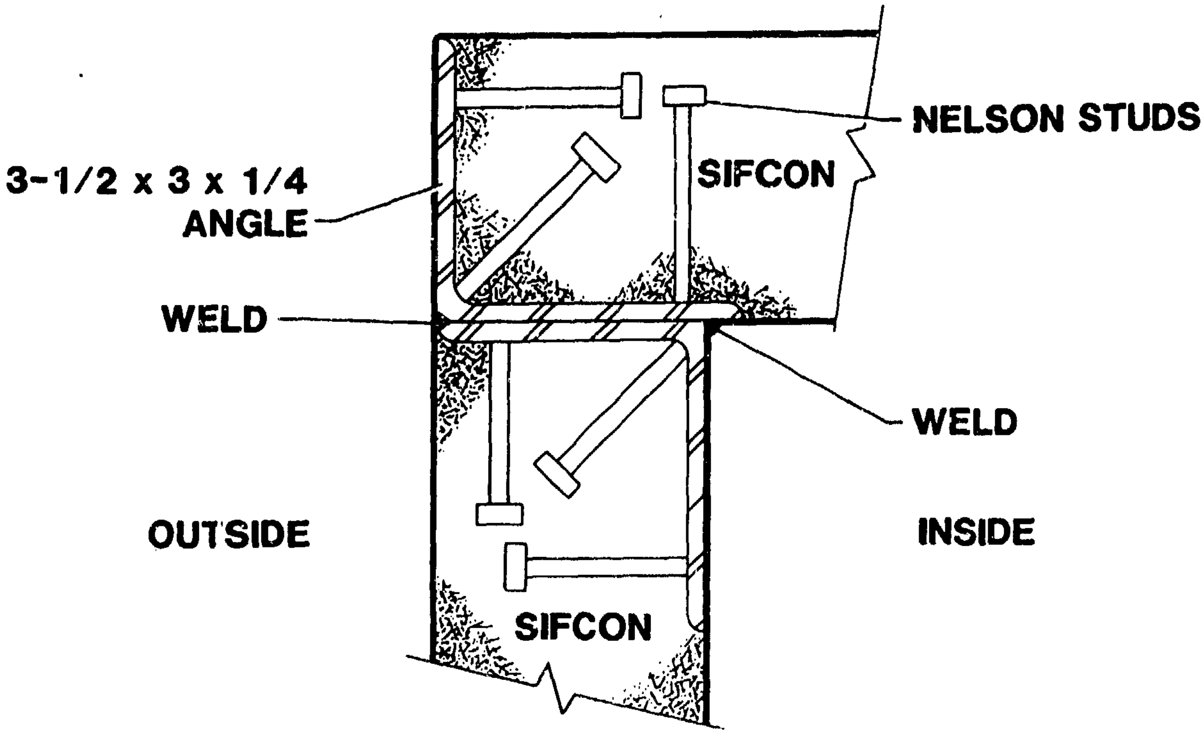


Panel Arrangement for the Modular Unit
Figure 5.

1/4-inch diameter by 2-inch long headed anchor studs welded to the inside of both legs and in the fillet of the angle. The studs on each line were spaced at 6 inches, with a 2-inch offset on each of the lines along the legs and fillet to avoid interference. The use of the 3-1/2 inch leg on the inside of the panel provided a method of welding two adjacent panels together, as shown in Figure 7. A 5/8-inch diameter threaded insert was installed on the inside of two opposite sides of each frame. During assembly of the unit, an eye-bolt would be installed in the insert to aid in handling the panels.



Panel Edge Detail
Figure 6.



Typical Corner Detail
Figure 7.

11

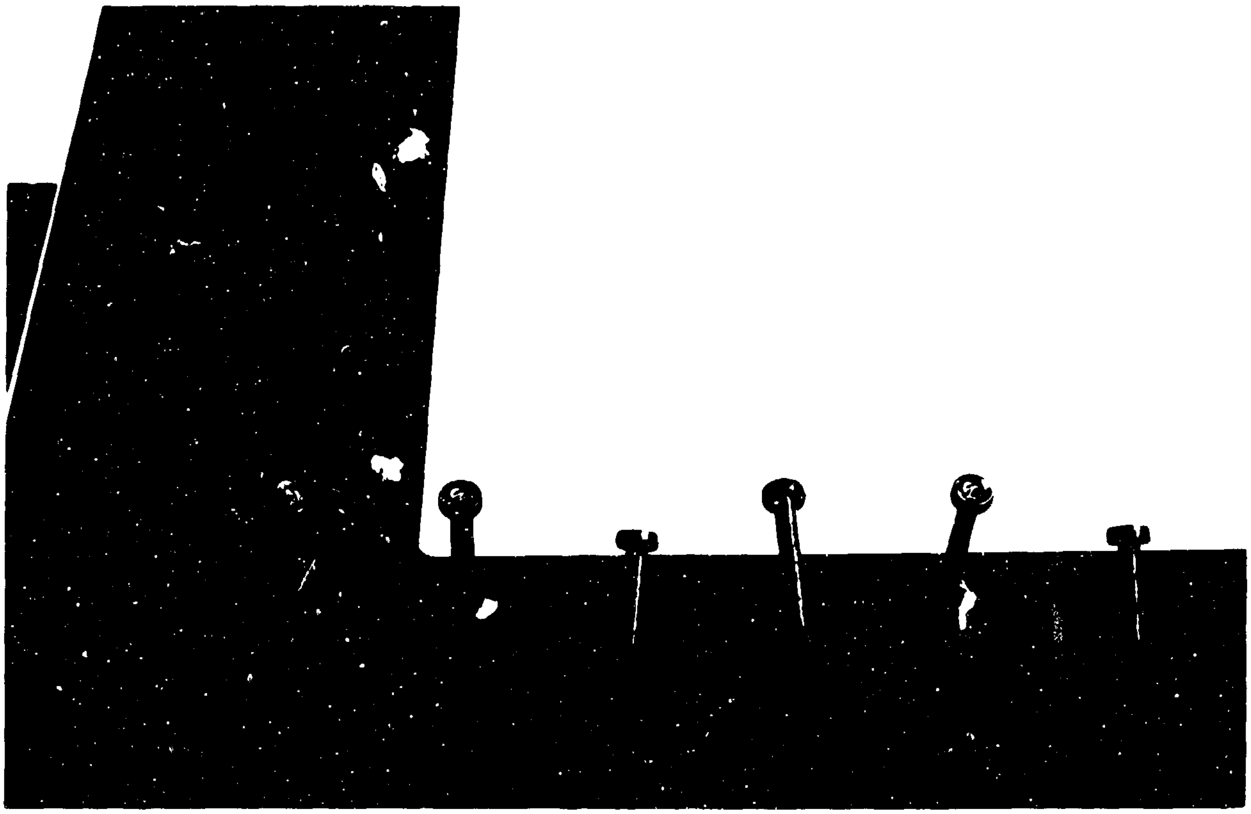
DOOR

Since Phase I was primarily a study of the feasibility of using SIFCON in the modular units, the details of the door system was not a major consideration. The only requirement was that the door act as a frangible panel during an internal explosive event, allowing quick venting of blast pressures in the unit. There was no requirement that the door be hard enough to resist a forced entry attack. Therefore, it was decided to use a 1/4-inch thick steel plate for the door on the prototype modular units.

PHASE I--UNIT FABRICATION

COMPONENT FABRICATION

The fabrication of the units began by welding the steel angle frames for the ten panels together. Figure 8 shows a corner detail of a typical angle frame, including the headed anchor studs, installed on a plywood base. The angle frame was caulked all around the outside at the plywood base to prevent any slurry from leaking out.



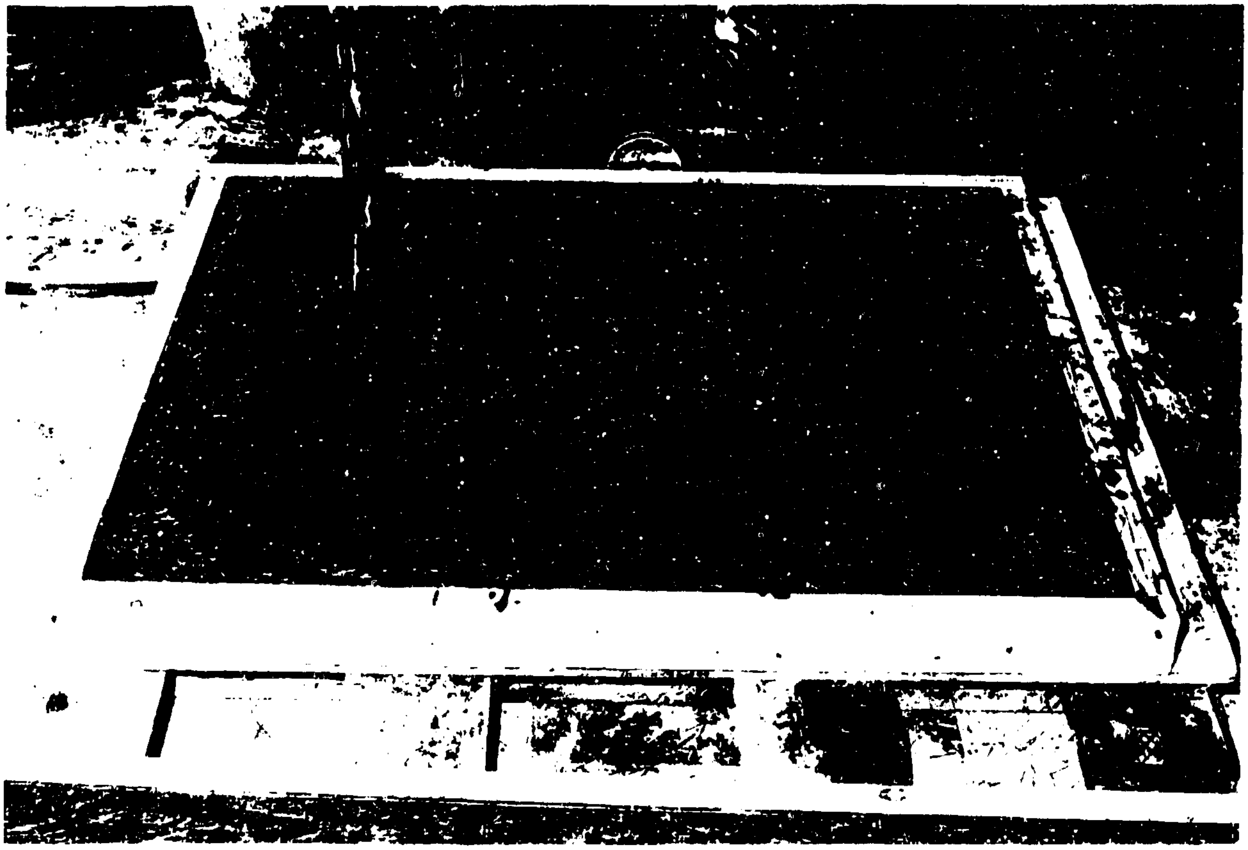
Steel Angle Frame
Figure 8.

The fiber selected for the prototype units was the Dramix ZL 30/50 brand manufactured by the Bekaert Steel Wire Corporation, Marietta, Georgia. The fiber was made from cold drawn steel wire with a minimum tensile strength of 150,000 psi. The fibers were 30-mm long and 0.50-mm in diameter. The fibers were placed by hand into the forms using a sprinkling method. This prevented clumps and allowed the fibers to interlock together.

The proportions used in the slurry are given in Table 1. The slurry was mixed in a double-tub grout mixer and pumped through a hose to the fiber filled forms. Starting at the center of the panel, the slurry was infiltrated into the fiber bed, (Figure 9). The panels were vibrated using small pneumatic vibrators to insure complete infiltration of the slurry into the fiber bed.

Table 1
SIFCON Slurry Mix Proportions
Phase I

Portland Cement, Type I-II	47.0 lbs
Fly Ash, Type C	0.0 lbs
Microsilica,	7.0 lbs
Sand, 50 Mesh	47.0 lbs
Water	19.0 lbs
Superplasticizer	23.5 ozs
Fiber Volume Density (FVD)	11%

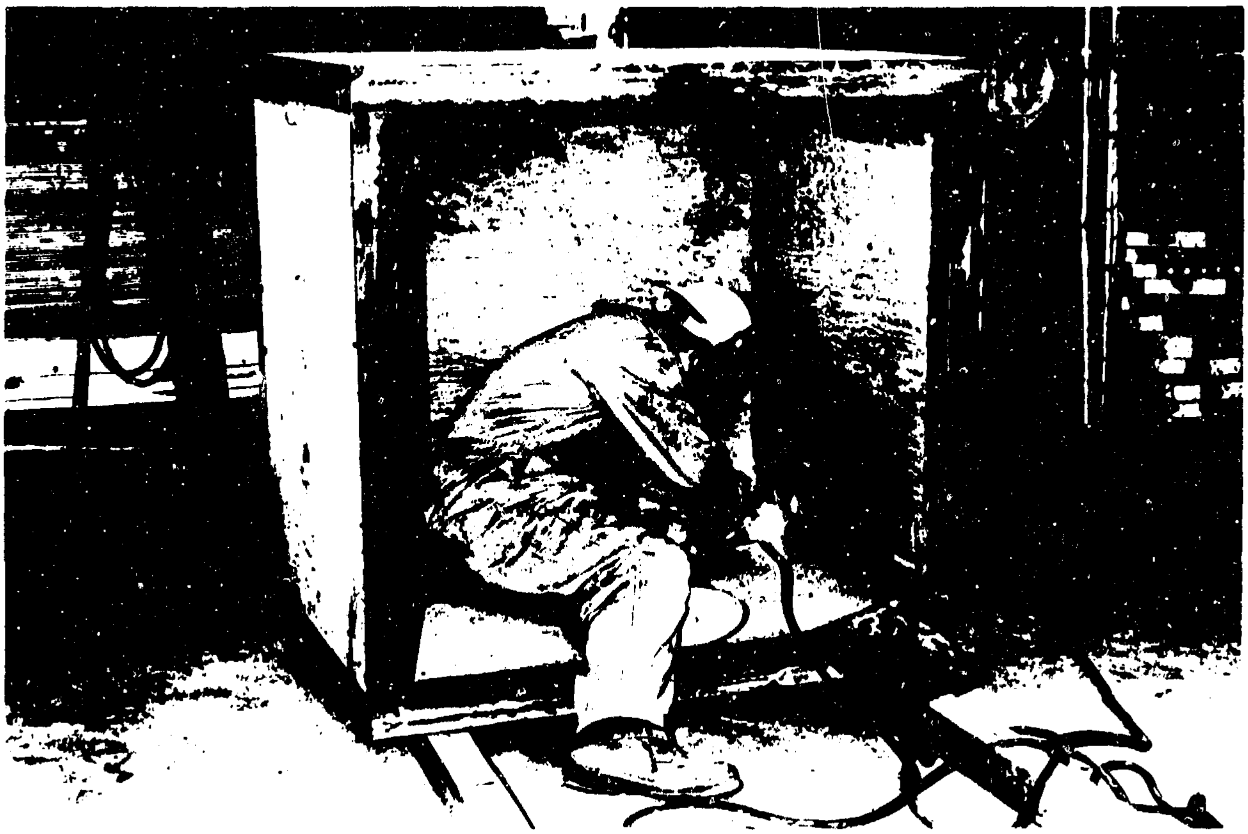


Infiltrating the Fiber Bed with Slurry
Figure 9.

During the fabrication procedure, samples of the slurry and the SIFCON were made in accordance with standard NMERI procedures. The average 28 day strength of the slurry was 11,300 psi, and the average 28 day strength of the SIFCON was 18,660 psi. By the test event, at 33 days after placing, the average SIFCON strength was 19,120 psi.

ASSEMBLY OF THE MODULAR UNITS

The modular unit was assembled starting with the bottom panel. The back and one side were then placed on the bottom panel, aligned perpendicular to each other and tack welded in place. This was followed by installing the remaining side and the top panel. The panels were welded together along both the inside and outside joints, (Figure 10). Welding was done in such a manner to minimize heat build-up in the SIFCON, and to prevent the panels from distorting along the joint.

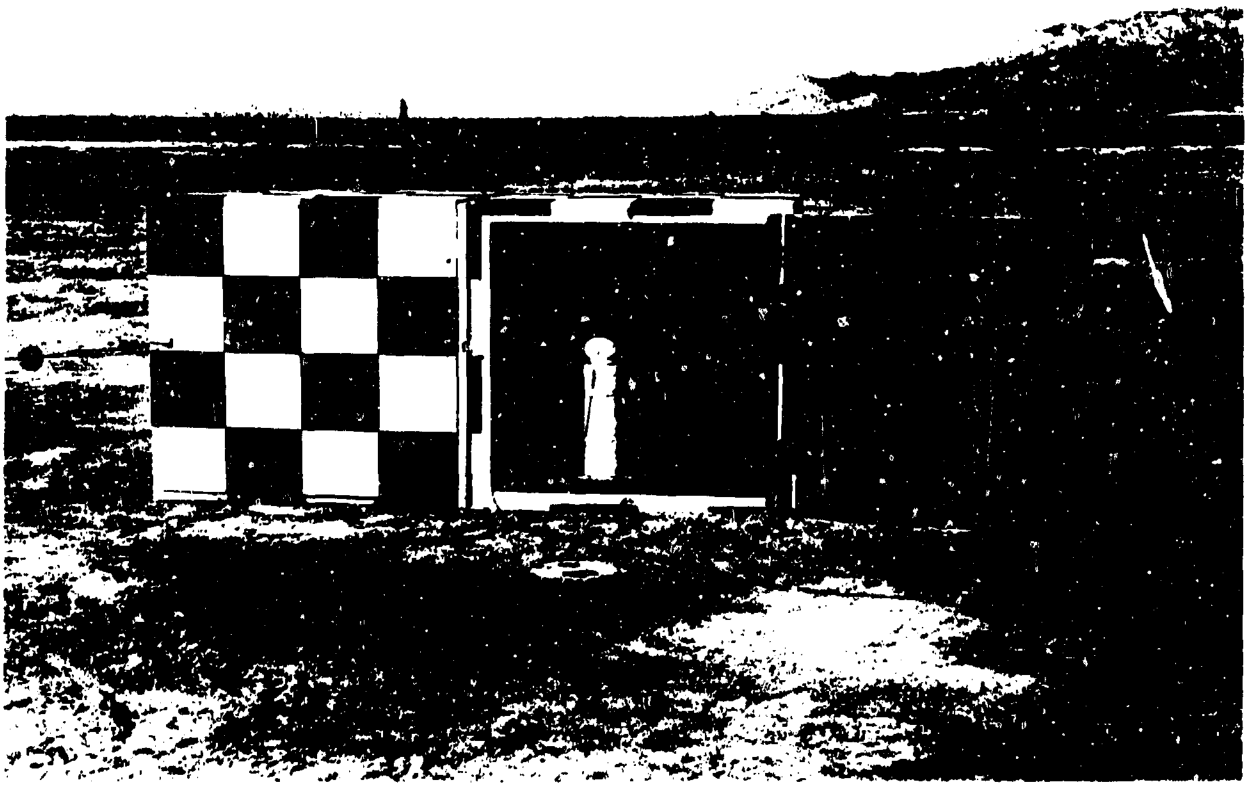


Welding the SIFCON Panels Together
Figure 10.

PHASE I--TEST

TEST SET-UP

The two modular units were transported to the test site and installed next to each other as shown in Figure 11. The units were separated by 1.5 inches of Micor board, a fire resistant, high density fiber board typically used as a specialty insulation material in the building industry.



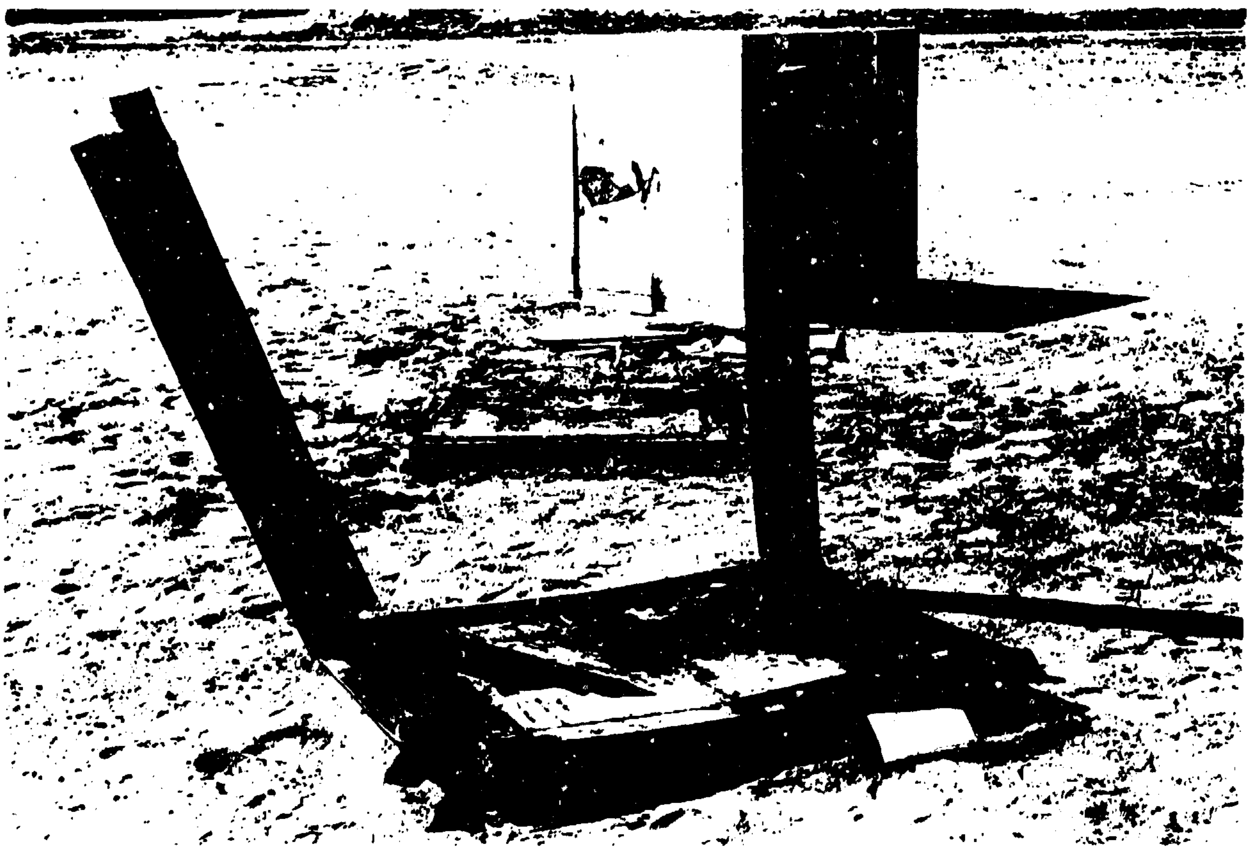
Phase I Test Set-up
Figure 11.

To represent a typical container in which explosives would be store in the ESC, an empty, closed aluminum car was placed on the floor of the acceptor unit. Following the test, the condition of the can would be an indication of the maximum pressure level inside the acceptor unit. This could be used to infer a probable condition of an explosive transportation container, and the possibility of a sympathetic detonation.

The explosive charge in the donor unit consisted of 5.64 pounds of composition C-4 explosive molded into a 6-inch diameter sphere. The center of the charge was located 21 inches above the floor, 18 inches from the back wall surface, and 15 inches from the wall adjacent to the acceptor unit, (see Figure 11).

TEST RESULTS

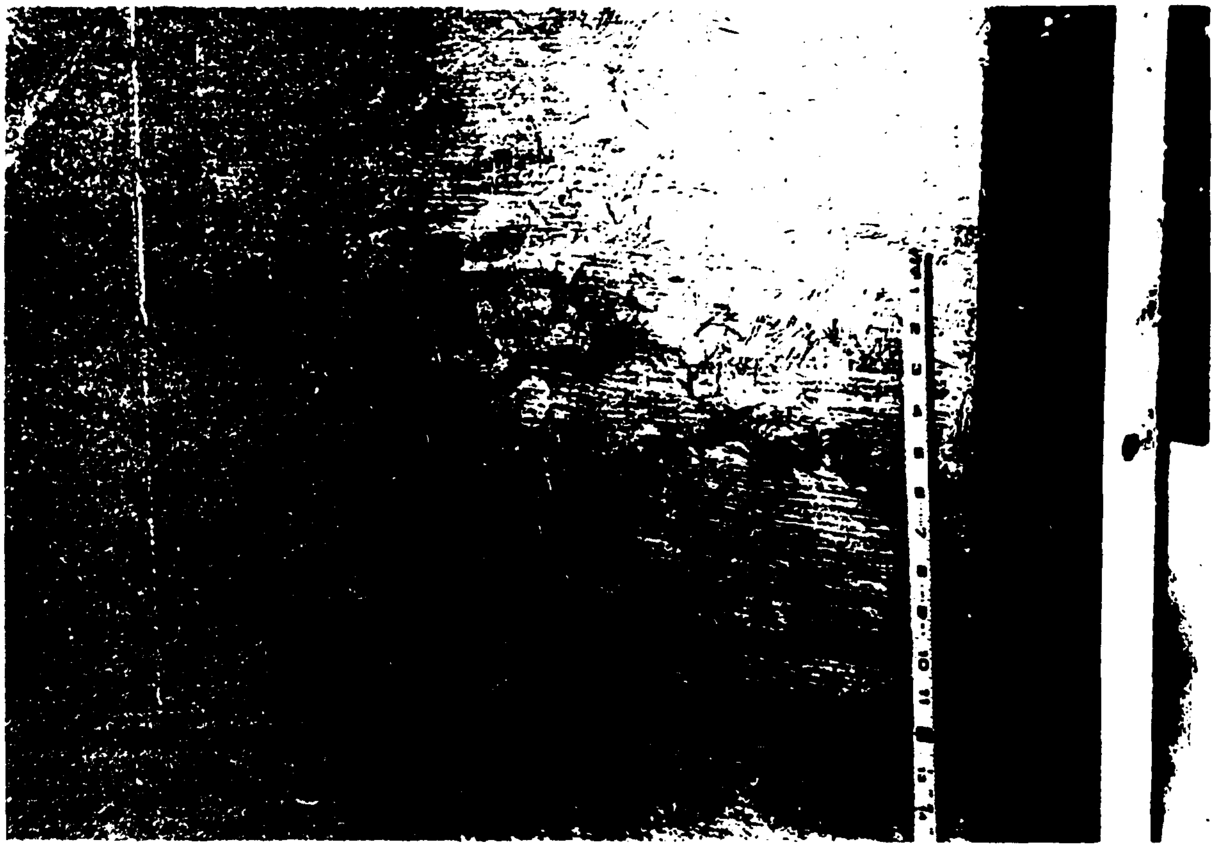
Following the test it was found that several of the individual SIFCON slabs of the donor unit had been blown out of their steel angle frames, and thrown a considerable distance away, (Figure 12). In those panels, it was noted that all the headed anchor studs holding the SIFCON slabs in the angle frames experienced a tension-shear failure in their shanks, and remained embedded in the SIFCON slab. For the other panels, where the SIFCON slab remained in the angle frame, it was observed that the base metal of the steel angle had been fractured allowing the panel to also be thrown outward.



Post-test View of Floor and Wall of Donor Unit--Phase I
(Acceptor Unit in Background)
Figure 12.

All the panels of the donor unit were found intact but severely bowed outward and with open flexural cracks along their centerlines on the outside surface. However, despite the large deformations and cracking, the panels could easily be handled without further deformation.

The acceptor unit was found displaced from its original position a few feet, but completely intact,(see Figure 12). The wall of the acceptor unit that was adjacent to the donor unit was bowed inward about 0.75 inch, and had a flexural crack visible on the inside surface, (Figure 13). There was no spalling of the inside surfaces, and no loose fibers were found in the acceptor unit. The aluminum can, used as a passive gage, was found intact and undamaged in the acceptor unit.



Inside Wall of Acceptor Unit--Phase I
Figure 13.

A complete description of the location and condition of each of the wall panels of the donor unit, and the condition of the acceptor unit is given in the Test Report for Phase I, (Reference 2).

CONCLUSIONS

The most striking result of this first test was the severity of damage suffered by the donor unit compared to the minimal damage experienced by the acceptor unit. The complete lack of back spall and the apparent low pressure level experienced inside the acceptor unit was also a pleasant finding.

Another interesting finding was the extreme ductility, or toughness, demonstrated by the SIFCON slabs. To see such a high level of deformation and cracking in the panels of the donor unit, and yet find them still in one piece was not expected, even of SIFCON. The toughness of SIFCON was also demonstrated by the fact that the headed anchor studs remained embedded in the thin SIFCON slab and reached their ultimate strength rather than pulling out.

PHASE II--DESIGN MODIFICATIONS AND FABRICATION

DESIGN MODIFICATIONS

Even though the baseline design acceptor unit survived the first test without problems, it was evident that there was room for some minor design changes. It was felt that if the strength of the donor unit could be increased, there would be less energy transferred to the adjacent acceptor units. In addition, an increased strength would also improve the ability of the acceptor units to resist the blast effects. The 3-inch thick SIFCON slab appeared to be economical, therefore, no changes to the thickness were recommended to gain the desired strength increase. However, the test indicated that the full potential of the SIFCON was not being utilized because of the limited capacity of the headed anchor studs and the angle frame.

Increasing the capacity of the studs and the frame would permit the full potential of the SIFCON slab to be realized, and optimize the complete system. It was therefore decided that the headed anchor studs be increased from 1/4-inch diameter to 3/8-inch diameter. This was a strength increase of 225%, and it was calculated that this increase should equal or exceed the pull-out capacity of the SIFCON slab. To reduce the possibility of the angle frame from tearing apart, it was decided to increase the thickness of the angle from 1/4 inch to 3/8 inch. A detailed description of the redesign calculations is given in the Program Plan for Phase II, (Reference 3).

Since the door to the acceptor unit did not blow inward on the first test, and the pressures experienced inside the acceptor unit were not high enough to crush the aluminum can, it was decided that the original door design was adequate, and no changes were made.

PHASE II TEST CONSIDERATIONS

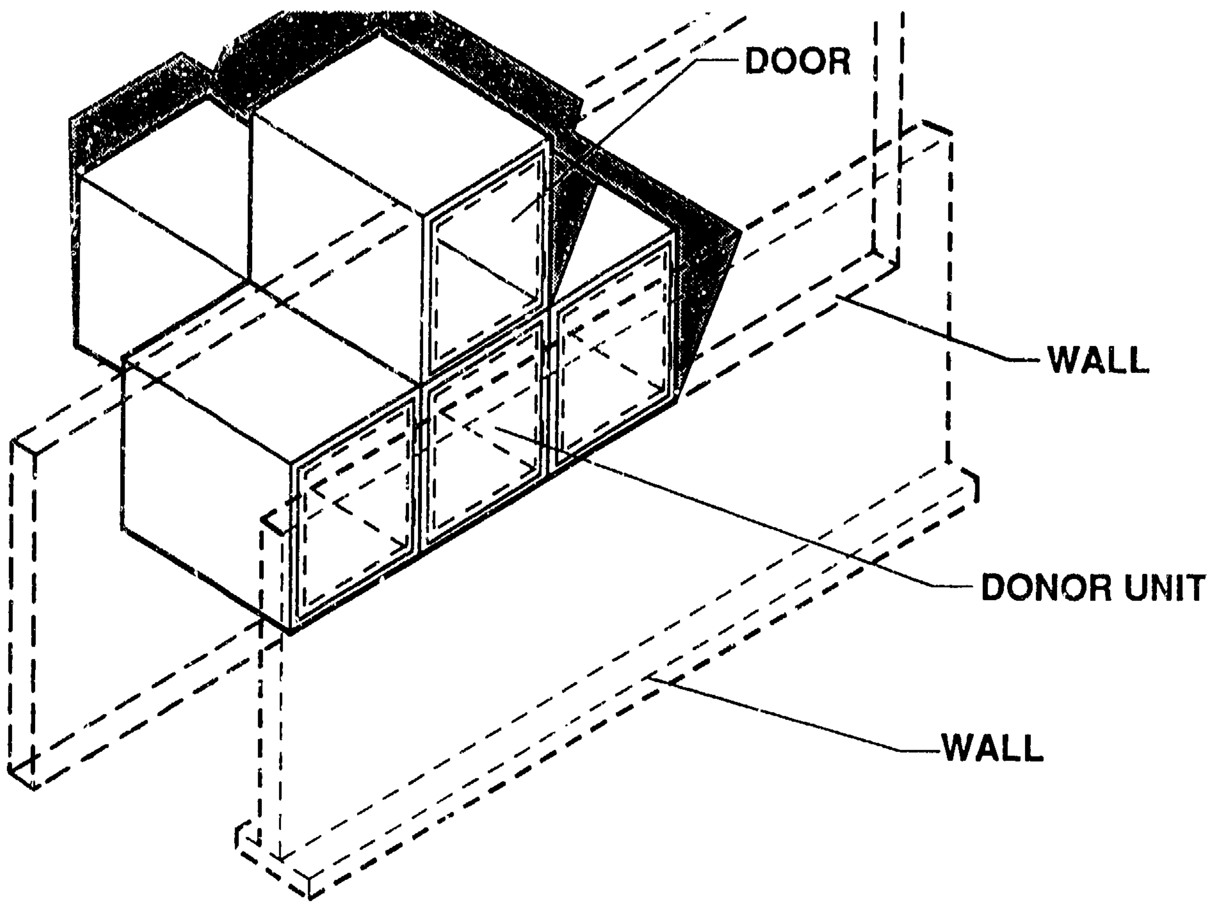
Because of the limited scope of the Phase I test, a number of important conditions could not be addressed. The effect of these conditions on the ESC needed to be determined before the cabinet system could be considered acceptable for service.

First, what would be the effect of the magazine building on the acceptor units? Reflected pressure and impulse on the doors and walls of the acceptor units would be different, and most likely higher, than that experienced in the Phase I test.

Second, what would be the effect on the donor and acceptor units by the presence of the other units of the cabinet system?

Would the confinement help direct more or less of the energy from the donor to the acceptor units? Would this result in a failure of the acceptor unit and a resulting sympathetic detonation?

In order to answer these questions, the Phase II test program was developed to include methods to simulate the effects of the magazine building and the confinement by the surrounding units. The proposed concept for the Phase II test is shown in Figure 14. It incorporated five modular units arranged as shown. In this arrangement, the four acceptor units would simulate the confinement of the donor unit. Earth berms and concrete walls were proposed to simulate confinement of the acceptor units. A concrete wall, placed in front of the modular units, would simulate the effect of the magazine building enclosing the ESC. The wall would extended above, and on eitner side of, the group of five units to minimize unwanted reflections of the shock wave from the free edges.



Proposed Concept for the Phase II Test
Figure 14.

UNIT FABRICATION and ASSEMBLY

The construction methods and materials used for the five Phase II units were identical to those used in Phase I. A few minor changes were made to the slurry mix proportions in an attempt to increase the strength of the SIFCON. The revised slurry mix is given in Table 2.

Table 2
SIFCON Slurry Mix Proportions
Phase II

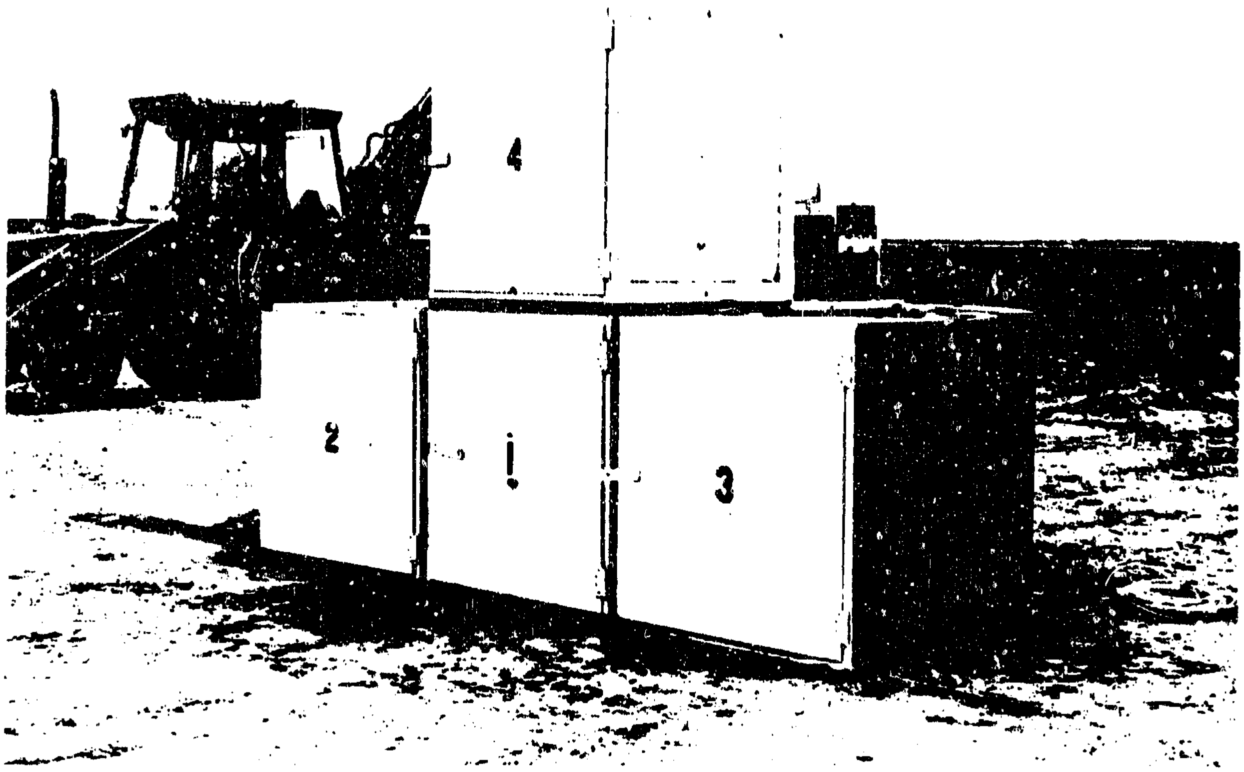
Portland Cement, Type I-II	60.0 lbs
Fly Ash, Type C	0.00 lbs
Microsilica,	9.0 lbs
Sand, 50 Mesh	30.0 lbs
Water	20.5 lbs
Superplasticizer	24.0 ozs
Fiber Volume Density (FVD)	11%

During the fabrication procedure, samples of the slurry and the SIFCON were made in accordance with standard NMERI procedures. The average 28 day strength of the SIFCON was in the donor unit was 27,740 psi, and the strength of the SIFCON in the acceptor units was 23,950 psi. By the day of the test event, the average strength of the SIFCON in the donor unit was 29,675 psi (62 days), and the average strength of the SIFCON in the acceptor units was 26,690 psi (42 days). At the time, these values were determined to be record high strengths for SIFCON made using production methods.

PHASE II--TEST

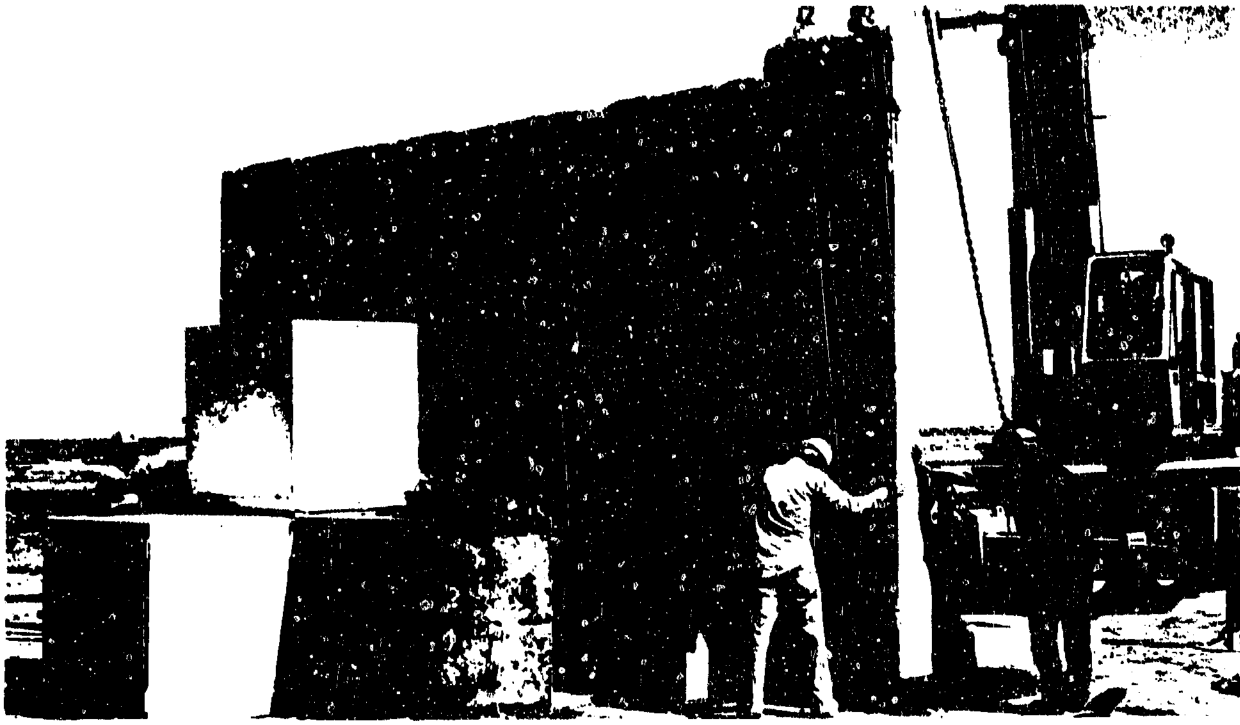
TEST SET-UP

The four front units were assembled on the test bed as shown in Figure 15. Unit #1 was the donor unit. Unit #5 was placed back-to-back with Unit #1,(see Figure 16). Two, 0.75 inch thick Micor boards were installed between all the units.

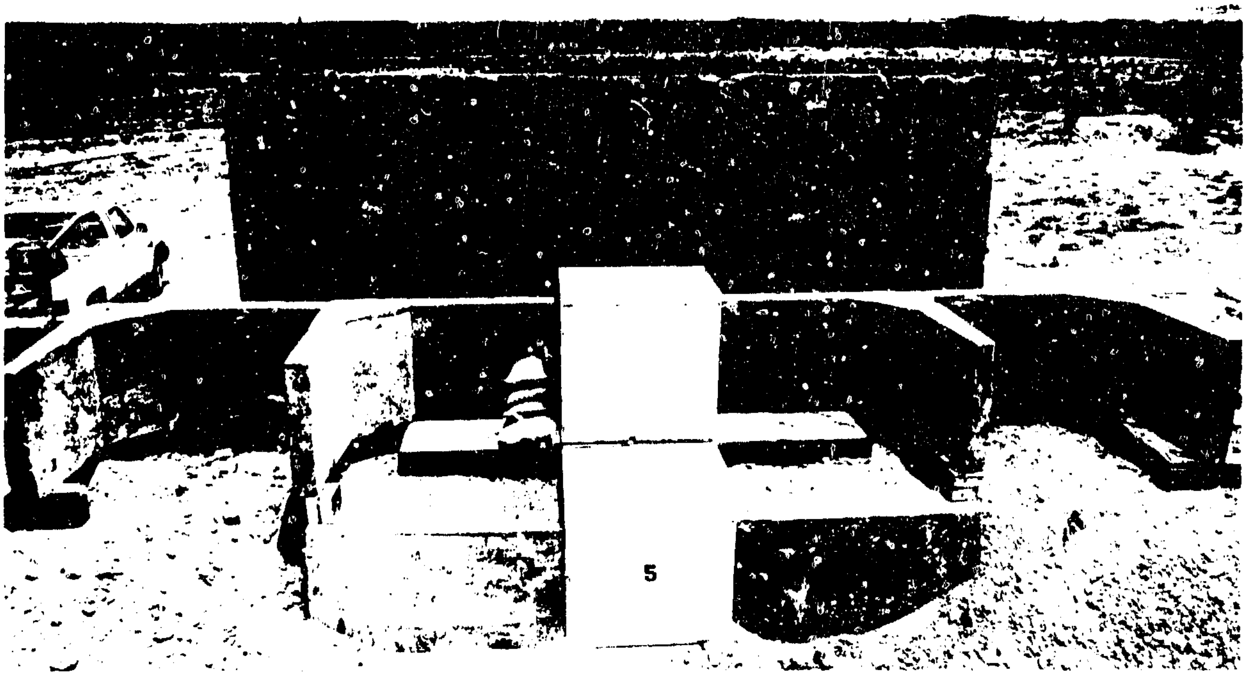


Four Front Units--Phase II
Figure 15.

To simulate the effect of the Explosives Component Facility magazine, seven precast concrete walls were placed 4 feet away from the four front units, (Figure 16). To simulate the confining effect of adjacent modular units, a series of precast concrete wall panels and earth backfill were constructed around the five units, (Figure 17).



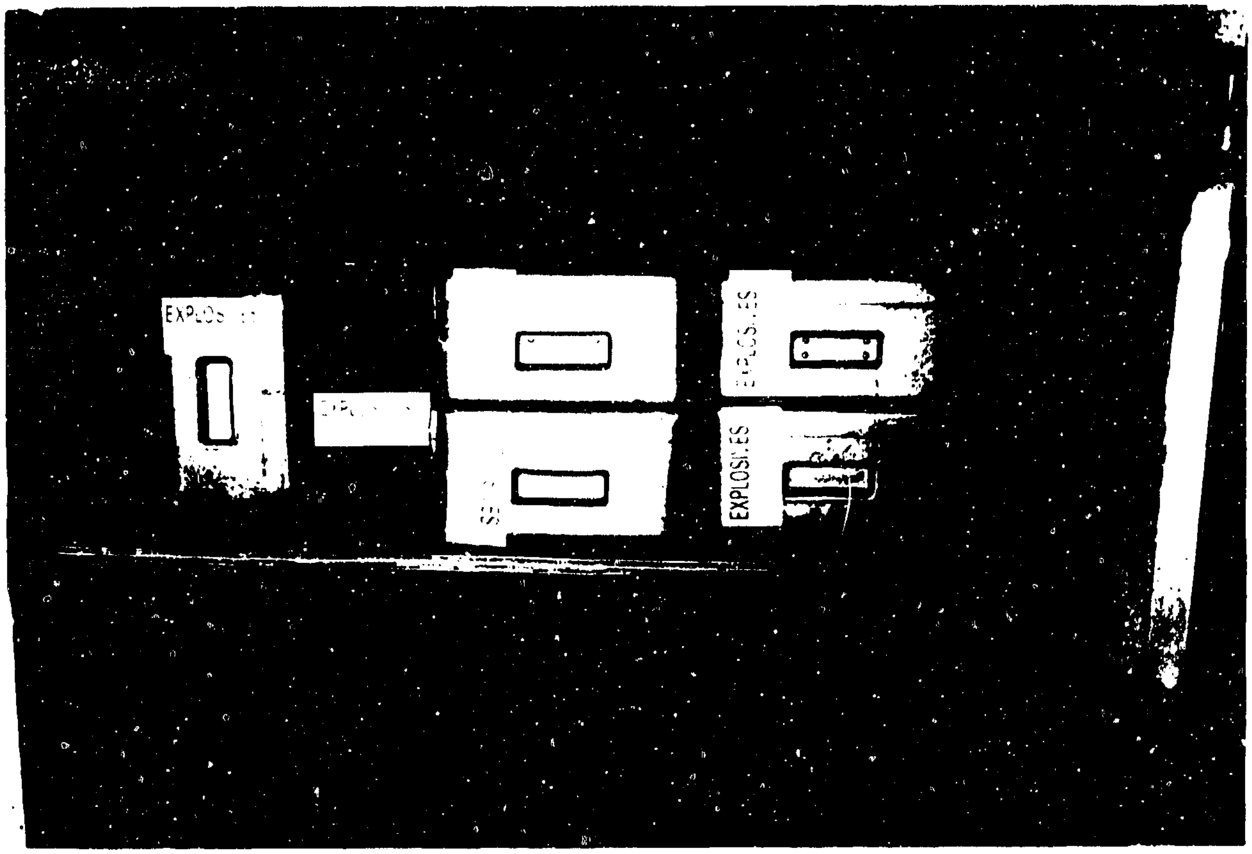
Installing the Wall Simulating the Magazine Building--Phase II
Figure 16.



Concrete Walls Simulating Confinement of Units--Phase II
Figure 17.

Ten channels of blast pressure measurements were recorded in the test. Four gages were located in the surface of the test bed, two gages were located on the wall simulating the building, and one gage was mounted on the front of the modular units. One pressure gage was located inside two of the acceptor units and one gage was installed inside the donor unit. A more detailed description of the gage types and locations are given in the Test Report for Phase II, (Reference 4).

Prior to the test, a number of different types of explosives were brought to the test site and placed in each of the four acceptor units. Figure 18 shows a typical placement of the explosives in an acceptor unit. Table 3 presents a listing of the types and weights of explosives stored in each of the units.



Typical Explosives Stored in an Acceptor Unit--Phase II
Figure 18.

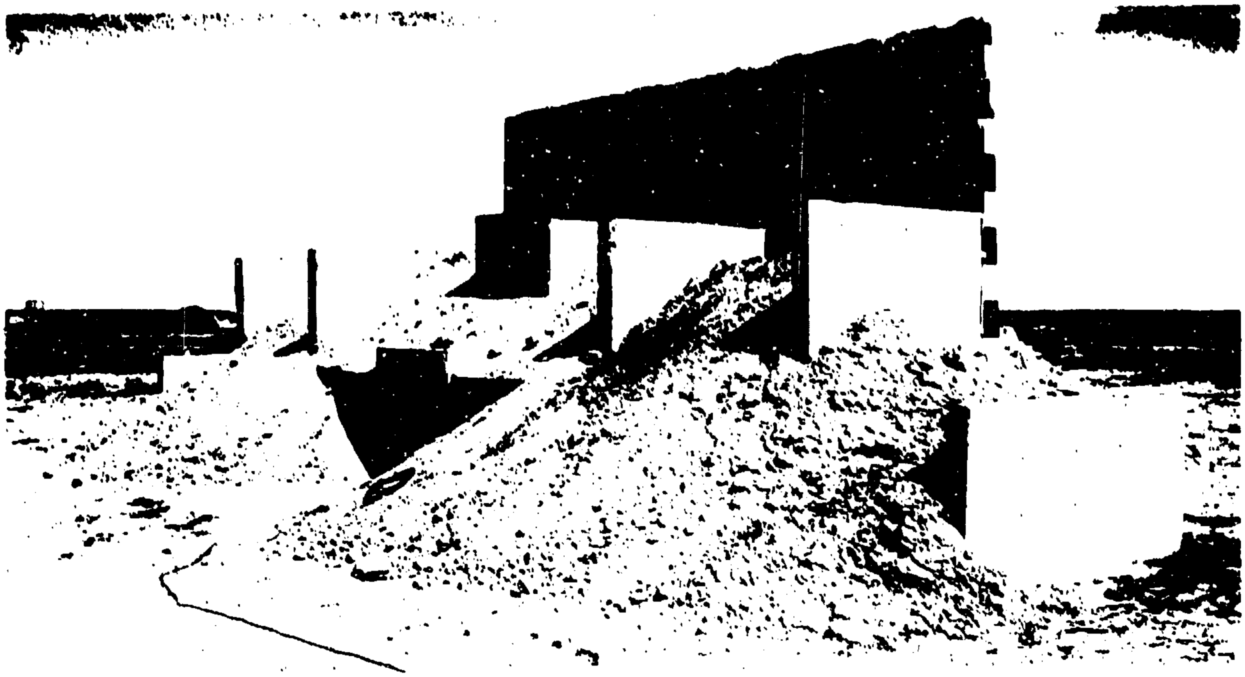
Table 3
Explosives Stored in the Acceptor Units
Phase II

Unit Number	Type of Explosives	Weight of Explosives
#2 and #4	PETN	25 gms
	Tetryl	25 gms
	CP	25 gms
	HMX	25 gms
	HNS	25 gms
	Lead Styphanate	25 gms
	Barium Styphanate	25 gms
	Lead Azide	2 gms
#3	C-4	5.0 lbs
#5	C-4	1.25 lbs
	LX-15	16.0 gms
	LX-13	12.5 gms
	Pyrotechnly	120.0 gms
	Propellant	170.0 gms

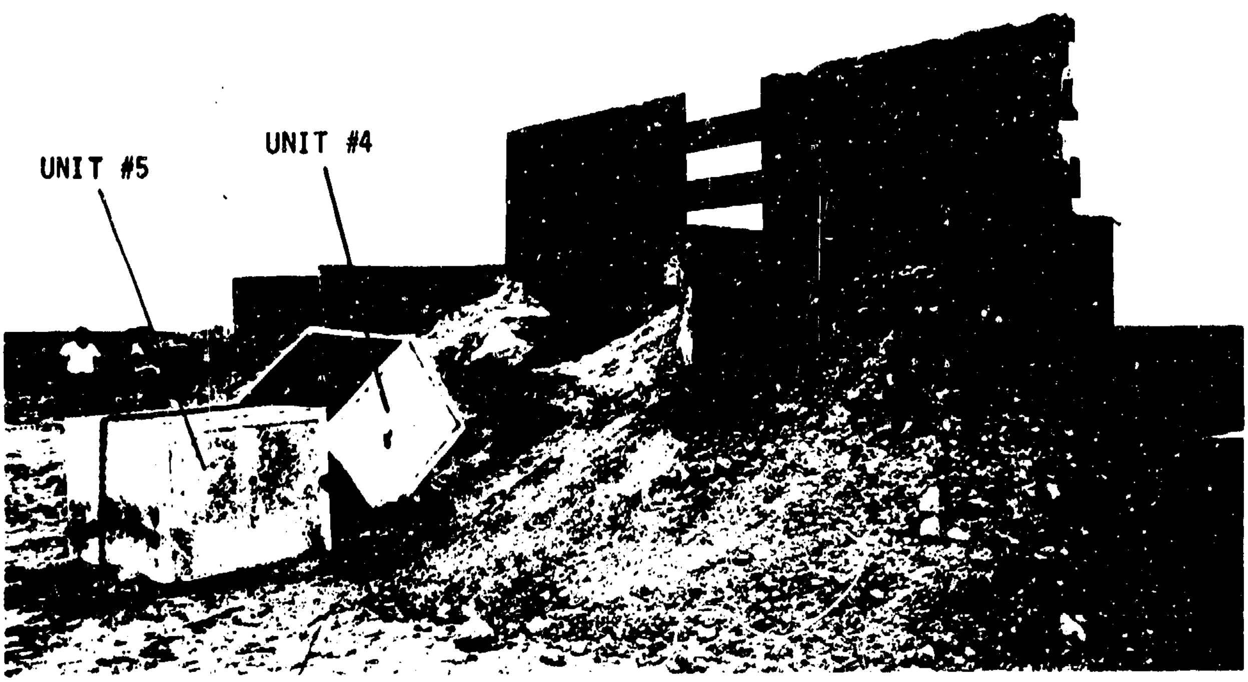
The explosive charge in the donor unit consisted of 5.64 pounds of composition C-4 explosive molded into a 6-inch diameter sphere. The center on the charge was located in the donor unit 21 inches above the floor, 18 inches from the back wall surface, and 15 inches from the wall adjacent to acceptor unit #2.

TEST RESULTS

Figure 19 shows the final set-up prior to the test. Following the test, the back acceptor unit (#5) was found displaced backwards from its original position approximately 8 feet, and lying on its door face. High speed photography showed that the top acceptor unit (#4) had been blown upwards and backwards by the blast. It was found lying on its backwall near the original location of acceptor unit #5, (Figure 20). Acceptor units #2 and #3, on either side of the donor unit, were found to have been pushed away from the donor box about 1 inch, and rotated backwards 3 to 4 inches from their original position. The donor unit was also found to have been pushed backwards about 3 inches. The doors of units #3, #4, and #5 were still attached to the wall panels and operable. The door of unit #2 was attached at only the bottom hinge, (Figure 21).



Back View of Test Set-up--Phase II
Figure 19.



Post-test Location of Acceptor Units #4 and #5--Phase II
Figure 20.

Post-test Condition of Acceptor Units--Phase II
(Front to back: Units #2, #1 (Donor), #3)
Figure 21.

The concrete walls on either side of acceptor units #2 and #3 were found to have been pushed away from the units about 3 to 4 inches. The concrete walls on either side of the top acceptor unit (#4) were rotated backwards about 3 inches. An area of the concrete wall panel simulating the magazine building, directly opposite the donor unit, was rubbelized to a depth of 1 to 2 inches when the steel plate door of the donor unit struck it, (partially visible in Figure 21). The wall itself was driven backwards into the earth backfill about 1.5 inches.

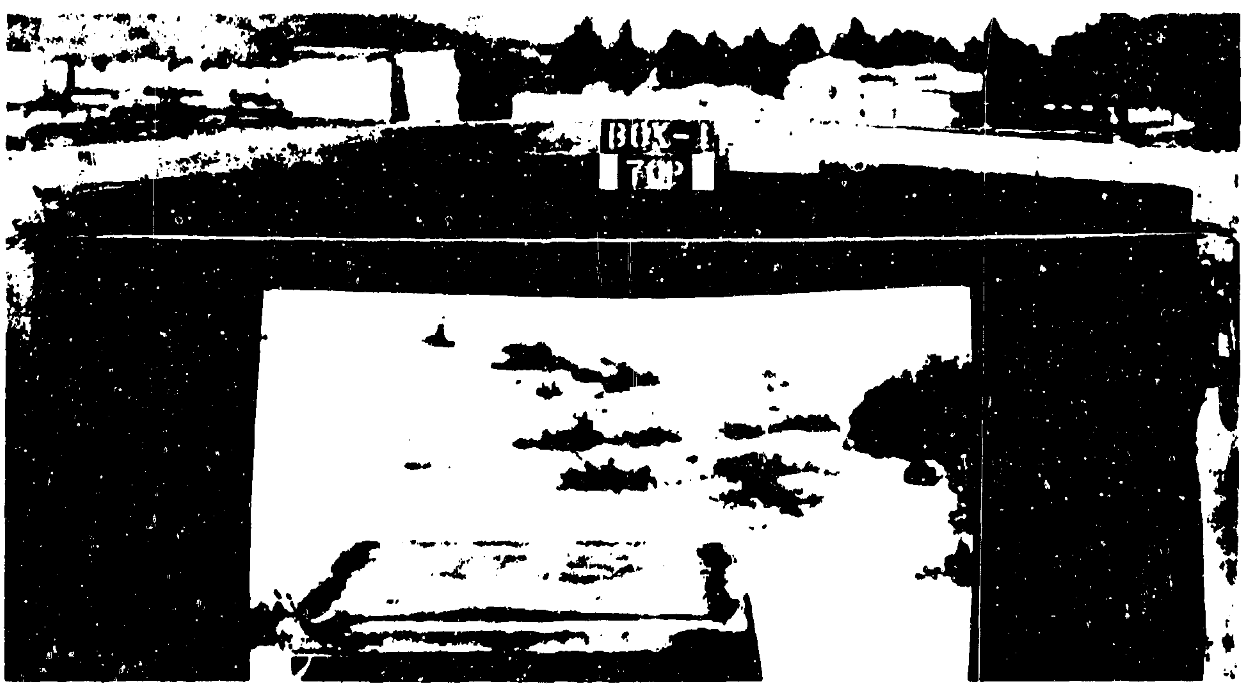
None of the explosives stored in the acceptor units were detonated, and none of the explosive's shipping containers were damaged during the test. One container with primary type explosives was ejected from acceptor unit #4 as it was falling backwards, but was found intact and undamaged nearby. All the explosives were recovered from their acceptor units following the test.

POST-TEST CONDITION OF UNITS

A more detailed description of the final locations and condition of the donor and acceptor units is presented in the Test Report for Phase II, (Reference 4).

Donor Unit, #1

The side walls, roof and floor of the donor unit were bowed outward but were still contained within their steel angle frames, (Figure 22). In some cases the headed anchor studs had failed in either the weld or in the shank. In no case did the stud pull out of the SIFCON panel. Some minor separation of the welds and tearing of the steel angles was observed at all the inside joints, especially near the front edges of the panels.



Typical Bowing of Wall Panels of Donor Unit--Phase II
Figure 22.

The SIFCON slab of the back wall of the donor unit was blown out of its steel angle frame, and was found resting against the back of the unit. Approximately 85% of the headed anchor studs in the slab showed failure in the welds. The remaining studs had failed in the shank. One stud near the lower corner of the panel remained tightly welded to the angle frame and appeared to have torn through the SIFCON panel.

Acceptor Unit #2

The wall panel next to the donor unit had been bowed inward about 0.50 inch. A thin layer of the slurry had been knocked off over an area about 8 inches in diameter on the inside surface of the wall. Although some of the fibers were exposed, no loose fibers were noted inside the unit. The other panels of unit #2 were found undeformed and undamaged.

Acceptor Unit #3

Acceptor unit #3 experienced a similar bowing of the wall which was adjacent of the donor unit as that of unit #2, but to a slightly lesser degree. The amount of slurry knocked off the inside of the wall surface was also less then that found in unit #2. No other panels of unit #3 were deformed or damaged.

Acceptor Unit #4

The bottom panel of unit #4 was bowed upward about 0.75 inches, and a wide, shallow crack along the centerline was evident on the inside surface of the panel. However, no spalling or loose fibers were noted inside the unit. The remaining panels of unit #4 were not deformed or damaged.

Acceptor Unit #5

The back panel of unit # 5 was bowed slightly inward. A very small area of slurry was knocked of the inside surface of the back panel. No spalling or loose fibers were found in the unit, and no other panels were deformed or damaged.

CONCLUSIONS and COMMENTS

The obvious result of the Phase II test was that none of the explosives stored in any of the four acceptor units were sympathetically detonated. Since this was the basis of acceptance for the system, it was concluded that the current design of the SIFCON modular units for the Explosives Storage Cabinet met the design criteria.

In terms of the structural response of the units, the most striking result of the second test was the much lower level of damage experienced by the donor unit (#1) compared to the first test. The majority of the difference can probably be attributed to the thicker steel angle frame and larger diameter anchor studs around the edges of the SIFCON panels. In addition, the higher strength SIFCON achieved in the Phase II series, and the effects of confinement by the adjacent acceptor units may also have contributed to the reduction in the damage to the donor unit.

The damage experienced by any of the four acceptor units of the Phase II test was significantly less than that received by the acceptor unit of the Phase I test, and was considered to be trivial. Again this difference can probably be attributed to the increased strength of the angle frame and the higher SIFCON strength used in the units.

As in the Phase I test, the extreme ductility, or toughness, of the SIFCON slabs was again clearly demonstrated, especially in the panels of the donor unit (#1). The toughness of SIFCON was also demonstrated by the fact that even the larger sized headed anchor studs still remained embedded in the thin SIFCON slab rather than pulling out.

After observing the minimal damage experienced by the acceptor units, it would appear that the SIFCON units could resist a significant larger explosion. The economic and safety benefits of having a larger rated capacity for the units are obvious. For example, a 50% increase in the amount of explosives that could safely be stored in a single unit would mean a 50% reduction in the amount of storage facilities required for a given amount of explosives. This would directly result in lower construction costs for the facility and in land area required. In addition, it would allow for more flexibility in the storage of different types and amounts of explosives. It is, therefore, recommended that SNL consider a program to determine the maximum amount of explosives that could be stored in the SIFCON cabinet system.

Although this program was limited to using SIFCON in a specific explosives storage system, it is clear that the material would have economical applications in virtually any system dealing with explosives storage or containment. SIFCON would also have application in many structural systems required to resist blast and shock loadings, fragment and ballistic penetration, or forced entry. It is recommended that SNL and/or the Department of Energy conduct a review of their facilities currently being designed to see if SIFCON would be of benefit.

It is also suggested that SIFCON be considered in future plans for new or renovated facilities.

In conclusion, it is recommended that the SIFCON ESC development program advance to Phase III, and that appropriate engineering drawings and specifications be prepared for fabrication the SIFCON modular units. The structural details and the SIFCON mix design used for the units in the Phase II test should be the guideline.

REFERENCES:

1. Schneider, Bruce, Development of a SIFCON Explosives Storage Cabinet--Phase I, A Program Plan for Sandia National Laboratory, Division 2514, NMERI OC-89/120, New Mexico Engineering Research Institute, Albuquerque, New Mexico, August, 1989.

2. Schneider, Bruce, Development of a SIFCON Explosives Storage Cabinet--Phase I, A Task Report for Sandia National Laboratory, Division 2514, NMERI OC-90/13, New Mexico Engineering Research Institute, Albuquerque, New Mexico, November, 1989.

3. Schneider, Bruce, Development of a SIFCON Explosives Storage Cabinet--Phase II, A Program Plan for Sandia National Laboratory, Division 2514, NMERI OC-90/15, New Mexico Engineering Research Institute, Albuquerque, New Mexico, April, 1990.

4. Schneider, Bruce, Development of a SIFCON Explosives Storage Cabinet--Phase II, A Task Report for Sandia National Laboratory, Division 2514, NMERI OC-90/18, New Mexico Engineering Research Institute, Albuquerque, New Mexico, September, 1990.

INBLAST--A New and Revised Computer Code for the Prediction of Blast Inside Closed or Vented Structures

prepared by

Paul E. Montanaro
and
Michael M. Swisdak, Jr.
Naval Surface Warfare Center
10901 New Hampshire Avenue
Silver Spring, MD 20903-5000

ABSTRACT

The computer code INBLAS was developed and published in the early 1970's to describe the blast produced by the reaction of energetic materials inside closed or partially vented structures. Since that time, refinements have been made to several of the code algorithms. These changes have been collected into a new version of the code called INBLAST. This version is designed to run on a desk top personal computer. The code is briefly described. Sample problems are presented and some of the results are compared with experimental data.

BACKGROUND

In 1972, Proctor[1] published the first version of a computer code designed to describe the phenomena associated energetic reactions inside closed structures. Since that original publication, many of the basic algorithms and concepts contained within the code have been improved and/or expanded and have become widely used in later versions of the same code or incorporated into other codes. In 1976, Ward and Lorenz of the Naval Surface Weapons Center (NSWC) developed a module for the program that allowed the use of time-dependent burning of the energetic material (rather than detonation). Other sections have become obsolete or superceded as new technology or information has become available. The best example of the latter are the sections of the code dealing with shock wave reflections within the chamber and the accompanying loading on the chamber walls. Waterways Experiment Station (WES) and their contractor Applied Research Associates (ARA) replaced the original shock calculations in INBLAS with more accurate shock reflection and superposition algorithms to form the BLASTINW code in the early 1980's[2,3,4].

The original code was designed and written to run on a main-frame computer. With the proliferation of both versions of the computer code and of desk top computers, the Department of Defense Explosives Safety Board (DDESB) deemed desirable to both update the original code and to produce a version which would run on a personal computer. This updated code could be compared with experimental data and then become a benchmark against which future versions or variations of the code could be compared.

In order to accomplish this task, it was felt that the "best parts" of both the INBLAS code and the BLASTINW code should be combined and a new and improved code produced. This effort was undertaken by the Boeing Military Airplane Company (Mr. Richard Lorenz) under contract to the Naval Surface Warfare Center (NAVSWC). This task was accomplished in 1989. At that time, however, it was felt that the program was still not "user friendly". NAVSWC then began the task of developing an input module which, through a series of interactive screens, generates, runs, and displays the output of the INBLAST program.

The remainder of this paper is a brief description of the basic program as well as a discussion of the interactive screens and the solution of two sample problems. It should be noted that this paper is not designed as a tutorial on the structure and uses of INBLAST. Rather the paper describes the program in general, with emphasis on the recent changes and improvements.

DESCRIPTION OF THE CONFINED EXPLOSION GAS PRESSURE CALCULATION

The chemical reaction of the explosion/burning and mixing with air in a closed structure creates the combustion products Al_2O_3, H_2O, CO, CO_2, C, Al, H_2, O_2, and N_2. A priority in the reaction is assumed as follows: (1) The aluminum in the energetic material reacts with oxygen to form the solid Al_2O_3; if there is insufficient oxygen, the remaining Al is treated as a solid. (2) The hydrogen has the next priority on the oxygen to form H_2O; again for insufficient oxygen, the remaining hydrogen is treated as H_2. (3) If there is an overabundance of oxygen in the energetic material and structure atmosphere, complete combustion occurs such that all carbon appears as CO_2 and the remaining oxygen not needed in any of the reactions appears as O_2. (4) If there is insufficient oxygen in the system after the Al_2O_3 and H_2O reactions, then CO and CO_2 are produced in quantities given by the the following equations:

$$n(C) + m(O) \Rightarrow a(CO) + b(CO_2) \qquad \text{for } m>n$$

$$\begin{matrix} a + b = n & & a = 2n - m \\ & \text{or} & \\ a + 2b = m & & b = m - n \end{matrix}$$

where

a = number of moles of CO produced
b = number of moles of CO_2 produced
n = number of moles of C
m = number of remaining moles of O

and no O_2 exists in the final combustion products. (5) In the above equations, if m<n, no CO_2 will be formed or if b = 0, then CO is produced such that a=m and solid carbon particles will appear in the combustion products in the amount n-m. (6) The nitrogen does not participate in the reaction and appears as N_2 in the final mixture. From the above calculations, the number of moles of component gases and solids that make up the final products in the closed structure can be calculated. Once these are known, the final pressure and temperature within the chamber can be calculated.

The following information is required to perform an INBLAST quasi-static pressure calculation:

(1) C-H-N-O content of the energetic material
(2) Heat of formation of the energetic material
(3) Weight of energetic material.
(4) Volume of initial chamber
(5) Vent area of exit from initial chamber
(6) Volume of secondary chamber
(7) Vent area of exit from secondary chamber
(8) Ambient pressure and temperature.

The program allows for multiple chambers with energetic events possible in any of them. Each chamber may be vented to any other chamber or to an ambient reservoir. The equations governing the flow between the chambers are the appropriate ones for both supersonic and subsonic flow through a perfect nozzle. The ratio of the specific heats, γ, is not taken as a constant of 1.4--rather it is allowed to assume an appropriate value determined by the pressure, volume, temperature and mix of constituents of the gases exiting the chamber.

COMPUTATIONAL RANGE

The original version of the program (INBLAS) was demonstrated to accurately predict the confined gas pressures as a function of loading density (charge weight divided by chamber volume) over several orders of magnitude in pressure. This has not changed. In fact, the range has been extended even further. This comparison is shown in Figure 1. The computation is for TNT and was performed with this latest version of the code.

DESCRIPTION OF THE SHOCK CALCULATION

The program utilizes techniques and algorithms developed for the LAMB (Low Altitude Multi-Burst) computer code to predict the direct and multiply reflected shockwaves present after a detonation inside a closed chamber. For a description of these techniques, the reader is referred to References 2 and 3.

HARDWARE REQUIREMENTS

The program is designed to run on any IBM-compatible machine using DOS 3.1 operating system (or higher) with 640 kilobytes of memory and a hard disk. The program supports CGA, EGA, and VGA color monitors. An IBM-AT (or faster) machine with math co-processor is required.

GENERAL

Before running INBLAST copy all files from the INBLAST floppy disk to a directory on your hard disk. The file INBLAST2.EXE is the INBLAST program. It is written in FORTRAN 77 and performs all of the internal blast calculations. It reads all of its input data from the file INBLAST.IN. MENU.EXE is an interactive screen input program, which is written in BASIC. It reads the file INBLAST.IN, allows easy modification and then rewrites INBLAST.IN. The file GO.EXE controls both INBLAST2.EXE and MENU.EXE allowing them to be run as one unit.

To run INBLAST type **GO** from inside the directory which contains the INBLAST files. A message will appear asking you whether you want to use the values from the previous run, or use all default values. Using the previous values will cause the program to read the file INBLAST.IN, which contains input information used for the last run of INBLAST. Using the default values will reset all input values to their default.

The input to the program is prepared interactively through a series of screens which question the user. The are a total of twelve input screens; however, depending on the type of calculation being performed, not all of them will be used or seen by the user. Also some screens are used several times to allow for input of multiple energetic materials. The number of each input screen and its description are shown at the top of each screen. Notes are often shown at the bottom of the screen in red. Brief descriptions of each input item are shown in yellow. Items in brown cannot be changed. They either do not apply for the particular type of calculation or they are automatically set to a default value. Units for the inputs and their minimum and maximum values, are shown in green. The effect of function keys are shown in blue at the bottom of each input screen. Pressing F1 will set a number to its default value. F2 moves you to the next screen. F3 takes you back to the main menu.

When an input screen is shown, you may change any value by over-typing it and then pressing "Enter". You must press "Enter" here; pressing F2 will take you to the next screen but does not enter the new value. If a value does not need to be changed, just press "Enter". This will move you to the next input. If all items on the screen are correct, press F2. Continue doing this until you have gone through all of the input screens, and have returned to the main menu.

DESCRIPTION OF INPUT SCREENS

MAIN MENU

See Figure 3. Upon entering the program, you will see the Main Menu. Item 1 should always be selected before running INBLAST. It allows you to modify the input conditions for INBLAST. Select item 1 by typing a 1 and pressing the "Enter" key ("Return" key on some keyboards). Item 2 runs the INBLAST program after input is completed. Item 3 displays the program output on the screen or printer. Item 4 exits the program, returning you to DOS.

Let us assume that item 1 was initially selected.

INPUT SCREEN 1 - GENERAL OPTIONS

See Figure 4. This first item is the title of the run. This can be up to 80 characters long. It will be printed at the top of the program output.

The second and most important item is the type of calculation. Select number 1 for shock loading in a closed room. This option calculates direct and multiply-reflected shocks in a single closed chamber. However multiple chambers and multiple energetic materials can be specified if you wish to do many different closed chamber calculations at one time. Option 2 is for shock and combustion. This is similar to option 1 but also performs instantaneous combustion and calculates the confined explosion gas pressure (quasi-static pressure). Option 3 is for shock, combustion, and venting. This is similar to option 2 but also performs venting calculations into multiple chambers. Option 4 is instantaneous combustion. It reacts energetic materials instantaneously and determines quasi-static pressure. Option 5 is combustion and venting. Time dependent burning is allowed only here. Energetic materials can time dependently react and their gases vent into other chambers.

The third and fourth items are self explanatory. You can have up to 20 energetic materials and chambers.

The last item is the number of targets in confined shock calculations. This only applies for calculation options 1, 2, and 3, where shocks are calculated. A target is a location in a chamber where the shock is calculated. You can have up to 20 targets.

INPUT SCREEN 2 - GENERAL OPTIONS CONTINUED

See Figure 5. Enter the maximum time to be calculated. INBLAST will stop its calculations after this period of time. If zero is entered, the program selects a maximum computational time.

Select the default type of calculation appropriate to this run. Gas pressure refers to quasi-static pressure.

The maximum order of reflected rays is the maximum number of shock reflections calculated.

The run identification name is used for generating plot files. A plot file is an ASCII file generated by the program containing a table of time vs. pressure and impulse.

INPUT SCREEN 3 - EXPLOSIVE DATA

See Figure 6. At the top of the screen the program tells you the number of the energetic material you are inputting. For each energetic material, this screen will be duplicated. For each energetic material, select whether it will be a single energetic material from the table (see Table 1, Table of Energetic Materials), or a mixture of energetic materials from the table, or a material not in the table, or a gaseous material not in the table.

For a single material you will have to select the material from the list and then go on to the next screen. For a mixture of materials, you will select each one and type in their weight fraction in the mixture. The total weight fraction should add up to 1 (if the weight fraction does not add up to 1, the program adjusts the values until they do). Also enter the equivalent weight of the mixture. If zero is entered, then a weighted average of the equivalent weights of the mixed components is used. For a material not in the table you must enter its name, equivalent weight, energy of formation, and a table of material components vs. weight fraction respectively. For a gaseous explosive, the molar fraction of the explosive in the chamber and the molecular weight of the explosive must also be entered. A gaseous explosive cannot be used for shock calculations.

INPUT SCREEN 4 - EXPLOSIVE DATA CONTINUED

See Figure 7. This screen must be input for each energetic material. Enter the weight of the material, and the chamber in which it will burn or detonate.

For shock calculations, enter the X, Y, and Z coordinates of the explosion. These numbers must be less than the dimensions of the chamber.

Enter the minimum chamber temperature required to initiate the explosive. If this is zero, the explosive initiates immediately. Also you can enter the time required to initiate the explosive at that temperature.

For time dependent burning, enter the initial weight of the energetic material burned. This amount will be burned in the first step of the reaction. If this is zero, then it will be set to the weight of the material divided by 1000.

If the material undergoes time dependent burning answer Y to the question, otherwise answer N.

INPUT SCREEN 5 - 1ST BURN TABLE

See Figure 23. This screen will only appear if an energetic material undergoes time dependent burning, and must be input separately for each of these materials. Enter a table of burn area vs. weight burned. Up to 50 pairs can be entered in this table. To calculate numbers for the table use the following procedure:

CONSIDER FIRST, A SINGLE PROPELLANT GRAIN AS SHOWN IN FIGURE 2.

It is assumed that the energetic material (grain) is a cylindrical solid with multiple cylindrical perforations.

STEP 1: Calculate total surface area and volume of unreacted grain

R_0	Radius of grain (in)
R_i	Radius of perforation (in)
L	Length of Grain (in)
n	Number of perforations
Δx	Small increment change in dimension (in)
r	density of grain (lbs/in^3)
W	weight of propellant (lbs)

Initial Area: $(2*\pi*R_0*L) + n*(2*\pi*R_i*L) + 2*(\pi*R_0^2 - n*\pi*R_i^2)$

Initial volume $(\pi*R_0^2 - n*\pi*R_i^2)*L$

STEP 2 Change dimensions by Δx

R_0 becomes $R_0-\Delta x$

R_i becomes $R_i+\Delta x$

L becomes $L-2*\Delta x$

STEP 3 Calculate new Surface Area and new volume and new weight (density * volume)

STEP 4 Repeat Steps 2 & 3

Continue until either:

$R_0-\Delta x$ becomes 0

$L-2*\Delta x$ becomes 0

$\pi*(R_0-\Delta x)^2 - n*\pi*(R_i+\Delta x)^2$ becomes 0

NOTE Δx should be chosen such that the change in area/volume is adequately described

STEP 5 Generate a table consisting of pair of numbers (total burn area, weight burned). This table can contain up to fifty pairs (Note: the first pair must be (initial surface area, 0) and final pair must be (0, weight of grain))

STEP 6 Calculate total number of grains (total weight/weight of one grain)

STEP 7 Multiply each entry in table generated in STEP 5 by the total number of grains--this will give a burn area vs. weight burned table

INPUT SCREEN 6 - 2ND BURN TABLE

See Figure 24. Again, this screen will only appear if an energetic material undergoes time dependent burning, and must be input separately for each of these materials. Enter a table of burn rate times explosive density vs. pressure. Up to 20 pairs can be entered in this table. To calculate numbers for the table use the following procedure:

Determine rate equation for material: must be of form--

$r = a*P^n$ where

r	rate in in/sec
a,n	coefficients of rate equation chosen to give proper units for r
ρ	Propellant density

Estimate highest expected pressure to be produced during burning--

Generate a table of (burn rate * explosive density ($r*\rho$) vs. pressure)--note: first entry must be for 0 pressure--last entry should be for a pressure 5*highest expected

INPUT SCREEN 7 - AMBIENT CONDITIONS

See Figure 8. Enter the default pressure and temperature for the ambient chamber (the atmosphere). If zero is entered, the 1959 ARDC standard atmosphere is used for pressure and temperature.

Enter the altitude above sea level to be used in the calculations.

Enter the default initial pressure, temperature, and mole (volume) fraction of oxygen (O_2) in the chambers. If zero is entered for the pressure and temperature, the ambient pressure and temperature will be used. The mole fraction of oxygen must be > 0 and ≤ 1. The remainder is nitrogen.

INPUT SCREEN 8 - CHAMBER DATA

See Figure 9. The first line input here is the default for all of the chambers. If you have more than one chamber, you can override this default for each individual chamber as needed, starting with chamber 2. Enter the chamber volume, the dimensions of the chamber, and whether a plot file of time vs. pressure and impulse is desired. Make sure that the chamber dimensions are compatible with the chamber volume. If the volume is set to zero, the volume will be calculated from the dimensions of the chamber. An ambient chamber (the atmosphere) is defined by setting the volume to less than zero.

INPUT SCREEN 9 - CHAMBER DATA CONTINUED

See Figure 10. This is a continuation of the previous screen. For each chamber shown, enter the print option, the type of calculation, the initial pressure and temperature, and the mole (volume) fraction of oxygen. A print option of zero will print only peaks. A one will print P(t) and I(t). Enter the appropriate type of calculation from the options shown at the bottom of the screen. Enter zero to use the default initial pressure, temperature, and mole fraction of oxygen, which were already specified on input screen 7.

INPUT SCREEN 10 - VENTING DATA

See Figure 28. Enter the number of vent paths connecting the chambers. Vents can be permanent or can form after a wall fails.

The number of venting cycles is the total number of venting calculations made during the INBLAST run. The higher this number, the more accurate the answers will be, however, the run will also take longer. When using a high number of venting cycles, the program output becomes too long. For this reason, you can choose the number of venting cycles to be calculated between printouts.

Enter a constant time step to be used between venting calculations. If zero is entered, the program uses a variable time step.

INPUT SCREEN 11 - VENT FAILURE DATA

See Figure 29. In this screen, you specify which two chambers are connected by each vent, the minimum pressure differential for wall failure to occur, and the minimum time at this pressure difference for wall failure. A secondary failure is where a vent between chambers becomes enlarged at a later time due to a larger area of the wall failing.

INPUT SCREEN 12 - TARGET DATA

See Figure 11. In this screen you enter the chamber where each target is located, and its coordinates.

SAMPLE CALCULATIONS

Let us consider two problems. Each will be described. Samples of the input screens and the output will be presented.

PROBLEM 1 (Figures 4 - 12)

Eighteen pounds of Composition C-4 are detonated inside a closed chamber. The chamber has dimensions 10 ft. by 10 ft. by 10 ft. The explosive is located in the center of the chamber. The target is located at coordinates (5, 0, 5) within the chamber). Calculate the direct and reflected shock wave parameters at the target for this event.

PROBLEM 2 (Figures 13 - 30)

This problem illustrates multiple explosions in multiple chambers. One charge detonates in Chamber 1. Two charges, one delayed, detonate in Chamber 8. Gases vent between chambers as walls fail, and finally into Chamber 7 which vents to the ambient atmosphere (Chamber 9). Time-dependent burning takes place in Chamber 2, which is isolated from the others. Final conditions should compare with the initial conditions, following the explosion in Chamber 1. Note that the slow burning in Chamber 2 uses up all of the oxygen before all of the carbon can react.

There are four energetic materials and nine chambers. A 200 pound charge of Pentolite detonates in Chamber 1. A 200 pound charge of Pentolite undergoes time-dependent burning in Chamber 2. In Chamber 8, 150 pounds of HMX detonate. Also in Chamber 8, there are 150 pounds of OCTOL which detonate when the Chamber temperature reaches 800°R for 0.02 seconds.

All chambers have a volume of 1000 ft^3, with the exception of Chamber 9, which is an ambient reservoir.

There are 10 vents multiply connecting the chambers.

REFERENCES

1. Proctor, James F., "Internal Blast Damage Mechanisms Computer Program," NOL TR 72-231, 31 August 1972.

2. Britt, J.R. et. al., "BLASTINW User's Manual," ARA 5986-2, Applied Research Associates, Inc., Vicksburg, MS, April 1986.

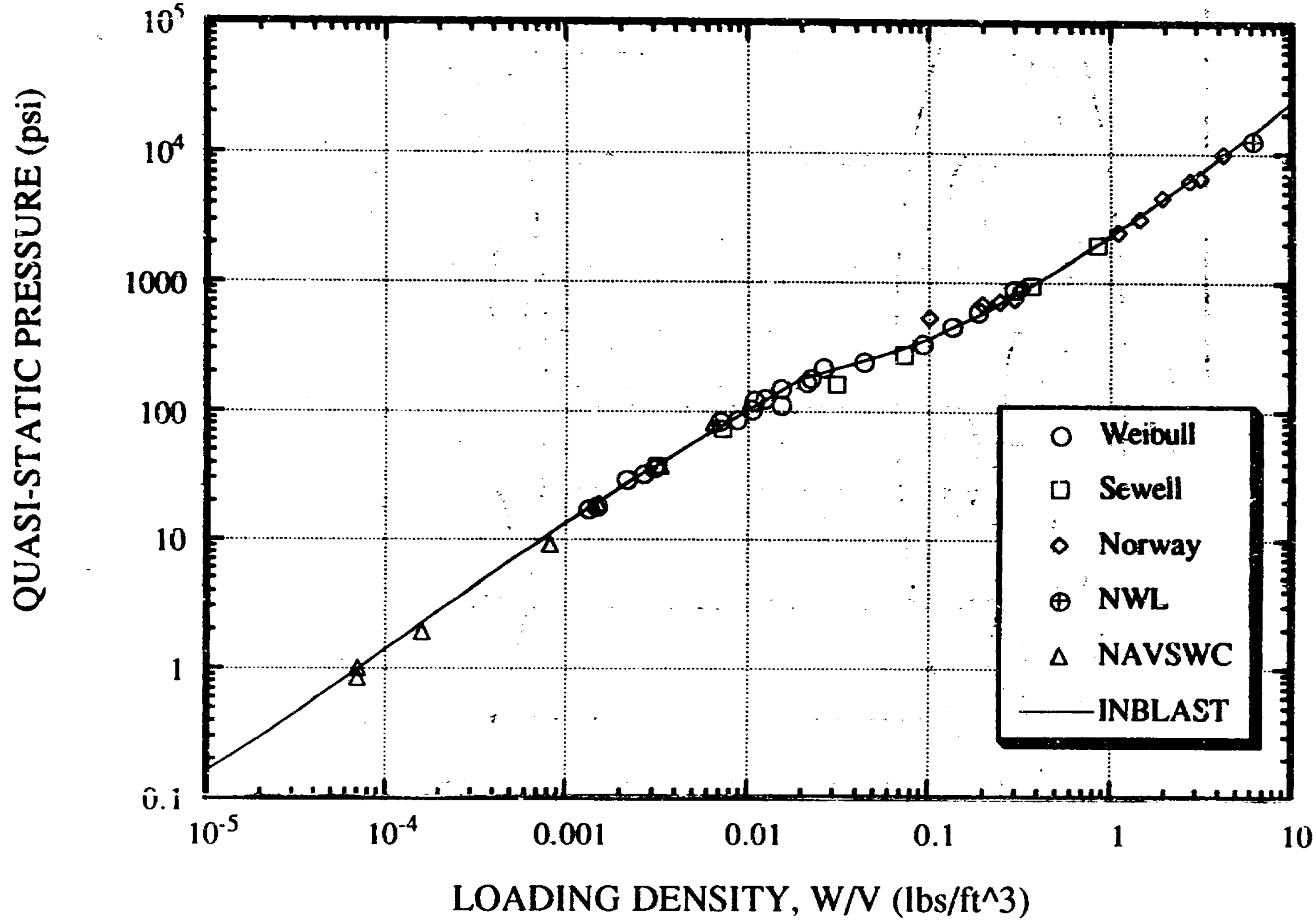
3. Britt, J. R. and Drake, J. L., "Blast Loads from Internal Explosions and Other Reflected Shock Waves," International Symposium on the Interaction of Conventional Munitions with Protective Structures, 9-13 March 1987.

4. Nelson, D. H. and Watt, J. M., "Analysis of Internal Blast Loads in Vented Chambers," Minutes of the Twenty-Third Explosives Safety Seminar, Volume II, 9-11 August 1988.

TABLE 1 TABLE OF EXPLOSIVES

NUMBER	NAME	EQWT	EFORM	C	H	N	O	Al
1	TNT	1.00	-70.50	0.3702	0.0222	0.1850	0.4227	0.0000
2	TNETB	1.13	-307.10	0.1860	0.0170	0.2170	0.5800	0.0000
3	EXPLOSIVE D	0.85	-382.00	0.2926	0.0246	0.2276	0.4551	0.0000
4	PENTOLITE (50/50 PETN/TNT)	1.40	-237.10	0.2798	0.0239	0.1807	0.5155	0.0000
5	PICRATOL (52/48 EXPL D/TNT)	0.90	-238.50	0.3290	0.0240	0.2070	0.4400	0.0000
6	CYCLOTOL (70/30)	1.14	26.22	0.2254	0.0257	0.3193	0.4294	0.0000
7	COMPOSITION B	1.10	11.48	0.2513	0.0264	0.2983	0.4241	0.0000
8	RDX/WAX (98/2)	1.19	57.00	0.1760	0.0300	0.3710	0.4230	0.0000
9	COMPOSITION A-3	1.09	28.40	0.2233	0.0375	0.3428	0.3964	0.0000
10	TNETB/Al (90/10)	1.23	-276.40	0.1680	0.0140	0.1960	0.5220	0.1000
11	TNETB/Al (78/22)	1.18	-239.50	0.1460	0.0120	0.1700	0.4520	0.2200
12	TNETB/Al (72/28)	1.18	-221.10	0.1340	0.0110	0.1570	0.4180	0.2800
13	TNETB/Al (65/35)	1.23	-199.60	0.1210	0.0100	0.1420	0.3770	0.3500
14	TRITONAL (TNT/Al 80/20)	1.07	-53.68	0.2960	0.0178	0.1480	0.3382	0.2000
15	RDX/Al/WAX (88/10/2)	1.30	50.38	0.1600	0.0270	0.3330	0.3800	0.1000
16	RDX/Al/WAX (78/20/2)	1.32	43.76	0.1440	0.0240	0.2950	0.3370	0.2000
17	RDX/Al/WAX (74/21/5)	1.30	29.36	0.1630	0.0270	0.2800	0.3200	0.2100
18	RDX/Al/WAX (74/22/4)	1.30	33.28	0.1540	0.0260	0.2800	0.3200	0.2200
19	RDX/Al/WAX (62/33/5)	1.19	21.42	0.1430	0.0240	0.2350	0.2680	0.3300
20	TORPEX II (42/40/18 RDX/TNT/Al)	1.24	-3.57	0.2161	0.0203	0.2328	0.3507	0.1800
21	H-6	1.38	-17.48	0.2250	0.0259	0.2238	0.3171	0.2100
22	HBX-1	1.17	-25.40	0.2482	0.0265	0.2216	0.3336	0.1700
23	HBX-3	1.14	-25.30	0.2003	0.0221	0.1709	0.2566	0.3500
24	TNETB/RDX/Al (39/26/35)	1.24	-102.60	0.1150	0.0130	0.1840	0.3380	0.3500
25	ALUMINUM	0.00	0.00					1.0000
26	WAX	0.00	-392.00	0.8560	0.1440	0.0000	0.0000	0.0000
27	RDX	1.10	66.16	0.1621	0.0272	0.3782	0.4322	0.0000
28	PETN	1.27	-407.10	0.1898	0.0255	0.1772	0.6074	0.0000
29	TETRYL	1.07	16.26	0.2928	0.0176	0.2439	0.4458	0.0000
30	HMX	1.10	61.00	0.1621	0.0272	0.3782	0.4322	0.0000
31	OCTOL (HMX/TNT 75/25)	1.10	28.62	0.2135	0.0260	0.3303	0.4302	0.0000
32	PBXW-9 (estimated)	1.30	72.40	0.2050	0.0340	0.3480	0.4130	0.0000
33	MOTOR OIL	0.00	-400.00	0.8470	0.1410	0.0000	0.0000	0.0000
34	POLYISOBUTYLENE	0.00	-840.00	0.8600	0.1400	0.0000	0.0000	0.0000
35	DI-SEBACATE	0.00	-780.00	0.7300	0.1200			
36	AMMONIUM NITRATE (AN)	0.70	-1084.00	0.0000	0.0504	0.3497	0.5998	0.0000
37	IREMITE-60	1.00	-999.50	0.0000	0.0462	0.3029	0.5499	0.0330
38	NITROMETHANE	1.00	-442.00	0.1966	0.0495	0.2295	0.5244	0.0000
39	PBX-9404	1.20	0.80	0.1705	0.0281	0.3650	0.4364	0.0000
40	POLYSTYRENE	0.00	181.70	0.9226	0.0774	0.0000	0.0000	0.0000
41	WATER	0.00	-3792.00	0.0000	0.1119	0.0000	0.8881	0.0000
42	ANFO (94/6 AN/FO)	0.87	-1043.40	0.0515	0.0558	0.3289	0.5638	0.0000
43	COMPOSITION C-4	1.40	32.43	0.2185	0.0357	0.3444	0.4014	0.0000
44	NITROCELLULOSE (NC)(12%N)	0.50	-658.00	0.2646	0.0278	0.1260	0.5816	0.0000
45	NITROCELLULOSE (NC)(13.35%N)	0.50	-574.00	0.2529	0.0252	0.1345	0.5874	0.0000
46	NITROCELLULOSE (NC)(14.14%N)	0.50	-525.00	0.2425	0.0237	0.1414	0.5924	0.0000
47	NITROGYLCERINE (NG)	1.80	-390.00	0.1585	0.0222	0.1850	0.6343	0.0000
48	TATB (Triaminitrinitrobenzene)	1.00	-142.70	0.2790	0.0234	0.3255	0.3720	0.0000
49	CYCLOTOL (75/25)	1.14	32.89	0.2141	0.0260	0.3299	0.4300	0.0000
50	M1 PROPELLANT	1.00	-539.00	0.3039	0.0309	0.1265	0.5387	0.0000
51	LX-14	1.80	15.00	0.1824	0.0294	0.3626	0.4256	0.0000
52	NITROGUANIDINE (NQ)	1.00	-212.00	0.1154	0.0387	0.5383	0.3076	0.0000
53	FUEL OIL (FO)	0.00	-406.70	0.8591	0.1409	0.0000	0.0000	0.0000

FIGURE 1 COMPARISON OF MEASURED QUASI-STATIC PRESSURE WITH INBLAST COMPUTATIONS



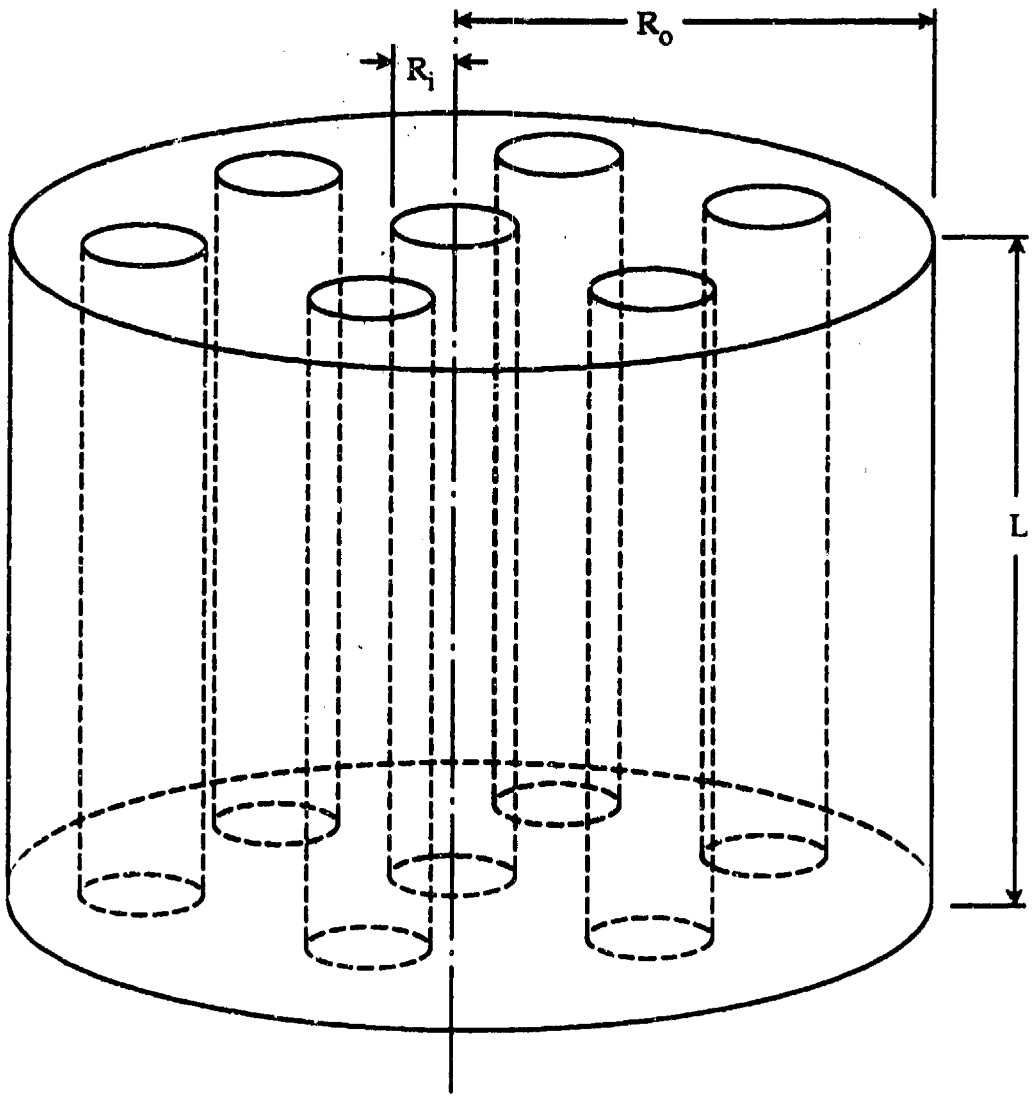


FIGURE 2 SCHEMATIC OF GRAIN

Figure 3: MAIN MENU

```
INBLAST PROGRAM
 (MAIN MENU)

1. CHANGE INPUT CONDITIONS

2. RUN INBLAST PROGRAM

3. DISPLAY OUTPUT FILE

4. EXIT PROGRAM

ENTER SELECTION NUMBER AND PRESS ENTER
```

Figure 4: INPUT SCREEN 1 - PROBLEM 1

```
                  INBLAST PROGRAM
        (Input Screen 1 / GENERAL OPTIONS)

Title of Run
TEST1.....SHOCK LOADING in a closed chamber

Select Type of Calculation  1

  1. SHOCK loading in a closed room
  2. SHOCK and COMBUSTION
  3. SHOCK and COMBUSTION and VENTING
  4. INSTANTANEOUS COMBUSTION
  5. COMBUSTION and VENTING (time dependent burning)

Number of Sources of Energetic Materials (1 - 20)  1

Number of Chambers (1 - 20)  1

Number of Targets in Confined Shock Calcs (1 - 20)  1

F1 SET TO    F2 GOTO NEXT   F3 GOTO      NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU       UNTIL RETURN KEY IS PRESSED
```

Figure 5: INPUT SCREEN 2 - PROBLEM 1

```
                        INBLAST PROGRAM
               (Input Screen 2 / GENERAL OPTIONS cont.)

Maximum Time to be Calculated (sec)  15
(If ZERO, time is unlimited and a maximum
time is calculated for confined shocks)

Default Type of Calculation  2

  0. Shock & Gas & Venting
  1. Gas Pressure Only
  2. Shock Pressure Only
  3. Shock & Gas, and Average Target

Maximum order of reflected rays to be
used in the confined shock calculations  6

RUN IDENTIFICATION NAME
(used for PLOT FILE NAMES)  TEST1


F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 6: INPUT SCREEN 3 - PROBLEM 1

```
ENERGETIC SOURCE #1           INBLAST PROGRAM
                      (Input Screen 3,1 / EXPLOSIVE DATA)
ENTER SELECTION  1

1. One Energetic Material from Table
2. Mixture of Energetic Materials from Table
3. Energetic Material not in Table
4. Gaseous Energetic Material not in Table

Name of Energetic Materials Used       Weight Fraction of Material in Mixture
COMP C-4                               1


Note: If total weight fraction >1.0 then each is adjusted so the new total = 1.0
      If total weight fraction <1.0 then the remainder is assumed an INERT SOLID

F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 7: INPUT SCREEN 4 - PROBLEM 1

```
ENERGETIC SOURCE #1          INBLAST PROGRAM
                     (Input Screen 4,1 / EXPLOSIVE DATA cont.)

Weight of Energetic Material (lb)  18

Number of Chamber in Which Energetic Material will Burn or Detonate  1

X - Coordinate of Explosion (ft)  5

Y - Coordinate of Explosion (ft)  5

Z - Coordinate of Explosion (ft)  5

Minimum Chamber Temp. Required to Initiate Explosive (deg R)  0

Minimum Time at Temperature to Initiate Explosive (sec)  0

Initial Weight of Energetic Material Burned (lbs)  0
(If ZERO, Initial Weight is set to Weight of Energetic Material/1000)

Does This Energetic Material Undergo Time Dependent Burning (Y/N)  N


F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 8: INPUT SCREEN 7 - PROBLEM 1

```
                         INBLAST PROGRAM
                 (Input Screen 7 / AMBIENT CONDITIONS)

Default Pressure in Ambient Chamber (psia)  14.6959
(If ZERO, the 1959 ARDC standard atmosphere is used)

Default Temperature in Ambient Chamber (deg C)  15

Altitude Above Sea Level (kft)  0

Default Initial Pressure in Chambers (psia)  0
(If ZERO, the Ambient Pressure will be used)

Default Initial Temperature in Chambers (deg C)  0
(If ZERO, the Ambient Temperature will be used)

Default Mole (vol %) Fraction of Oxygen (O2) in Chambers  .2095
(Fraction must be > 0 and <= 1, Remainder is Nitrogen (N2))


F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 9: INPUT SCREEN 8 - PROBLEM 1

```
                         INBLAST PROGRAM
                 (Input Screen 8 / CHAMBER DATA)

Chamber   Chamber     Length       Length       Length       Plot File
Number    Volume      X-Direction  Y-Direction  Z-Direction  (Y/N)
          (cu ft)     (ft)         (ft)         (ft)
Default   1000        10           10           10           Y



Note: If Chamber Volume = 0, volume is set to XLEN * YLEN * ZLEN
Note: Chamber Dimensions are not checked for compatibility with Chamber Volume
Note: An Ambient Chamber is Defined by Setting Volume < 0

F1 SET TO    F2 GOTO NEXT   F3 GOTO      NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU       UNTIL RETURN KEY IS PRESSED
```

Figure 10: INPUT SCREEN 9 - PROBLEM 1

```
                         INBLAST PROGRAM
               (Input Screen 9 / CHAMBER DATA (Cont.)

Chamber   Print    Type Of       Init. Pres.      Init. Temp.      Mole Fraction
Number    Option   Calculation   In Chamber       In Chamber       Of Oxygen
                                 (0 for Default)  (0 for Default)  (0 for Default)
                                 (psia)           (deg C)          (0 - 1)
Default   1        2             0                0                0



Print Option   0 = Print only peaks        1 = Print P(T) & Impulse I(T)

Type of        0 = Shock & Gas & Venting   1 = Gas Pressure Only
Calculation    2 = Shock Pressure Only     3 = Shock & Gas & Average Shock

F1 SET TO    F2 GOTO NEXT   F3 GOTO      NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU       UNTIL RETURN KEY IS PRESSFD
```

Figure 11: INPUT SCREEN 12 - PROBLEM 1

INBLAST PROGRAM
(Input Screen 12 / TARGET DATA)

Target Number	Chamber Where Target is Located	X-Coordinate of Target (ft)	Y-Coordinate of Target (ft)	Z-Coordinate of Target (ft)
1	1	5	0	5

F1 SET TO DEFAULT   F2 GOTO NEXT SCREEN   F3 GOTO MAIN MENU   NOTE: INDIVIDUAL DATA IS NOT SAVED UNTIL RETURN KEY IS PRESSED

Figure 12: INBLAST OUTPUT - PROBLEM 1

```
INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, JULY 1989

 TEST1.....SHOCK LOADING in a closed chamber


NOPT= 1     NEXPL=   1     NCHAMS=   1     NTARGS=   1     NTITLE=   1

TMAX(SEC)=  15.00        ICALCG=  2     MAXORD=   6     RUN ID=                    TEST1

DEFINE  EXPLOSIVE(S).....................................

 COMP C-4                                   43
EXPLOSIVE (  1) POSITION IN CHAMBER (  1):  X(FT)=  5.0000       Y(FT)=  5.0000       Z(FT)=  5.0000
EXPLOSIVE (  1) PROPERTIES.....CHARGE WEIGHT(LB) =  18.00
NUMBER EQWT   EFORM    EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G     O2       N2       C        H2
  43   1.400  .032430   .4014    .3444    .2185    .0357

                            ..................EXPLOSIVE SUMMARY....................
                             EXPLOSIVE    CHAMBER    TIME DELAY(SEC)    BURN TEMP(DEG R)
                                1            1          .0000              .0000

PAMB(PSIA)=  14.70       TAMB(C)=  15.00       PCHAM(PSIA)=  14.70       TCHAM(C)=  15.00       FRAC O2=  .2095

CHAMBER DATA.....NO. OF CHAMBERS =   1
 KO   VOL(CU FT)    P(PSIA)     TEMP(C)      GAS(LB)       GAMMA    FRAC-O2   ICALC   IPRINT   IPLOT    X(FT)       Y(FT)       Z(FT)
  1    1000.        14.70       15.00        76.18        1.3996    .2095      2        1        1      10.00       10.00       10.00



    BLAST - MULTIPLE EXPLOSIONS INSIDE A ROOM WITH VENTING BETWEEN ROOMS
        DATE                          ROOM NUMBER =  1

 TEST1.....SHOCK LOADING in a closed chamber

        TARGET LOCATION (FT)   NO.  1
X =     5.000    Y =     .000    Z =     5.000

        PLOT FILE = TEST1T01


           CHARGE NUMBER   1
        CHARGE LOCATION (FT)
X =     5.000    Y =     5.000    Z =     5.000
CHARGE MASS (POUNDS) = 1.80000E+01      DETONATION DELAY (MSEC) = 0.00000E+00
    EXPLOSIVE COMPOSITION (DECIMAL FRACTION)
        COMP C-4               1.00000
```

DIRECT PRESSURE (PSI) = 2.476E+02   ARRIVAL TIME (MSEC) = 6.410E-01

TOTAL VALUES

```
FIRST PRESSURE (PSI)            =  1.597E+03     TIME (MSEC) =  6.410E-01
PEAK PRESSURE (PSI)             =  1.597E+03     TIME (MSEC) =  6.410E-01
MINIMUM PRESSURE (PSI)          = -5.709E+00     TIME (MSEC) =  4.914E+00
PEAK IMPULSE (PSI*SEC)          =  1.391E+00     TIME (MSEC) =  1.307E+01
LAST TIME =  1.307E+01     PRESSURE =  4.159E+01     IMPULSE =  1.391E+00
NUMBER OF STEPS = 1000     MAXIMUM ORDER OF RAYS =   6
```

TIME (MSEC)	PRESSURE	IMPULSE
6.410E-01	0.000E+00	0.000E+00
6.410E-01	1.597E+03	0.000E+00
6.535E-01	1.463E+03	1.906E-02
6.659E-01	1.340E+03	3.651E-02
6.784E-01	1.227E+03	5.250E-02
6.908E-01	1.124E+03	6.715E-02
7.033E-01	1.031E+03	8.057E-02
7.157E-01	9.446E+02	9.287E-02
7.282E-01	8.661E+02	1.041E-01
7.406E-01	7.943E+02	1.145E-01
7.531E-01	7.286E+02	1.240E-01
7.656E-01	6.685E+02	1.327E-01
7.780E-01	6.135E+02	1.407E-01
7.905E-01	5.632E+02	1.480E-01
8.029E-01	5.172E+02	1.547E-01
8.154E-01	4.751E+02	1.609E-01
8.278E-01	4.365E+02	1.666E-01
8.403E-01	4.012E+02	1.718E-01
8.528E-01	3.689E+02	1.766E-01
8.652E-01	3.393E+02	1.810E-01
8.777E-01	3.122E+02	1.851E-01
8.901E-01	2.873E+02	1.888E-01
9.026E-01	2.645E+02	1.922E-01
9.150E-01	2.437E+02	1.954E-01
9.275E-01	2.245E+02	1.983E-01
9.400E-01	2.069E+02	2.010E-01
9.524E-01	1.908E+02	2.035E-01
9.649E-01	1.760E+02	2.058E-01
9.773E-01	1.625E+02	2.079E-01
9.898E-01	1.500E+02	2.098E-01
1.002E+00	1.385E+02	2.116E-01
1.015E+00	1.280E+02	2.133E-01
1.027E+00	1.183E+02	2.148E-01
1.040E+00	1.094E+02	2.162E-01
1.052E+00	1.013E+02	2.175E-01
1.065E+00	9.373E+01	2.188E-01
1.077E+00	8.680E+01	2.199E-01
1.089E+00	8.042E+01	2.209E-01
1.102E+00	7.454E+01	2.219E-01
1.114E+00	6.912E+01	2.228E-01
1.127E+00	6.412E+01	2.236E-01
1.139E+00	5.951E+01	2.244E-01
1.152E+00	5.526E+01	2.251E-01
1.164E+00	5.133E+01	2.258E-01

1.177E+00	4.771E+01	2.264E-01
1.189E+00	4.436E+01	2.269E-01
1.202E+00	4.126E+01	2.275E-01
1.214E+00	3.839E+01	2.280E-01
1.226E+00	3.574E+01	2.284E-01
1.239E+00	3.329E+01	2.289E-01
1.251E+00	3.114E+01	2.293E-01
1.264E+00	2.939E+01	2.296E-01
1.276E+00	2.774E+01	2.300E-01
1.289E+00	2.619E+01	2.303E-01
1.301E+00	2.471E+01	2.307E-01
1.314E+00	2.332E+01	2.310E-01
1.326E+00	2.201E+01	2.312E-01
1.339E+00	2.077E+01	2.315E-01
1.351E+00	1.960E+01	2.318E-01
1.363E+00	1.849E+01	2.320E-01
1.376E+00	1.744E+01	2.322E-01
1.388E+00	1.646E+01	2.324E-01
1.401E+00	1.552E+01	2.326E-01
1.413E+00	1.464E+01	2.328E-01
1.426E+00	1.381E+01	2.330E-01
1.438E+00	1.302E+01	2.332E-01
1.451E+00	1.228E+01	2.333E-01
1.463E+00	1.158E+01	2.335E-01
1.476E+00	1.092E+01	2.336E-01
1.488E+00	5.492E+02	2.371E-01
1.501E+00	5.388E+02	2.439E-01
1.513E+00	5.285E+02	2.505E-01
1.525E+00	5.184E+02	2.570E-01
1.538E+00	5.086E+02	2.634E-01
1.550E+00	4.989E+02	2.697E-01
1.563E+00	4.895E+02	2.759E-01
1.575E+00	4.802E+02	2.819E-01
1.588E+00	4.711E+02	2.878E-01
1.600E+00	4.622E+02	2.936E-01
1.613E+00	4.535E+02	2.993E-01
1.625E+00	4.449E+02	3.049E-01
1.638E+00	4.366E+02	3.104E-01
1.650E+00	4.284E+02	3.158E-01
1.662E+00	4.204E+02	3.211E-01
1.675E+00	4.126E+02	3.263E-01
1.687E+00	4.048E+02	3.314E-01
1.700E+00	3.973E+02	3.364E-01
1.712E+00	3.899E+02	3.413E-01
1.725E+00	3.826E+02	3.461E-01
1.737E+00	3.755E+02	3.508E-01
1.750E+00	3.685E+02	3.555E-01
1.762E+00	3.616E+02	3.600E-01
1.775E+00	3.550E+02	3.645E-01
1.787E+00	3.484E+02	3.688E-01
1.799E+00	3.419E+02	3.731E-01
1.812E+00	3.356E+02	3.774E-01
1.824E+00	3.294E+02	3.815E-01
1.837E+00	3.233E+02	3.856E-01
1.849E+00	3.174E+02	3.896E-01
1.862E+00	3.115E+02	3.935E-01
1.874E+00	3.058E+02	3.973E-01
1.887E+00	3.002E+02	4.011E-01
1.899E+00	2.946E+02	4.048E-01
1.912E+00	2.893E+02	4.084E-01

(860 lines removed)

1.262E+01	4.544E+01	1.378E+00
1.264E+01	4.447E+01	1.378E+00
1.265E+01	4.351E+01	1.379E+00
1.266E+01	4.255E+01	1.379E+00
1.267E+01	4.159E+01	1.380E+00
1.269E+01	4.064E+01	1.380E+00
1.270E+01	3.970E+01	1.381E+00
1.271E+01	3.877E+01	1.381E+00
1.272E+01	3.783E+01	1.382E+00
1.274E+01	3.690E+01	1.382E+00
1.275E+01	3.598E+01	1.383E+00
1.276E+01	3.507E+01	1.383E+00
1.277E+01	3.416E+01	1.384E+00
1.279E+01	3.325E+01	1.384E+00
1.280E+01	3.235E+01	1.384E+00
1.281E+01	3.146E+01	1.385E+00
1.282E+01	3.057E+01	1.385E+00
1.284E+01	2.968E+01	1.386E+00
1.285E+01	2.880E+01	1.386E+00
1.286E+01	2.792E+01	1.386E+00
1.287E+01	2.705E+01	1.387E+00
1.289E+01	2.619E+01	1.387E+00
1.290E+01	2.533E+01	1.387E+00
1.291E+01	2.447E+01	1.388E+00
1.292E+01	2.362E+01	1.388E+00
1.294E+01	2.277E+01	1.388E+00
1.295E+01	2.193E+01	1.388E+00
1.296E+01	2.110E+01	1.389E+00
1.297E+01	2.027E+01	1.389E+00
1.299E+01	1.944E+01	1.389E+00
1.300E+01	1.862E+01	1.389E+00
1.301E+01	1.780E+01	1.390E+00
1.302E+01	1.699E+01	1.390E+00
1.304E+01	1.618E+01	1.390E+00
1.305E+01	1.538E+01	1.390E+00
1.306E+01	1.457E+01	1.390E+00
1.307E+01	4.159E+01	1.391E+00

Figure 13: INPUT SCREEN 1 - PROBLEM 2

```
                    INBLAST PROGRAM
          (Input Screen 1 / GENERAL OPTIONS)

Title of Run
TEST5.....COMBUSTION and VENTING - multiple explosions in multiple chambers

Select Type of Calculation  5

  1. SHOCK loading in a closed room
  2. SHOCK and COMBUSTION
  3. SHOCK and COMBUSTION and VENTING
  4. INSTANTANEOUS COMBUSTION
  5. COMBUSTION and VENTING (time dependent burning)


Number of Sources of Energetic Materials (1 - 20)  4

Number of Chambers (1 - 20)  9

Number of Targets in Confined Shock Calcs (0 - 20)  0


F1 SET TO    F2 GOTO NEXT   F3 GOTO     NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU      UNTIL RETURN KEY IS PRESSED
```

Figure 14: INPUT SCREEN 2 - PROBLEM 2

```
                    INBLAST PROGRAM
          (Input Screen 2 / GENERAL OPTIONS cont.)

Maximum Time to be Calculated (sec)  0
(If ZERO, time is unlimited and a maximum
time is calculated for confined shocks)

Default Type of Calculation  2

  0. Shock & Gas & Venting
  1. Gas Pressure Only
  2. Shock Pressure Only
  3. Shock & Gas, and Average Target

Maximum order of reflected rays to be
used in the confined shock calculations  0

RUN IDENTIFICATION NAME
(used for PLOT FILE NAMES)  TEST5


F1 SET TO    F2 GOTO NEXT   F3 GOTO     NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU      UNTIL RETURN KEY IS PRESSED
```

Figure 15: INPUT SCREEN 3.1 - PROBLEM 2

```
ENERGETIC SOURCE #1          INBLAST PROGRAM
                     (Input Screen 3,1 / EXPLOSIVE DATA)
ENTER SELECTION  1

1. One Energetic Material from Table
2. Mixture of Energetic Materials from Table
3. Energetic Material not in Table
4. Gaseous Energetic Material not in Table

Name of Energetic Materials Used       Weight Fraction of Material in Mixture
PENTOLITE (PETN/TNT,50/50)             1








Note: If total weight fraction >1.0 then each is adjusted so the new total = 1.0
      If total weight fraction <1.0 then the remainder is assumed an INERT SOLID

F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 16: INPUT SCREEN 3.2 - PROBLEM 2

```
ENERGETIC SOURCE #2          INBLAST PROGRAM
                     (Input Screen 3,2 / EXPLOSIVE DATA)
ENTER SELECTION  1

1. One Energetic Material from Table
2. Mixture of Energetic Materials from Table
3. Energetic Material not in Table
4. Gaseous Energetic Material not in Table

Name of Energetic Materials Used       Weight Fraction of Material in Mixture
PENTOLITE (PETN/TNT,50/50)             1








Note: If total weight fraction >1.0 then each is adjusted so the new total = 1.0
      If total weight fraction <1.0 then the remainder is assumed an INERT SOLID

F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 17: INPUT SCREEN 3,3 - PROBLEM 2

```
ENERGETIC SOURCE #3          INBLAST PROGRAM
                         (Input Screen 3,3 / EXPLOSIVE DATA)
ENTER SELECTION  1

1. One Energetic Material from Table
2. Mixture of Energetic Materials from Table
3. Energetic Material not in Table
4. Gaseous Energetic Material not in Table

Name of Energetic Materials Used       Weight Fraction of Material in Mixture
HMX                                    1




Note: If total weight fraction >1.0 then each is adjusted so the new total = 1.0
      If total weight fraction <1.0 then the remainder is assumed an INERT SOLID

F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 18: INPUT SCREEN 3,4 - PROBLEM 2

```
ENERGETIC SOURCE #4          INBLAST PROGRAM
                         (Input Screen 3,4 / EXPLOSIVE DATA)
ENTER SELECTION  1

1. One Energetic Material from Table
2. Mixture of Energetic Materials from Table
3. Energetic Material not in Table
4. Gaseous Energetic Material not in Table

Name of Energetic Materials Used       Weight Fraction of Material in Mixture
OCTOL                                  1




Note: If total weight fraction >1.0 then each is adjusted so the new total = 1.0
      If total weight fraction <1.0 then the remainder is assumed an INERT SOLID

F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 19: INPUT SCREEN 4,1 - PROBLEM 2

```
ENERGETIC SOURCE #1          INBLAST PROGRAM
                    (Input Screen 4,1 / EXPLOSIVE DATA cont.)

Weight of Energetic Material (lb)  200

Number of Chamber in Which Energetic Material will Burn or Detonate  1

X - Coordinate of Explosion (ft)  5

Y - Coordinate of Explosion (ft)  5

Z - Coordinate of Explosion (ft)  5

Minimum Chamber Temp. Required to Initiate Explosive (deg R)  0

Minimum Time at Temperature to Initiate Explosive (sec)  0

Initial Weight of Energetic Material Burned (lbs)  0
(If ZERO, Initial Weight is set to Weight of Energetic Material/1000)

Does This Energetic Material Undergo Time Dependent Burning (Y/N)  N

F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 20: INPUT SCREEN 4,2 - PROBLEM 2

```
ENERGETIC SOURCE #2          INBLAST PROGRAM
                    (Input Screen 4,2 / EXPLOSIVE DATA cont.)

Weight of Energetic Material (lb)  200

Number of Chamber in Which Energetic Material will Burn or Detonate  2

X - Coordinate of Explosion (ft)  5

Y - Coordinate of Explosion (ft)  5

Z - Coordinate of Explosion (ft)  5

Minimum Chamber Temp. Required to Initiate Explosive (deg R)  0

Minimum Time at Temperature to Initiate Explosive (sec)  0

Initial Weight of Energetic Material Burned (lbs)  0
(If ZERO, Initial Weight is set to Weight of Energetic Material/1000)

Does This Energetic Material Undergo Time Dependent Burning (Y/N)  Y

F1 SET TO     F2 GOTO NEXT    F3 GOTO       NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT       SCREEN          MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 21: INPUT SCREEN 4,3 - PROBLEM 2

```
ENERGETIC SOURCE #3          INBLAST PROGRAM
                      (Input Screen 4,3 / EXPLOSIVE DATA cont.)

Weight of Energetic Material (lb)  150

Number of Chamber in Which Energetic Material will Burn or Detonate  8

X - Coordinate of Explosion (ft)  5

Y - Coordinate of Explosion (ft)  5

Z - Coordinate of Explosion (ft)  5

Minimum Chamber Temp. Required to Initiate Explosive (deg R)  0

Minimum Time at Temperature to Initiate Explosive (sec)  0

Initial Weight of Energetic Material Burned (lbs)  0
(If ZERO, Initial Weight is set to Weight of Energetic Material/1000)

Does This Energetic Material Undergo Time Dependent Burning (Y/N)  N

F1 SET TO    F2 GOTO NEXT   F3 GOTO      NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU       UNTIL RETURN KEY IS PRESSED
```

Figure 22: INPUT SCREEN 4,4 - PROBLEM 2

```
ENERGETIC SOURCE #4          INBLAST PROGRAM
                      (Input Screen 4,4 / EXPLOSIVE DATA cont.)

Weight of Energetic Material (lb)  150

Number of Chamber in Which Energetic Material will Burn or Detonate  8

X - Coordinate of Explosion (ft)  5

Y - Coordinate of Explosion (ft)  5

Z - Coordinate of Explosion (ft)  5

Minimum Chamber Temp. Required to Initiate Explosive (deg R)  800

Minimum Time at Temperature to Initiate Explosive (sec)  .02

Initial Weight of Energetic Material Burned (lbs)  0
(If ZERO, Initial Weight is set to Weight of Energetic Material/1000)

Does This Energetic Material Undergo Time Dependent Burning (Y/N)  N

F1 SET TO    F2 GOTO NEXT   F3 GOTO      NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU       UNTIL RETURN KEY IS PRESSED
```

Figure 23: INPUT SCREEN 5 - PROBLEM 2

ENERGETIC SOURCE #2 INBLAST PROGRAM
(Input Screen 5,2 / 1ST BURN TABLE)

BURN AREA (sq in) vs. WEIGHT BURNED (lb) TABLE

Burn Area	Wt. Burned	Burn Area	Wt. Burned	Burn Area	Wt. Burned
100	0				
100	200				
0	200				

F1 SET TO DEFAULT F2 GOTO NEXT SCREEN F3 GOTO MAIN MENU NOTE: INDIVIDUAL DATA IS NOT SAVED UNTIL RETURN KEY IS PRESSED

Figure 24: INPUT SCREEN 6 - PROBLEM 2

ENERGETIC SOURCE #2 INBLAST PROGRAM
(Input Screen 6,2 / 2ND BURN TABLE)

BURN RATE x EXPLOSIVE DENSITY vs. PRESSURE TABLE

Burn Rate x Explosive Density (in/sec x lb/cu in)	Pressure (psia)	Burn Rate x Explosive Density (in/sec x lb/cu in)	Pressure (psia)
100	0		
100	1000		

Note: Pressures must be in ascending order

F1 SET TO DEFAULT F2 GOTO NEXT SCREEN F3 GOTO MAIN MENU NOTE: INDIVIDUAL DATA IS NOT SAVED UNTIL RETURN KEY IS PRESSED

Figure 25: INPUT SCREEN 7 - PROBLEM 2

```
                    INBLAST PROGRAM
         (Input Screen 7 / AMBIENT CONDITIONS)

Default Pressure in Ambient Chamber (psia)  14.7
(If ZERO, the 1959 ARDC standard atmosphere is used)

Default Temperature in Ambient Chamber (deg C)  20

Altitude Above Sea Level (kft)  0

Default Initial Pressure in Chambers (psia)  0
(If ZERO, the Ambient Pressure will be used)

Default Initial Temperature in Chambers (deg C)  0
(If ZERO, the Ambient Temperature will be used)

Default Mole (volume) Fraction of Oxygen (O2) in Chambers  .2095
(Fraction must be > 0 and <= 1, Remainder is Nitrogen (N2))


F1 SET TO    F2 GOTO NEXT   F3 GOTO     NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 26: INPUT SCREEN 8 - PROBLEM 2

INBLAST PROGRAM
(Input Screen 8 / CHAMBER DATA)

Chamber Number	Chamber Volume (cu ft)	Length X-Direction (ft)	Length Y-Direction (ft)	Length Z-Direction (ft)	Plot File (Y/N)
Default	1000	10	10	10	N
9	-1	10	10	10	N

```
Note: If Chamber Volume = 0, volume is set to XLEN * YLEN * ZLEN
Note: Chamber Dimensions are not checked for compatibility with Chamber Volume
Note: An Ambient Chamber is Defined by Setting Volume < 0

F1 SET TO    F2 GOTO NEXT   F3 GOTO     NOTE: INDIVIDUAL DATA IS NOT SAVED
   DEFAULT      SCREEN         MAIN MENU        UNTIL RETURN KEY IS PRESSED
```

Figure 27: INPUT SCREEN 9 - PROBLEM 2

INBLAST PROGRAM
(Input Screen 9 / CHAMBER DATA (Cont.)

Chamber Number	Print Option	Type Of Calculation	Init. Pres. In Chamber (0 for Default) (psia)	Init. Temp. In Chamber (0 for Default) (deg C)	Mole Fraction Of Oxygen (0 for Default) (0 - 1)
Default	1	2	0	0	0
9	1	2	0	0	0

F1 SET TO DEFAULT   F2 GOTO NEXT SCREEN   F3 GOTO MAIN MENU   NOTE: INDIVIDUAL DATA IS NOT SAVED UNTIL RETURN KEY IS PRESSED

Figure 28: INPUT SCREEN 10 - PROBLEM 2

INBLAST PROGRAM
(Input Screen 10 / VENTING DATA)

Number of Vent Paths Connecting Chambers (1 - 80) 10

Total Number of Venting Cycles (1 - 1000) 1000

Number of Venting Cycles Between Printouts (1 - 50) 50

Constant Time Step (sec) 0
(If ZERO, a variable venting time step will be used)

F1 SET TO DEFAULT   F2 GOTO NEXT SCREEN   F3 GOTO MAIN MENU   NOTE: INDIVIDUAL DATA IS NOT SAVED UNTIL RETURN KEY IS PRESSED

FIGURE 30: INBLAST OUTPUT - PROBLEM 2

```
INTERNAL BLAST DAMAGE MECHANISMS PROGRAM, JULY 1989

 TEST5.....COMBUSTION and VENTING - multiple explosions in multiple chambers

 NOPT= 5     NEXPL=   4     NCHAMS=   9     NTARGS=   0     NTITLE=   1

 TMAX(SEC)=  .0000       ICALCG=  2     MAXORD=  10     RUN ID=                TEST5

 DEFINE EXPLOSIVE(S)...................................

  PENTOLITE (PETN/TNT,50/50)              4
 EXPLOSIVE (  1) PROPERTIES.....CHARGE WEIGHT(LB) =  200.0
 NUMBER EQWT  EFORM   EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G    O2      N2      C       H2
    4  1.400 -.237100  .5155   .1807   .2798   .0239

  PENTOLITE (PETN/TNT,50/50)              4
 EXPLOSIVE (  2) PROPERTIES.....CHARGE WEIGHT(LB) =  200.0
 NUMBER EQWT  EFORM   EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G    O2      N2      C       H2
    4  1.400 -.237100  .5155   .1807   .2798   .0239

 TIME-DEPENDENT BURNING OF EXPLOSIVE (  2)     INITIAL WEIGHT BURNED (WLB) =  .2000        INITIAL WT FRAC BURNED =  .0010

       3 POINTS IN BURN AREA VS WEIGHT BURNED TABLE
           A(SQ IN)       W(LB)         A(SQ IN)      W(LB)         A(SQ IN)      W(LB)         A(SQ IN)      W(LB)
            100.000       .000000        100.000       200.000       .000000       500.000

       2 POINTS IN BURN RATE VS PRESSURE TABLE
         R(LB/IN2/SEC)   P(PSIA)       R(LB/IN2/SEC)  P(PSIA)      R(LB/IN2/SEC)  P(PSIA)      R(LB/IN2/SEC)  P(PSIA)
            100.000       .000000        100.000       1000.00       100.000      1.000000E+07

  HMX                                   30

 .....WEIGHT OF INERT MATERIAL IN THE EXPLOSIVE = 4.49993-02 LBS. (WEIGHT FRACTION = .0003)
 EXPLOSIVE (  3) PROPERTIES.....CHARGE WEIGHT(LB) =  150.0
 NUMBER EQWT  EFORM   EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G    O2      INERT   N2      C       H2
   30  1.100  .061000  .4322   .0003   .3782   .1621   .0272

  OCTOL                                 31
 EXPLOSIVE (  4) PROPERTIES.....CHARGE WEIGHT(LB) =  150.0
 NUMBER EQWT  EFORM   EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G    O2      N2      C       H2
```

```
31  1.100  .028620   .4302   .3303   .2135   .026

                    ...................EXPLOSIVE SUMMARY....................
                    EXPLOSIVE   CHAMBER   TIME DELAY(SEC)   BURN TEMP(DEG R)
                        1          1          .0000             .0000
                        2          2          .0000             .0000
                        3          8          .0000             .0000
                        4          8       2.0000E-02           800.0

PAMB(PSIA)=  14.70       TAMB(C)=  20.00       PCHAM(PSIA)=  14.70       TCHAM(C)=  20.00       FRAC O2=  .2095

CHAMBER DATA.....NO. OF CHAMBERS =   9
  K0   VOL(CU FT)    P(PSIA)     TEMP(C)      GAS(LB)       GAMMA    FRAC-O2    ICALC  IPRINT  IPLOT    X(FT)       Y(FT)       Z(FT)
   1    1000.         14.70       20.00        74.90        1.3996    .2095       2       1       0      10.00       10.00       10.00
   9    .0000         14.70       20.00        28.85        1.3996    .2095       2       1       0      10.00       10.00       10.00

VENTING DATA.....NO. OF VENTS =  10
  IV     K1     K2    AREA(SQ FT)    PFAIL(PSIA)    TFAIL(SEC)
   1      1      3      36.00          .0000          .0000
   2      1      5      36.00          20.00        2.0000E-02
   3      3      4      36.00          20.00        2.0000E-02
   4      3      7      36.00          20.00        2.0000E-02
   5      4      8      36.00          20.00        2.0000E-02
   6      5      6      36.00          20.00        2.0000E-02
   7      5      7      36.00          20.00        2.0000E-02
   8      7      8      36.00          20.00          .0000
   9      6      8      36.00          20.00        2.0000E-02
  10      7      9      16.00          .0000          .0000


BEGIN VENTING CALCULATION.........................................................

***** EXPLOSIVE (  1) HAS BEEN ACTIVATED IN CHAMBER (  1) AT TIME =  .00000     SEC IN STEP    0 OF 1000 STEPS

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER    1  AT TIME =  .00000     SEC IN STEP    0 OF 1000 STEPS
          OVERPR(PSI)    V(CU FT)     TEMP(DEG R)     GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)     ESOL(BTU)
INITIAL     .0000         1000.          527.7        1.3996       74.90          .0000
PERCENT LAST PRODUCT (CO2  ) =     1.757
FINAL       700.3         1000.          6424.        1.2384       274.9          .0000           1.256           4.7807E+05    .00000

OVERPR =    704.7       USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =   .6176

***** EXPLOSIVE (  2) HAS BEEN ACTIVATED IN CHAMBER (  2) AT TIME =  .00000     SEC IN STEP    0 OF 1000 STEPS

***** EXPLOSIVE (  3) HAS BEEN ACTIVATED IN CHAMBER (  8) AT TIME =  .00000     SEC IN STEP    0 OF 1000 STEPS

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER    8  AT TIME =  .00000     SEC IN STEP    0 OF 1000 STEPS
          OVERPR(PSI)    V(CU FT)     TEMP(DEG R)     GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)     ESOL(BTU)
INITIAL     .0000         1000.          527.7        1.3996       74.90          .0000
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PERCENT LAST PRODUCT (CO2  ) =    53.910
FINAL      645.9        1000.        7575.        1.2176     224.9        4.4999E-02      1.711              4.84698E+05    85.228

OVERPR =   649.2     USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =    .5050

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   2  AT TIME =  .00000      SEC IN STEP     0 OF 1000 STEPS
          OVERPR(PSI)      V(CU FT)       TEMP(DEG R)      GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)    ESOL(BTU)
INITIAL    .0000          1000.          527.7           1.3996      74.90          .0000
OXIDATION COMPLETE
FINAL      2.096          1000.          601.6           1.3977      75.10          .0000         2.656              7788.7       .00000

OVERPR =   2.125     USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =    .1685

***** WALL (  1) HAS FAILED BETWEEN CHAMBERS (  1) AND (  3) AT TIME =  .00000     SEC IN STEP    0 OF 1000 STEPS

***** WALL (  8) HAS FAILED BETWEEN CHAMBERS (  8) AND (  7) AT TIME =  .00000     SEC IN STEP    0 OF 1000 STEPS

***** WALL ( 10) HAS FAILED BETWEEN CHAMBERS (  7) AND (  9) AT TIME =  .00000     SEC IN STEP    0 OF 1000 STEPS

VENTING CALCULATION
TIME(SEC)      STEP OF NSTEPS     DT(SEC)        MAX PRESSURE DROP
  .0000           0      1000      .0000         IN CHAMBER K0 =    0

 K0   OVERPR(PSI)   DPDT(PSI/SEC)   #V  AREA(SQ FT)   V(CU FT)    GASES(LB)     SOLIDS(LB)     TEMP(R)     GAMMA    EGAS(BTU)     ESOLID(BTU)
  1     700.3          .0000         1    36.00       1000.        274.9         .0000         6424.       1.2384  4.78074E+05   .00000
  2     2.096          .0000         0    .0000       1000.        75.10         .0000         601.6       1.3977  7788.7        .00000
  3     .0000          .0000         1    36.00       1000.        74.90         .0000         527.7       1.3996  6813.5        .00000
  7     .0000          .0000         2    52.00       1000.        74.90         .0000         527.7       1.3996  6813.5        .00000
  8     645.9          .0000         1    36.00       1000.        224.9       4.4999E-02      7576.       1.2176  4.84698E+05   85.228
  9     .0000          .0000         1    16.00       .0000        28.85         .0000         527.7       1.3996  2624.1        .00000

......SUMMARY OF TIME-DEPENDENT BURNING OF EXPLOSIVES......
EXPLOSIVE   CHAMBER   TOTAL WEIGHT    WEIGHT BURNED    FRACTION
    2          2      200.00           .20000          .0010

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   3  AT TIME = 4.95395E-04 SEC IN STEP    50 OF 1000 STEPS
          OVERPR(PSI)      V(CU FT)       TEMP(DEG R)      GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)    ESOL(BTU)
INITIAL    75.20          1000.          2862.           1.2868      85.82          .0000
OXIDATION COMPLETE
FINAL      75.76          1000.          2881.           1.2862      85.82          .0000         .0000              50249.       .00000

OVERPR =   75.93     USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =    .1926

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   7  AT TIME = 4.95395E-04 SEC IN STEP    50 OF 1000 STEPS
          OVERPR(PSI)      V(CU FT)       TEMP(DEG R)      GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)    ESOL(BTU)
INITIAL    54.07          1000.          2213.           1.3079      83.68        1.8780E-03
OXIDATION COMPLETE
FINAL      54.21          1000.          2218.           1.3077      83.68        1.8780E-03      .0000              35941.       1.0416

OVERPR =   54.34     USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =    .1878
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COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   2  AT TIME = 4.95395E-04 SEC IN STEP   50 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)      TEMP(DEG R)      GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)    ESOL(BTU)
INITIAL    45.93           1000.          2062.          1.3094      79.95           .0000
OXIDATION COMPLETE
FINAL      46.73           1000.          2087.          1.3084      80.05           .0000          2.656            31945.       .00000

OVERPR =   46.84      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =   .1797

VENTING CALCULATION
TIME(SEC)      STEP OF NSTEPS     DT(SEC)        MAX PRESSURE DROP
 4.9539E-04      50      1000     1.0175E-05     IN CHAMBER K0 =   1

 K0    OVERPR(PSI)    DPDT(PSI/SEC)   #V  AREA(SQ FT)   V(CU FT)     GASES(LB)     SOLIDS(LB)      TEMP(R)     GAMMA   EGAS(BTU)      ESOLID(BTU)
  1      666.1        -6.8912E+04      1   36.00        1000.         264.0         .0000         6371.       1.2386 4.54662E+05    .00000
  2      46.73          .0000          0    .0000       1000.         80.05         .0000         2087.       1.3084  31945.        .00000
  3      75.76         8.3086E+04      1   36.00        1000.         85.82         .0000         2881.       1.2862  50249.        .00000
  7      54.21         9.1113E+04      2   52.00        1000.         83.68        1.8780E-03     2218.       1.3077  35941.        1.0416
  8      613.1        -6.6003E+04      1   36.00        1000.         215.4        4.3112E-02     7515.       1.2178 4.60067E+05    81.002
  9      .0000          .0000          1   16.00         .0000        28.85         .0000         527.7       1.3996  2624.1        .00000

......SUMMARY OF TIME-DEPENDENT BURNING OF EXPLOSIVES......
EXPLOSIVE  CHAMBER  TOTAL WEIGHT   WEIGHT BURNED   FRACTION
    2          2       200.00          5.1539        .0258


COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   3  AT TIME = 1.01908E-03 SEC IN STEP  100 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)      TEMP(DEG R)      GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)    ESOL(BTU)
INITIAL    136.6           1000.          4324.          1.2578      96.85           .0000
OXIDATION COMPLETE
FINAL      137.0           1000.          4339.          1.2575      96.85           .0000          .0000            93881.       .00000

OVERPR =   137.3      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =   .2174

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   7  AT TIME = 1.01908E-03 SEC IN STEP  100 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)      TEMP(DEG R)      GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)    ESOL(BTU)
INITIAL    98.67           1000.          3321.          1.2801      92.11         3.7442E-03
OXIDATION COMPLETE
FINAL      98.79           1000.          3325.          1.2800      92.11         3.7442E-03       .0000            64509.       3.1121

OVERPR =   99.03      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =   .2067

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   2  AT TIME = 1.01908E-03 SEC IN STEP  100 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)      TEMP(DEG R)      GAMMA      GASES(LB)      SOLIDS(LB)   E RELEASED(KCAL/GM)  EGAS(BTU)    ESOL(BTU)
INITIAL    84.55           1000.          3201.          1.2763      85.18           .0000
OXIDATION COMPLETE
FINAL      85.30           1000.          3222.          1.2759      85.29           .0000          2.656            57481.       .00000

OVERPR =   85.49      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =   .1914
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VENTING CALCULATION
TIME(SEC)      STEP OF NSTEPS    DT(SEC)        MAX PRESSURE DROP
 1.0191E-03     100     1000     1.0771E-05     IN CHAMBER K0 =    1

 K0   OVERPR(PSI)  DPDT(PSI/SEC)  #V  AREA(SQ FT)  V(CU FT)   GASES(LB)   SOLIDS(LB)   TEMP(R)   GAMMA   EGAS(BTU)    ESOLID(BTU)
  1     632.0       -6.5192E+04    1    36.00       1000.      252.9        .0000      6315.     1.2388  4.31248E+05   .00000
  2     85.30         .0000        0    .0000       1000.      85.29        .0000      3222.     1.2759  57481.        .00000
  3     137.0        7.0374E+04    1    36.00       1000.      96.85        .0000      4339.     1.2575  93881.        .00000
  7     98.79        7.6695E+04    2    52.00       1000.      92.11      3.7442E-03   3325.     1.2800  64509.        3.1121
  8     580.3       -6.2314E+04    1    36.00       1000.      205.9      4.1211E-02   7452.     1.2180  4.35482E+05   76.777
  9     .0000         .0000        1    16.00       .0000      28.85        .0000      527.7     1.3996  2624.1        .00000

......SUMMARY OF TIME-DEPENDENT BURNING OF EXPLOSIVES......
EXPLOSIVE  CHAMBER  TOTAL WEIGHT   WEIGHT BURNED   FRACTION
    2         2       200.00          10.391        .0520


COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   3  AT TIME = 1.57436E-03 SEC IN STEP  150 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)      TEMP(DEG R)     GAMMA      GASES(LB)      SOLIDS(LB)    E RELEASED(KCAL/GM)   EGAS(BTU)     ESOL(BTU)
INITIAL     192.6          1000.          5373.         1.2416      108.0          .0000
OXIDATION COMPLETE
FINAL       193.0          1000.          5386.         1.2413      108.0          .0000          .0000           1.37724E+05    .00000

OVERPR =    193.5      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =    .2424

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   7  AT TIME = 1.57436E-03 SEC IN STEP  150 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)      TEMP(DEG R)     GAMMA      GASES(LB)      SOLIDS(LB)    E RELEASED(KCAL/GM)   EGAS(BTU)     ESOL(BTU)
INITIAL     139.0          1000.          4142.         1.2654      100.2        5.5905E-03
OXIDATION COMPLETE
FINAL       139.1          1000.          4145.         1.2653      100.2        5.5905E-03       .0000             92371.        5.7932

OVERPR =    139.4      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =    .2250

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   2  AT TIME = 1.57436E-03 SEC IN STEP  150 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)      TEMP(DEG R)     GAMMA      GASES(LB)      SOLIDS(LB)    E RELEASED(KCAL/GM)   EGAS(BTU)     ESOL(BTU)
INITIAL     121.2          1000.          4158.         1.2571      90.73          .0000
OXIDATION COMPLETE
FINAL       122.0          1000.          4176.         1.2568      90.84          .0000          2.656             84558.        .00000

OVERPR =    122.3      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =    .2039

VENTING CALCULATION
TIME(SEC)      STEP OF NSTEPS    DT(SEC)        MAX PRESSURE DROP
 1.5744E-03     150     1000     1.1439E-05     IN CHAMBER K0 =    1

 K0   OVERPR(PSI)  DPDT(PSI/SEC)  #V  AREA(SQ FT)  V(CU FT)   GASES(LB)   SOLIDS(LB)   TEMP(R)   GAMMA   EGAS(BTU)    ESOLID(BTU)
  1     597.8       -6.1492E+04    1    36.00       1000.      241.8        .0000      6257.     1.2391  4.07834E+05   .00000
  2     122.0         .0000        0    .0000       1000.      90.84        .0000      4176.     1.2568  84558.        .00000
  3     193.0        6.1818E+04    1    36.00       1000.      108.0        .0000      5386.     1.2413  1.37724E+05   .00000
  7     139.1        6.5974E+04    2    52.00       1000.      100.2      5.5905E-03   4145.     1.2653  92371.        5.7932
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  8     547.6        -5.8643E+04      1   36.00          1000.       196.4      3.9295E-02  7386.      1.2182 4.10945E+05    72.556
  9      .0000         .0000          1   16.00          .0000        28.85       .0000      527.7      1.3996  2624.1        .00000

......SUMMARY OF TIME-DEPENDENT BURNING OF EXPLOSIVES......
EXPLOSIVE  CHAMBER  TOTAL WEIGHT   WEIGHT BURNED   FRACTION
    2          2      200.00          15.944        .0797


COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   3  AT TIME = 2.16511E-03 SEC IN STEP  200 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)       TEMP(DEG R)      GAMMA      GASES(LB)       SOLIDS(LB)   E RELEASED(KCAL/GM)   EGAS(BTU)     ESOL(BTU)
INITIAL     245.7          1000.           6166.         1.2306      119.3            .0000
OXIDATION COMPLETE
FINAL       246.1          1000.           6177.         1.2304      119.3            .0000          .0000            1.81791E+05   .00000

OVERPR =    246.8      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =   .2677

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   7  AT TIME = 2.16511E-03 SEC IN STEP  200 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)       TEMP(DEG R)      GAMMA      GASES(LB)       SOLIDS(LB)   E RELEASED(KCAL/GM)   EGAS(BTU)     ESOL(BTU)
INITIAL     176.3          1000.           4777.         1.2554      108.1          7.4103E-03
OXIDATION COMPLETE
FINAL       176.4          1000.           4780.         1.2553      108.1          7.4103E-03       .0000            1.19409E+05   8.8563

OVERPR =    176.8      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =   .2426

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER   2  AT TIME = 2.16511E-03 SEC IN STEP  200 OF 1000 STEPS
          OVERPR(PSI)     V(CU FT)       TEMP(DEG R)      GAMMA      GASES(LB)       SOLIDS(LB)   E RELEASED(KCAL/GM)   EGAS(BTU)     ESOL(BTU)
INITIAL     157.3          1000.           4986.         1.2431      96.63            .0000
OXIDATION COMPLETE
FINAL       158.0          1000.           5001.         1.2428      96.75            .0000          2.656            1.13364E+05   .00000

OVERPR =    158.4      USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS =   .2171
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(693 lines removed)

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VENTING CALCULATION
TIME(SEC)      STEP OF NSTEPS     DT(SEC)         MAX PRESSURE DROP
 5.2596E-02     921      1000     3.0677E-04      IN CHAMBER K0 =   3

 K0   OVERPR(PSI)    DPDT(PSI/SEC)    #V  AREA(SQ FT)    V(CU FT)      GASES(LB)      SOLIDS(LB)    TEMP(R)     GAMMA    EGAS(BTU)     ESOLID(BTU)
  1     257.8          2074.           2    72.00         1000.         123.1         2.1293E-05    5490.      1.2424 1.77966E+05   2.92231E-02
  2     695.0          .0000           0    .0000         1000.         269.3          5.584        6676.      1.2276 4.96169E+05    15900.
  3     255.9       -1.0544E+04        3   108.0          1000.         111.3         2.5842E-04    6782.      1.2194 1.97787E+05    .43814
  4     258.3          -2659.          2    72.00         1000.         119.5         2.8567E-03    6336.      1.2294 1.90835E+05    4.5250
  5     255.9          -9774.          2    72.00         1000.         117.2         2.4719E-03    6522.      1.2223 1.95184E+05    4.0307
  6     258.5          -35.26          1    36.00         1000.         116.3         4.1236E-03    6476.      1.2263 1.93390E+05    6.6755
  7     255.3        1.6354E+04        4   124.0          1000.         107.7         6.5756E-03    6712.      1.2220 1.94149E+05    11.033
  8     256.4          -6941.          3   108.0          1000.         109.5          1.668        6130.      1.2301 1.86059E+05    4276.9
  9     .0000          .0000           1    16.00         .0000         28.85          .0000        527.7      1.3996  2624.1       .00000
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COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER 4 AT TIME = 9.23196E-02 SEC IN STEP 971 OF 1000 STEPS

	OVERPR(PSI)	V(CU FT)	TEMP(DEG R)	GAMMA	GASES(LB)	SOLIDS(LB)	E RELEASED(KCAL/GM)	EGAS(BTU)	ESOL(BTU)
INITIAL	205.3	1000.	6152.	1.2294	99.14	3.5092E-03			
OXIDATION COMPLETE									
FINAL	205.6	1000.	6163.	1.2293	99.14	2.4281E-03	.0000	1.53780E+05	3.7414

OVERPR = 206.0 USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS = .2225

COMBUSTION OF EXPLOSIVE PRODUCTS IN CHAMBER 6 AT TIME = 9.23196E-02 SEC IN STEP 971 OF 1000 STEPS

	OVERPR(PSI)	V(CU FT)	TEMP(DEG R)	GAMMA	GASES(LB)	SOLIDS(LB)	E RELEASED(KCAL/GM)	EGAS(BTU)	ESOL(BTU)
INITIAL	206.4	1000.	6274.	1.2267	97.16	3.7136E-03			
OXIDATION COMPLETE									
FINAL	206.5	1000.	6276.	1.2267	97.16	3.4708E-03	.0000	1.55995E+05	5.4453

OVERPR = 207.0 USING A REAL GAS APPROX.....PERCENT DIFFERENCE FROM PERFECT GAS = .2181

VENTING CALCULATION

TIME(SEC)	STEP	OF NSTEPS	DT(SEC)	MAX PRESSURE DROP
9.2320E-02	971	1000	5.4213E-04	IN CHAMBER K0 = 3

K0	OVERPR(PSI)	DPDT(PSI/SEC)	#V	AREA(SQ FT)	V(CU FT)	GASES(LB)	SOLIDS(LB)	TEMP(R)	GAMMA	EGAS(BTU)	ESOLID(BTU)
1	205.9	-819.2	2	72.00	1000.	103.0	5.1683E-05	5325.	1.2428	1.43635E+05	6.87971E-02
2	695.0	.0000	0	.0000	1000.	269.3	5.584	6676.	1.2276	4.96169E+05	15900.
3	204.6	-1.2829E+04	3	108.0	1000.	93.33	4.7162E-04	6520.	1.2208	1.58850E+05	.76873
4	205.6	5395.	2	72.00	1000.	99.14	2.4281E-03	6163.	1.2293	1.53780E+05	3.7414
5	203.3	-4981.	2	72.00	1000.	93.25	1.7322E-03	6637.	1.2165	1.61221E+05	2.8743
6	206.5	483.1	1	36.00	1000.	97.16	3.4708E-03	6276.	1.2267	1.55995E+05	5.4453
7	200.4	1.3941E+04	4	124.0	1000.	90.38	9.5517E-02	6392.	1.2234	1.53361E+05	254.06
8	204.2	-1.0100E+04	3	108.0	1000.	91.45	.4117	6074.	1.2304	1.50448E+05	1039.8
9	.0000	.0000	1	16.00	.0000	28.85	.0000	527.7	1.3996	2624.1	.00000

VENTING CALCULATION

TIME(SEC)	STEP	OF NSTEPS	DT(SEC)	MAX PRESSURE DROP
.2201	1000	1000	3.2068E-02	IN CHAMBER K0 = 6

K0	OVERPR(PSI)	DPDT(PSI/SEC)	#V	AREA(SQ FT)	V(CU FT)	GASES(LB)	SOLIDS(LB)	TEMP(R)	GAMMA	EGAS(BTU)	ESOLID(BTU)
1	142.1	274.9	2	72.00	1000.	77.25	9.1658E-05	5079.	1.2434	1.01674E+05	.11830
2	695.0	.0000	0	.0000	1000.	269.3	5.584	6676.	1.2276	4.96169E+05	15900.
3	138.5	-1883.	3	108.0	1000.	68.99	5.6310E-04	6135.	1.2225	1.09671E+05	.86374
4	140.8	-706.7	2	72.00	1000.	73.72	1.8201E-03	5857.	1.2298	1.07989E+05	2.6649
5	137.0	-1618.	2	72.00	1000.	69.97	1.1077E-03	5964.	1.2236	1.07877E+05	1.7454
6	140.7	-2324.	1	36.00	1000.	72.14	2.5958E-03	5941.	1.2276	1.08814E+05	3.8557
7	115.8	-210.5	4	124.0	1000.	59.10	1.4311E-02	5968.	1.2251	92090.	33.860
8	146.2	954.1	3	108.0	1000.	70.01	3.5644E-03	6076.	1.2264	1.12786E+05	5.4138
9	.0000	.0000	1	16.00	.0000	28.85	.0000	527.7	1.3996	2624.1	.00000

TEST PROGRAM FOR DETERMINATION OF REFLECTED PRESSURES IN ACCEPTOR BAYS

Darrell D. Barker, PE
Steven L. Young, PE

Mason & Hanger - Silas Mason Co., Inc.

ABSTRACT: Criteria for protection of personnel in DOE facilities requires that, for Class II explosives operations, all personnel in occupied areas other than the bay of occurrence not be exposed to overpressures greater than 15 psi. Several of the operating bays used at DOE facilities are World War II-era structures consisting of two or three wall cubicles with a "soft" roof. Of particular concern are bays which have a clay tile wall adjacent to the open front. A test program was initiated to determine the pressures reflected by this wall from a detonation in a donor bay into an adjacent bay. A 1/8th scale steel model of two adjacent bays was built, instrumented and tested to determine these pressures. Charge and gage locations were varied to determine relationships between pressure and scaled distance from a reflecting surface. Variations in scaled weight of the wall were used to determine reflectance effects. Test program, model fabrication, and results are discussed.

INTRODUCTION

A test program was initiated to determine overpressures reflected into adjacent occupied areas by an accidental detonation in an explosives operations bay. An overstrong steel model was built to model donor and acceptor bays to verify compliance with protection criteria. In the first phase of the program, a rigid steel wall was used to create a worst case configuration for measuring the maximum pressures reflected into the adjacent bay. The second phase of the program incorporated frangible reflecting walls to produce reflected pressures more representative of the conditions in the structure.

BACKGROUND

Department of Energy (DOE) criteria requires that, for Class II operations, all personnel in occupied areas, other than the bay of occurrence, be protected from overpressures greater than 15 psi. Several explosives operating facilities are in use today which are in excess of 40 years old. These facilities were designed to conform to criteria which was not as stringent as that required today. Facilities which cause particular concern are those with adjacent operating bays with open front walls and a connecting corridor as shown in Figure 1. The corridor is composed of a concrete floor slab, clay tile exterior wall and a "soft" roof. The bays are two and three wall cubicles with 12" reinforced concrete walls. Roofs are either reinforced concrete or asbestos cement panels. A typical three wall bay is 19 ft. wide, 17.5 ft. high, and 23.5 ft. deep. "Thru" bays are 48 ft. deep two wall cubicles (open front and rear).

Explosives limits in the bays are 12 lbs. of high explosives (HE). A typical operating bay contains several operations with small quantities of explosives. The design charge weight for determining overpressures is taken as the entire bay limit converted to TNT using an equivalency factor. This yields a conservative predictions of overpressure but allows maximum flexibility for the operations. The Design Basis Accident (DBA) is a handling error occurring at any location within the bay which is more than three feet from any wall.

TEST PROGRAM

Description of Model

The 1/8th scale model used in the program was designed to remain elastic under the design loading to allow a large number of tests to be conducted. The model was constructed of A36 steel with welded and bolted (A307) connections. A plan view of the model is shown in Figure 2. The 1/2" floor plate was connected to 1/4"x 6" continuous plates on 6" centers to allow access to gage mounting holes. The 1/2" front wall was bolted to the floor and the 1/4" roof plate to allow removal. This provided a method for determining "wrap-around" pressures without the effects of a reflecting front wall. The roof was also bolted to the 1-1/2" side walls to allow testing of the model as a three wall cubicle without a roof. The back wall of the donor bay was bolted to allow modeling as a "thru" bay.

Gage mounting holes were provided at four locations in the floor along the front of the donor bay and at the front, 1/4 point, and center of the acceptor bay to measure side-on pressures. Six inch angles were bolted to the floor of the acceptor bay with pressure gages installed at 3" above the floor to measure reflected pressures at each gage line. Gages were installed in the front wall at eight locations to measure reflected pressures 3" above the floor. The 3 inch measurement was equivalent to 2 feet in the full scale structure. The model was placed in an 11 ft. diameter test fire chamber before testing began. This permitted tests to be run in all weather conditions.

Instrumentation

Pressure gages were PCB Model 102A02, high resolution transducers with built-in amplifier. The gages were installed flush with the mounting surface and covered with an opaque material to protect against flashes from the detonation. All gages performed well during testing and appeared to sustain no appreciable damage during the tests. The gages are rated for 0-100 psi but will remain functional up to 1000 psi. The highest pressures measured during testing were less than 170 psi. The gages were coupled to a Neff Model 122 DC amplifier with a PCB Model 483A power unit and Beldon RG58-AU cabling. Signals from the amplifier were fed into a Sangamo 80, 14 channel magnetic tape recorder operating at 120 ips. The analog signal for each channel was digitized at 200 samples per millisecond using a Biomation Model 8100 Digital Waveform Recorder. The digitized voltages were recorded on magnetic disk and converted to pressure values using calibration voltage data and an HP 9845 computer. Pressure data was plotted using a thermal plotter. A typical pressure plot is shown in Figure 3.

Test Plan

Phase I

The high explosive used for each test was a single pressed, cylindrical charge of LX-10 weighing 10.64 grams with a diameter of 0.75" (L/D=1.05). This explosive has a TNT equivalency of 1.1. An RP-2 detonator was used to detonate the HE. The orientation of the charge was varied in the first four tests to determine directional effects of the cylindrical charge and detonator. End effects from the cylinder were negligible in the confined model, based on pressure measurements, and detonator effects were limited to an increase in reflected pressures from the back wall. It was determined that a forward orientation with the detonator at the rear would be used because the accident scenario was a handling error not involving a detonator.

Several model configurations were used to determine the effects of distance and reflective surfaces. The charge locations for the test program are shown in Figure 4. Initially the charge was placed in the center of the donor bay and reflected pressures were measured at the reflecting wall and the face of the acceptor bay. Measured pressures were compared to predicted pressures to verify that results were within the range for which the gages had been calibrated. Results of these comparisons were used to modify the prediction of a calibration pressure range for each gage location.

Three gage lines were used in the acceptor bay to establish side-on and reflected pressures at various obliquities and distances from the reflecting wall. These lines covered the front half of the bay and were used to describe pressure contours for the bay. The front wall and roof were removed for some of the test shots to allow separation of "wrap around" pressures from the reflected pressures caused by the front wall.

The first phase of the program was designed to determine worst case effects for pressures reflecting off of a rigid wall. Fifty tests were conducted in the first phase. This rigid wall configuration produced pressures in the acceptor bay which were slightly above the 15 psi maximum. Phase II was initiated to determine a more accurate picture of the reflected pressures by substituting frangible walls of various densities for the rigid reflecting wall.

Phase II

The second phase of the program consisted of 10 test shots with three wall types and three charge locations. The first type tested was a wall composed of two layers of 6 mil polyethylene clamped to the front of the model with 1x4 blocking and bolts. This material was used for two tests to determine how much pressure would be reflected from an essentially massless wall. The charge was placed at the center of the bay for the first test and an equivalent of six feet from the front of the bay for the second test.

The second type of wall used in Phase II was 1/4" plywood. This was held in place with 1x4 blocking and bolted to the model. Two tests were also conducted for this type with the charge locations the same as for the polyethylene tests.

Gypsum board was use for the third wall type. This material was chosen to closely model the scaled weight of the clay tile wall in the structures of interest. The weight of the clay tile is 31 pounds per square foot of wall surface (psf). Two layers of 1/2" gypsum weighing approximately four psf were used to give an equivalent velocity in the scale model. This would reflect the same peak pressures into the acceptor bay in the scale model as the clay tile wall would produce in the actual structure. This material was supported at the bottom by 1x4 blocking bolted to the floor. For the first test, the top of the gypsum board was nailed at three inches on center to 1x6 blocking which was bolted to the roof of the model. For the second test half of the nails were removed. The remaining four tests used a single nail in the top. This fastening method was used to model the weak supports for the clay tile wall.

RESULTS

Pressure Measurements

Peak pressures were read directly from the plotted traces. Since only the maximum pressures were of interest, with respect to the criteria, impulses were not computed. A summary of the measured pressures in Phase I for a charge in the center of the donor bay is given in Table 1.

Four locations were provided along each gage line to allow comparisons of measured values in close proximity to each other. This provided a means for evaluating results and determining the validity of the pressure measurements. Measurements which differed greatly from those of nearby gages were analyzed to determine if the difference resulted from reflections or gage malfunctions. Readings which were significantly different with adjacent gages or repetitive tests of the same gage were not included in calculation of average maximum pressures.

Phase I

Reflected pressures

Results of Phase I testing are shown in Table 1. Reflected pressures were measured at eight gage locations along the reflecting wall to allow a comparison with Pr values predicted using Figure 4.6 of Reference 1. Figure 5 shows reflected pressure measurements versus scaled distance for gages 1 to 4 which are directly in front of the donor bay. These measurements are bounded by Pr and 1.75*Pr for scaled distances of 5 to 20 ft/lb**1/3. The 1.75 factor, although not applied as described in Chapter 4 of Reference 1, serves as a convenient multiplier to predict the maximum pressure expected at a gage.

Reflected pressures were also measured at each gage line in the acceptor bay. A 6"x3"x1/4" angle was used to provide a reflecting surface and was bolted to the floor so that the front face was flush with the gage line. The pressure gages were installed in the angle 3" above the floor. This allowed measurement of the maximum effectual pressure in accordance with the criteria. At the face of the acceptor bay, the average reflected pressure for a center charge (location 4) was 17.4 psi. The average pressure at the center of the acceptor bay, gage line 3, was 12.8 psi. With the charge located an equivalent of three feet off of the common wall and six feet from the front of the bay (location 9), the average pressure at the front and center of the acceptor bay were 17.0 and 9.9 psi respectively. One test was run with the charge located at the extreme front corner of the bay (location 8) to determine the worst case pressures even though this is not a credible configuration. Pressures for this test average 25.4 psi at the face of the acceptor bay.

Reflected pressure versus scaled distance is plotted for several charge locations in Figures 6 and 7. These curves represent the measurements taken at the first and third gage lines in the acceptor bay with the reflecting front wall in place. Most of the gages parallel the Pr curve from Reference 1 and are roughly bounded by applying a 1.75 multiplier to this curve as was done for the front wall gages. Gages 10 and 11 however, do not follow this curve and actually show a rise in pressure with increasing scaled distance.

The distribution of pressure in the front half of the acceptor bay indicated that the common wall between the bays shielded areas close to the wall from reflected pressures. The exception to this was gage 9 which was located adjacent to the common wall but was also at the face of the bay and therefore was not shielded. The pressures measured next to the exterior wall were higher than at locations in the center of the bay because of the reflection of the pressure wave on the wall. These two phenomena caused a distribution of pressure which actually increased with distance from the charge in some cases.

When the front wall and roof were removed, reflected pressures at the first gage line averaged 7.5 psi for a center charge. This indicates that the pressures reflected by the wall are approximately 10 psi higher than the wrap around pressures. For charges located closer to the front of the bay, the difference between pressures with the reflecting wall in place and pressures with it removed decreased. This was due to the increasing influence of wrap around and direct pressures as the charge was moved forward.

The back wall of the donor bay on the model was removed for some tests to allow the charge to be placed in the rear half of the bay. This also allowed comparison of pressure measurements with the wall in place and with it removed. This was done to determine the effects of back wall reflections. Some increase in pressure was observed with the back wall in place; however, additional testing will be required to determine a valid method for predicting this increase. In all cases, removal of the back wall to model the "thru" bay condition resulted in pressures equal to or less than the 3-wall cubicle configuration.

Side-on pressures

Side-on pressures were measured only in the acceptor bay. These pressures were measured to examine the relationship between side-on and reflected pressures in the model. These pressures were also useful in determining the actual pressures personnel would be exposed to during a detonation. The most probable configuration in a bay is personnel located away from reflecting surfaces, such as a wall, and thus not subjected to the higher reflected pressures.

Pressures along the first gage averaged 10.4 psi for a charge located in the center of the donor bay (location 4). When the charge was moved to the front (location 9), the pressures increased to an average of 12.2 psi. Removal of the front wall and roof reduced the average pressure to 7.5 psi for a center charge and 9.3 psi for a front position charge.

All side-on pressures measured in the acceptor bay were less than 15 psi except when the charge was placed at the face of the donor bay. For these locations, the acceptor gages were directly across from the charge and were not shielded at all by the common wall. When side-on pressures are compared to reflected pressures, the ratio is less than predicted in the literature (1,2). A definite explanation for this was not determined, however it is most likely due to the obliquity of the reflecting angle to the pressure wave.

Phase II

Reflected pressures

The results of Phase II testing are shown in Table 2. This table contains reflected pressures measured at the first two gage lines. The maximum average pressure recorded was 13.8 psi for a center charge at gage line one and 10.5 psi at gage line two. The pressures measured for a charge located in the front corner of the bay were slightly less than the center charge. It presumed that this is due to a higher wall velocity for the front charge resulting in less pressure being reflected. The additional time that the gypsum board remained in place relative to the plywood produced slightly greater pressures reflected into the acceptor bay.

Charge location 13 was used in Phase II to measure pressures for the DBA charge location which was three feet from the common wall and three feet from the face of the donor bay. This configuration produced an average reflected pressure of 9.1 psi.

Side-on pressures

Pressures measured at gage line one for the polyethylene wall averaged 7.7 psi for a center charge and 11.0 for a front charge. Pressures for the plywood wall for center and front charge locations measured 8.2 and 10.8 respectively. When the gypsum board was installed the pressures increased to 8.7 for the center charge location and decreased slightly to 10.1 for the front charge.

Wall response

The polyethylene sheared along the edges for both tests with no tensile failure over the surface. Although the time that the polyethylene remained in place was not known it was presumed to be very short because of the mode of failure. Pressures measured with this material in place were slightly higher than pressures with no reflecting wall at all.

The plywood was displaced enough to clear the extension of the floor of the model and was lying on the floor of the chamber after the test. A crack had formed along the yield line with a permanent deflection of approximately one inch. This response showed that the plywood remained in place long enough to develop a significant portion of its bending resistance and therefore was able to reflect pressures. Reflected pressures for the plywood were slightly higher than the polyethylene for a center charge and significantly higher for a charge located near the front of the bay.

The gypsum board material, as expected, reflected more pressure into the acceptor bay than the other materials. In the first test, with a close spacing of fasteners, the gypsum board had a permanent deflection of 1/8 inch. The displacement in the second test with a six inch nail spacing was approximately 1/2 inch. The gypsum board split the length of the wall at mid-height for the remainder of the tests with a single nail at the top. This indicates that the board remained in place long enough to develop some bending but only because of its mass and not the supports. The effects of wall mass on reflected pressures are shown in Figure 8 for gages at the second line.

Analysis

The principal objective of this test program was to determine whether or not personnel protection requirements were being met. The criteria requires that maximal effective pressures in adjacent occupied areas be less than 15 psi. For both center and front charge locations in Phase I, the average reflected pressure exceeded the maximum allowable by the criteria by about 2.5 psi. Although this is a small disparity it is not technically acceptable. In addition, some individual gage measurements were much higher than the average. The explosives limits had already been reduced as much as possible and continuation of the operations would require an exemption from the criteria for the duration. Three alternatives were considered to resolve the problem. The first was to change the DBA to take advantage of the actual configuration in the bay. The operations in the explosives facilities are performed on work benches and fixed equipment at several locations in a bay. Only a portion of the total HE weight in the bay is located at any given work location. This makes the DBA very conservative since it assumes that the entire explosives limit will be placed in the worst possible location. The center of these charges as a group is likely to be between the center of the bay and the back wall. This makes the center bay charge location a suitable configuration for evaluating the true overpressure hazard. The disadvantage of this alternative was that it reduced the flexibility of the operations and required strict administrative control to ensure that the explosives weights and locations chosen were not changed. This alternative was eliminated because of these disadvantages. The second alternative was to file for an exemption of the 15 psi requirement for these operations. This alternative was eliminated because it was desirable to operate without an exemption wherever possible. The third alternative was to continue the test program to model the actual reflecting wall response and determine the actual pressures. This alternative was chosen and Phase II was initiated.

A secondary objective of the test program was to develop a method of predicting overpressures in similar facilities. Several attempts were made to predict pressures in the acceptor bay using various multipliers on the charge weight, total scaled distance to the point of interest, and Figure 2-15, Ref. 2. These were not successful mainly due to a lack of correlation in the data for some of the gages, ie. increasing pressure with increasing distance. The method chosen, based on the available data, was to multiply the reflected pressure predicted by using Figure 2-15 of Reference 2 by 1.75. The scaled distance was equal to the distance from the charge to the reflecting wall plus the distance to the point of interest divided by the cubed root of the charge weight. This method provided a reasonable upper bound for the pressure. Another alternative for predicting pressures was to produce graphs relating pressure to: scaled distance to the reflecting surface, angle of obliquity, and scaled distance from the reflecting surface to the point of interest. Additional testing with variations in charge weight and location would be required to establish meaningful values for this method.

Conclusions

The results of Phase II testing support the assumption that when the response of the clay tile wall is modeled, the pressures reflecting into adjacent acceptor bays are below 15 psi. This will allow the operations to continue without the need for an exemption from the criteria. The test program produced a method for determining an estimate on the maximum pressures in adjacent bays for facilities with this configuration.

Application

The results of the test program will be used to verify compliance with protection requirements for a particular facility; however, a large number of facilities in use today have similar geometries, construction, and explosives limits. Variations in charge weight, charge location, and gage positioning used in this test will allow prediction of pressures in many of these facilities in which the protection provided is not accurately known. Many times explosives limits are set artificially low because these values are not available; however, there will also be instances in which limits will have to be lowered based on the results of this test program. Results of the tests can also be used to reduce personnel exposure by allowing evaluation of restrictions on HE location in a donor bay and physical barriers for personnel in critical locations of an acceptor bay.

SUMMARY

Test Plan

The test program provided a means for evaluating personnel exposure to hazardous overpressures for a particular configuration of explosives operations bays. Existing methods for accurately determining pressures which are reflected into adjacent bays have not been previously available. This has resulted in the use of simplifying, conservative assumptions to predict these pressures. The test plan varied charge location, gage position, and reflective surface configuration to accurately measure reflected and side-on pressures.

Results

The measured pressures for the most realistic charge location indicated that protection requirements were not met for the rigid wall configuration used in Phase I. Pressure measurements which were above the limits were concentrated in the front portion of the acceptor bay. When the response characteristics of the clay tile wall were incorporated into the model, the pressure measurements were in strict compliance with the criteria.

Application

The abundance of facilities with a similar configuration necessitated the variation of charge location and gage positioning to allow application of the results to other operating bays. The methods for determining pressures for other charge weights will be developed during later testing. The results will be used to set HE limits and evaluate personnel protection in other facilities.

Future Testing

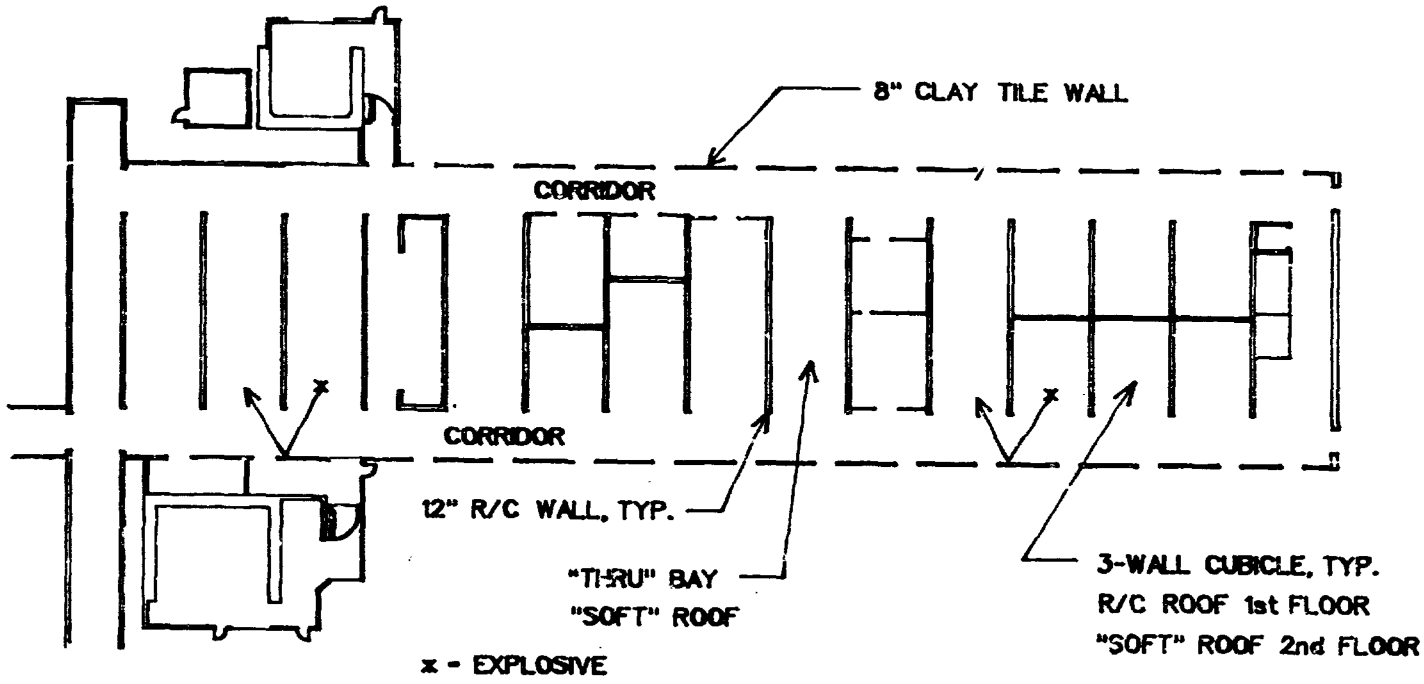
Currently 60 test shots have been made and the first two phases have been completed. The configurations tested were used to establish boundaries for pressure measurements and to determine critical locations. The most obvious need for further testing is variation in the charge weight to expand the applicability of the results.

Other tests planned for the program include determination of back wall effects on the reflected pressures. Phase I results indicated that pressures reflecting off the back wall became significant when the charge was placed between the center and back of the bay. Incorporation of this effect into the prediction method could be a significant improvement.
Determination of leakage pressures from this type of facility is also an important consideration. A follow on phase of the project is planned to determine the pressures transmitted down the open corridor connecting the bays.

REFERENCES

1. A Manual For the Prediction of Blast and Fragment Loadings on Structures, Department of Energy Technical Manual DOE/TIC-11268, Nov. 1989.

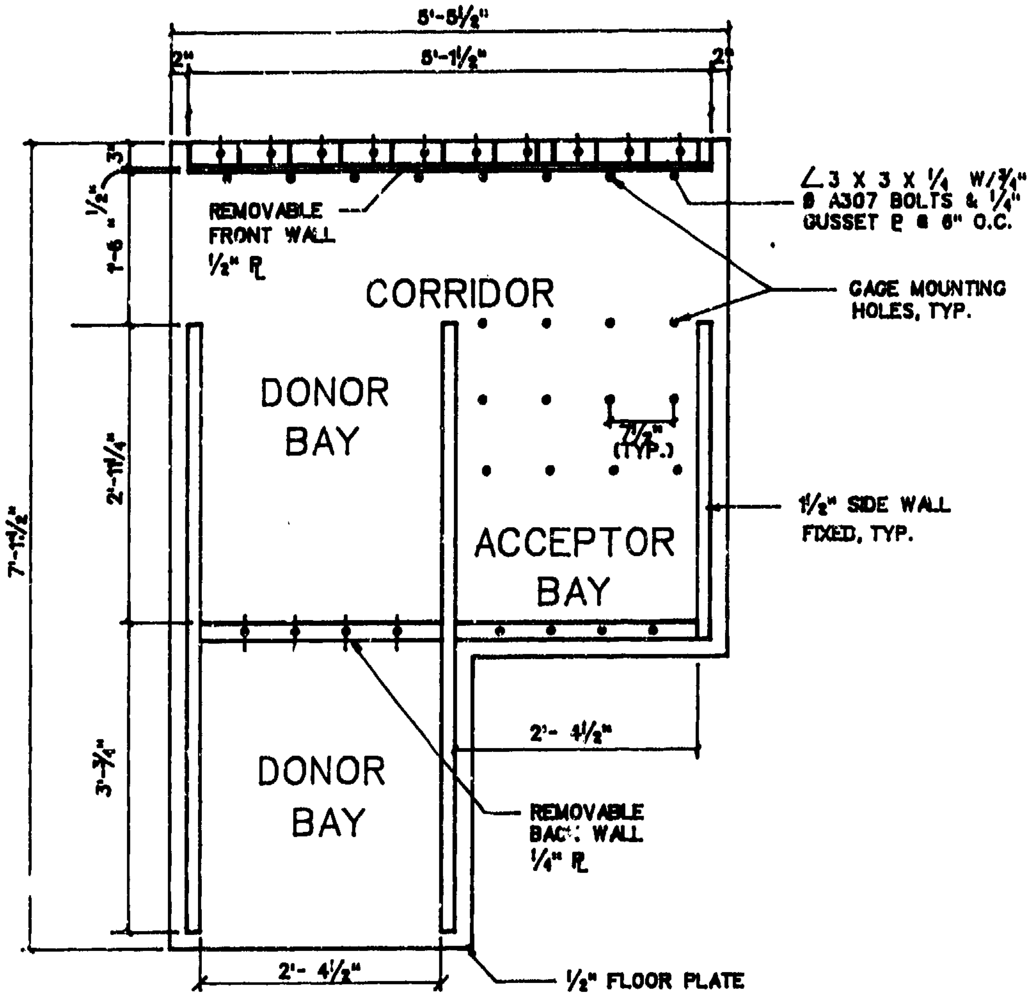
2. Structures to Resist the Effects of Accidental Explosions, Volume II, Blast, Fragment, and Shock Loads, Department of the Army Special Publication ARLCD-SP-84001, Dec. 1986.



TYPICAL EXPLOSIVES OPERATING BUILDING

FIGURE 1

13

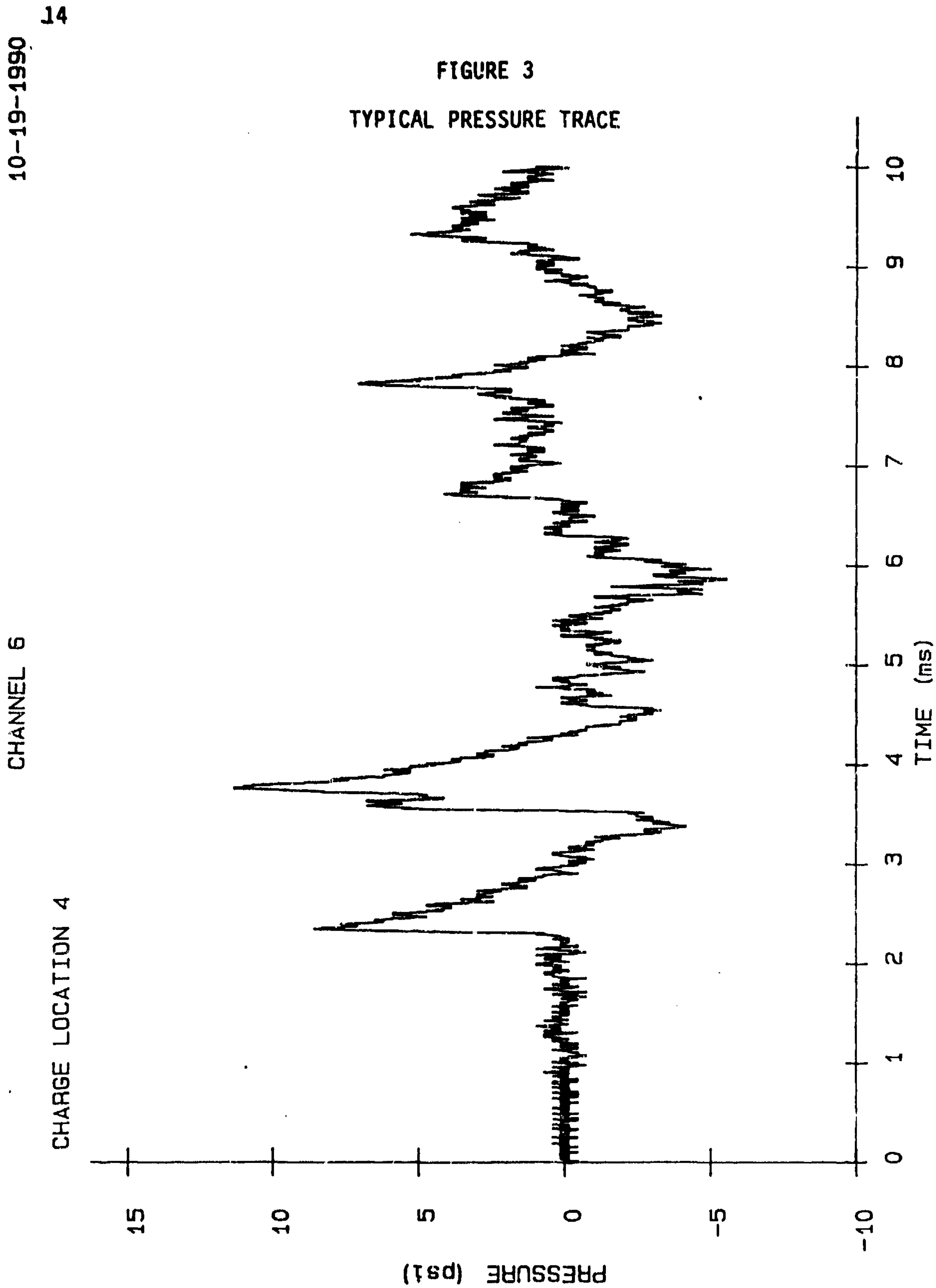


PLAN VIEW
(ROOF ℞ NOT SHOWN)
SCALE: 1" = 1'- 0"

FIGURE 2

FIGURE 3

TYPICAL PRESSURE TRACE



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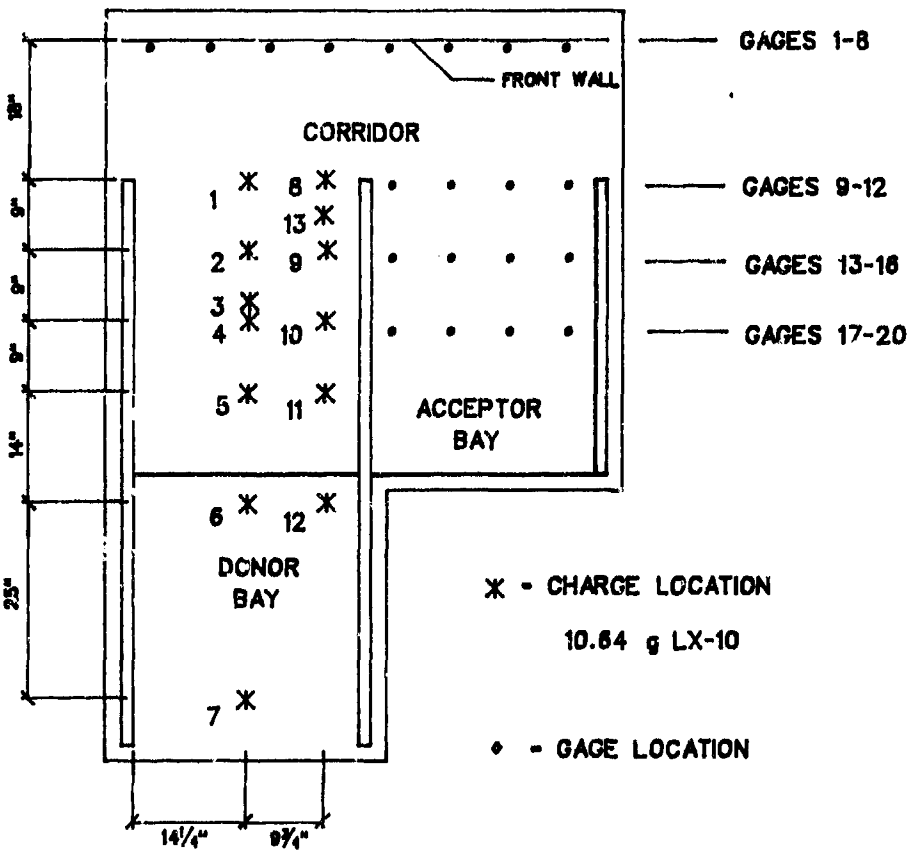

Figure 4 CHARGE LOCATIONS

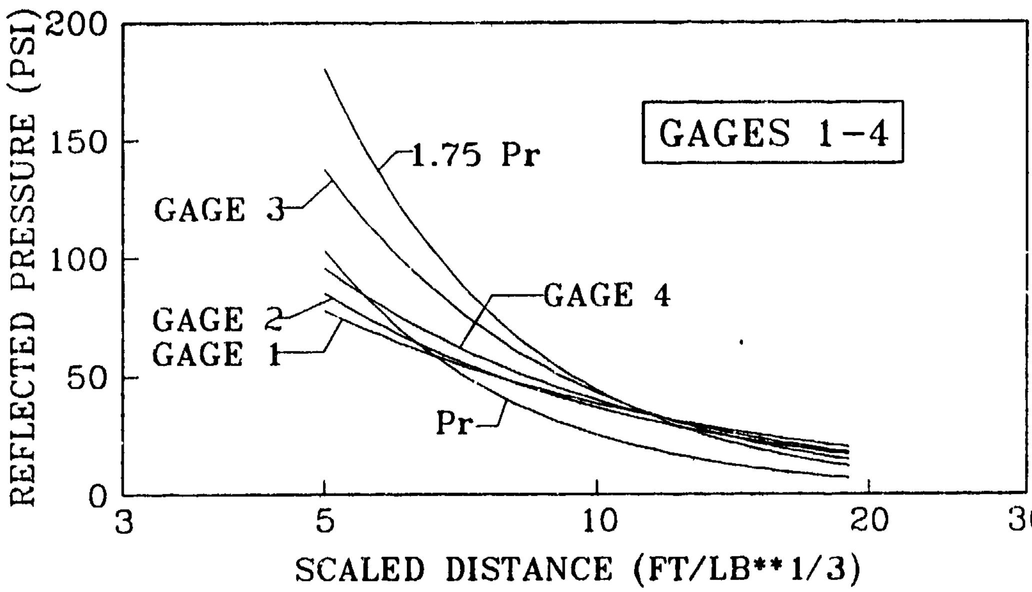

FIGURE 5 REFLECTED PRESSURES AT WALL

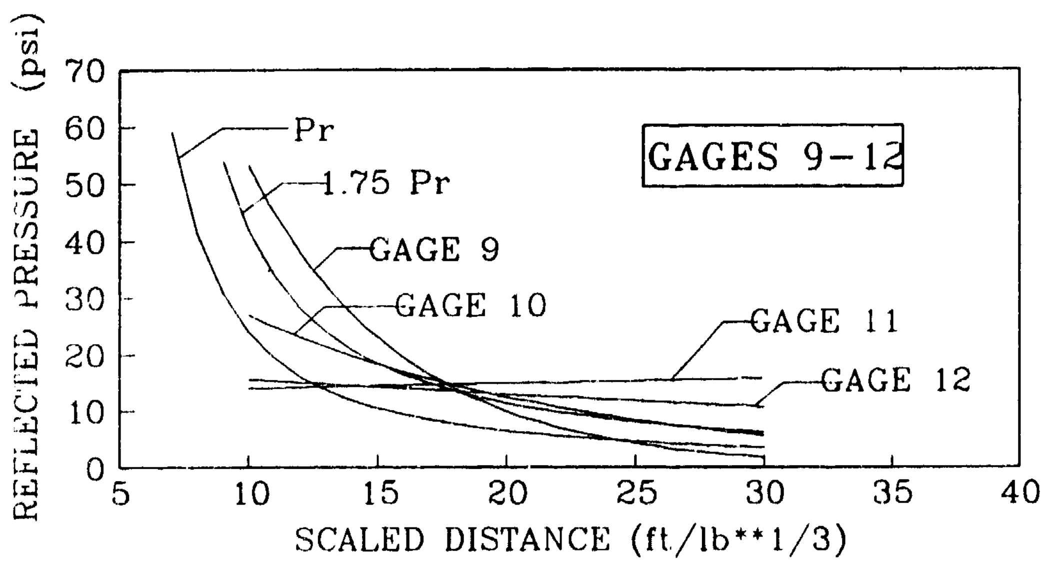

FIGURE 6 REFLECTED PRESSURES IN ACCEPTOR BAY

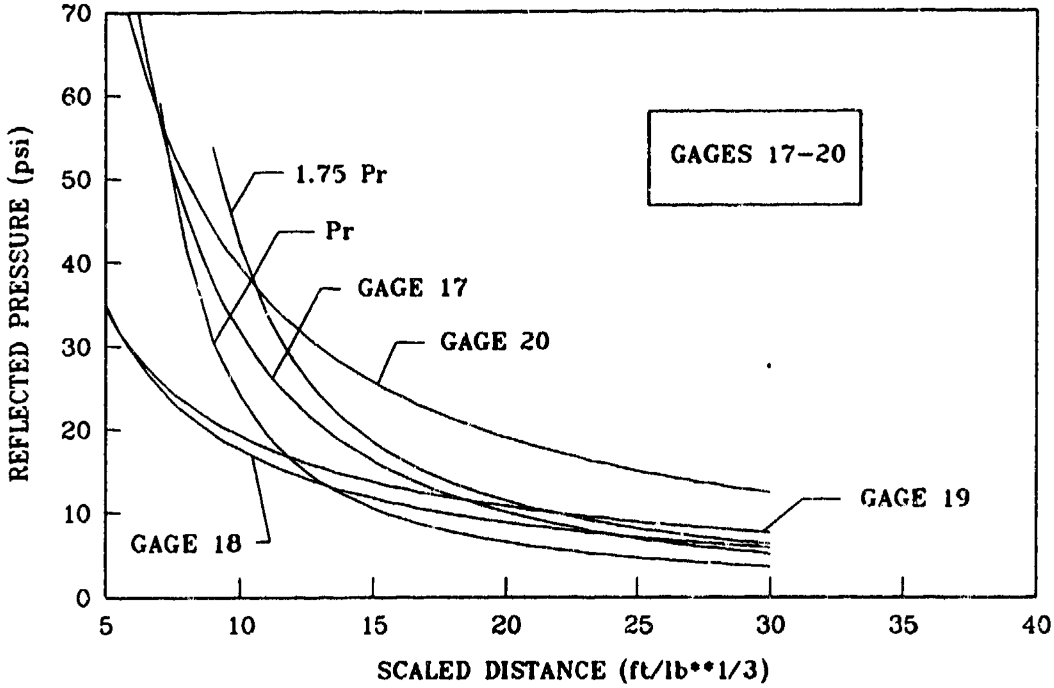

FIGURE 7 REFLECTED PRESSURES ACCEPTOR BAY

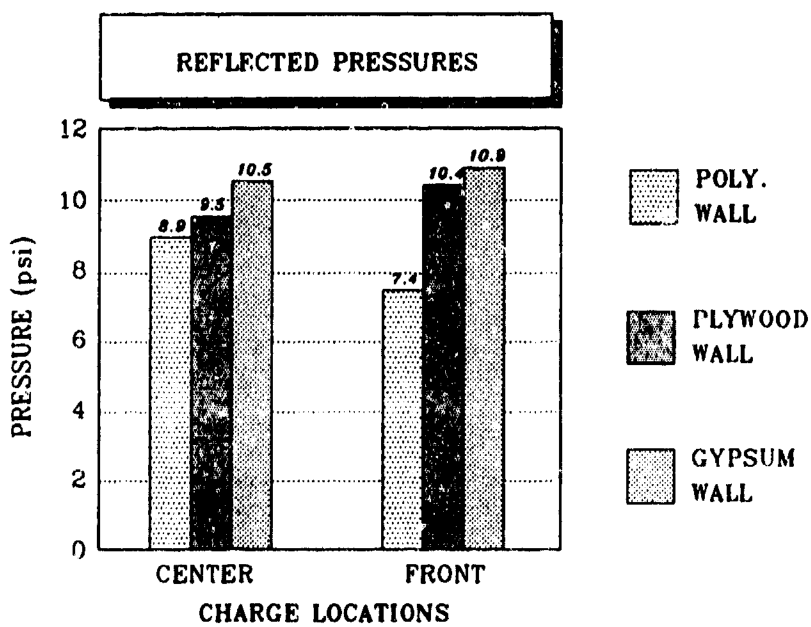

FIGURE 8 WALL RESPONSE EFFECTS

PHASE I

TYPE	LINE	MEASURED	Pr CURVE (**)
REFLECTED	1	17.4	7.7
REFLECTED	3	12.8	5.3
SIDE-ON	1	10.4	3.5
SIDE-ON	3	8.3	2.5

(CHARGE LOCATION 4)

* AVERAGE REFLECTED PRESSURES AT 1st GAGE LINE > 15 PSI FOR ALL CHARGE LOCATIONS IN FRONT HALF OF DONOR BAY

* IF FRONT WALL IS REMOVED, ALL PRESSURES < 15 PSI FOR ALL CHARGE LOCATIONS EXCEPT FACE OF DONOR BAY

** REFLECTED PRESSURE FROM FIG. 2-15, REF. 2

TABLE 1 PHASE I RESULTS

PHASE II

REFLECTED PRESSURES

CHARGE LOCATION	MATERIAL	GAGE LINE	PRESSURE (PSI)
CENTER	POLY.	2	8.9
FRONT CORNER		2	7.4
CENTER	PLY.	2	9.5
FRONT CORNER		2	10.4
CENTER	GYP.	1	13.8
		2	10.5
FRONT CORNER		1	9.1
		2	10.9

CENTER = LOC. 4 FRONT = LOC. 9

TABLE 2 RESULTS PHASE II

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VENTED BOMB TESTS TO CHARACTERIZE PROPELLANT AND COMBUSTIBLE CASE EXTINGUISHMENT

by
C. James Dahn
Bernadette N. Reyes
&
Abdollah Kashani

Safety Consulting Engineers, Inc.
Rosemont, Illinois 60018

and

Everet Applet
Armtec Defense Products Co.
Coachella, California USA

ABSTRACT

A study was conducted at Safety Consulting Engineers, Inc. to simulate ballistic cycle pressure reduction and its effect on propellant and unpredictable combustible cartridge case (CCC) residue development. A new vented bomb system was developed and designed to simulate a 120 mm propellant/combustible cartridge case ballistic environment to 80,000 psi pressure and associated ballistic times. Full-diameter burst discs were used to suddenly reduce pressure to atmospheric level.

Numerous tests were conducted monitoring chamber pressure time. Residuals, if any, were collected after extinguishments.

The results of the low pressure testing showed the formation of CCC's residue were dependent on many factors such as localized region of increased density, region of lower nitrocellulose content or foreign material between the propellant and the combustible case.

1. INTRODUCTION[1]

Armed conflict can occur anywhere, any time, in any part of the world. When that happens, highly mobile armament systems must be immediately deployable. And when forces engage, firing crews and their weapons must perform reliably, even under the most adverse conditions. This includes ammunition which will be easier to transport, deploy, load and fire when it includes safe, dependable combustible ordnance products.

Today, combustible ordnance materials find many uses on the battlefield. They replace heavier metal cases in tank ammunition. They replace cloth propellant containers attached to mortar rounds, and they provide rigid propellant containers to replace cloth bags in artillery ammunition. The list is growing longer as experimental applications move from R&D to production.

These products are formed from wood fiber pulp which has been strengthened with resin binders and stabilizers, then heat-molded into rigid, dimensionally stable shapes. Nitrocellulose added to the composition contributes energy to the round's combustion cycle and causes the material to be totally consumed in the process.

Combustible ordnance products yield many important advantages regardless of application:

- Manufacturing facilities require less investment
- Material costs are lower
- Strategic metals are conserved
- Shipping and handling costs are lower
- Lighter weight improves field mobility
- Firing crew fatigue is reduced during rapid load-and-fire sequences
- Strategic scrap materials are denied to enemy scavengers
- Combustion residue is eliminated, even under sustained fire

The positive contributions made by combustible ordnance products to combat effectiveness are leading to accelerated development of this technology for sea and air armament systems.

2. EXPERIMENTAL

Safety Consulting Engineers, Inc., in cooperation with Armtec Defense Products Company, conducted low-pressure testing of the combustible cartridge case material in an attempt to identify factors which could have contributed to the formation of the residue in a gun firing environment. In this experiment, a vented bomb was chosen because the propellant and combustible casing burn could be interrupted by rapid release of the interior pressure. This will prevent consumption of the sample by the retention of the high pressure conditions in a normal closed bomb apparatus. Also, the resultant shape of the time/pressure trace of the vented-bomb could be made to approximate the shape of actual low-pressure firing tests.

2.1 VENTED BOMB TESTS

A series of vented bomb tests were conducted on the case materials to gain a qualitative understanding of how the case materials burn in a gun environment. In field use, the combustible case is normally ignited by the flame of the burning propellant which is contained within the combustible case. Design of the vented bomb utilized in this test is illustrated in Figure 1.

2.1.1 Material Description

Two types of combustible cartridge cases, post impregnated (PI) and beater additive (B/A) are available for the 120 mm tank gun system. Both case types are composed primarily of nitrocellulose fibre (NC), kraft wood fibre, and a resin binder, although the percentage of each ingredient varies according to the specific application. The primary difference between the case types is that the resin is mixed in with the other ingredients before molding in the beater additive case, while the post impregnated case is dipped in resin after molding[2]. The PI case has shell-like, high resin density regions near its outer surfaces and a very low resin density in its interior, while the B/A case has a much more uniform resin density, and is much more flexible.

The B/A combustible cases were used in this study.

2.1.2 Chamber Size

In an effort to closely replicate firing chamber conditions in the vented-bomb apparatus, a device with the same interior diameter as the 120 mm Smoothbore Cannon was constructed. The device chamber length was arbitrarily set at 3 inches.

The construction of the device in this manner allows the testing of a 3-inch ring of undisturbed 120 mm combustible cartridge case sidewall material. Because the gun chamber diameter was chosen as the device chamber diameter, the same air gap remains between the chamber wall and the outer surface of the combustible cartridge case material. Maintenance of identical gaps allows study of the effects, or amount, of exterior wall ignition during firing.

The known, existing vented-bomb device designs were reviewed prior to initiating the design of a new device. The existing devices are constructed with a very small chamber of approximately 2 inches in diameter.

When loading a vented-bomb chamber of 2-inch diameter with 120 mm CCC material, it is only possible to test a segment of the circumference of the casing material. Additionally, this material segment is normally modified by the cutting of longitudinal V-shaped grooves along the interior wall of the segment. The grooves allow the outer circumference of the segment to be reduced to fit the 2-inch diameter chamber.

Modification of the material sample as described above, alters the burning rate by exposing additional surface area to the propellant flame. It also alters the interior burning pattern of the sample because of the cut-out sections of material. Also, the separation between the surface of the sample and the chamber wall is eliminated, which alters or eliminates potential ignition of the sample on the outer surface.

2.1.3 Pressure Limitations

The vented-bomb was designed to have a maximum working pressure of 80,000 psi. This allows for a substantial safety margin since the tests were anticipated to be performed at below 30,000 psi.

2.1.4 Venting Method

A design which utilizes a full-diameter burst disc was chosen. Several iterations of burst-discs were tested with the final units being simple, flat steel discs that were machined to a specific thickness and hardened to provided repeatable burst pressures.

2.1.5 Ignition System

Ignition of the propellant in the vented-bomb was accomplished by using an electrically operated squib to ignite a small primer charge. The final residue tests utilized 5 gm of black powder (BP) as the igniter material. This BP was contained in the center region of the DIGLRP propellant bundle.

Experimentation with igniter materials was performed until the leading edge of the vented-bomb testing pressure/time curve approximated that seen in actual low-pressure gun firings.

2.1.6 Propellant Loading

Preliminary tests were performed with various propellant loading densities. Since the tests were intended to duplicate 120 mm High Energy Anti-Tank (HEAT) round firing conditions, only DIGLRP propellant was utilized.

The sticks of DIGLRP propellant were cut to approximately 3 inches in length and bundled into a cylindrical shape and placed in the center of the vented-bomb chamber.

After experimentation, the final residue generation tests were performed using 110 pieces of DIGLRP as the propellant charge.

2.1.7 Pressure Sensing

A single pressure transducer was used to record the internal pressure of the vented-bomb. This information was fed to a computer for development of the time/pressure traces.

2.2 TEST PROCEDURE

2.2.1 Sample Preparation

Beater additive (B/A) 120 mm CCC's were produced which had regions of increased density, regions of decreased NC content and increased coating thickness. Special production techniques were utilized to introduce the defects into the cases.

Once the cases were produced, rings of material of the proper length were cut from the case body sidewall to precisely fit the chamber of the vented-bomb test apparatus. The region of the case ring where the defects were introduced was identified on each of the samples.

The density variation of the samples ranged from 0.85 gm/cc to 1.2 gm/cc. The depleted NC regions ranged from 0% NC to 50% NC. The coating was varied from the normal 2 mils to 10 mils thickness.

After manufacture, these samples were sealed in plastic bags and transported to the test site for storage. They were stored under cover but not under controlled temperature and humidity conditions.

2.2.2 Procedure Details

Each test sequence consisted of firing the vented-bomb with a single sample of modified combustible cartridge case material. The material was fired using DIGLRP propellant which was ignited by a small igniter charge. During the test sequence the various combinations of igniter material and propellant were tested. These combinations were tested to develop a combination which would produce a pressure/time profile in the vented-bomb chamber which closely approximated that of an actual low-pressure gun firing.

In each firing, the material sample was placed in the vented-bomb chamber along with the propellant, igniter material, and electric squib. Refer to Photograph 1 for the arrangement of these materials in the vented-bomb chamber. As indicated in the photograph, the propellant was centered in the chamber to insure an even distribution of propellant flame to the inner surface of the combustible case sample. Also, the igniter material was placed in the center of the propellant bundle. After re-assembly of the vented-bomb, the ignition was started by the use of a remotely activated electrical squib.

Upon activation of the electrical squib, a computer system monitored and recorded the pressure in the chamber through the use of a fast transient response pressure transducer. This data was then stored on disk for a permanent record and also displayed on the computer monitor for evaluation at the site. Refer to Figure 2 for a typical pressure/time trace of a vented-bomb test firing.

After each test firing, the vented-bomb apparatus was disassembled, cleaned, and the spent venting disk was discarded. The Teflon O-Ring utilized for sealing the chamber was also replaced after each test firing.

At 18,000 ±2% psi venting pressure, the combustible case material, performing similar to the propellant, extinguished immediately upon being ejected from the vented-bomb chamber. This allowed recovery of material that was intact except for the material that was missing due to combustion during the firing sequence.

The unburned combustible cartridge case material was collected after each firing from the area around the vented-bomb. These pieces of post-firing residue material were photographed, and then sections of the material were encapsulated and cut with a diamond saw to produce an undisturbed cross section of the residue. Photographs and explanations are shown in this paper.

3.0 TEST RESULTS and CONCLUSIONS

Results of the low-pressure vented-bomb testing showed that the following factors have contributed to the development of the residue from B/A combustible cartridge case:

- Region of increased density
- Region of reduced NC content
- Presence of foreign material between the propellant and interior combustible case

These tests also indicated that the coating thickness would not have been a contributing factor.

The most likely causal factor indicated by the testing was the presence of a foreign material (such as masking tape or aluminized duct tape) which interrupted the flame between the propellant and the interior combustible case wall. Refer to Figure 3 showing the progression of material consumption during the firing sequence. The delay in flame propagation, which resulted in the residue, could also have been caused by an uneven ignition of the propellant.

REFERENCES

1. Excerpts from "This is Armtec" brochure,

2. Armtec Defense Products Co., "Combustible Ordnance in the United States," Sub Panel 2, Panel IV, NATO, November 1984.

3. The Society of the Plastics Industry, Inc., "Pressure Vessel Test", Suggested Relative Hazard Classification of Org. Peroxides by Org. Peroxide Producers Safety Division.

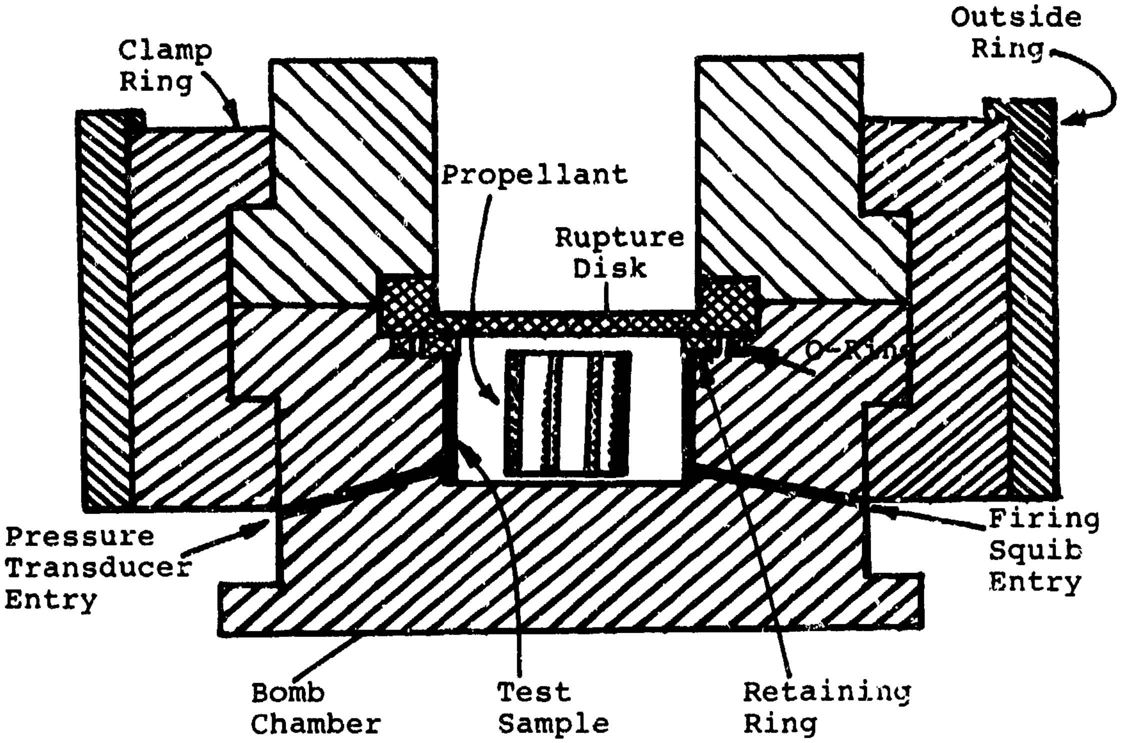


Figure 1. Cross section of Vented-Bomb Chamber Test setup.

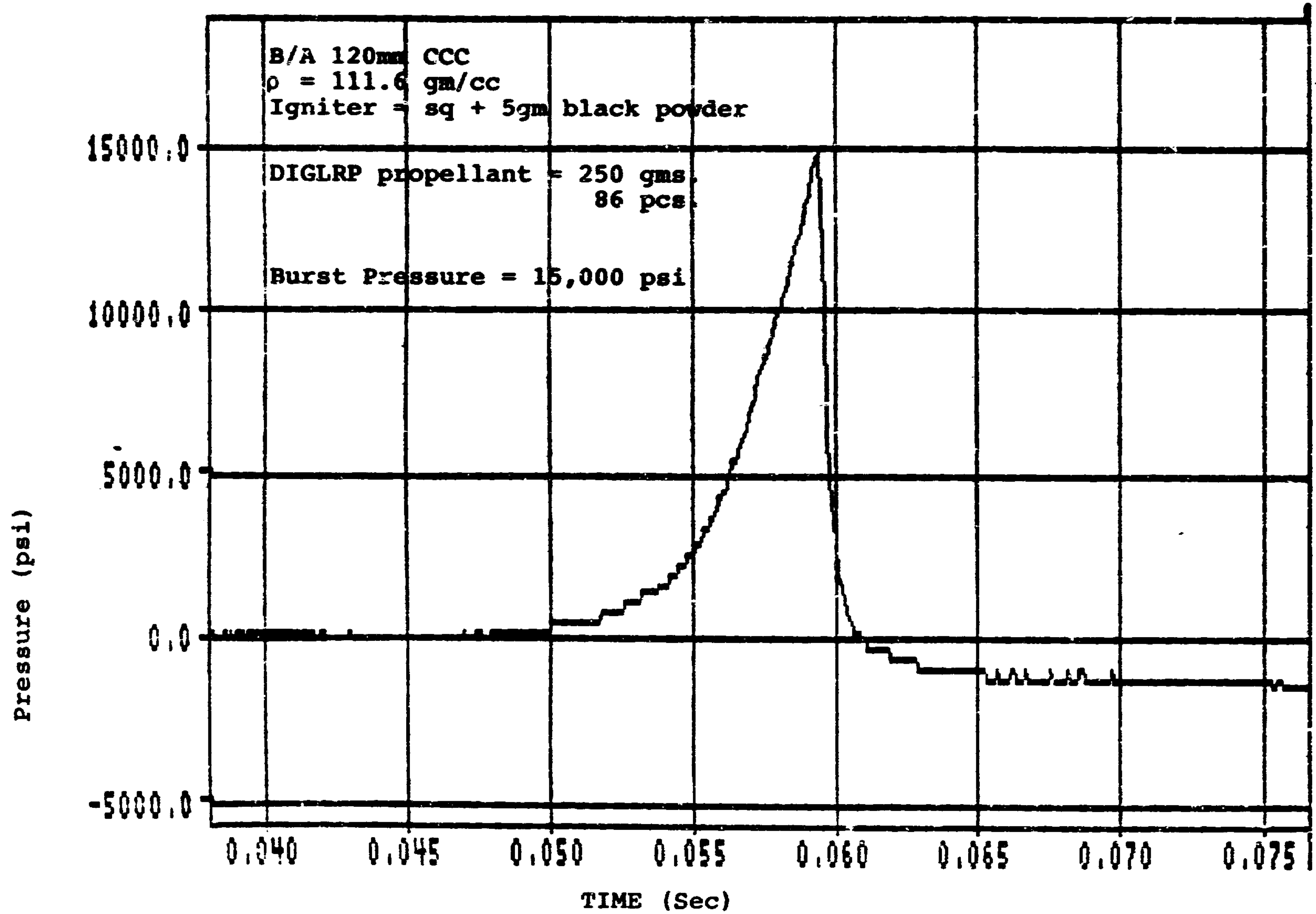


Figure 2. Typical pressure/time trace from vented-bomb firing of B/A 120 mm combustible case.

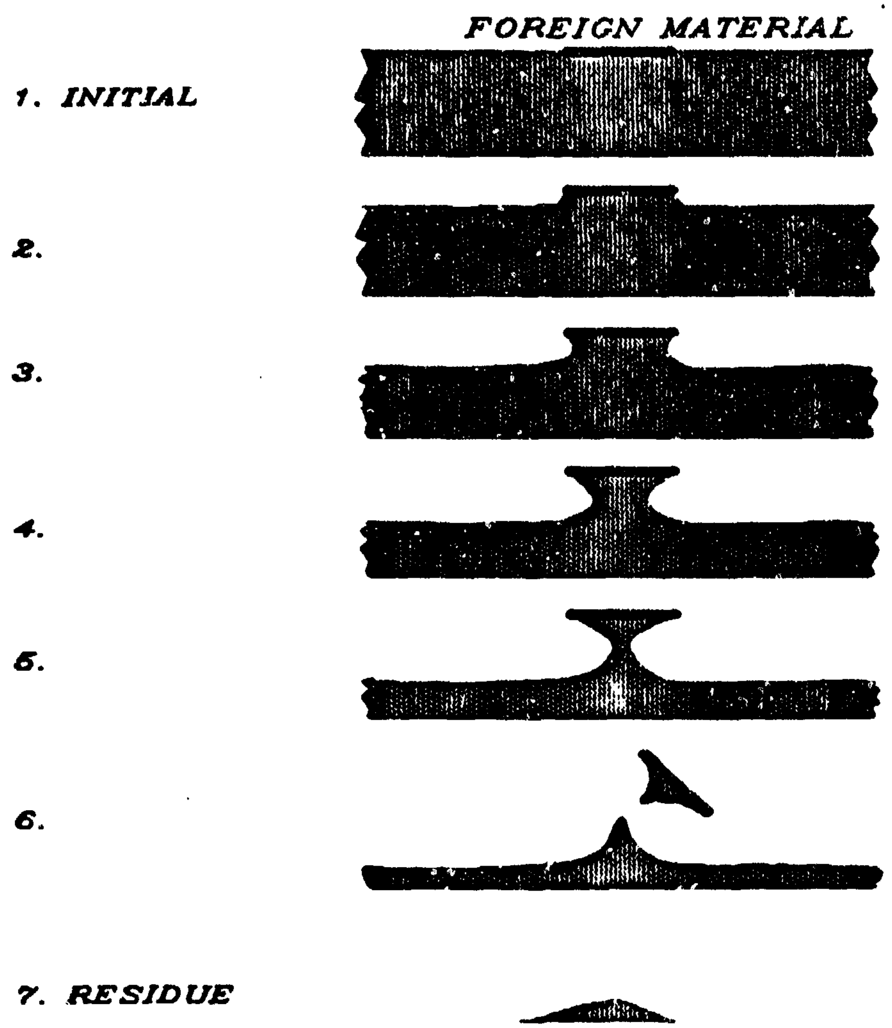


Figure 3. Residue Formation due to foreign material impeding flame front of propellant burn.

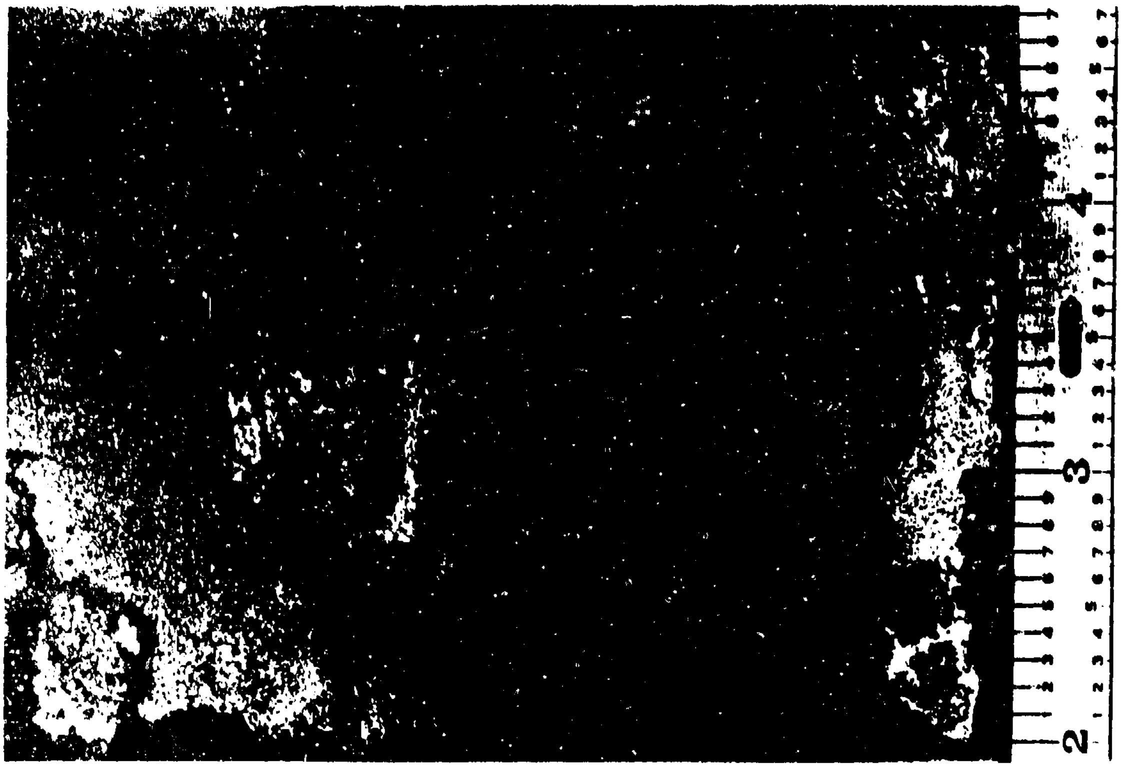
Photograph 1. Arrangement of propellants, igniter material and electric squib inside the vented-bomb chamber.

Photograph 2. Interior view of a residue sample with normal density located on the left and high density located on the right.

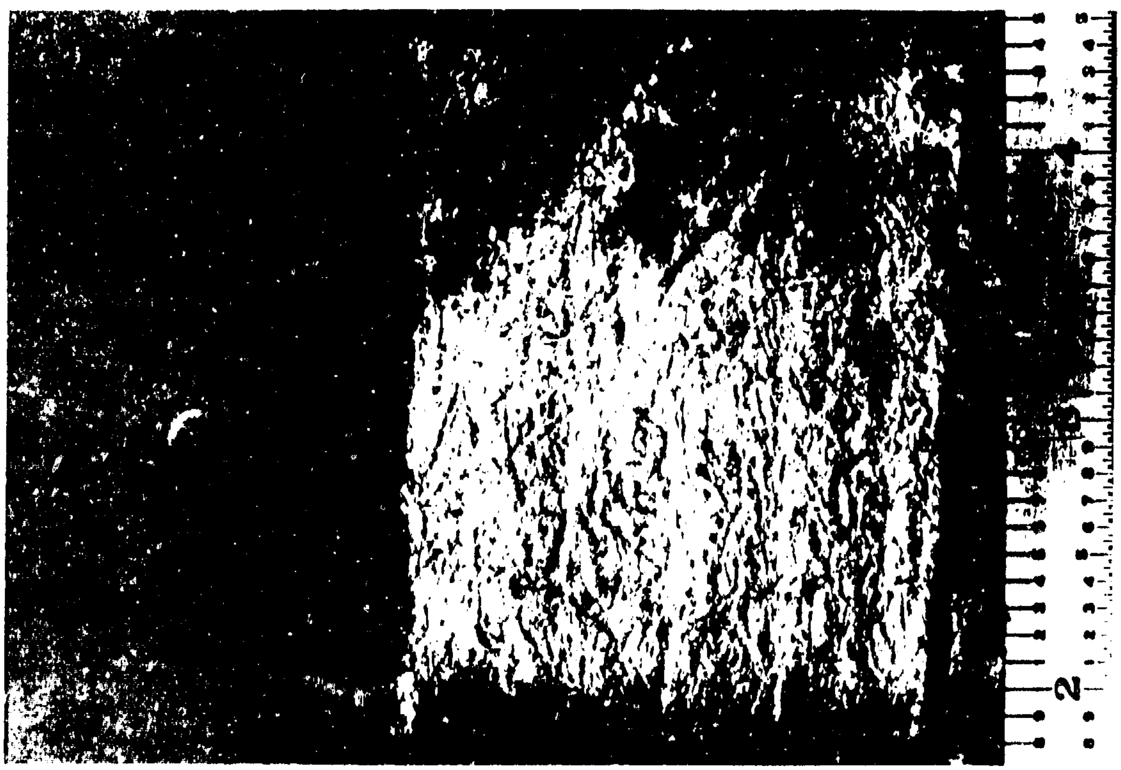
[illegible]

Photograph 4. Cross-section view of the region with normal density.

Photograph 5. Cross-section view of the region with high density.

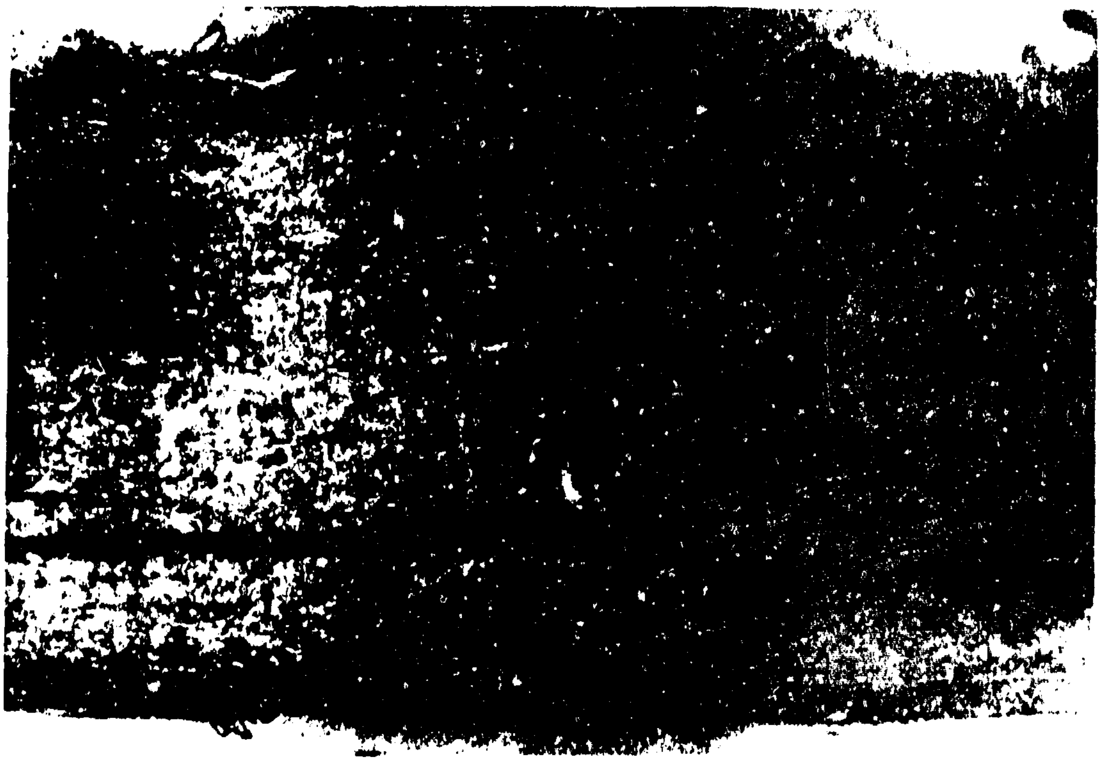


Photograph 6. Interior view of a residue sample with normal material region on left and 0% NC material on the right.



Photograph 7. Exterior view of the same region.

Photograph 8. Interior view of a residue [illegible] tape pressed to the interior.



Photograph 9. Cross-section view of the [illegible] the tape [illegible].

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NEW CONCEPTS IN STUDYING ELECTROSTATIC DISCHARGE HAZARDS OF PROPELLANTS, PYROTECHNICS AND EXPLOSIVES

by
C. James Dahn
Diane Jennings
Abdollah Kashani
&
Missy Nguyen

Safety Consulting Engineers, Inc.
Rosemont, Illinois 60018

ABSTRACT

A study of electrostatic discharge hazards was conducted to determine the worse case situation in handling and producing propellants, pyrotechnics and explosives (PEP). Electrostatic charge generation, storage and mechanisms of discharge were studied. External versus internal generated discharges were studied.

A set of guidelines were established to evaluate electrostatic charging, charge transfer, storage and discharges. Impedance matching is essential for ignition of a wide variety of materials in processing and handling.

INTRODUCTION

As a result of numerous incidents attributed to electrostatic discharge initiations, there is a great need for having proven methods of testing sensitive materials. Military applications are of particular interest here because of the large-scale production, handling, and storage of explosive, propellant, and pyrotechnic items.

The purpose of this paper is threefold:

(1) to review the history of work on electrostatic sensitivity testing of explosive materials.

(2) to review the testing procedures performed by various government agencies and by Safety Consulting Engineers, Inc.

(3) to conduct electrostatic discharge tests using various methods in order to determine worst-case initiation thresholds.

ESD HAZARDS

Static electricity can be generated and retained in one of the following ways, thus creating an electrostatic ignition hazard:[1,2]

(1) Charging of explosive powders, large solid particles, or mixtures. This typically can occur from the pneumatic transport or loading of explosive materials in bulk form, sieving and grinding operations, and mixing/blending operations.

(2) Charging of surfaces that are made from poorly conducting substances which come in contact with explosive material. Typical scenarios for this include the use of Teflon or plastic coatings on rocket motor mandrels for the purpose of reducing metal-to-metal contact friction between parts and during mandrel extraction operations, and the use of large containers or piping made from or lined with materials possessing insulating properties.

(3) Charging of personnel in areas where explosive material operations are being carried out. Common instances of this can occur from walking on nonconducting flooring, wearing shoes with nonconducting soles, rising from a chair, brushing against an object, acquiring the charge from another object in the vicinity by the process of induction, and removing and article of clothing that contains synthetic fibers.

(4) Charging of metal objects that are isolated from ground and which come in contact with explosive material. This might be seen with process equipment that is involved in the direct handling of explosive materials or in the fabrication of explosive, propellant or pyrotechnic items.

ESD TESTING HISTORY

There has been much previous work regarding the development of useful electrostatic sensitivity testing procedures. Some highlights of this work is presented from a historical perspective in Table 1.[3]

ESD SENSITIVITY TESTING

The first step towards establishing safety measures is to have reliable methods for electrostatic discharge testing which relate to ESD mechanisms that might occur under processing and handling conditions. The immediate goals of such testing are (a) to determine how sensitive the material is in the presence of an electrostatic discharge; (b) to develop a mechanism that explains how a discharge takes place in the material under study; and (c) to establish an acceptable value for the minimum ignition energy for each potential condition.

Government Agency Testing Procedures

Several government agencies have contributed extensively to the field of electrostatic sensitivity testing of explosive materials; namely the U.S. Bureau of Mines, the Picatinny Arsenal, the Los Alamos National Laboratory, the Naval Weapons Center, and the Naval Ordnance Station. All of these agencies have developed an approaching-electrode device for which only the testing parameters vary. This information is summarized in Table 2.[4,5,7,8] The approaching-electrode devices developed by the U.S. Bureau of Mines and the Picatinny Arsenal are shown in Figures 1, 2, and 3. The electrode devices developed by the Los Alamos National Laboratory, the Naval Weapons Center, and the Naval Ordnance Station are similar in design. The approaching-electrode device is described below.[4,5,7,8]

The basic principle of operation for the approaching-electrode apparatus involves charging capacitors from a high voltage DC supply, and then discharging the stored energy through the test material under study. The electrical discharge occurs in the region between a needle or a flat plate, referred to as the upper electrode, and a steel cylinder base that holds the sample in place. The approaching-electrode (spring-loaded) apparatus is rapidly released from the sample being tested. The sensitivity of the material is evaluated as a discharged spark that jumps a critical distance across an air gap and through the sample. Steel phonograph needles or brass pins are utilized for the upper electrode. Test samples can be unconfined on a flat metal disk or confined by placing the powder in a plastic tube or by placing tape over the powder on a disk.

The position of the needle or flat plate is adjusted by a set screw so that the space between the base and the upper electrode is approximately equal to the critical gap for a given voltage. This distance is usually estimated by running trial tests. After sample preparation, the upper electrode is cocked to its initial position and the voltage supply is turned on. Charging of the capacitor is monitored by an electrostatic voltmeter. When it reaches the desired level, a switch is closed which allows electrical contact to be made between the capacitor and the upper electrode. When the electrode release button is pressed, the needle or flat plate undergoes a contracting motion and evidence of a reaction is noted by examining the test sample.

How results are obtained from the approaching-electrode test does depend upon which agency's procedure is being used. The U.S. Bureau of Mines and the Los Alamos National Laboratory fix the voltage, vary the size of the capacitor, and conduct several trials at each discharge energy level. The ignition probability point method is then applied to the data. The Picatinny Arsenal procedure calls for varying the voltage in an incremental fashion for a series of different sized capacitors. The Naval Weapons Center fixes the discharge energy (by fixing the voltage and capacitance) at a level that simulates a discharge from a person. Several consecutive tests showing a "no initiation" response are required before the material under study can be authorized for use in military applications. The Naval Ordnance Station follows this same test format, the exception being that a range of fixed energy levels are used.

General Testing Procedures at Safety Consulting Engineers, Inc.

Safety Consulting Engineers also routinely performs electrostatic sensitivity testing of explosive, propellant, and pyrotechnic materials. There are five basic electrode configurations used: ball, sharp, flat plate, pipette plate and pipette sharp. These configurations are shown in Figure 5 and a brief description of each is provided below.

1. Ball Electrode

The upper electrode is a ball electrode configuration consisting of a solid metal sphere approximately 0.925" in diameter attached to a copper rod. The base electrode is a flat metal disk that is attached by adhesive to an insulating surface. Two different sizes of disks are used, depending upon the size of the sample being tested: 0.3" and 2". The ball electrode is connected directly to the positive side of a charged capacitor circuit; when a vacuum relay switch is tripped, the capacitor discharges its energy through various resistances to the ball and subsequently through the sample. This test can be carried out as a no-gap, fixed-gap or approaching-electrode procedure. The no-gap procedure requires that the ball electrode just touch the sample. The fixed-gap procedure requires that the ball electrode be suspended a distance that is slightly above the sample. The approaching-electrode procedure involves lowering the charged ball to a point just slightly above the surface of the sample.

2. Sharp Electrode

The sharp electrode setup is similar in design and operation to the ball electrode; however, the upper electrode is instead a piece of copper wire 0.10" in diameter sharpened to a point at its lower end. The sharp electrode setup can be used in a fixed-gap or approaching-electrode test.

3. Flat Plate Electrode

The flat plate electrode test is operated in the same manner as the metal ball and the pointed-probe electrode tests. In this case; however, the upper electrode consists of a metal disk with raised edges, similar in shape to a bottle cap. The outside diameter of the disk is approximately 0.955" and the inside diameter, comprising the actual contact surface, is about 0.755". The flat plate electrode is used to determine the energy at which electrical breakdown causing ignition of the material occurs. Both breakdown and initiation thresholds can be found using this test. A burn hole that passes completely through the sample is evidence of electrical breakdown. The flat plate electrode setup can be used in a no-gap or fixed-gap test position.

4. Pipette Plate Electrode

The pipette plate electrode configuration receives its name from the manner in which the sample is confined during testing. Samples are first prepared for this test by obtaining 1/2" long pieces from a plastic pipette. A small amount of test powder is loosely scooped into a pipette holder until a sample height of about 0.1" is achieved. The electrode setup is that of a set of flat plates separated by a fixed distance and shielded by a plastic cover. The sample holder is positioned between two copper wire electrodes 0.10" in diameter by raising the upper electrode is then lowered into the tube until it just touches the powder sample without compressing it. After placing a plastic shield over the electrode region, the apparatus is ready for operation. As with the other electrode tests, a charged capacitor discharges energy via resistors to the upper plate and subsequently through the sample. A white spark indicates no reaction with the explosive material, while a colorless spark indicates that a partial reaction has occurred. If the sample holder is ruptured, ignition is said to have occurred.

5. Pipette Sharp Electrode

The pipette sharp electrode setup is similar to the pipette plate electrode, with the exception being that the upper electrode is a sharpened piece of 0.10" diameter copper wire. The pointed end of the electrode is allowed to just contact the sample, the energy in the capacitor is discharged, and evidence of a reaction is recorded in the same manner as with the pipette plate electrode test.

The electrode configuration is not the only important parameter in electrostatic sensitivity testing. The configuration of the electrical circuit affects the results as well. At safety Consulting Engineers, Inc. three different circuit arrangements have been used in testing explosive materials: a capacitive circuit, a capacitive-resistive circuit, and a capacitive-inductive circuit. These circuit arrangements are shown in Figure 6.

TEST PERFORMED AT SAFETY CONSULTING ENGINEERS, INC.

Test Description

Electrostatic sensitivity tests on black powder, nitrocellulose, and solid rocket propellant have been performed at Safety Consulting Engineers. A wide variety of electrode and circuit combinations were tried, so that minimum ignition energies could be calculated and compared for each material. The black powder was FFF grade. The nitrocellulose was tested in a powder form having 13.4% nitrogen composition, and in sheets having a 70% nitrocellulose content and a thickness of 0.04". The solid rocket propellant consists (by weight) of 68% ammonium perchlorate, 20% powdered aluminum, and 12% HTPB-based binder. The propellant was tested in minus 20 mesh powder form and sheets having a thickness of 0.04". Black powder and nitrocellulose were the reference materials for these tests. The specific information being sought from these tests is the effects that the electrode configuration, the circuit configuration, and the circuit resistance have on causing electrostatic initiation.

To determine the electrode configuration effect, electrodes were tested with a capacitive-resistive tester, in which the capacitor discharged its energy through either zero, 100 kilohms, or noe megohm resistance.

To determine the circuit configuration and circuit resistance effects, electrodes were tested with a capacitive-resistive and a capacitative-inductive test apparatus. The resistances used within these circuits were also zero 100 kilohms, and 1 megohm. Thus, a variety of circuit configurations were obtained in the SCE-designed instruments. These include capacitative-only, capacitative-resistive, capacitative-inductive, and capacitative-resistive-inductive.

Test Results

Some selective results from these tests are presented in Tables 3, 4, and 5.

What can be drawn from Table 3 is a ranking of the electrode configurations in terms of the level of stored energy that caused ignition. The materials tested showed different levels of sensitivity depending upon the electrode that was used for the test. In general, the ball electrode yields the lowest energy for ignition, so that explosives look very sensitive when using this apparatus. the sharp electrode ranks next, showing somewhat less sensitivity. This is followed by the flat plate electrode, which makes the explosive appear not very sensitive to ignition. The pipette plate electrode falls somewhere in between the other electrodes, having given much less definite results that vary widely with the type of explosive powder being tested.

It can be concluded from Table 4 that, given the same electrode, using the capacitative-inductive test apparatus generally yields lower stored energy values. This implies that if an explosive material is tested with this apparatus, it will look more sensitive to ignition than if it is tested with the capacitative-resistive apparatus. Thus, the presence of an impedance in the test circuit has a definite effect on the electrostatic test sensitivity of explosive materials.

Additional information can be drawn from Table 4 since two different electrodes were studied. The ball electrode generally gives lower energy values than the sharp electrode when using the capacitative-resistive tester. The exact opposite occurs with the capacitative-inductive tester, in that the sharp electrode gives lower energy values than the ball electrode. Thus, in one situation, the explosive material looks more sensitive with the ball electrode, and under different conditions, it looks more sensitive with the sharp electrode.

The energies listed in Tables 3 and 4 are the minimum stored values in the capacitors that were capable of causing a discharge. The spark energies comparison of the spark energy with the stored energy for tests using the sharp, flat plate, and ball electrodes is provided in Table 5. The spark energy is the true measure of a material's sensitivity, and in all cases shown in Table 5, it proved to be less than the stored energy, regardless of the capacitance and the voltage used in the test.

Conclusion

The overall conclusion that can be drawn from the tests performed at Safety Consulting Engineers is that the combined effect of electrode configuration and circuit configuration makes explosive materials respond differently under varying test conditions. Thus, it remains a difficult task to specify a minimum initiation threshold value that could be used reliably in any situation for a given explosive.

REFERENCES

1. Loveland, R.J., "Electrostatic Ignition Hazards in Industry," J. Electrostatics, Vol. 11, 1981, pp. 3-11.

2. Williams, G.M., "Evaluation of Hazardous Electrostatic Discharges," 1989 JANNAF Propulsion Systems Hazards Subcommittee Meeting, San Antonio, Texas, CPIA Publication 509, Vol. 1 pp. 337-355.

3. Federoff, B.T., Encyclopedia of Explosives and Related Items, PATR 2700, Vol. 5, 1972, Picatinny Arsenal, New Jersey, pp. E 39, E52-E55.

4. Brown, F.W., D.J. Kusler and F.C. Gibson, "Sensitivity of Explosives to Initiation by Electrostatic Discharges," U.S. Bureau of Mines Report of Investigations 5002, September 1953.

5. Kirshenbaum, M., "Response of Primary Explosives to Gaseous Discharges in an Improved Approaching-Electrode Electrostatic Sensitivity Apparatus," Picatinny Arsenal Technical Report 4955, Dover, New Jersey, October 1976.

6. American Society for Testing and Materials, "Proposed Standard Test Method for Electrostatic Sensitivity of Solid-Phase Hazardous Materials."

7. Larson, T.E., et al, "Electrostatic Sensitivity Testing of Explosives at Los Alamos," 1986 Propulsion Systems Hazards Subcommittee Meeting, Monterey, California CPIA Publication 446, Vol.1, pp. 367-377.

8. The Naval Weapons Center, "Safety and Performance Tests for Qualification of Explosives," NAVORD OD 44811, Vol. 1, January 1, 1972, China Lake, California p. 5-9.

TABLE 1

HISTORICAL PERSPECTIVE OF WORK ON
ESD SENSITIVITY TESTING OF EXPLOSIVE MATERIALS

Year	Researcher	Nature of Work
1947	Fleischer and Burtle	Described effect of electrostatic charges on variety of lead azides
1949	Rathburg and Schmitz	Measured electrostatic and ignition sensitivity of primary and initiating explosives
1953	Peace	Noted presence of electrostatic charges on sieved explosive powders
1954	Damon and vanDolah	Reported electrostatic spark test results for several explosive samples
1956	Moore, Sumner and Wyatt	Developed electrostatic spark sensitivity tests for initiators
1959	Sciafe and Wyatt	Continued work on spark sensitivity tests for initiators
1963	Jackson	Studied electrical characteristics of secondary explosives
1965	Clear	Outlined test procedures for electrostatic sensitivity of explosives
1967	Hannah and Polson	Observed accumulation of static charge during handling of lead azide
1969	Montesi	Described a fixed-gap ESD apparatus for testing explosives
1969	Perkins	Review of current ESD testing methods for explosives
1972	Westgate, Pollock and Kirshenbaum	Reviewed current ESD testing practices used on explosives at some major government agencies

TABLE 2

SUMMARY OF ESD TESTING PARAMETERS

	Apparatus & Type of Electrode	Sample Quanity	Sample Confined	Gap Distance	Capacitance	Applied Voltage	Energy Stored In Capacitor
U.S. Bureau of Mines	Approaching Point	50 mg	Partly and No	---	0.0001 - 1.0 F	5 KV Fixed	0.0013 - 12.50 J
Picatinny Arsenal	Approaching Point	5-10 mg	Yes	0.18 mm	54 - 6980 pF	7.5 KV and down	Not specified
Picatinny Arsenal	Approaching Point	3-8 mg	Partly	0.19 mm	54 - 6980 pF	7.5 KV and down	Not specified
Los Alamos National Laboratory	Approaching Point	Constant-volume basis	Yes	Not Known	0.0002 - 3.0 F	5 KV Fixed	Range not specified
Naval Weapons Center	Approaching Point	50 mg	No	Not Known	0.0001 - 0.5 F	5 KV Fixed	0.25 J
Naval Ordnance Station	Approaching Point	50 mg	No	Not Known	0.0001 - 0.1 F	5 KV Fixed	0.001 - 6.25 J
Safety Consulting Engineers, Inc.	Pipette Plate	50 mg	Yes	2.5 mm	0.0005 - 0.1 F	up to 25 KV	0.001 - 24 J
Safety Consulting Engineers, Inc.	Fixed and Approaching Ball	50 mg - 10 g	No	Variable	0.0005 - 0.1 F	up to 25 KV	0.001 - 24 J

TABLE 3

EFFECT OR ELECTRODE CONFIGURATION

ON STORED ENERGY REQUIRED

TO ESD INITIATE MATERIALS

Capacitive - Resistive ESD Testing 1 M Resistance

(ENERGY IN mJ)

ELECTRODE	PROPELLANT SHEET	PROPELLANT POWDER	NC SHEET	NC (13.4%) POWDER	BLACK POWDER
Ball	3200	320	-	36	49
Ball-Approaching	3200	>2800	405	144	640
Flat Plate	5500	720	6050	-	36
Sharp	3610	550	4500	49	122
Sharp-Approaching	8450	-	-	-	-
Pipette Plate	-	500	-	64	289

TABLE 4

EFFECT OF CIRCUIT RESISTANCE & TEST APPARATUS

ON STORED ESD ENERGY THRESHOLDS

		STORED ESD ENERGY - mJ		
CAPACITIVE-RESISTIVE TESTER	RESISTANCE OHM	PROPELLANT POWDER	13.4% NC	BLACK POWDER
Ball Electrode	0	156		360
	100 K	300	90.2	640
	1 M	320	90.2	49
Sharp Electrode	0	-	-	-
	100 K	-	49	810
	1 M	550	49	122
INDUCTIVE CAPACITIVE TESTER				
Ball Electrode	0	156	36	100
	100 K	300	30	169
	1 M	>12,800	36	36
Pointed Electrode	0	-	42	81
	100 K	-	36	64
	1 M	-	42	49

TABLE 5

SPARK ENERGY AS A FUNCTION

OF STORED

CAPACITOR ENERGY

CAPACITOR		CAPACITOR STORED ENERGY		SPARK ENERGY
CAPACITANCE	VOLTAGE	(mJ)	ELECTRODE	(mJ)
0.1	12,000	7200	Sharp	325.0
0.01	17,000	1445	Sharp	72.0 to 270.0
0.002	7,000	49	Sharp	24.0
0.002	7,000	49	Flat Plate	14.7
0.002	7,000	49	Ball	14.7

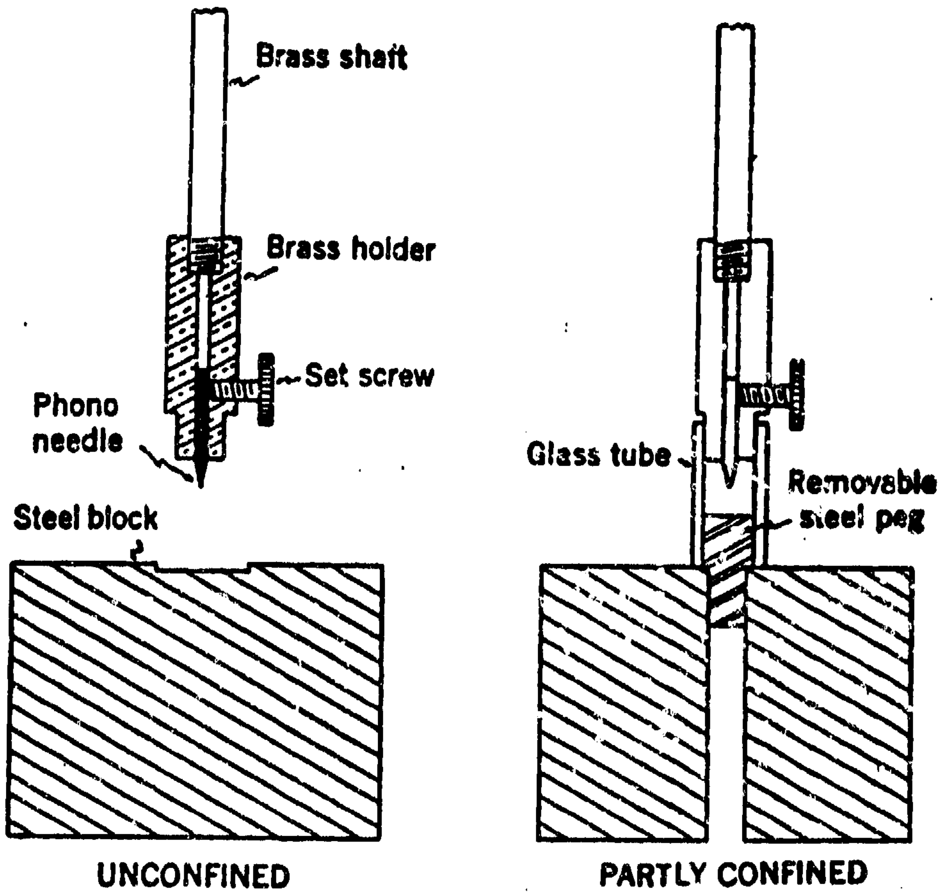


Figure 1. U.S. Bureau of Mines Approaching-Needle Electrode Apparatus. (Ref 4)

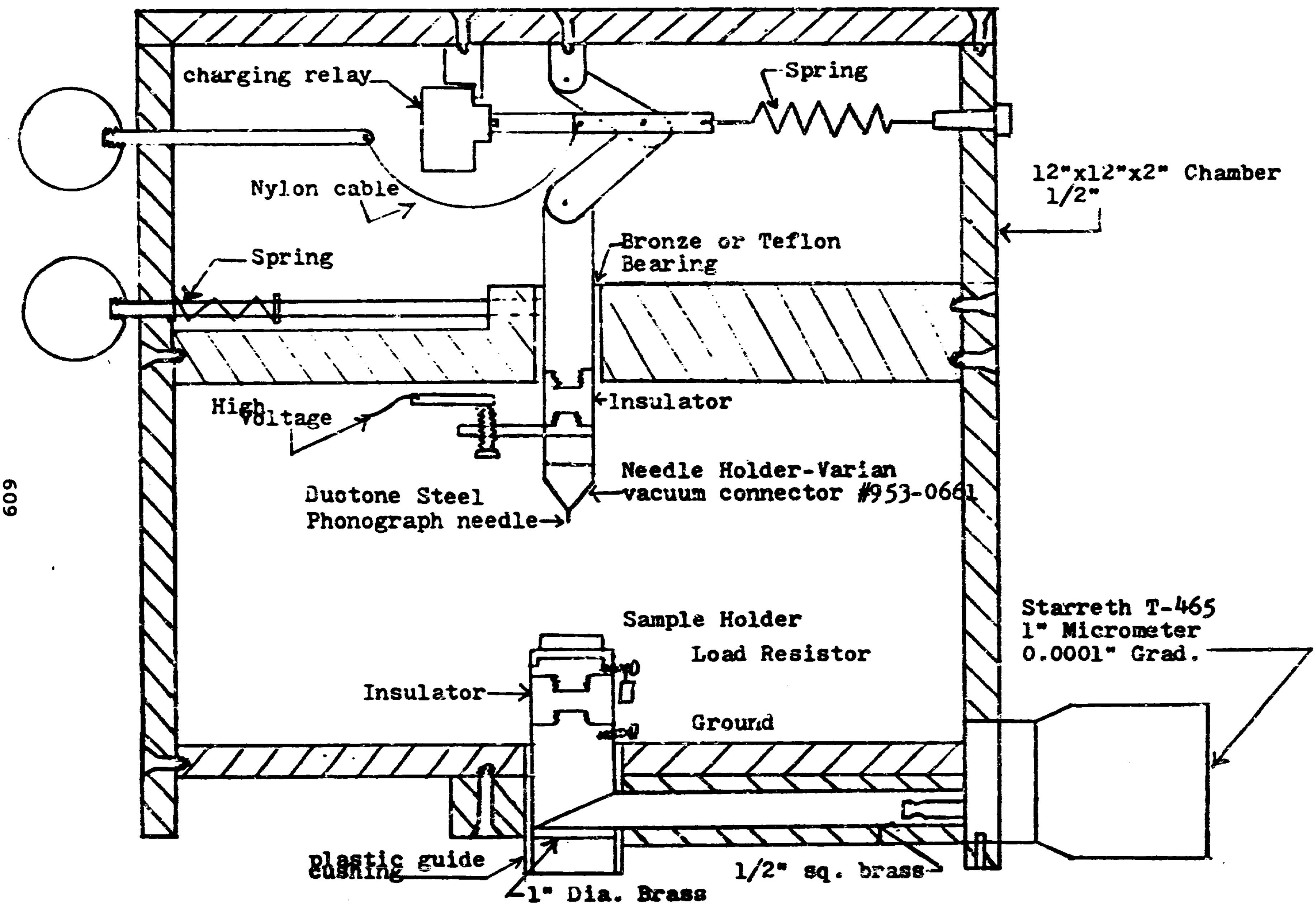


Figure 2. Picatinny Arsenal Approaching-Needle Electrode Apparatus. (Ref 6)

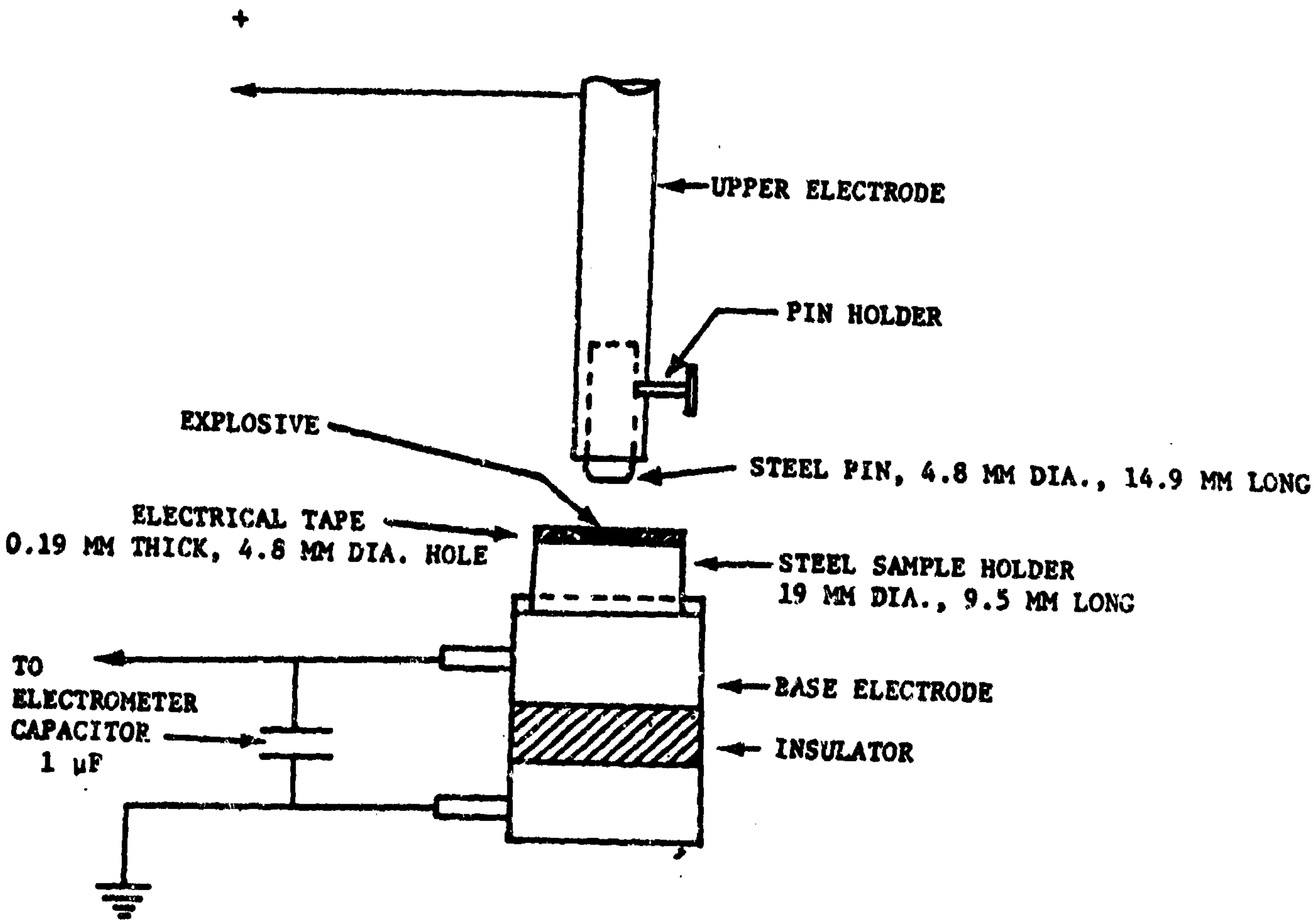
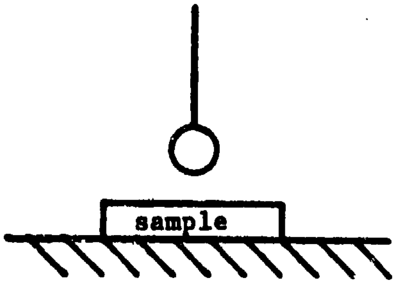
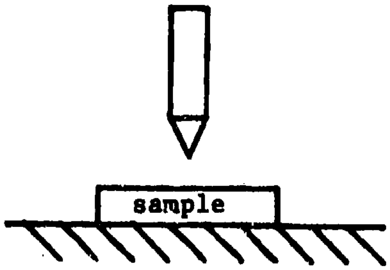


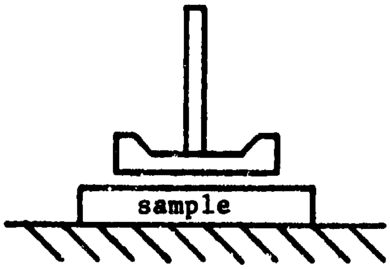
Figure 3. Picatinny Arsenal Approaching-Plate Electrode Apparatus. (Ref 5)



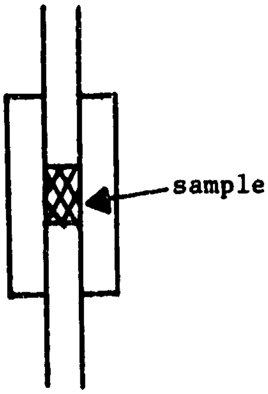
(A) Ball Electrode
No-gap, fixed-gap, and approaching test positions



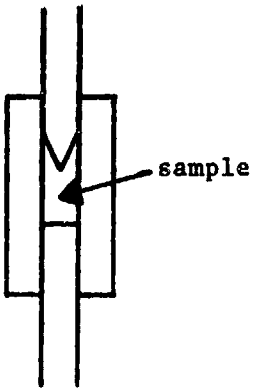
(B) Sharp Electrode
Fixed-gap and approaching test positions



(C) Flat Plate Electrode
No-gap and fixed-gap test positions

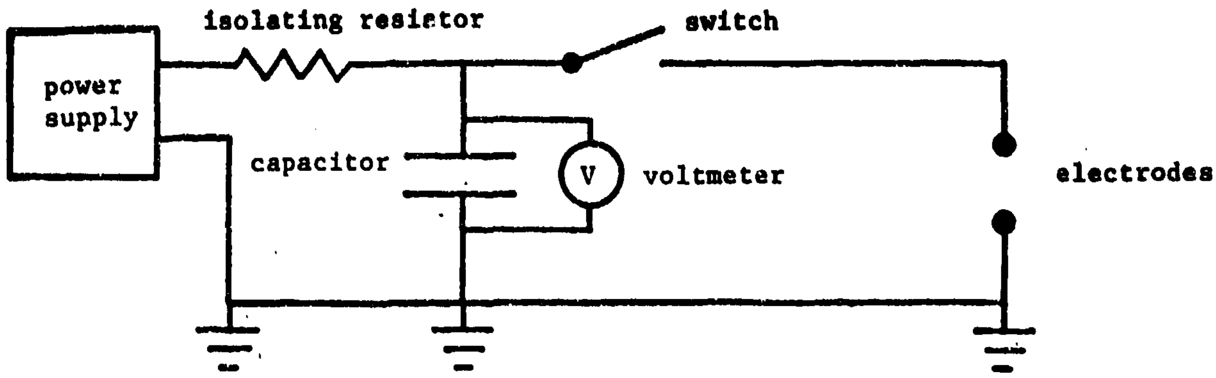


(D) Pipette Plate Electrode
Fixed test position

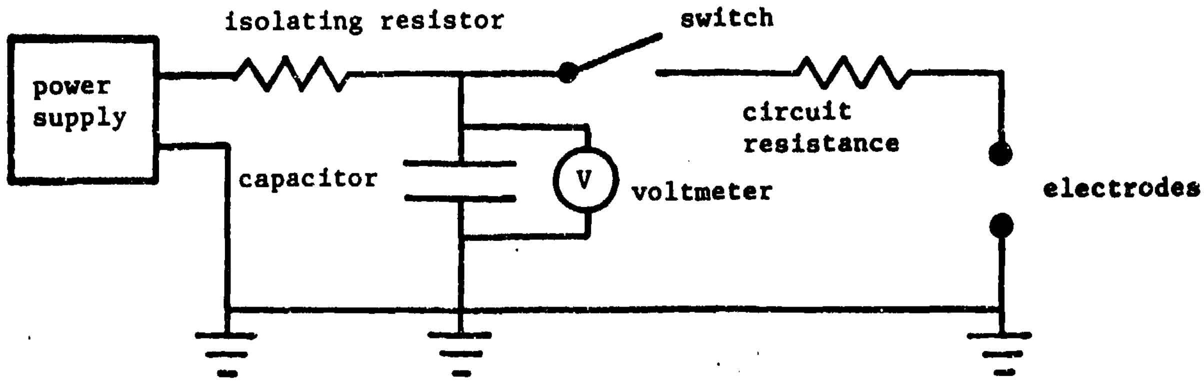


(E) Pipette Sharp Electrode
Fixed test position

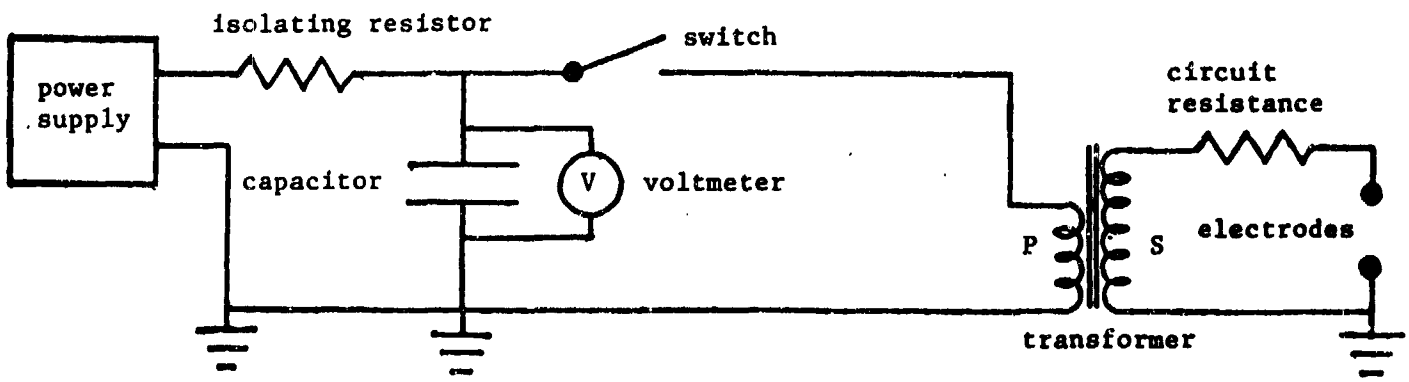
Figure 4. Electrode Configurations Used in Electrostatic Sensitivity Testers at Safety Consulting Engineers.



(A) Capacitive Circuit



(B) Capacitive-Resistive Circuit



(C) Capacitive-Inductive Circuit

Figure 5. Electrical Circuit Configurations for Electrostatic Sensitivity Testers at Safety Consulting Engineers.

MASS DETONATION HAZARD ASSESSMENT FROM

VIOLENTLY DEFLAGRATING MUNITIONS

M. Chick, T.J. Bussell and L. McVay

Materials Research Laboratory
Melbourne, Victoria, Australia

ABSTRACT

We report on an investigation aimed at assessing whether the controlled, violent deflagration of Composition B loaded 105 mm shell can lead to the detonation of nearby rounds. Tests were grouped into 3 categories; single deflagrating donor - multiple acceptor arrays, projection of acceptor shell by a deflagrating donor and its impact on structural surfaces and multiple impacts causing transient interactions in acceptor shell. Trials were conducted with shell without boosters and fuzes, shell with boosters and plugs representing fuzes and recovered, damaged rounds.

Acceptors were recovered intact but with flattened faces and cracked fillings with no signs of reaction. No detonations were recorded. Separate experiments with single shell indicated that when low order reactions were deliberately stimulated in part of the filling then a deflagration to detonation transition could occur.

Consequently our results do not support the processes occurring in the deflagrating donor/acceptor tests as contributors to the mass detonation hazard of Composition B loaded 105 mm shell.

1. INTRODUCTION

Evidence presented by Frey et al [1] and Stosz [2] has shown that mass detonation can result from reactions other than the shocks generated by detonating donor rounds. Some of these events take several milliseconds [1] and are therefore not associated with shock initiation. The details of the origin and growth of these reactions are not understood. It is not surprising therefore that tracking down the causes of mass detonation in large munition arrays has proved difficult and has lead to the need to design simplified tests to evaluate candidate processes. To this end we have been investigating the likely consequences emanating from a donor shell undergoing a violent deflagration while positioned in various munition arrays. The arrays were designed to reproduce conditions encountered during munition storage and transport. Our investigation utilises a recently developed technique that allows the production of a controlled deflagration of a munition without the possibility of a transition to detonation invalidating the result [3].

Our aim is to investigate a range of munition types. The first part of the program has been undertaken using Composition B loaded 105 mm shell because of its availability and widespread use. Further testing is planned using munitions with thinner cases and a higher explosive charge / case mass ratio.

This paper presents the results of our investigation using 105 mm shell.

2. TECHNIQUE FOR PRODUCING CONTROLLED DEFLAGRATING DONOR SHELL

The technique for violently deflagrating donor 105 mm shell [3] consists of firing a shaped charge jet along the axis of the round with a velocity below the threshold to produce detonation of the filling. In this way the reaction produced in and behind the bow wave set-up in front of the penetrating jet sweeps through the length of the filling leaving no bulk explosive for a deflagration to detonation transition. Detonation does not result directly from the bow wave since the pressure-time profile is subcritical. Criteria for the jet initiation of explosive fillings has been discussed in detail elsewhere [4,6].

The application of the technique to a Composition B filled 105 mm HE M1 donor shell is shown in Figure 1 and summarised below.

The MRL 38 mm diameter shaped charge was used in the tests since there is a considerable data base on its effect on munition fillings [4-6]. This shaped charge contains a conventional copper liner with a 42° apex angle. The subcritical jet velocity was produced by firing the jet at 2 charge diameters standoff through a steel barrier of appropriate thickness placed in contact with the shell case. The minimum thickness of the steel barrier (τ) was determined from the known critical jet velocity for the detonation threshold (V_j) using the Dipersio/Simon equation [7] to calculate the total thickness of steel required and subtracting the case thickness at the jet entry position;

$$\tau = s \left[\left\{ \frac{V_t}{V_j} \right\}^{1/\gamma} - 1 \right]$$

where s the standoff from the shaped charge to the top of the steel barrier,

V_t the velocity of the jet tip, and

γ the square root of the ratio of the steel barrier and jet densities.

For the 38 mm diameter shaped charge jet V_j was adjusted downwards to take account of the effect of the 105 mm shell side confinement on the Composition B filling, determined as 4.85 km/s [8]: this was equivalent to a total steel thickness of 72.5 mm. Since the thickness of the steel case at the jet entry position was 17.5 mm, a minimum of 55 mm of extra steel was required. The side confinement also holds the explosive together thereby assisting the deflagration process.

Characteristics of a deflagrating Composition B filled 105 mm shell that may be important in a mass detonation hazard assessment have been determined and are summarised below. Recovered fragments are shown in Figure 2 and were dispersed over an area of about 350 m radius. They are considerably larger and show different fracture patterns compared to those recovered form a detonating round , see Figure 3. The witness block under the nose of the shell exhibited no indentation but had the compressed remains of the booster can stuck to it. A detonation produced a well formed dent. Peak overpressure was measured at about 25% less than for a detonating round. High speed photography showed that initial shell burst occurred in the region of the driving band after an expansion of about 30% of a shell diameter (i:e 15 mm increase in shell radius).

Initial jet penetration velocities through the filling can be varied by adjusting the thickness of the added steel barrier on the base of the shell; the value selected for the tests was 3 km/s. Since the bow wave is coupled to the jet and reaction occurs within the bow wave, it is assumed that the deflagration velocity will have a similar value. This high reaction velocity and the characteristics measured above confirm that our tests are studying the effects from a particularly violent type of deflagration.

3. SINGLE DONOR-MULTIPLE ACCEPTOR TESTS

The direct effect of the expanding case, fragment impact and blast from a deflagrating donor round on adjacent shell was determined using the set-up shown in Figure 4. These tests were based on the methods used at BRL by Howe [9] for studying the effects of detonating donors. Acceptor standoff distances were 0,10,25 and 50 mm as measured from the driving bands. In some of the tests large fibreboard packs were placed 1 m from the shell for controlled recovery, in other tests the shell were recovered after free flight and impact with the ground. Tests were performed on shell with no boosters and fuzes (2 shots), shell with pressed flake boosters and plugs representing fuzes (PRF) (1 shot) and recovered, damaged shell (1 shot). Four shots were fired in which all acceptors were in contact with the donor.

A test was performed using the set-up in Figure 5 to assess the effect of shell jostling. The donor and row of acceptor shell were in contact and backed by a 25 mm thick steel plate and supporting sandbags.

In the tests in this and sections 4.0 and 5.0 the type of event was determined from witness block indentation, recovered fragment characteristics, impacted surface damage and in some tests, instrumentation records (overpressure, high speed photograph). Some donor rounds included probes on either side of the steel barrier as a check on the performance of the shaped charge jet. No substandard jets were detected.

All donor rounds deflagrated as planned. Recovered acceptor shell without the boosters and fuzes form the Figure 4 type firing set-up were flattened on the side adjacent to the donor, see Figure 6. Driving bands were either dislodged or distorted. Aluminium booster cans were crumpled but in position; when removed they showed that the filling was cracked without signs of reaction. The increased sensitivity of the filling to shock type stimuli was assessed by determining the critical jet velocity for the detonation threshold using the 38 mm diameter shaped charge. The critical value of 4.8 km/s compares to a value of 5.2 km/s for the undamaged material.

Recovered rounds with boosters and PRF exhibited similar damage with the addition that the plugs were bent, see Figure 7. Repeat firings using recovered shell produced cases with two flattered faces, no driving bands, dislodged or badly distorted booster cans and a filling with extensive cracking but no signs of reaction.

Acceptor shell from the shot where they were placed in a row (Figure 5) were recovered intact within 1 m of ground zero. The acceptor adjacent to the donor showed similar damage to that described above. The other acceptors showed progressively less damage as the original position moved away form the donor i:e the closer rounds appeared to act as a buffer for this type of impact.

The tests from this section suggest that the effect of case expansion, fragment impact and blast from a deflagrating Composition B loaded 105 mm shell can inflict severe damage on neighbouring rounds without being the direct cause of mass detonation.

4. ACCEPTOR SHELL PROJECTION AND IMPACT TESTS

These tests were undertaken to assess the hazard from the impact of projected shell on hard structural surfaces. A potential source for this type of event would be from a deflagrating donor shell ejecting neighbouring rounds when located in a munition stack during storage (temporary or permanent) and transport. Important structural surfaces would include concrete and steel.

The velocity of a projected acceptor from a deflagrating donor shell was measured at 40 m/s using multiple glass break screens [11]. This value is considerably lower than the critical fragment impact velocities of several hundred metres per second and upward reported by Howe et al [10] using a range of fragment sizes and Composition B with a steel cover thickness of 10 mm. The 105 mm shell case has a similar thickness along its central section. In our tests and for the type of event under study however the filling in the shell prior to impact would be damaged as a result of the deflagration projection process. This was shown in the examination of the fillings from the soft recovery tests described in Section 3.0 and critical jet velocity tests confirmed the accompanying increased sensitivity. A further feature of our tests is that the shell/target impact represents a fragment size beyond that reported in Reference 10.

The test set-up is shown in Figure 8 with the concrete target positioned 2 m from ground zero. Firings were undertaken with shell without boosters and fuzes, recovered damaged shell and shell fitted with boosters and a PRF. Separate tests were conducted with unboostered shell in which the concrete block was used to support a 10 mm thick steel plate.

All donors deflagrated as planned and projected rounds were recovered damaged but intact. Both the steel and concrete targets produced similar effects. The acceptor rounds had a flattened area on one corner with surface marks continuing along the length of the case. This type of corner-side slap on the target was compatible with the shape of the impression formed by the shell impact on the fibreboard packs in the soft recovery experiments reported in Section 3.0. Visual inspection showed the filling cracked but there was no signs of reaction. Rounds with a booster and PRF were likewise damaged plus the plug was bent. The experiment with damaged acceptors produced a second flattened face but the round remained intact; this retesting of damaged shell may be considered a worse case situation.

It is concluded that the projection of Composition B loaded 105 mm shell at velocities likely to be encountered from a neighbouring round undergoing a violent deflagration is unlikely to be the direct cause of a mass detonation. Our study has not addressed the impact of a shell projected by a detonating donor where higher flight velocities may be achieved.

5. TRANSIENT INTERACTIONS IN SHELL FILLINGS

Tests in this category were designed to assess weather transient interactions within the explosive filling would promote a deflagration to detonation transition (DDT). Such interaction may arise as a result of two rounds deflagrating either simultaneously or within a limited time frame of one another.

In the test shown in Figure 9 the central acceptor was subjected to the simultaneous impact from two adjacent deflagrating donors. For the set-up in Figure 10 two shell were deflagrated within a predetermined time interval. Thus the expanding case from the first shell deflagrated impacted on the second shell. The time delay was to allow the compression wave from the case impact to pass through the explosive filling and interact with the deflagrating front sweeping through the second shell. The concept is illustrated by the sketch in Figure 11. Experiments were conducted with time intervals of 16, 19 and 100 μs. For the shorter time intervals the deflagration fronts were calculated to be about 50 mm apart. Thus the effect of case interaction was expected to occur after both deflagrations were well established. Jet penetration equations and measurements [4,6,7] gave an estimated time for the jet to traverse the Composition B filling in the 105 mm shell of 92 μs. Consequently the 100μs time interval set between the deflagration of the two shell was designed to allow the compression wave resulting from case expansion and impact of the first shell to form a wide front prior to its interaction with the deflagration in the filling of the second shell.

The baffle in Figure 10 was designed to avoid the blast and fragmentation from the first shaped charge detonated moving the second shaped charge. Examination of the blast and fragment patterns on the walls of the baffle (they were symmetrical with respect to one another) and the jet penetration holes in the recovered steel barriers (central alignment and no key holing) indicated there was no interference between the shaped charges. This conclusion was supported by the Hycam photography records taken at between 35,000 and 40,000 pictures per second.

The central shell from the double, simultaneous impact experiment was recovered intact with two flattened faces, no driving bands and a cracked filling. Again visual inspection showed no signs of reaction. In the delayed interaction experiments all shell deflagrated without detonation occurring. Consequently these tests failed to provide any evidence that this type of transient interaction within the filling may be a contributing process to a mass detonation hazard of Composition B loaded 105 mm shell.

6. DEFLAGRATION TO DETONATION IN SINGLE SHELL TESTS

Other experiments investigating the response of Composition B loaded 105 mm shell to shaped charge jets have produced DDT. In these tests, jets with subcritical velocities (for detonation) in the range 2.8 to 5.0 km/s were fired across the diameter of the shell towards the nose end of the filling, but not close to the booster cavity. Four shots out of 12 produced a DDT at the base end of the shell - this was clearly evident from the changing indentation pattern along the steel witness plate. Penetration holes in the case from these jets are 10 mm diameter and less and hence the reaction stimulated by the jet cannot effectively vent. Consequentially the pressure build-up promotes a DDT in the large unconsumed mass of explosive towards the shell base. These results demonstrate that once a low order reaction has been stimulated in Composition B loaded 105 mm shell the potential exists for a mass detonation hazard. They further suggest that the impact and interaction processes in our tests did not produce the initial low order reaction.

7. CONCLUSIONS

Deflagrating donor, Composition B loaded 105 mm shell without boosters and fuzes did not cause the detonation of adjacent rounds in the following types of test;

(a) single donor - multiple acceptor array
(b) acceptor projection (at 40 m/s) and impact on concrete and steel targets,
(c) simultaneous double impact on an acceptor,
(d) interaction between two deflagrating rounds.

Trials using tests (a) and (b) with recovered, damaged shell and with shell containing boosters and plugs representing fuzes also did not produce detonations.

Consequently the processes in these tests are not supported as contributors to the mass detonation hazard of Composition B loaded 105 mm shell. Separate DDT experiments on single shell suggest this is because the impact and interaction processes did not produce the initial low order reaction.

8. ACKNOWLEDGEMENTS

We should like to record our gratitude to the Commanding Officer and support personnel of the Army Proof and Experimental Establishment (P&EE) Graytown, Victoria, for assistance with the field firings and ensuring the ready availability of support resources.

9. REFERENCES

1. Frey R.B, Watson J., Gibbons G, Boyle V. and Lyman O., "The Response of Compartmentized Ammunition", Proceedings of the Joint Government Industry Symposium on Insensitive Munitions Technology, NSWC, White Oak, Maryland, US, March 1990.

2. Stosz M. Private Communication 1987.

3. Chick M. and Bussell T.J. Paper in course of publication.

4. Chick M. and Hatt D.J., "The Mechanism of the Initiation of Composition B, by a Metal Jet", Proceedings of the Seventh Symposium (International) on Detonation, NSWC MP 82-334, 1981.

5. Chick M., MacIntyre I.B. and Frey R.B., "The Jet Initiation of Solid Explosives", Proceedings of the Eighth Symposium (International) on Detonation, NSWC MP 86-194, 1985.

6. Chick M., Bussell T.J., Frey R.B. and Bines A, "Jet Initiation mechanisms and Sensitivities of Covered Explosives", Preprints of Ninth Symposium (International) on Detonation, 1989.

7. DiPersio R. and Simon J., "The Penetration Standoff Relationship for Idealised Shaped Charge Jets", BRL Report BRL 1542, 1964.

7

8. Chick M., Bussell T.J. and McVay L., "Terminal Effects of Shaped Charge Jets on Thick Cased Munitions", Proceedings of 11th International Symposium on Ballistics, 1989.

9. Howe P., "The Phenomenology of Interround Communication and Techniques for Prevention", BRL Report ARBRL-TR-02048, 1978.

10. Howe P., Watson J.L. and Frey, R.B., "The Response of Confined Explosives Charges to Fragment Attack", Proceedings of Seventh Symposium (International) in Detonation, NSWC MP 82-334, 1981.

11. Bussell T.J., Box P. and Marian F., Paper in course of publication.

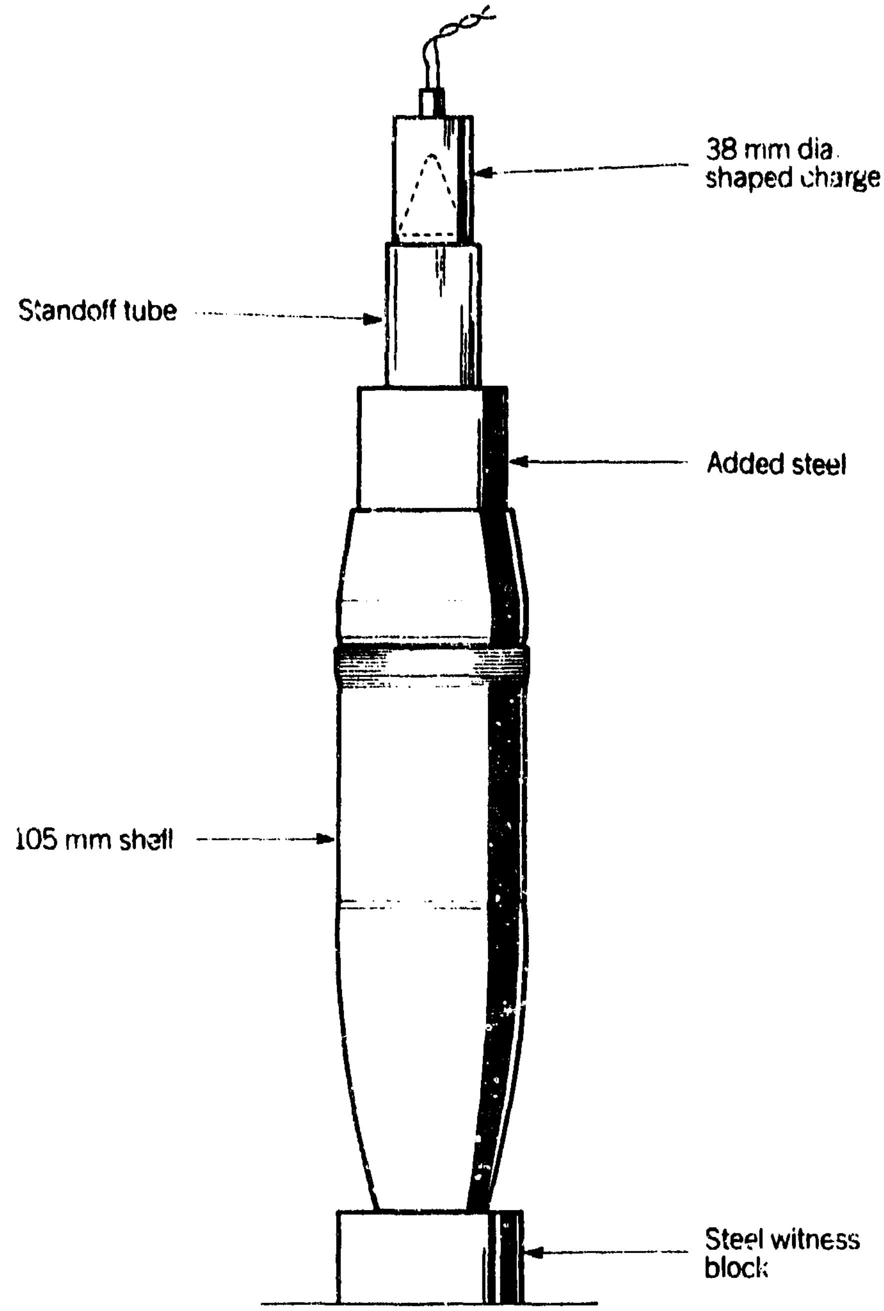


FIGURE 1.

SET-UP FOR USING A SUBCRITICAL SHAPED CHARGE JET TO VIOLENTLY DEFLAGRATE A 105 mm SHELL FILLING

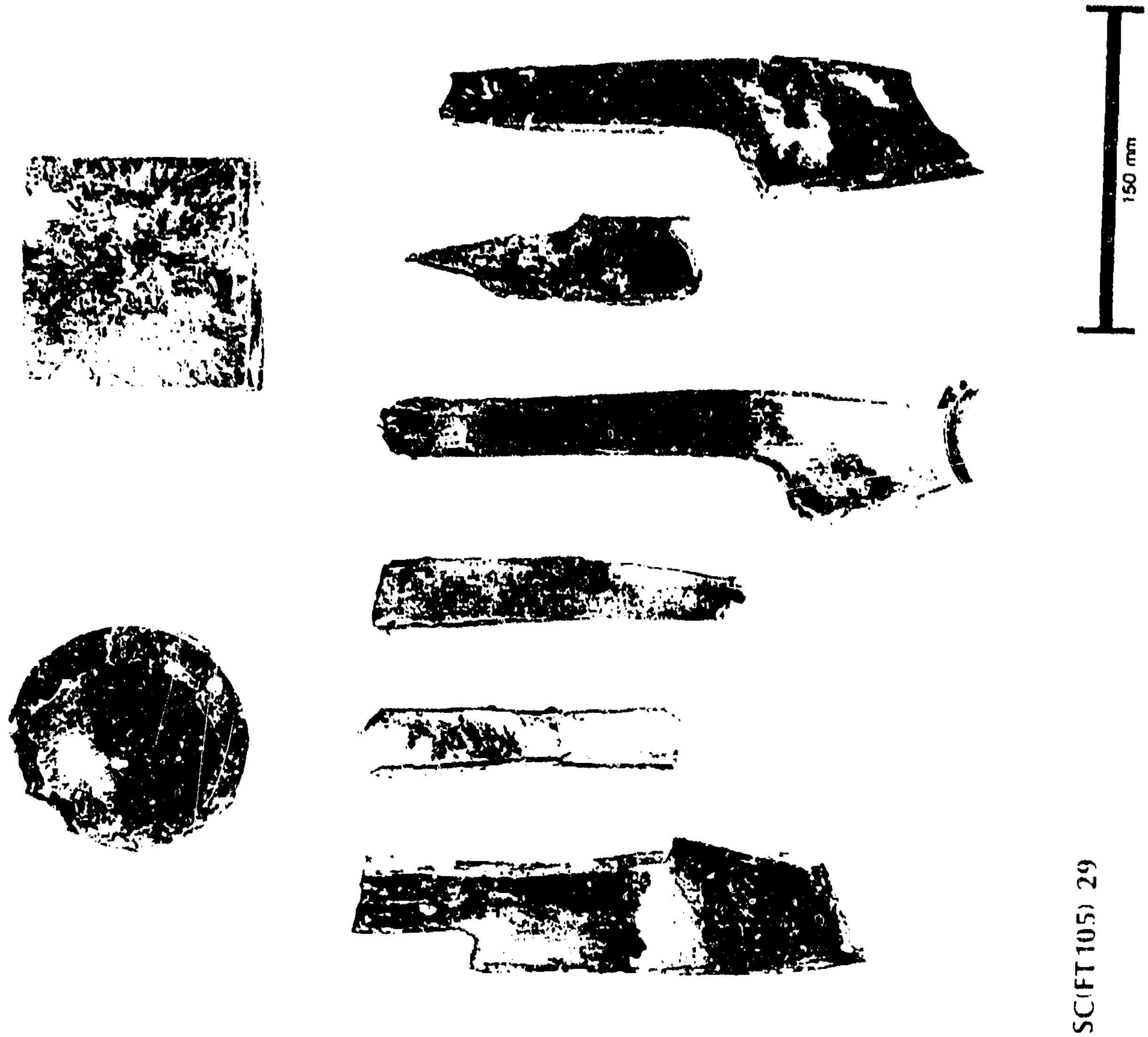


FIGURE 2

RECOVERED FRAGMENTS AND WITNESS PLATE
FROM VIOLENT DEFLAGRATION OF 105 mm COMPOSITION B
FILLED SHELL

FIGURE 3

RECOVERED FRAGMENTS AND WITNESS PLATE FROM DETONATION OF 105 mm COMPOSITION B FILLED SHELL

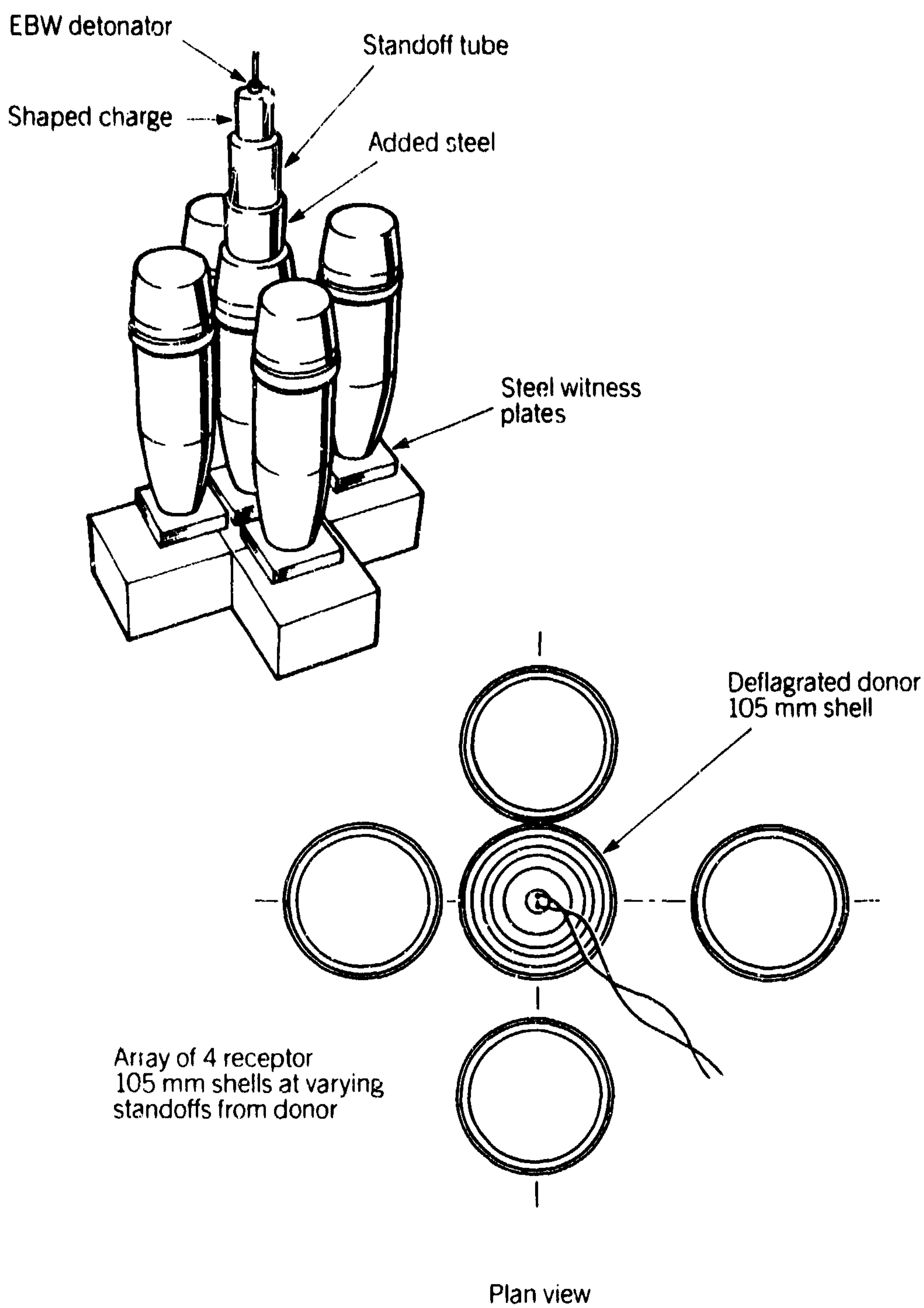


FIGURE 4.

SET-UP FOR SINGLE DEFLAGRATING DONOR - MULTIPLE ACCEPTOR TESTS

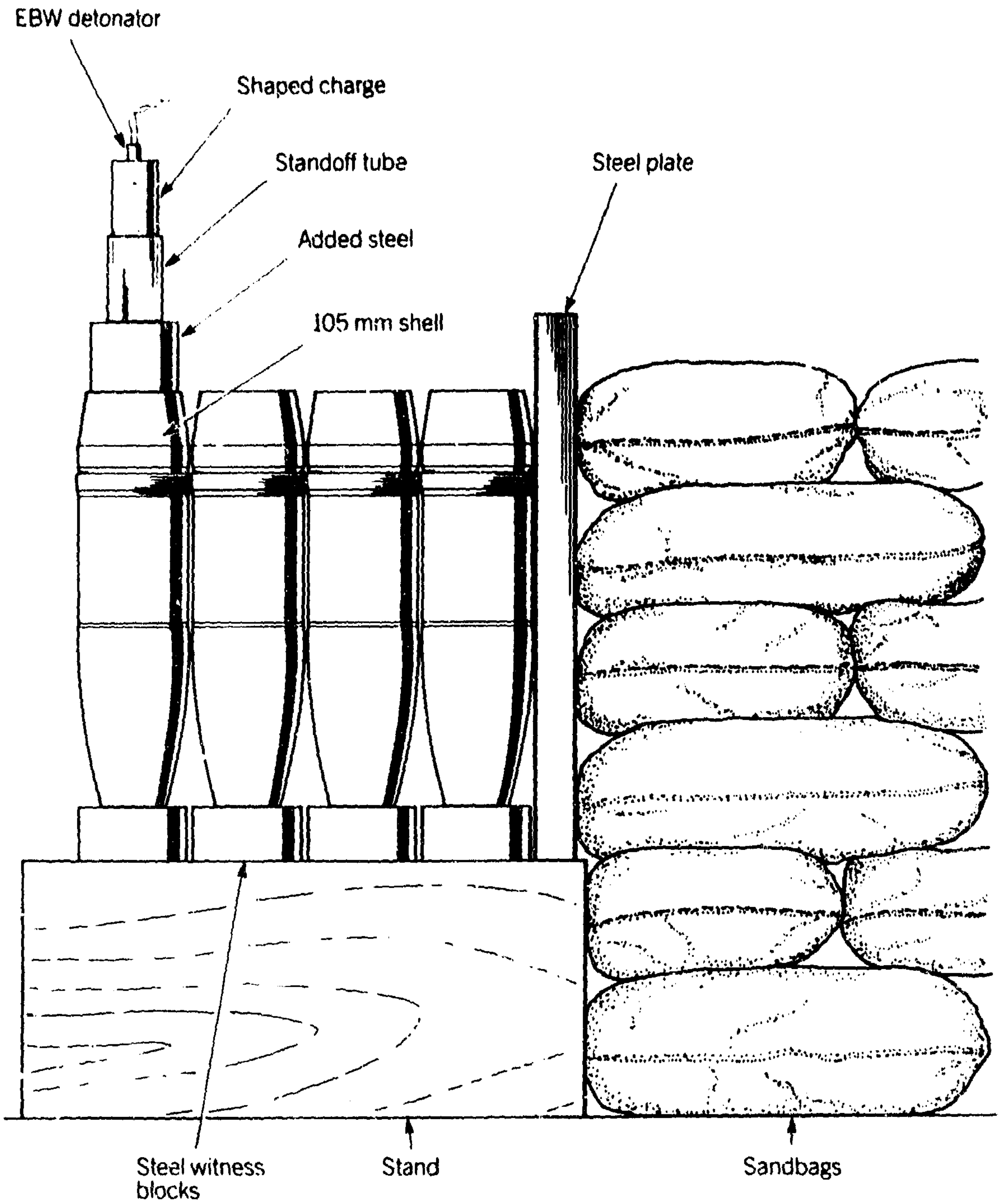


FIGURE 5.

SET-UP FOR SINGLE DEFLAGRATING DONOR - ROW OF ACCEPTOR TEST

FIGURE 6.

SHELL RECOVERED FORM A SINGLE DEFLAGRATING DONOR - MULTIPLE ACCEPTOR TEST

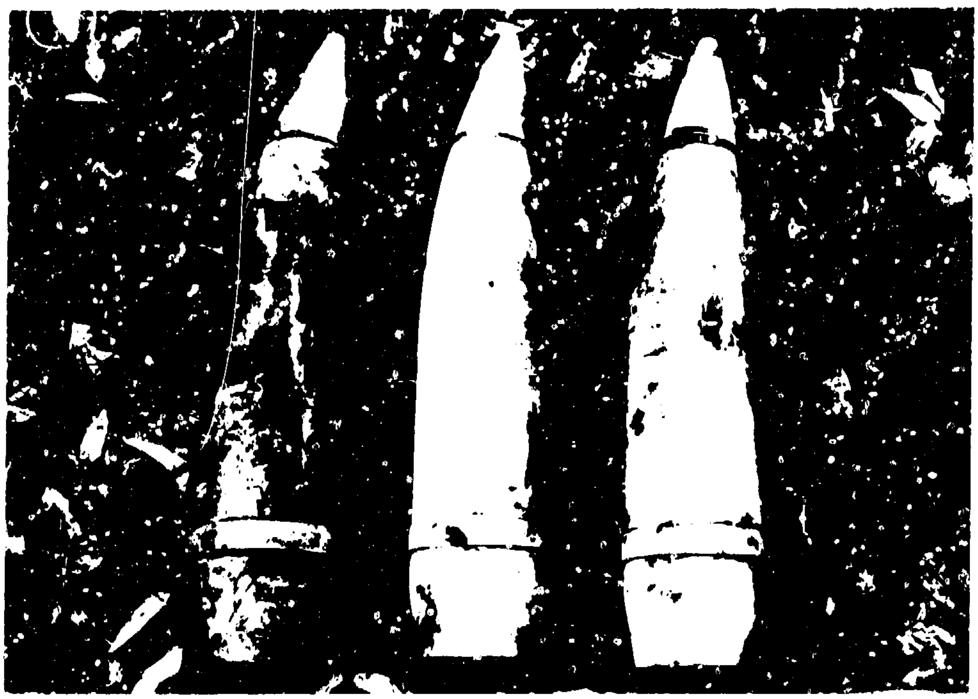


FIGURE 7.

SHELL RECOVERED FORM TESTS USING ROUNDS WITH BOOSTERS AND PLUGS REPRESENTING FUZES

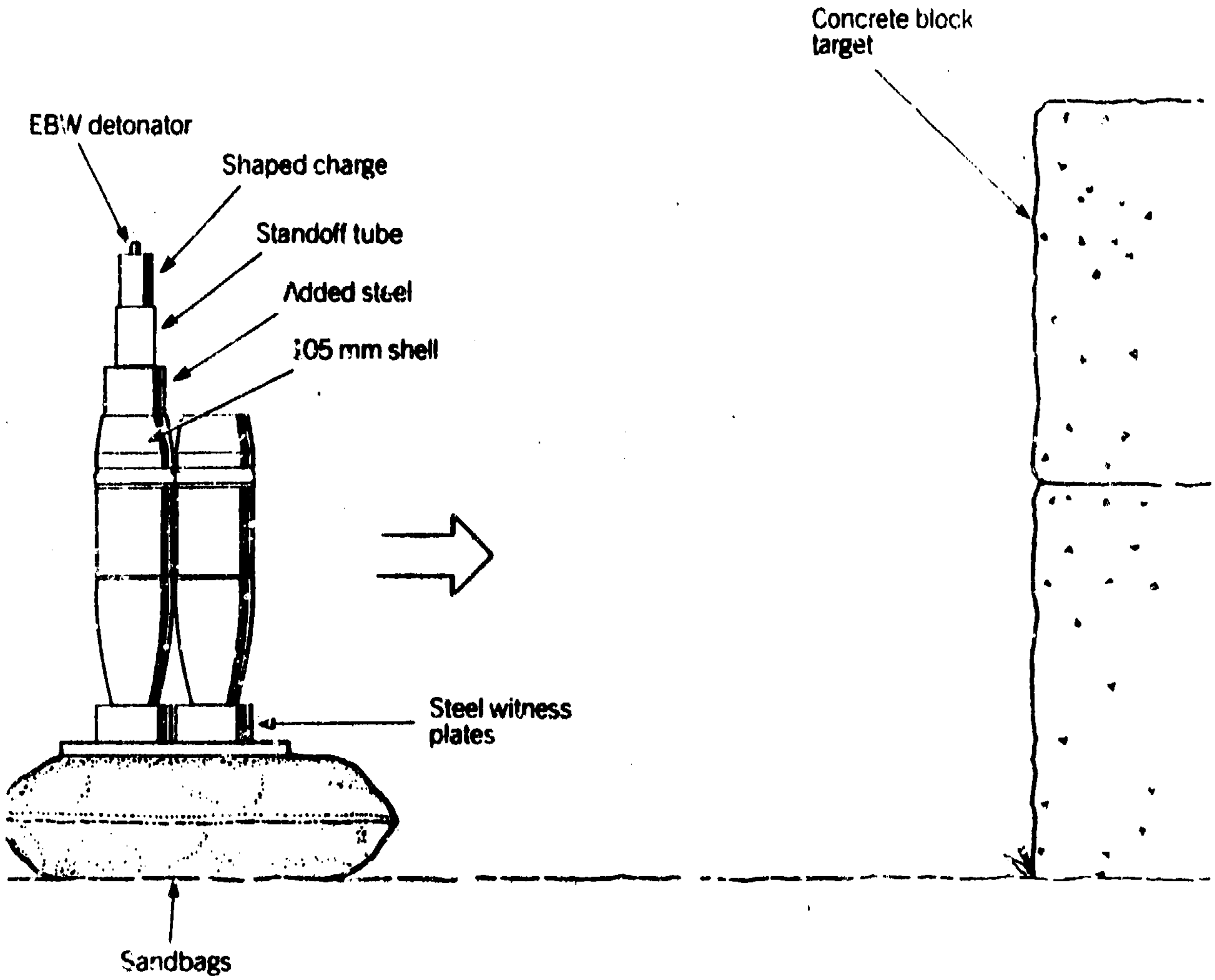


FIGURE 8.

SET-UP FOR ACCEPTOR SHELL PROJECTION AND IMPACT ON A HARD SURFACE

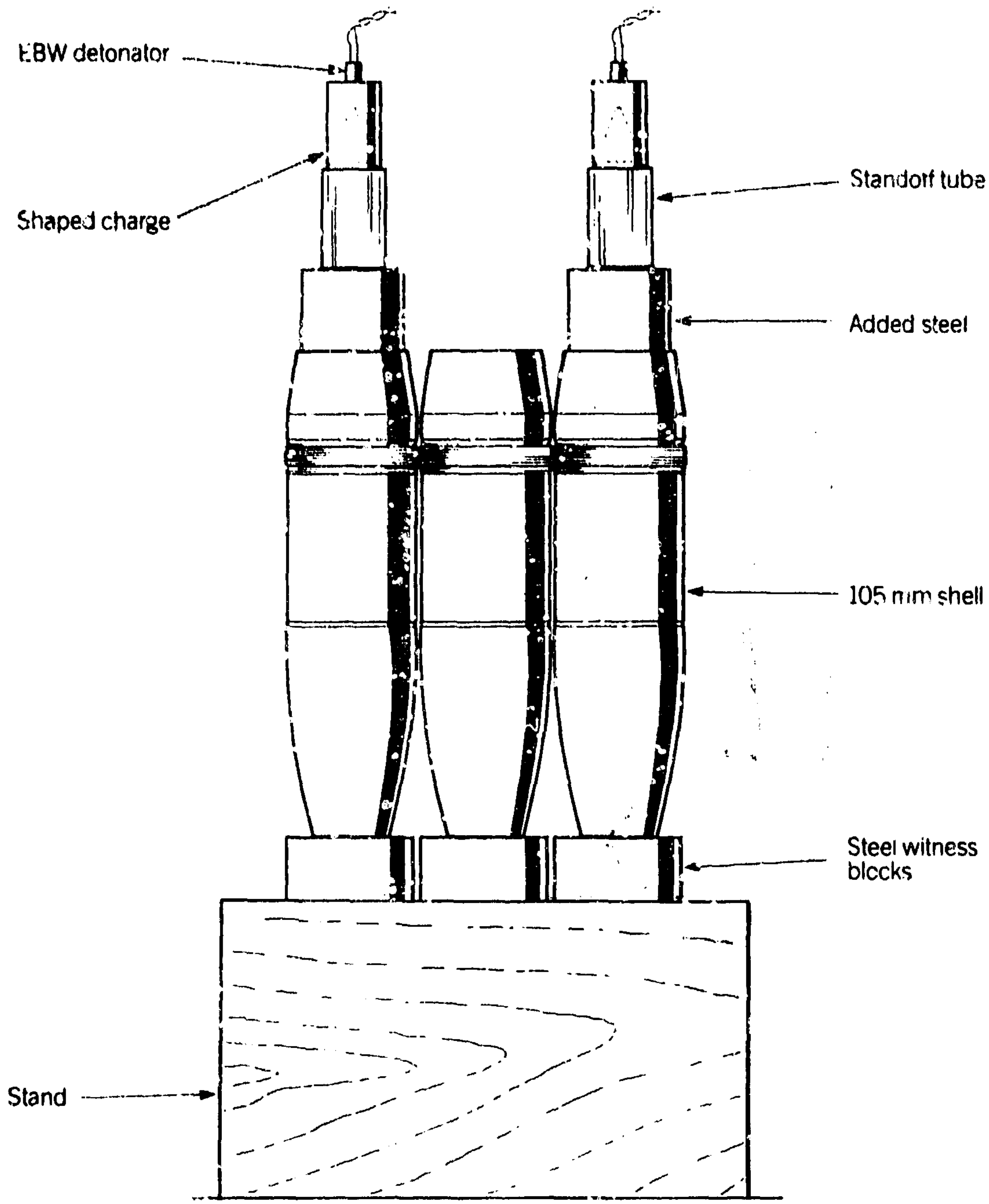


FIGURE 9.

SET-UP FOR SINGLE ACCEPTOR SIMULTANEOUSLY IMPACTED BY TWO DEFLAGRATING DONOR ROUNDS

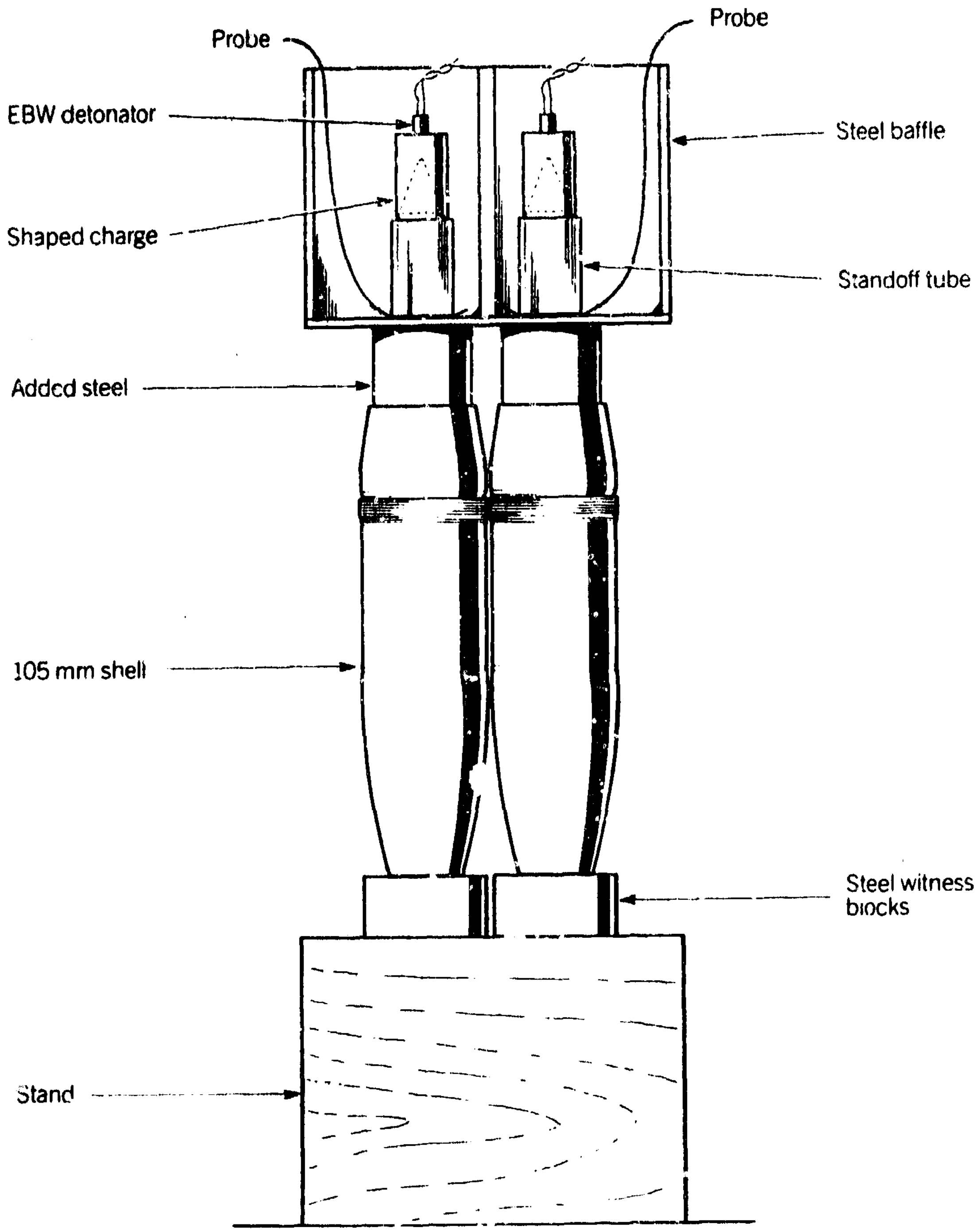


FIGURE 10.

SET-UP FOR THE DEFLAGRATION OF TWO SHELL AT A PREDETERMINED TIME INTERVAL

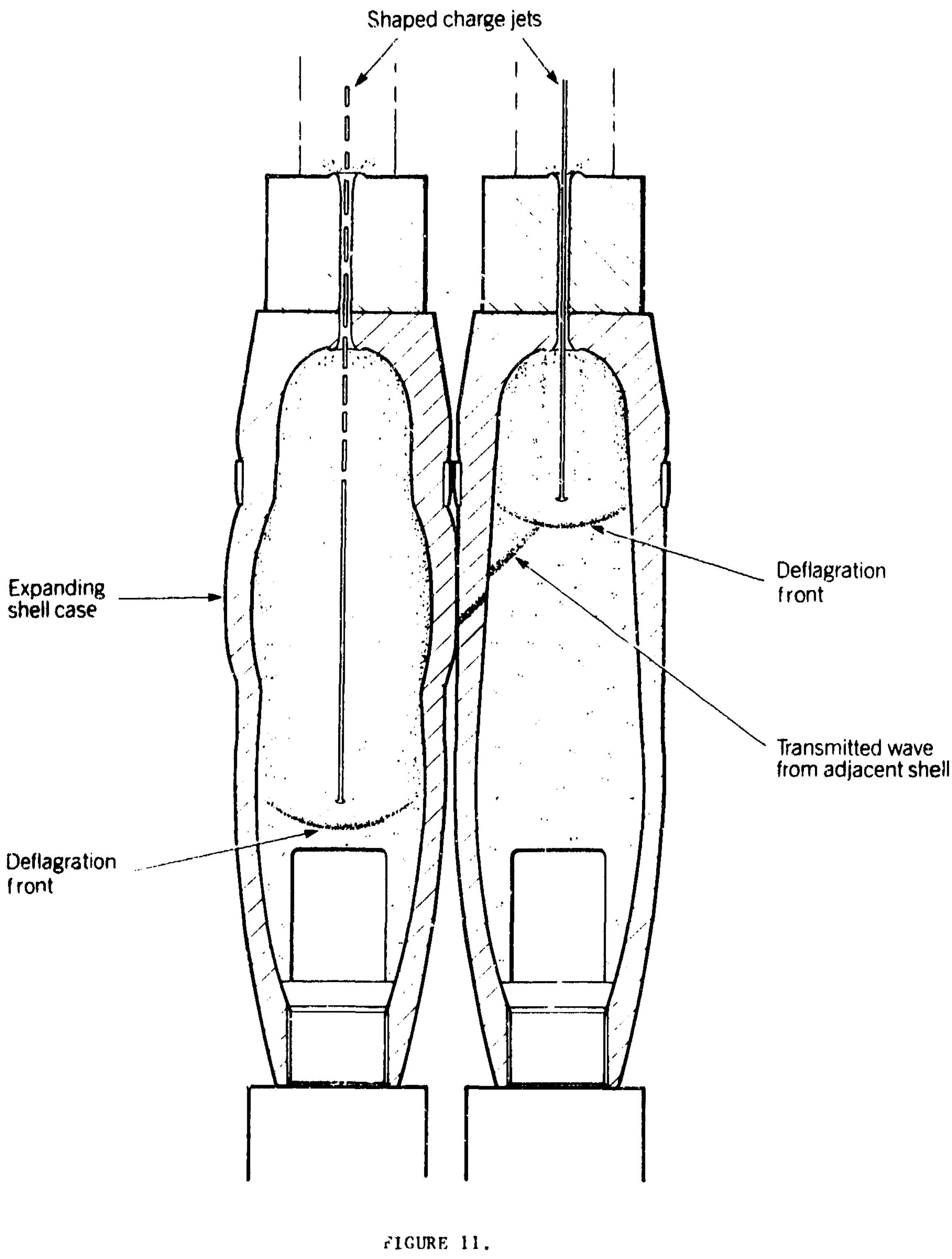


FIGURE 11.
ILLUSTRATION OF DEFLAGRATING SHELL INTERACTION

1

SAFETY DISTANCES FOR THE UNDERGROUND DEMOLITION OF EXPLOSIVE ORDNANCE

Prepared by
John J. Goold
Australian Ordnance Council
August 1990

INTRODUCTION

1. The Australian Defence Force has an explosive ordnance disposal mission that encompasses the disposal and destruction of stray explosive ordnance (EO), improvised explosive devices and also unexploded ordnance (UXO) resulting from its own training and operational activities. There have at times been requirements to detonate EO close to structures or on ranges not large enough to contain the resulting fragmentation and debris. In these situations, EOD personnel have provided "public" protection by either sandbagging the EO or by burying it prior to detonation. Safety distances applicable, depths of burial and protective measures, have largely been "rule of thumb" based on previous experience.

2. The Australian Army, supported by the other Armed Services, and with the aim of aligning these EOD procedures on a more scientific basis, approached the Australian Ordnance Council for guidance. The Materials Research Laboratory (MRL) of the Defence Science and Technology Organisation was tasked to consider the requirement. As a result the Australian Army's Proof and Experimental Establishment at Graytown Victoria, conducted confirmatory trials to test the MRL recommendations.

AIM

3. The aim of this paper is to advise the MRL recommendations for safety distances applicable for underground demolition of EO and to report the results of confirmatory trials.

THE INITIAL TASK

Standards and Limitations

4. Prior to tasking research establishments, the effects of an underground explosion were itemised and safety criteria allocated. The following effects were considered:

a. air blast,

b. noise,

c. atmospheric focussing of blast and noise,

d. primary and secondary fragmentation effects ie consideration of the fragments produced by the EO as well as soil and debris ejecta, and

e. seismic phenomena.

5. The Australian Defence Force is extremely safety conscious especially in matters relating to explosives. In explosives demolition matters that could affect members of the public, safety is of the highest standard. Consequently, any safety distances recommended should meet the following criteria:

a. **Air Blast** Overpressures at the nominated safety distance should not exceed 200 Pascals. This overpressure is the onset of possible damage to windows (one window in a thousand could expect to be damaged) though normally this overpressure would only cause windows and dishes to rattle[1][2]. It is considered appropriate as EOD teams may have to operate in civilian controlled areas or adjacent to important national buildings.

b. **Noise** Noise at the nominated distances would be unlikely to exceed 140 db and though quite loud, provided it was not repetitive, would only constitute a nuisance value.

c. **Atmospheric Focussing** This phenomena is related to weather conditions at the time of detonation, and in particular temperature inversion. EOD personnel are already trained to consider its effects and consequently, the phenomena will not be discussed further in this paper.

d. **Fragmentation** Fragmentation at the safety distance was not to exceed the currently accepted hazard density criteria for surface demolitions[3][4] ie one hazardous fragment per 56 m^2 where a hazardous fragment has an energy greater than 79 Joules.

e. **Seismic Effects** The current Australian Standard[5] providing guidance on blasting adjacent to buildings and structures, recommends peak particle velocities ranging from 2 mm s^{-1} (at historical or important buildings), 10 mm s^{-1} (at standard housing) to 25 mm s^{-1} (for commercial and industrial structures).

6. **Explosives Limits** The largest anticipated individual item in service that may have to be destroyed underground is the Mk 84 HE bomb (Net explosive quantity [NEQ] about 590 kg TNT equivalent). Smaller items such as artillery projectiles, grenades and improvised explosive devices would also be destroyed. Hence EOD operators should be provided guidance for demolition of NEQs between 0.5 and 600 kg.

Task Elements

7. As a consequence of the above factors, the Explosives Division of the Australian Department of Defence's Materials Research Laboratory (MRL) was tasked to:

a. conduct an initial literature search to provide data useful to the determination of underground demolition safety distances,

b. assess air blast, fragmentation/debris throw and ground shock factors,

c. derive procedures to determine the required safety distances,

d. plan a confirmatory trial (if deemed necessary by MRL), and

e. prepare an "aide-memoir" for use in the field by EOD personnel.

PRELIMINARY RESEARCH

8. The research task at MRL was conducted by Mr Doug Oliver and he was initially assisted by Ms A. Kennett. Following a review of unclassified literature, Mr Oliver advised[6][7] that safety distances could be derived using the following procedures.

However, much of the information is old and would require verification by a fairly simple experimental program.

Air Shock

9. Reports on the suppression of air shock by burial are not numerous and those acquired and examined by MRL were sometimes contradictory in their conclusions.

10. Vortman[8] (1968) gives a valuable discussion of air shock from underground explosions and analyses a number of tests to deduce blast suppression factors. This is the best data we could find as far as it goes. However the data terminates at ground ranges of 8 $m.kg^{-1/3}$ and these ranges may be too short for EOD purposes (eg for a 20 kg charge, the data applies only to ranges up to 22 m, for a 500 kg charge up to 64 m). Some research quoted by Vortman indicates that overpressures may also depend on the nature of the ground. For information, the Vortman curve is at Figure 1.

11. Bishoff[9] (1968) provides at Figure 2, data originating from the US Department of Defense Explosives Safety Board. This data suggests inter alia that peak overpressures may be enhanced rather than diminished by shallow burial. This may be true as air shock can arise from a precursor ground shock as well as from the venting of the explosive gases. MRL considers that at depths of burial below 0.2 $m.kg^{-1/3}$ the probability of such behaviour can be ignored at ranges of interest in EOD tasks.

12. At Figure 3 is a graphical solution proposed by Perkins and Jackson[10] in 1964. The source of information is not revealed but the data makes blast pressure predictions that are between the Vortman and Bishoff estimates and which extend to ground ranges beyond either.

13. None of the above data provides a general rule that can confidently be recommended. Of the data, the Bishoff procedure seems preferable to that of Perkins and Jackson because it predicts higher peak overpressures and is therefore likely to err towards enhanced safety. However, extrapolation from any of the data without experimental verification is risky.

Fragmentation

14. Information on the dispersal of missiles from buried explosives is given by Vortman[11] in 1967 and quoted by Johnson[12] (1971) in the graphical form reproduced at Figure 4. Results deduced from the graph are credible, eg a charge of 500 kg buried to 3 m would give a missile range of 540 m. However as is not certain how "missiles" are defined, it would be advisable

for EOD operators applying this graph to add a contingency safety factor of 25% to the ranges deduced from it.

Seismic Effects

15. Possibly the best guide to the probability of seismic shock damage to a structure is the peak particle velocity in the earth at the site of the structure. The peak particle velocity (V_p) is the vector sum of the three velocity components and, when not measured directly by an instrument, may be determined from the formula:

$$V_p = (V_x^2 + V_y^2 + V_z^2)^{1/2}$$

where V_x, V_y and V_z are the instantaneous components of particle velocity on x, y and z axes respectively.

16. In 1980, the US Bureau of Mines recommended[13] that V_p should not exceed 13 mm/s at typical US housing sites. The current Australian standard specifies 10 mm/s with lower limits in certain circumstances - see para 5e above.

17. For field expedients, MRL advises that any form of seismic damage is likely to be negligible beyond a distance of 32 "distance units" where a distance unit is a distance in metres numerically equal to the square root of the charge mass in kilograms. At this distance V_p is approximately 5 mm/s. Note that square root scaling applies here rather than the more usual cube root scaling.

TRIAL REQUIREMENTS

Trial Outline

18. On considering the above advice from MRL, the Australian Ordnance Council tasked the Army's Proof and Experimental Establishment at Graytown in Victoria to conduct a limited trial to provide data to be compared with the theoretical considerations. Army's Engineering Development Establishment was tasked to obtain overpressure and seismic data.

19. The trial consisted of a series of fourteen test detonations of stacked modified (the boosters and fuzing systems were removed) Mines Anti-tank Mk5 (AUST) buried at various depths and with differing burial procedures. Two surface test firings were conducted for calibration purposes. Mines were prepared for detonation as shown at Figure 5. Each charge was 19 kg NEQ TNT and 37 mm projectiles were taped to each charge to simulate

fragmentation. Additional projectiles were buried adjacent to the top mine in the stack. The mines were placed at three depths ie one metre, one point five metres and two metres, in three burial modes:

a. buried (backfilled) in an augered 60 cm diameter post hole;

b. buried in a parallel sided, back hoed trench; and

c. placed in an open parallel sided trench but not buried (1.5 m only).

Data Requirements

20. **Overpressure** Overpressures for each detonation were measured by dynamic transducers and Anderson Blasgages at 32 m and at 40+/- 1 m from ground zero.

21. **Fragmentation** The magnetic bearing and distance from GZ of the 37 mm projectiles, and crater ejecta greater than 500 g was to be recorded after each detonation. Depending on burial depth, a surface fragment search was conducted to 480 m (1 m burial), 260 m (1.5 m burial) and 110 m (2 m burial).

22. **Seismic Vibration** Seismic vibrations were recorded by a vertically oriented geophone, and a set of concrete embedded axial accelerometers, both at 140 +/-2 m from GZ.

23. **Meteorological Data** Immediately before each firing, temperature (°C), barometric pressure, relative humidity, surface wind speed and direction were recorded.

24. **Supplementary Data** Demolition site survey and cartographic data were recorded and soil density determined at nominated burial depths (2092 $kg.m^{-3}$). Sound pressure levels were recorded at 238 +/-1 m from GZ and both normal speed and high speed videos of each detonation were recorded.

TRIAL RESULTS AND EVALUATION

General

25. Data arising from the trial was initially collated by Proof and Experimental Establishment Graytown[14]. Reduction and initial analysis was conducted by Army's Engineering Development Establishment[15]. A provisional final analysis and recommendations were made by Mr Doug Oliver of MRL[16]. A summary of the trial

7

results follows.

Overpressures/Air Blast

26. Mean overpressures in kPa recorded at the trial are at Tables 1 and 2.

Table 1 - Mean Overpressure Readings at 32 m from GZ (kPa)

Depth (m)	Filled Trench	Filled Hole	Open Trench	Predictions Ref 17	Ref 8	Ref 12
1.0	0.58	0.65	NR	0.52	0.44	1.45
1.5	0.62	0.54	10.4	0.18	0.2	0.75
2.0	0.62	0.62	NR	0.6	0.09	0.49

Table 2 -Mean Overpressure Readings at 40 m from GZ (kPa)

Depth (m)	Filled Trench	Filled Hole	Open Trench	Predictions Ref 17	Ref 8	Ref 12
1.0	0.63	0.41	NR	0.38	0.41	1.11
1.5	0.43	0.36	8.41	0.14	0.19	0.58
2.0	0.45	0.38	NR	0.03	0.08	0.38

27. In Table 1, there appears to be some inconsistency in the range of overpressures recorded for the filled trench and this is still under consideration. The recorded results were compared with predictions from References 9 and 10 as well as those references specified in the prediction columns of the tables above. Values calculated from these references did not improve on those predicted. The predictions give an order of magnitude accuracy notwithstanding the observed inconsistencies. This is probably all that can be expected since they were based on data obtained from large charges and consequently suffer a scaling effect. The high overpressures from the unfilled trench is noteworthy. It would take a ground reflection factor of about 1.7 to achieve similar results from a 19 kg NEQ surface burst. This was not expected.

Noise Levels

28. Table 3 provides noise levels (dBA) recorded at 288 m from ground zero. This data cannot be interpreted in terms of overpressure or any other characteristic which damage potential could be assessed. The noise level data is provided for information only. They show that explosions are noisy, that open trenches are noisier than filled ones and that depth of burial (at the scaling used for the trial) doesn't suppress noise much.

Table 3 - Sound Pressure Levels (dB) at 288 m

Depth (m)	Filled Trench	Filled Hole	Open Trench
1.0	100+(a)(b)	92.4	NR
1.5	92.7	92.1	112.5+
2.0	95.5+	99.7(b)	NR

<u>Notes</u>:

(a) a "+" sign indicates level meters over-ranged. Values will be higher than indicated.

(b) only one useful recording obtained.

Fragmentation

29. A tabulated summary of fragment throw distance data and predicted distances is at Table 4. There was some difficulty in identifying earth debris and it is probable that many substantial clods were projected beyond the 37 mm shot limits shown in the table.

Table 4 - Maximum Fragmentation Throw (m)

Depth (m)	Filled Trench	Filled Hole	Prediction (Ref 11)
1.0	159	113 (187*)	317
1.5	63	40	183
2.0	51	29	68

[*Clod of earth: all others 37 mm projectiles]

30. The predictions are based on the Vortman Curve[11]. This curve has done remarkably well considering that it is presumably based on much larger charges. Rough calculations suggest the projectiles from the 1.0 m deep charges had an exit velocity of about 60 $m.s^{-1}$ at an exit angle of 65° above the horizontal. A clod from the same area and weighing about two or three kilograms could be projected to about 190 m. Note also that the maximum projectile throw from trench burials exceeds that from holes. There are a number of possible reasons for this, but at this stage of the data analysis, these would be guesses.

31. Explosions in the 1.5 m deep open trench produced no acceptable fragment throw data. It therefore seems reasonable to accept this geometry as a charge surrounded by a barricade rather than as a buried charge. This geometry could prove useful if EOD tasks must be performed amongst fragment-sensitive structures. However, such an arrangement is exceptionally noisy.

Seismic Effects

32. Tables 5 and 6 provide seismic data recorded by tri-axial accelerometer and a vertical geophone, both sited at 140 +/-2 m from GZ, respectively.

Table 5 - Mean Maximum Particle Velocity $mm.s^{-1}$ -Accelerometer

Depth (m)	Filled Trench	Filled Hole	Open Trench
1.0	6.7	8.0	-
1.5	6.0	8.1	NR
2.0	6.8	6.4	-

Table 6 - Mean Maximum Particle Velocity $mm.s^{-1}$ - Geophone

Depth (m)	Filled Trench	Filled Hole	Open Trench
1.0	4.3	3.6	-
1.5	3.6	4.3	7.9
2.0	3.7	2.8	-

33. Consider first the accelerometer data which is the primary seismic data from this trial. The particle velocity for holes seems to be slightly higher than for trenches, but the difference is not significant. Nor is there any significant effect due to burial depth. Pending completion of data analysis, we may provisionally assume these data to be all from a common distribution with a calculated mean of 7.06 $mm.s^{-1}$ and a standard deviation of 2.42 $mm.s^{-1}$. If, as seems likely, this distribution is gaussian, no more than 8 shots per 1000 will give particle velocities over 10 $mm.s^{-1}$ at this distance and in this terrain. The mean of 7 $mm.s^{-1}$ may be compared with the prediction at paragraph 17 that at $32*NEQ^{1/2}$, the maximum particle velocity would be approximately 5 $mm.s^{-1}$ ($32*19^{1/2}$ = 139.5 m).

34. Unfortunately, there is no accelerometer data for the two open trench shots. This is regrettable as these velocities may have been exceptionally high. The geophone data in Table 6, which gives the vertical component of the seismic motion, is roughly half the vector sum data from the accelerometers. Where comparison is possible, we might guess that the velocity from the open trenches would be twice the geophone figures, ie about 15 $mm.s^{-1}$. While velocities less than 10 $mm.s^{-1}$ are probably acceptable, velocities of the nature of 15 $mm.s^{-1}$ would more than likely be unacceptable to State authorities.

CONCLUSIONS

35. The results of the trial reported above are still being analysed and as a result, only some tentative conclusions can be offered at this stage. These are:

a. the Vortman curve for estimating debris throw appears suitable for use when determining safety distances for buried EOD operations, however it would be prudent to increase calculated distances by a 25% factor.

b. Hole burials appear to cast debris to a shorter distance than trench burials.

c. Peak overpressures estimated from various formulae and graphs give "ball park" figures but are not precise probably due to scaling effects. They appear to over estimate the decrease in overpressure due to depth of burial.

d. The 32*NEQ$^{1/3}$ rule for avoiding seismic damage fulfils expectations in the conditions for experiments conducted to date.

36. For open trench shots, overpressures are similar to surface bursts and shots are very noisy compared with buried demolitions. Seismic shock is noticeably higher, when measured by particle velocity, than for buried explosions. Fragment dispersal appears insignificant but this needs confirmation by separate experiment.

ACKNOWLEDGMENTS

37. This paper was prepared while the results of trials were still being assessed, in order to meet the deadline of the US Department of Defense's 24th Explosives Safety Seminar. The help given by Mr Doug Oliver of Materials Research Laboratory, Mr Garry Lampard and Mr Les Opie of Engineering Development Establishment and Captain John Boyter of the Proof and Experimental Establishment Graytown is gratefully acknowledged. The responsibility for any errors in reporting or interpreting their findings as reported above must rest with me.

JJG 9 Aug 90

FIGURES

REFERENCES

1. Reed J.W. (1982) "Blast Predictions for Coyote Canyon Explosions" Minutes of the 20th US DDESB Explosives Safety Seminar Vol 1 pp 169-201 (August 1982)

2. Imperial Chemical Industries (ICI) Australia - Blasting Tables Edition 2

3. NATO AC/258 "Manual on NATO Safety Principles for the Storage of Ammunition and Explosives 1977" Part II (as amended)

4. Australian Ordnance Council Proceeding 7/81 (Amdt No 2) "Restricted Airspace Above Explosives Facilities" dated 20 April 1982

5. Australian Standard AS 2187.2-1983 "SAA Explosives Code Part 2- Use of Explosives" pp 15 and 32

6. Australian Department of Defence Materials Research Laboratory Type F Task Report 64/4/1 "Quantity Distances for Underground Demolitions" dated 20 December 1985

7. Australian Department of Defence Materials Research Laboratory Type F Task Final Report 64/4/1 "Safety Distances for Underground Demolition of Explosive Ordnance" dated 26 October 1988

8. Vortman L.J. (1968) "Air Blast for Underground Explosions as a Function of charge Burial" Ann New York Academy of Science Vol 152 Art. 1 (1968) pp 362 - 377

9. Bishoff F.M. (1968) "Practical Solution to Problem of Computing Safety Zones for Cave Storage of Mass Detonating Ammunition and Explosives" Ann New York Academy of Science Vol 152 Art. 1 (1968) pp 43 - 50

10. Perkins B and Jackson W.F. (1964) "Handbook for Prediction of Blast Focussing" US Army Ballistic Research Laboratories Report BRL-MR-1640 (February 1967)

11. Vortman L.J. (1967) "Maximum Missile Ranges for Surface and Buried Explosions" Sandia Laboratories Alburquerque NM Report SC-RR-67-616 (September 1967)

12. Johnson S.M. (1971) "Explosives Excavation Technology" US Army Engineer Nuclear Cratering Group NCG Technical Report No 21 (June 1971) (also quotes pertinent paper by J.W. Reed]

13. Siskind D.E., Stagg M.S., Kopp J.W. and Dowding C.H. "Structural Response and Damages Produced by Ground Vibration from Surface Mine Blasting" US Bureau of Mines Report of Investigation RI-8507 (1980)

14. Australian Army Proof and Experimental Establishment Graytown letter P.980/500/626 dated 26 May 90

15. Australian Army Engineering Development Establishment draft Report LD2844 for Task LD7603 "Measurement of Blast Overpressures, Ground Vibration and Sound Pressure Levels during Underground Demolitions for the Australian Ordnance Council" (June 1990)

16. Australian Department of Defence Material Research Laboratory "Notes on Buried EOD Trial of May 1990" by Mr D. Oliver dated 1 August 1990

17. "Hazards of Chemical Rockets and Propellant Handbook" Vol 1 AD889763 CPIA/194 May 1972 pp 2-44 [AS DOD CP library AACA 23386 U]

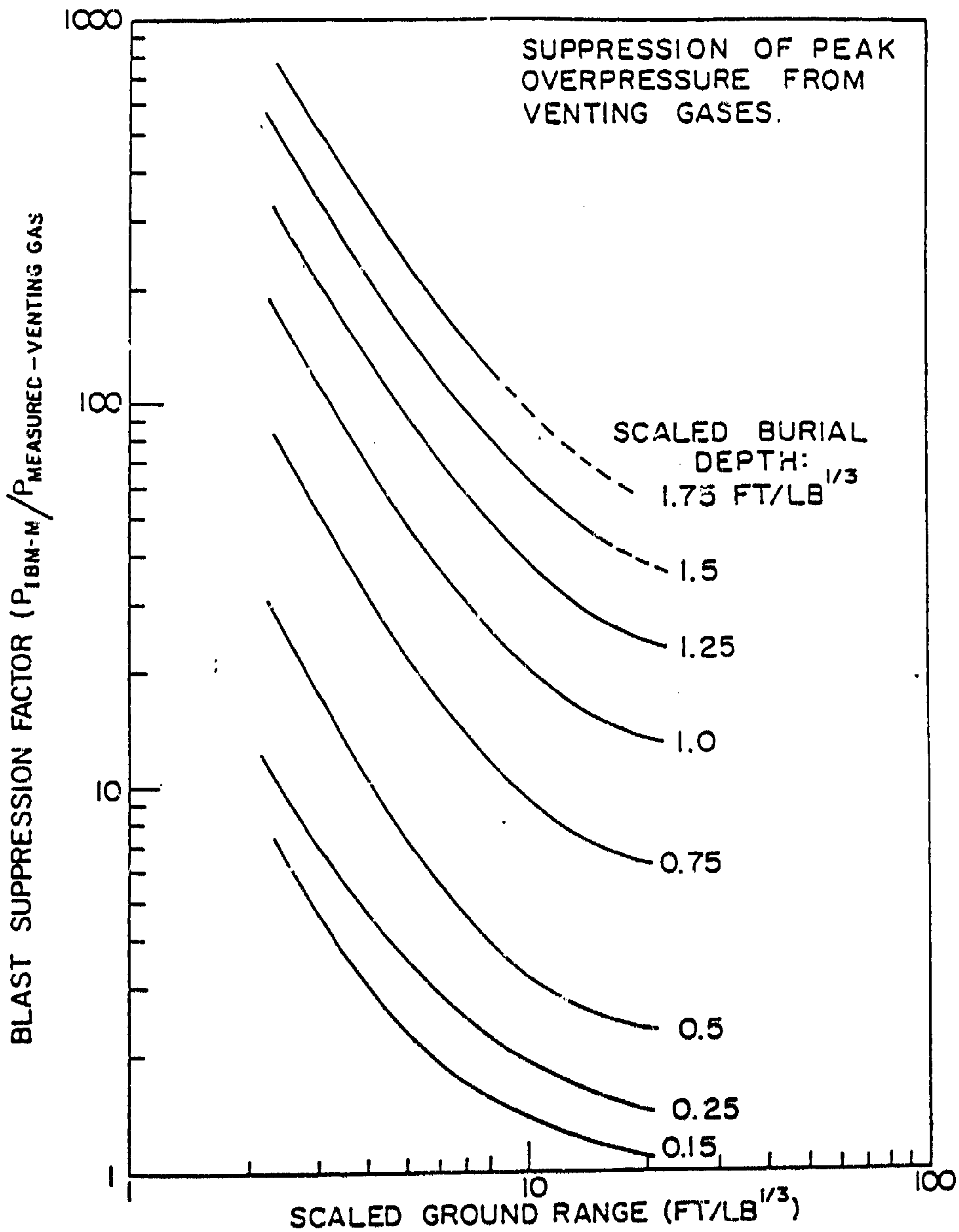


FIGURE 1 - SUPPRESSION OF OVERPRESSURE (VORTMAN 1968)

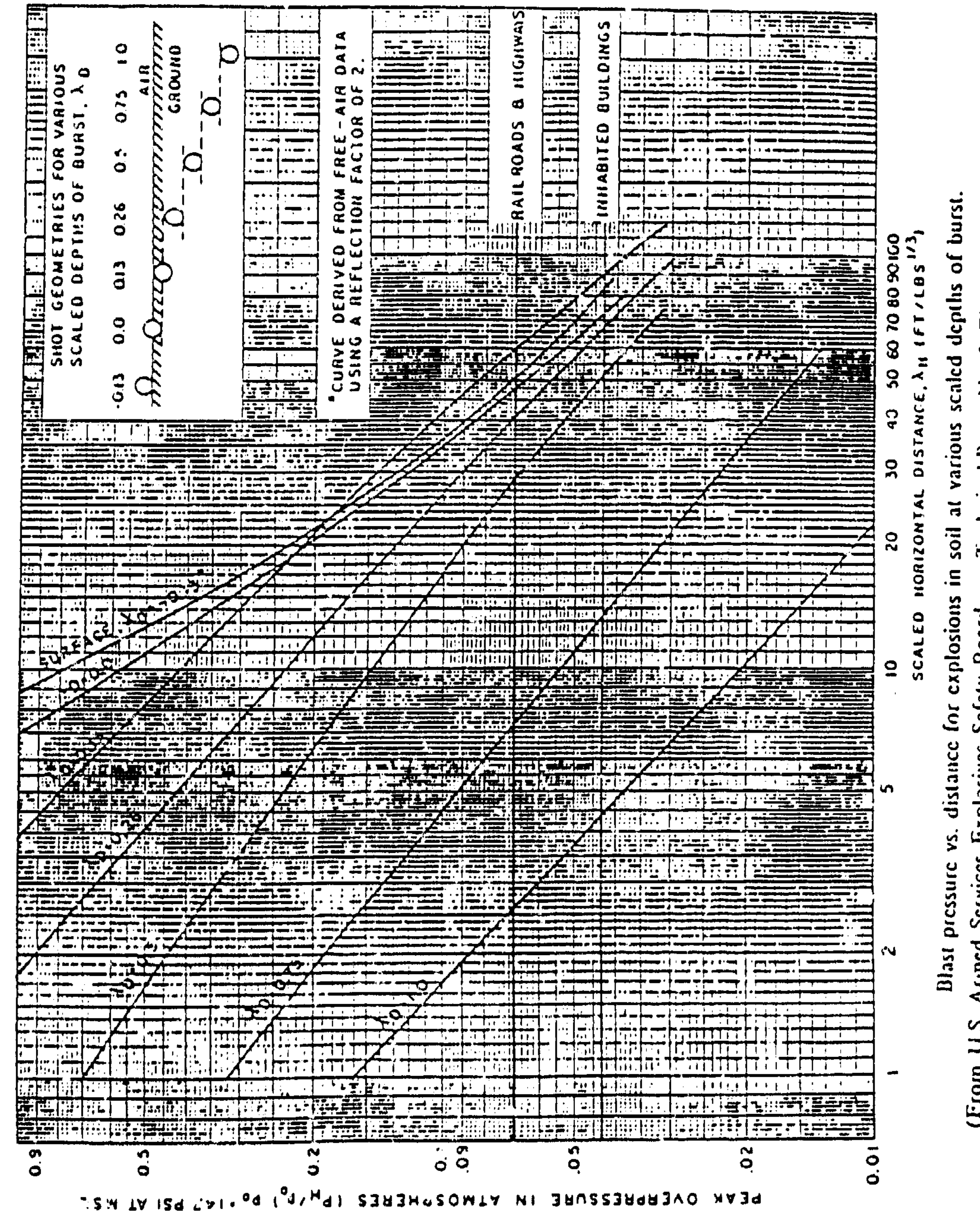
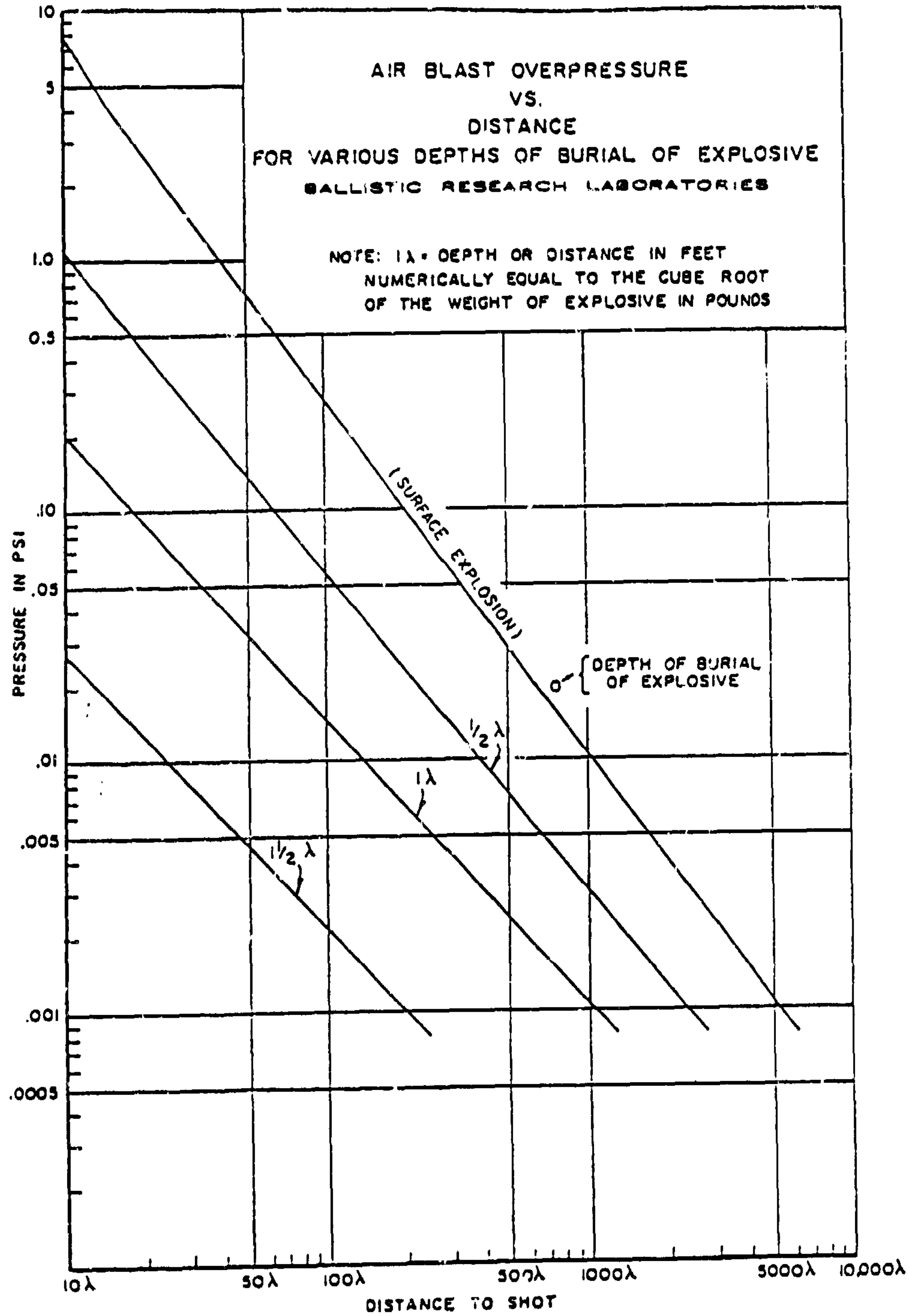
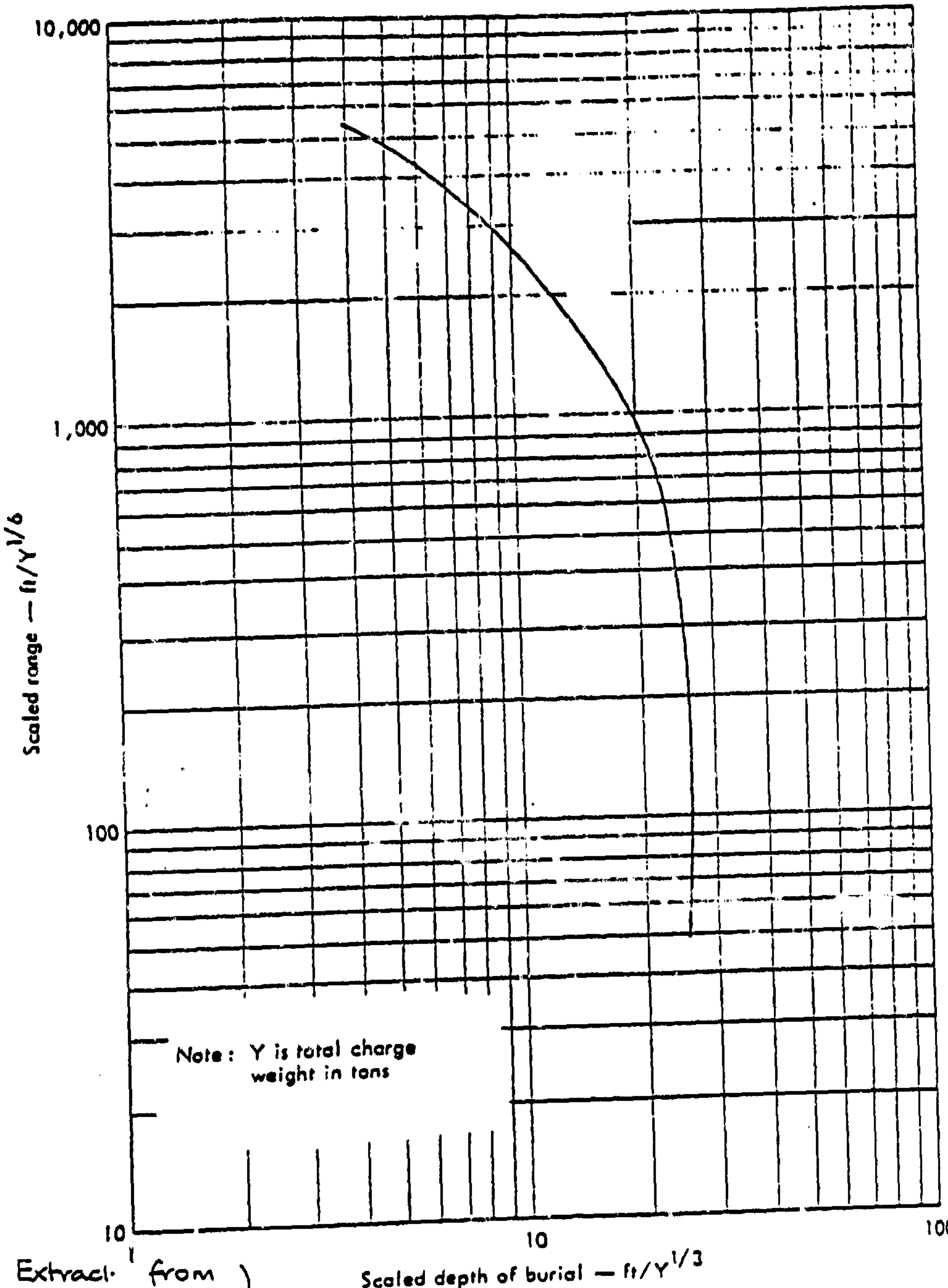


FIGURE 2 - BLAST PRESSURE vs DISTANCE (BISHOFF 1968)



SUPPRESSION OF AIR BLAST OVERPRESSURE BY BURIAL OF EXPLOSIVE

FIGURE 3 - AIR BLAST OVERPRESSURES (PERKINS & JACKSON 1964)

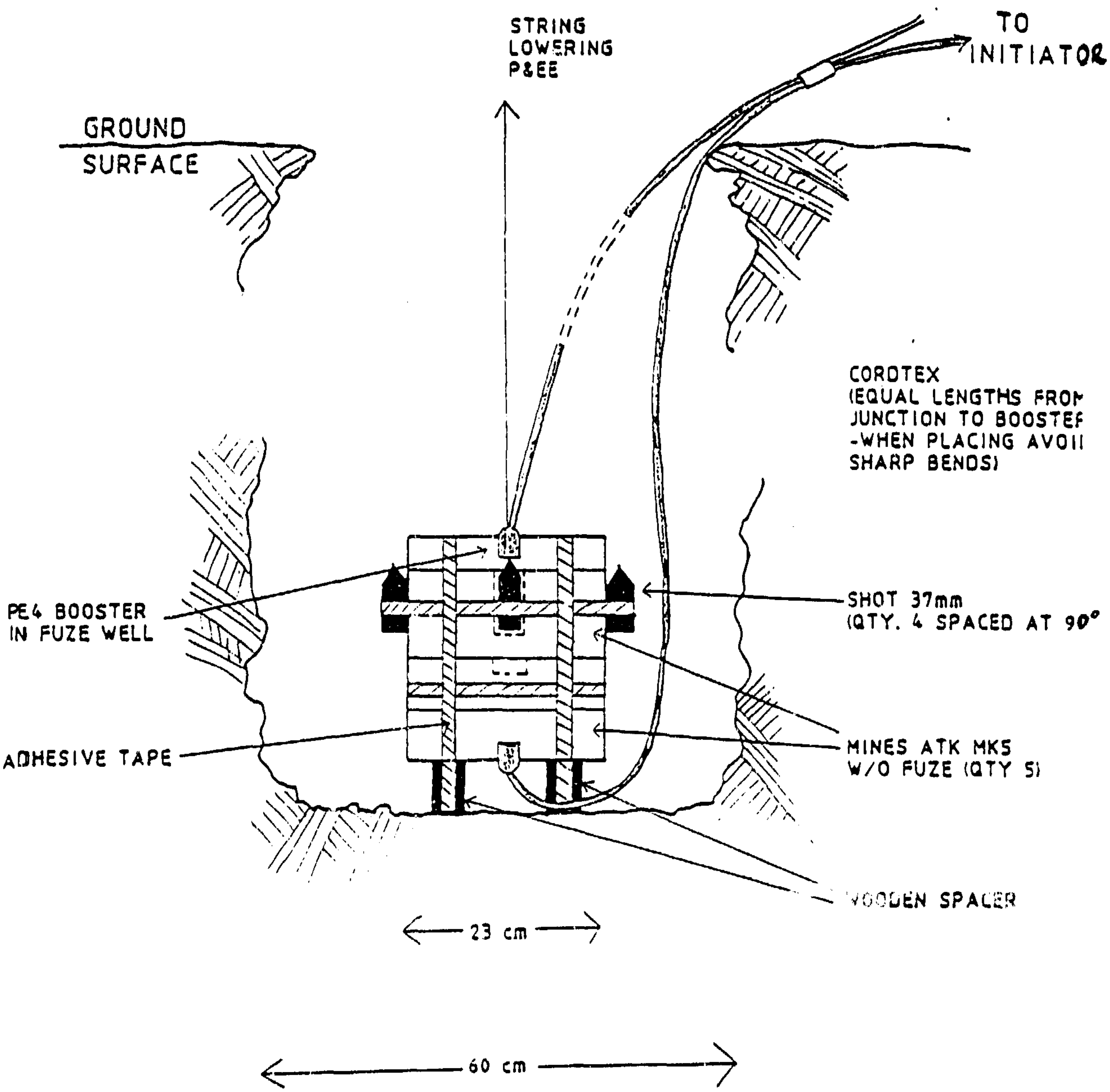


(Extract from Johnson 1971)

Prediction of maximum missile range from detonation of buried charges

FIGURE 4 - MAXIMUM MISSILE RANGES (VORTMAN 1967)

MINE FIRING CONFIGURATION



NOT TO SCALE

FIGURE 5 - MINE FIRING CONFIGURATION · UNDERGROUND DEMOLITION TRIAL (1990)

LARGE ROCKET MOTOR

DEMILITARIZATION TECHNOLOGY REVIEW

AND

RESEARCH AND DEVELOPMENT FUNDING REQUIREMENT

FOR

FISCAL YEAR 1991-1992

TWENTY-FOURTH DOD EXPLOSIVES SAFETY SEMINAR

28-30 AUGUST 1990

ST. LOUIS, MISSOURI

SOLIM S. W. KWAK
JOHN L. BYRD, JR.
GAYLE ZAJICEK
ED ANSELL

Joint Service Large Rocket Motor Disposal Program
Joint Ordnance Commanders Group (JOCG) Munitions
Demilitarization and Disposal Subgroup

ABSTRACT

As the result of increasingly stringent environmental regulations and public pressures, alternative disposal technologies for large rocket motor demilitarization must be developed to replace open burning and detonation. The restriction or loss of open burning and detonation disposal options could have a severe effect on the ICBM life cycle, since wastes are generated and must be dealt with at every step, from manufacturing through final disposition of the system. There is a critical need, then, to develop and transition new disposal technologies to the user that includes provisions for dealing with both 1.1 and 1.3 sensitivity category propellants. This need is particularly relevant since missiles containing over 150,000,000 pounds of solid propellant may have to be disposed of over the next few years.

In addition to waste disposal requirements at every stage of the ICBM life cycle, potential arms limitation treaties, if promulgated, will compound an already severe disposal problem. A mechanism must be established to identify maturing as well as emerging technologies and to provide sufficient resources and management emphasis to ensure promising technologies are developed within required time frames.

Nineteen large rocket motor demilitarization technologies and processes were reviewed and evaluated to determine the extent of the technical maturity and feasibility, engineering scale-up capability, and funding required for research and development efforts.

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INDEX OF TABLES, FIGURES, & CHART

1

INTRODUCTION

1. Background

Millions of pounds of solid propellants are produced annually in the United States to support the Nation's missile and rocket programs. An acute requirement exists today, within the Government, to establish the capability of demilitarization and disposal of the excess inventory generated from the disarmament treaties, the military's on-going upgrading program for the existing missile systems, and the aging stockpiles.

The development of technology for the demilitarization and disposal of Large Rocket Motors (LRM) is fragmented in its cohesiveness as a complete, operational, and production system. It is recognized that there are pockets of well defined and developed technology bases addressing segments of demilitarization and disposal operations for LRMs within the military agencies, private industries, and the academic communities. Often environmentally correct solid propellant disposal technology developments are at their embryonic stages which require monitoring and coordination to bring to full maturity.

Realizing that there was insufficient commitment to research and development (R&D) activities for the demilitarization of solid propellant rocket motors in an environmentally acceptable manner within the military organizations, in July 1989 and again in November 1989, the United States Senate Armed Services Committee assigned the Director of Defense Research and Engineering (DDR&E) to establish a consolidated Solid Rocket Motor Demilitarization Research and Development Program. This precipitated Dr. Joseph V. Osterman, Office of the Under Secretary of Defense (Research and Advanced Technology) Environmental and Life Sciences (OUSDA[R&AT]ELS), to task Mr. John L. Byrd, Jr., Director, U.S. Army Defense Ammunition Center and School (USADACS), to provide an overview of the LRM demilitarization and disposal technology and to make recommendations for the fiscal year (FY) 90-92 funding requirements for the implementation of the LRM demilitarization and disposal program (Appendix A).

Parallel to this effort, in March 1989, the Joint Ordnance Commanders Group (JOCG) tasked the chairman of the JOCG Munition Demilitarization and Disposal Subgroup to develop a charter for the Joint Large Rocket Motor Demilitarization Office (JLRMDO) which will develop a Department of Defense (DOD) corporate solution for the demilitarization of LRMs. The JLRMDO will manage and coordinate the investigation, R&D, documentation, evaluation, maintenance of the technology base, and the resources control to support the LRM demilitarization and disposal program. This draft charter was presented to the JOCG at the Keyport, WA meeting in September 1989 (Appendix B).

The Office of the Scientific Advisor, USADACS, was tasked by the JOCG Munition Demilitarization and Disposal Subgroup, to imperatively conduct a survey of technology development efforts within the government organization, industry, and academic community, specifically for the LRM demilitarization and disposal program.

2. Scope

The purpose and limitation of this report is to selectively screen and review demilitarization technology development as applicable to the LRM demilitarization and identify the funding requirements to support the overall demilitarization efforts for FY 91-92 as requested.

3. Source of Information

A comprehensive assessment of LRM demilitarization and disposal technology would require critical and comparative evaluation of technical feasibility, engineering scale-up capability, process materials compatibility, demilitarization and disposal efficiency, operation safety, environmental impacts, and most importantly, construction and operation costs. Such a comprehensive study requires a long concerted effort by many engineers and scientists, and is beyond the scope of this report.

Notwithstanding, in writing this report, the author relies on the pertinent published reports, "Disposal of Solid Rocket Motor Propellants" by T. D. Wilson and T. Moskios at the Chemical Propulsion Information Agency (CPIA), "Solid Propellant Reclamation Study" by M. P. Coover and L. W. Pulter at Thiokol Corporation, and "Demilitarization Of Conventional Ordnance: Priorities For Database Assessment Of Environmental Contaminates" by D.W. Layton at Lawrence Livermore National Laboratory; literature surveys conducted at the U.S. Army Technical Center for Explosives Safety (USATCES) Technical Library; site visits for the currently available demilitarization technologies at Thiokol Corporation, Hercules Aerospace Inc., Lockheed Missiles and Space Research Center, Lawrence Livermore National Laboratory, Aerojet Strategic Propulsion Company, Environmental Systems Company, Ogden Environmental Services, Inc., Combustion Engineering Inc.; and the USADACS collective knowledge and expertise in dealing with energetic materials, including solid propellant, explosives, and pyrotechnics.

4. Technology Overview

There are two fundamentally contesting approaches, the reclamation or destruction techniques, to the LRM Solid Propellant Demilitarization and Disposal Program. The waterjet washout, the mechanical mining out, the solvation/solvolysis of the solid rocket propellants, and use of the recovered propellant as fuel supplement, obviously are some of the reclamation technologies. Whereas, the controlled incineration in a furnace, the biodegradation, the catalytic oxidations of the propellants belong to the destructive technology.

In many instances, both the reclamation and destruction technologies for the LRMs as they exist today are incomplete, overlapping, repetitive, fragmented and often have slight variations in identical unit operation equipment. Clearly, as stated, a systematic analysis of the LRM demilitarization and disposal technologies, regardless of the status, whether fully developed, emerging, conceptual, or past experimentations, would be exhaustive.

The process flow showing the major demilitarization technology for LRM is provided in Chart 1. The chart identifies the engineering knowledge gaps that exist between some of the major demilitarization process steps. Potential application and limitation of existing and emerging demilitarization technologies to the LRM Disposal Program, for the Army, are shown in Chart 2. Similar information for the Air Force and Navy is shown in Chart 3. Application of these technologies requires some finite R&D efforts to tie them together as a complete demilitarization system. As an example, the incineration is applicable to all propellant but the incineration of propellant must be proceeded by the removal process of the propellant in some form from the motor casing followed by the preparation of the material for the incineration. The engineering characteristics such as pumpability, material compatibility, separation, sedimentation, and safety must be carefully studied and engineered.

5. Organization of the Report

The LRM demilitarization and disposal technologies are discussed in four parts in chapter 3. The existing technology discussing the currently available demilitarization technology including washout, hogout, and incineration is given in the first section. The discussion of the past studies of applicable demilitarization and disposal works, including reclamation of Ammonium Perchlorate (AP) are given in the second section. These past development efforts merit recognition and discussion even though the research has been discontinued.

The third section discusses the emerging technologies, such as the U.S. Army Missile Command (MICOM) Super-Critical Fluid Extraction Method in which liquid ammonia was used to recover AP. These R&D efforts require coordination, monitoring, and funding to evolve them into useful and applicable technology. The last section briefly discusses technology at conceptual stages which includes exotic approaches such as confined static firing. Funding requirements are discussed in chapter 4. The conclusions and recommendations are given in chapter 5.

DEMILITARIZATION INVENTORY

1. Military Services.

As of 1986, the military's disposal inventory of all composite,

MAJOR DEMILITARIZATION TECHNOLOGY FOR LARGE ROCKET MOTORS

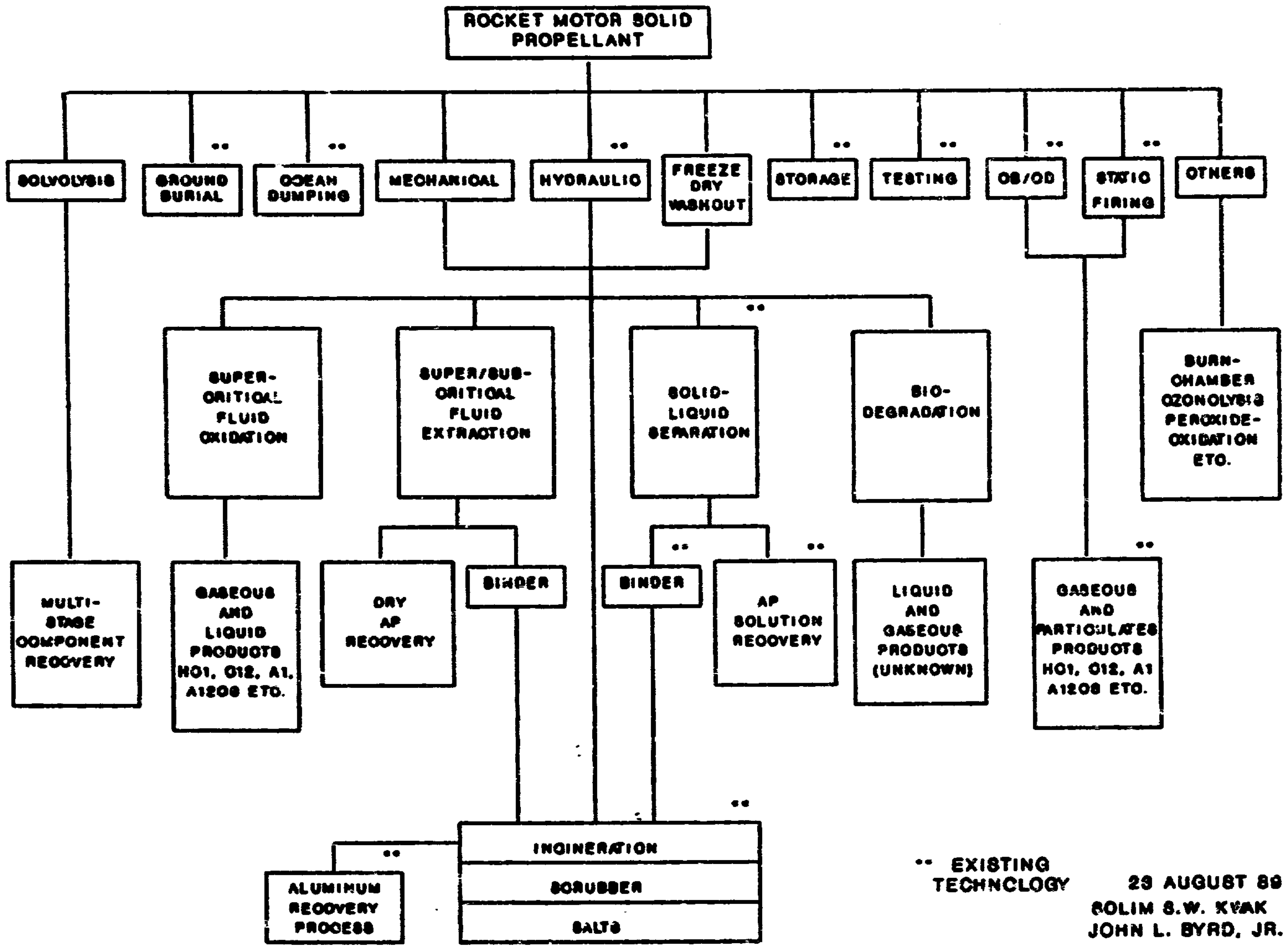


Chart 1.

DEMILITARIZATION TECHNOLOGY PROCESSES APPLICATION (ARMY)

INVENTORY	PROPELLANT TYPE	WASHOUT*	SOLVATION	CONTROLLED INCINERATION	CRITICAL FLUIDS	BIODEGRADATION	ENERGY RECOVERY	OXIDATION
ATACMS	AP	Y	Y	Y	Y	NDA	Y	NDA
AAWS-M	TBD	NDA	NDA	NDA	NDA	NDA	NDA	NDA
CHAPARRAL	XLDB	Y	NDA	Y	N	NDA	Y	NDA
DRAGON	DB	Y	NDA	Y	N	NDA	Y	NDA
FOTL	AP	Y	Y	Y	Y	NDA	Y	NDA
HAWK	AP	Y	Y	Y	Y	NDA	Y	NDA
HELLFIRE	XLDB	Y	NDA	Y	N	NDA	Y	NDA
HONEST JOHN	DB	Y	NDA	Y	N	NDA	Y	NDA
HYDRA-70	DB	Y	NDA	Y	N	NDA	Y	NDA
JSLTR	AP	Y	Y	Y	Y	NDA	Y	NDA
LANCE	LIQ PROP	n/a	n/a	Y	n/a	N	Y	N
LOSAT	XLDB	Y	NDA	Y	N	NDA	Y	NDA
LOS-F-H (ADATS)	DB	Y	NDA	Y	N	NDA	Y	NDA
M-22 (SS-11)	DB	Y	NDA	Y	N	NDA	Y	NDA
MLRS	AP	Y	Y	Y	Y	NDA	Y	NDA
MPIM	DB	Y	NDA	Y	N	NDA	Y	NDA
MSAM	TBD	NDA	NDA	NDA	NDA	NDA	NDA	NDA
NIKE HERCULES, BOOST	DB	Y	NDA	Y	N	NDA	Y	NDA
NIKE HERCULES, SUSTAIN	AP	Y	Y	Y	Y	NDA	Y	NDA
NLOS (FOG-M)	TBD	NDA	NDA	NDA	NDA	NDA	NDA	NDA
PATRIOT	AP	Y	Y	Y	Y	NDA	Y	NDA
PERSHING IA	AP	Y	Y	Y	Y	NDA	Y	NDA
PERSHING II, BOOST	AP	Y	Y	Y	Y	NDA	Y	NDA
PERSHING II, SUSTAIN	AP	Y	Y	Y	Y	NDA	Y	NDA
REDEYE	AP	Y	Y	Y	Y	NDA	Y	NDA
ROLAND	DB	Y	NDA	Y	N	NDA	Y	NDA
SHILLELAGH, BOOST	AP	Y	NDA	Y	Y	NDA	Y	NDA
SHILLELAGH, SUSTAIN	DB	Y	NDA	Y	N	NDA	Y	NDA
STINGER	AP	Y	Y	Y	Y	NDA	Y	NDA
TOW	DB	Y	NDA	Y	N	NDA	Y	NDA

*Waterjet 'Hogout' process is included in washout technology.

Y = Yes
N = No
n/a = not applicable
NDA = NO DATA AVAILABLE

AP = Ammonium Perchlorate
DB = Double Base
XLDB = Cross-Linked Double Base
LIQ = Liquid
TBD = To Be Determined

Chart 2.

APPLICATION OF

LARGE ROCKET MOTOR DISPOSAL TECHNOLOGY

ITEM	MOTOR DIMENSIONS (IN)** LENGTH	DIAMETER	CHEMICAL COMPOSITION**	PROPELLANT WEIGHT POUNDS**	BIODEGRADATION	SUPERCRITICAL WATER OXIDATION	PROPELLANT REMOVAL/ REUSE	STATIC FIRING W/SCRUBBER
ARMY								
NIKE HERCULES M30 SUSTAINER	93	28	AP/BINDER	2,396	BENCH DEMO	CONCEPT	YES	CONCEPT
NIKE HERCULES M42 BOOSTER	136	17	DOUBLEBASE	3,009	CONCEPT	CONCEPT	*YES	CONCEPT
AIR FORCE								
MM II, 1ST STAGE	295	66	AP/Al/PBAN	50,250	BENCH DEMO	CONCEPT	YES	CONCEPT
MM II, 2ND STAGE	162	52	AP/Al/CTPB	13,300	BENCH DEMO	CONCEPT	YES	CONCEPT
MM II, 3RD STAGE	85	38	CMDB	4,250	CONCEPT	CONCEPT	*YES	CONCEPT
MM III, 1ST STAGE	295	66	AP/Al/PBAN	50,250	BENCH DEMO	CONCEPT	YES	CONCEPT
MM III, 2ND STAGE	162	52	AP/Al/CTPB	15,500	BENCH DEMO	CONCEPT	YES	CONCEPT
MM III, 3RD STAGE	91	52	AP/Al/CTPB	7,305	BENCH DEMO	CONCEPT	YES	CONCEPT
NAVY								
POLARIS A-3, 1ST STAGE	181	54	AP/Al/BINDER	20,800	BENCH DEMO	CONCEPT	YES	CONCEPT
POLARIS A-3, 2ND STAGE	89	54	CMDB	15,900	CONCEPT	CONCEPT	*YES	CONCEPT
POSEIDON C-3, 1ST STAGE	188	74	AP/Al/BINDER	38,800	BENCH DEMO	CONCEPT	YES	CONCEPT
POSEIDON C-3, 2ND STAGE	97	74	CMDB	15,900	CONCEPT	CONCEPT	*YES	CONCEPT
TRIDENT C-4, 1ST STAGE	184	74	HMX/AP/Al/BINDER	38,900	CONCEPT	CONCEPT	*YES	CONCEPT
TRIDENT C-4, 2ND STAGE	97	74	HMX/AP/Al/BINDER	17,300	CONCEPT	CONCEPT	*YES	CONCEPT
TRIDENT C-4, 3RD STAGE	120	31	HMX/AP/Al/BINDER	4,800	CONCEPT	CONCEPT	*YES	CONCEPT

*SENSITIVITY OF HIGH PRESSURE FLUID JET IMPACT FOR CLASS 1.1 PROPELLANT HAS NOT BEEN ESTABLISHED.

**SOME OF THE INFORMATION LISTED IS POTENTIALLY SENSITIVE.

Office of the Scientific Advisor
U.S. Army Defense Ammunition Center
and School
12 April 1990

Chart 3.

doublebase, and modified doublebase propellants was 32.3 million pounds as reported in a CPIA study. The JOCG Munitions Demilitarization and Disposal Subgroup reported in 1989, that the current disposal inventory of the LRM propellant was over 3.2 million pounds. It is projected that the total demilitarization inventory will increase to 23.3 million pounds by 1995. During a JOCG conference, 13-14 February 1990, Eglin AFB, FL, the Army, Navy and Air Force reported there will be a total of 83.9 million pounds of solid propellant in the demilitarization inventory by FY 1996. The JOCG estimate did not include the propellants from the foreign military sales (FMS), the propellants which would result from the Strategic Arms Control Treaty (START), and the propellants from storage installations impacted by the military's proposed base closures.

2. Other Government Agencies

The disposal inventory of the LRM propellant among the government agencies such as the National Aeronautics and Space Administration (NASA) is not identified at this time. The NASA is currently pursuing an open-pit burning permit for the production rejects and scraps from its Advanced Solid Rocket Motor for the Space Shuttle Program.

3. Industry

The disposal inventory of the LRM propellant among the propellant production industry has not been identified at this time. Each propellant manufacturer has its own open-pit burning program for the disposal of the production rejects, scraps and excess propellant formulation during the motor casting process. It can be assumed that the disposal inventory will be substantial from the commercial production efforts.

REVIEW OF LRM PROPELLANT DEMILITARIZATION TECHNOLOGY

1. Introduction

The LRM Propellant demilitarization and disposal technology development efforts are fragmented. The segment of LRM demilitarization technology that has been developed is well defined and some has progressed through the development effort into the production stage. The LRM propellant disposal processes reviewed in this report were selected to demonstrate the extent of their maturity, applicability, and the cost to the government. In order to identify and facilitate the amount of fundings required to bring these technologies to a complete and unified process system, and to meet the governments needs, a description of essential process equipment and operation procedures is discussed for each technique, followed by a short narrative of the limitations of the process. An estimate of the development funding required is given in chapter 4.

2. Existing Technology

Twelve fully developed demilitarization technologies have been chosen for discussion. The first five reviewed are the washout methods, followed by one discussion on reclamation, and the rest are the controlled incineration processes.

a. Washout Technologies

(1) Thiokol Process

The Thiokol Corporation, Brigham City, UT, has a contract with the Navy to manufacture both Standard MK 104 missiles and the High Speed Anti-Radar Missile (HARM) motors. When a flawed motor is found, the motors are washed out and the cases are reused. The washout fixture will accept a missile motor from 10 to 60 inches in diameter with a maximum length of 220 inches. A 10,000 psig-120 gallon/minute waterjet is sprayed into the base of the missile through a bank of high pressure spray nozzles. The propellant is removed at a rate of approximately 1,500 pounds/hr. The waterjet cuts the propellant into small pieces which are removed in slurry form. The slurry is channeled to a screen where the solid propellant is collected and removed to be open-burned and the water is recycled.

Limitations: The holding fixtures and the washout nozzle will have to be redesigned to accommodate the LRM.

(2) Aerojet Process

The Aerojet Solid Propulsion Company, Sacramento, CA is operating a "hogout" operation to remove the propellant from the Minuteman Second Stage missile motors. The system is capable of removing about 1,000 pounds of propellant per hour. The missile motor is placed on a horizontal saddle and rotated during the hogout operation. The propellant is washed out and dewatered. The water is reused until it reaches a 10 percent AP concentration and sold to explosives manufacturers. The residue is packed into plastic-lined fiber drums and open burned on sand-lined concrete pads. The aerojet AP recovery process and incinerator are discussed in later sections.

Limitations: This process is a fully developed production scale operation.

(3) Western Area Demilitarization Facility (WADF) Process

The WADF, Hawthorne, NV has a Washout System located in the south tower of the Washout/Steamout Building. This washout system is designed to remove two types of press-loaded explosives, Explosive A3 and Explosive D, from medium and major caliber gun ammunition items. Explosive A3 is removed from projectiles by use of cold water at a pressure up to 15,000 psig, while Explosive D is removed by use of 195 ^{o}F water at 80 psig.

Two different methods are used for holding the projectiles while the explosives are removed; a washout turntable for projectiles ranging in size from 3 inches through 6 inches and a washout chamber for those from 8 inches through 16 inches. When items containing Explosive A3 are being processed, the mixture of water and explosives from the washout turntable are directed to a dewatering screen and separated. The contaminated water is directed to the Water Treatment Facility and the Explosive A3 is dried, weighed, packaged, and reclaimed. The Explosive D slurry from the washout process is directed from the turntable to the slurry collection tank where the materials are kept hot and stirred to prevent settling and caking. The material from the slurry collection tank is processed (grinding) and burned in the rotary kiln incinerators. Figure 1 shows a flow diagram of the Washout System. Figure 2 shows the arrangement of the washout system in the south tower.

Limitations: The washout/steamout building is configured to accommodate various sized projectiles. The building was designed to be modified as new methods and technologies emerged to replace outdated processes.

(4) Naval Weapons Support Center Crane (NWSCC) Process

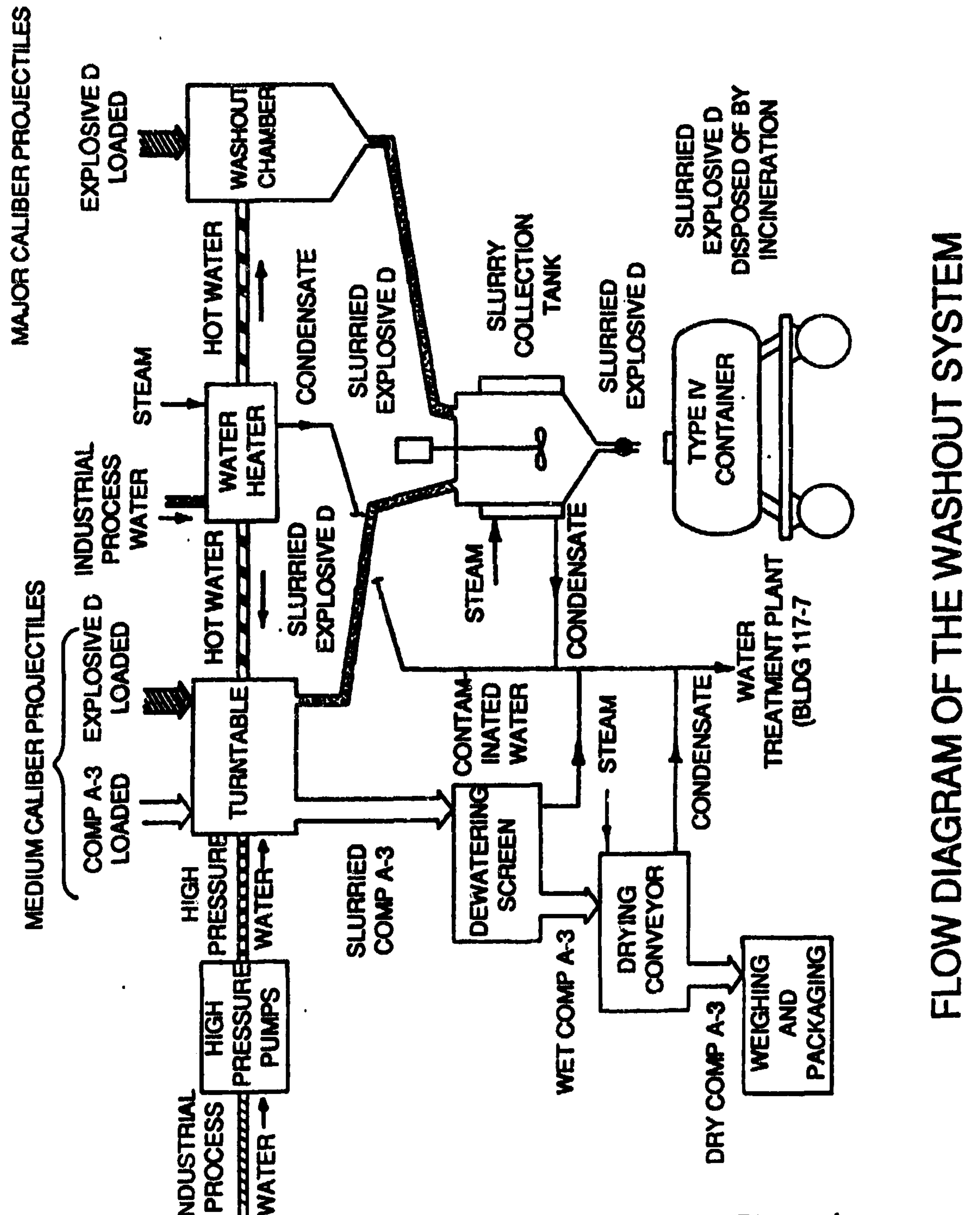
The NWSCC, Ordnance Engineering Department, has contracted the University of Missouri-Rolla (UMR), since 1982, to investigate the use of high pressure waterjets to remove plastic bonded explosives (PBX) from a variety of ordnance. An automated pilot system, the Waterjet Ordnance and Munitions Blastcleaner with Automated Tellurometry (WOMBAT), for removal of PBX from munitions has been designed, fabricated, installed and tested at UMR. The WOMBAT is a multi-tasking computer monitored and controlled, state-of-the-art, system for maneuvering the waterjet lance through a variety of different geometries to be encountered in the various munitions. The WOMBAT is located in an underground facility at the UMR experimental mine.

Limitations: The WOMBAT device would have to be sized for the LRM demilitarization and disposal program.

(5) Flow International Corporation Process

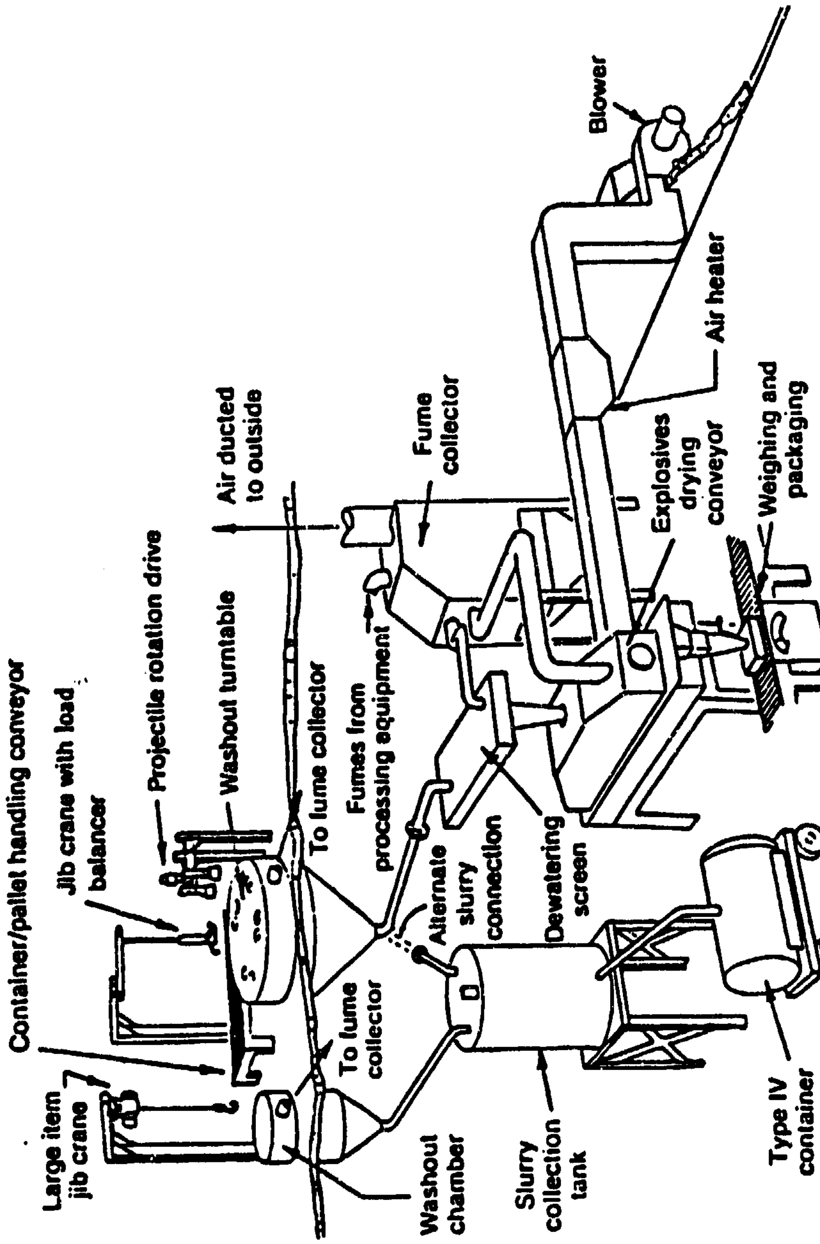
The Flow International Corporation, Kent, WA manufactures ultrahigh-pressure waterjets and abrasive jets for industrial cutting and milling. The ultrahigh-pressure intensifier pump pressurizes water up to 55,000 psi and forces it through a nozzle, as small as 0.004 inches in diameter, generating a high velocity waterjet at speeds up to 3,000 feet per second. This waterjet can cut a variety of non-metallic materials. To cut metallic or hard materials, a mixing device that entrains abrasives such as garnet or aluminum oxide into the waterjet has been developed to enhance the cutting capability.

The abrasivejet cuts with little heat, causes no metallurgical changes, can operate underwater, and leaves a quality edge that usually requires no



MAJOR CALIBER PROJECTILES
EXPLOSIVE D LOADED
WASHOUT CHAMBER
MEDIUM CALIBER PROJECTILES
COMP A-3 LOADED
EXPLOSIVE D LOADED
INDUSTRIAL PROCESS WATER
STEAM
WATER HEATER
HOT WATER
CONDENSATE
HOT WATER
SLURRIED EXPLOSIVE D
SLURRIED EXPLOSIVE D
SLURRY COLLECTION TANK
SLURRIED EXPLOSIVE D
TYPE IV CONTAINER
SLURRIED EXPLOSIVE D DISPOSED OF BY INCINERATION
INDUSTRIAL PROCESS WATER
HIGH PRESSURE PUMPS
HIGH PRESSURE WATER
TURNTABLE
SLURRIED COMP A-3
DEWATERING SCREEN
CONTAMINATED WATER
STEAM
CONDENSATE
WATER TREATMENT PLANT (BLDG 117-7
STEAM
CONDENSATE
WET COMP A-3
DRYING CONVEYOR
DRY COMP A-3
WEIGHING AND PACKAGING
FLOW DIAGRAM OF THE WASHOUT SYSTEM

Figure 1.



CONCEPTUAL ARRANGEMENT OF THE SOUTH TOWER

Figure 2.

additional finishing. The abrasivejet is easily integrated with computer controlled motion systems. The abrasivejet cutting head can be remotely operated. Figure 3 shows a line drawing of the abrasivejet cutting nozzle. Figure 4 shows a schematic of the intensifier system.

Limitations: This technology could be adapted for removal of the solid propellants and energetic materials. Nozzle design will have to be optimized for propellant hogout operation. The high velocity sensitivity of waterjet impacting on the propellant has not been established.

b. Reclamation Technology

(1) Aerojet Process

The Aerojet Solid Propulsion, Central Waste Management, Sacramento, CA has developed a full scale Propellant Thermal Processor (PTP) system equipped with AP recovery capability and binder separation system. This unit will remove approximately 95 percent of the AP contained in class 1.3 propellant.

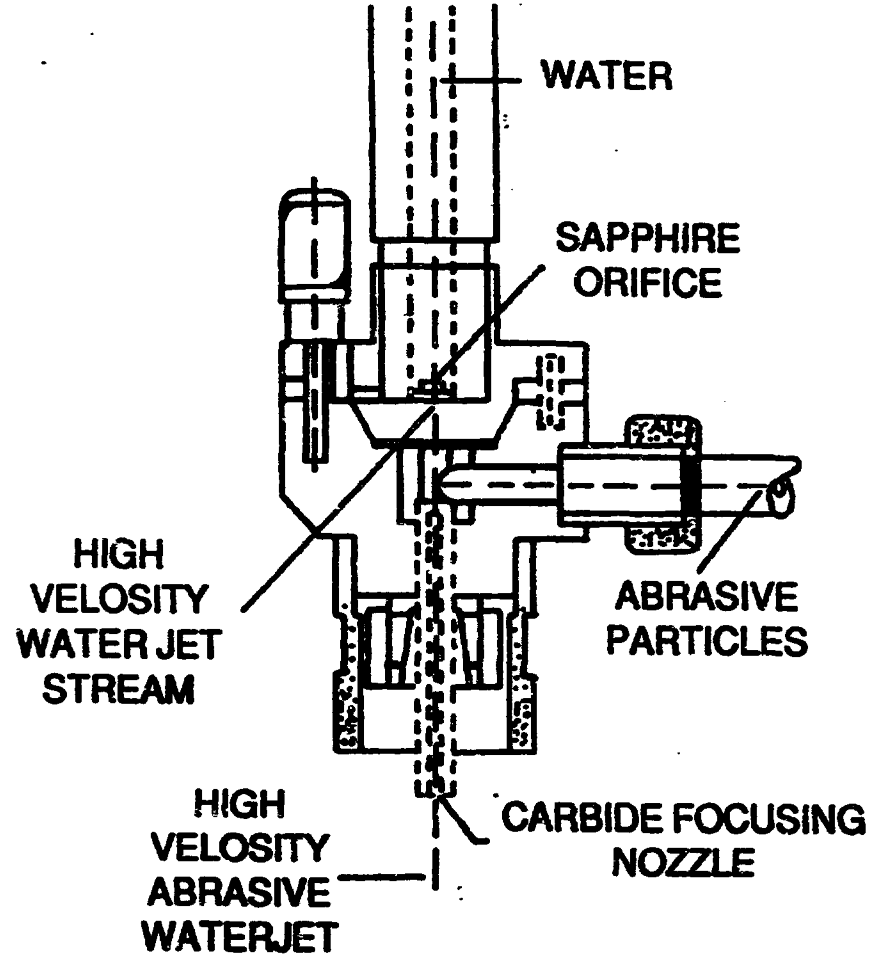
The reclaimed AP solutions is sold as a raw material to AP manufacturers. The residue that contains binder, aluminum, and 5 percent AP is incinerated in the two-stage PTP incinerator. Aerojet's initial requirement was to design a plant that would process approximately 2 million pounds of class 1.3 propellant per year. The final upgraded system would be able to handle 3 million pounds per year operating at 60 percent duty cycle. Figure 5 shows a line schematic of the proposed recovery process from a hogout operation.

Limitations: The washout and the AP recovery solvation system requires further process refinement.

c. Incineration Technology

(1) Rotary Kiln Process

The WADF, Hawthorne, NV has two refractory lined rotary kiln incinerators that are a part of the Bulk Incineration System (BIS). This BIS was designed to receive, prepare, and incinerate explosive slurry materials transported from the various demilitarization buildings. The explosives slurry feed rate may be varied from 0 to 10 gpm. The incinerators are equipped with a variable speed drive which is capable of rotating the incinerator body at the speed range of 1/2 to 6 rpm. A fuel oil burner is located at the discharge end of the incinerator and provides the heat required to maintain the incinerator body temperature and to burn slurry. The afterburner is located downstream from the rotary kiln body. It is a refractory lined chamber equipped with two burners that insure that all of the combustibles in the effluent gases are destroyed and emissions are reduced to acceptable environmental levels.



CROSS-SECTION OF FLOW's ABRASIVEJET CUTTING NOZZLE

Figure 3.

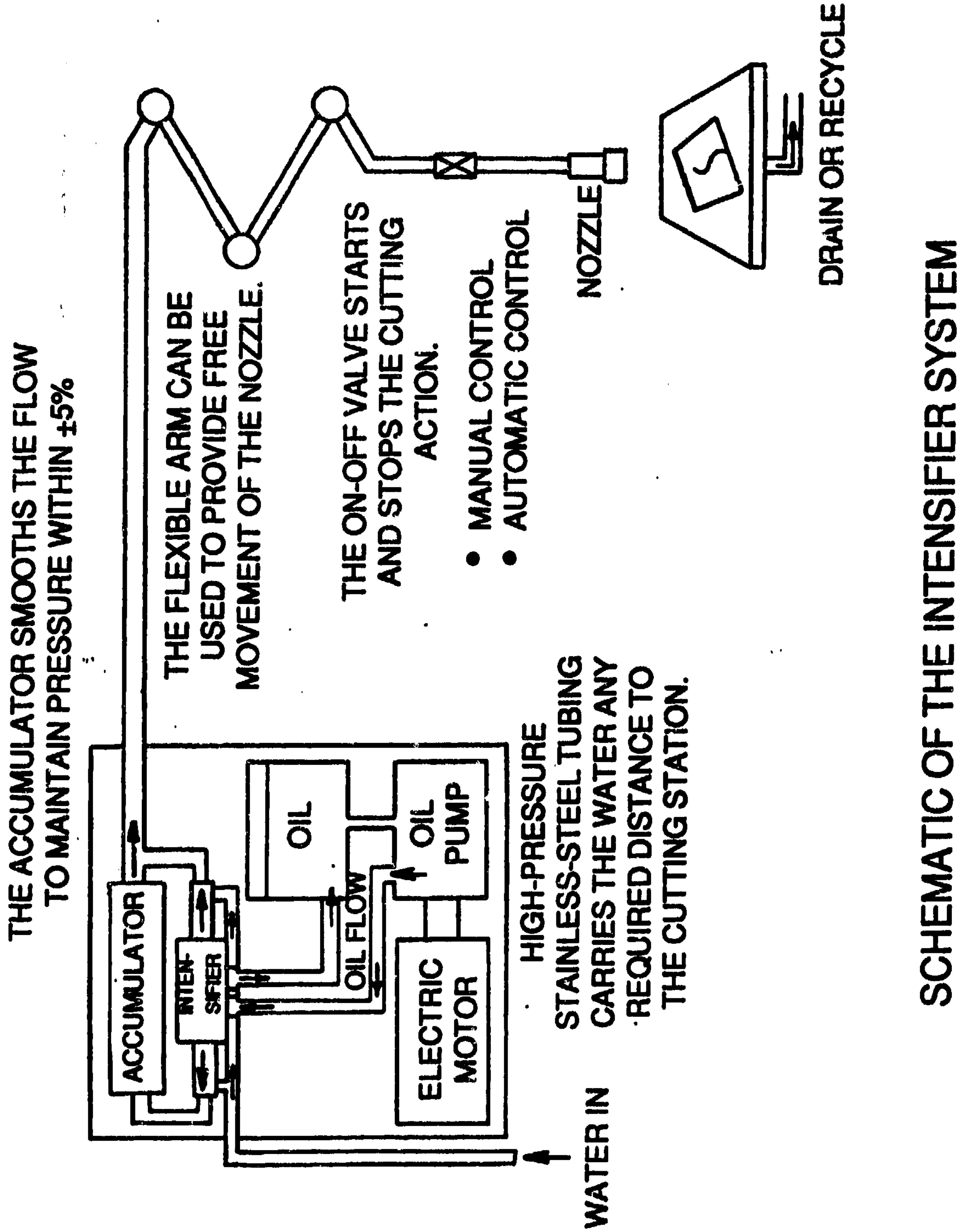

THE ACCUMULATOR SMOOTHS THE FLOW
TO MAINTAIN PRESSURE WITHIN ±5%
THE FLEXIBLE ARM CAN BE
USED TO PROVIDE FREE
MOVEMENT OF THE NOZZLE.
THE ON-OFF VALVE STARTS
AND STOPS THE CUTTING
ACTION.
• MANUAL CONTROL
• AUTOMATIC CONTROL
NOZZLE
DRAIN OR RECYCLE
ACCUMULATOR
INTEN-
SIFIER
OIL
OIL
PUMP
OIL FLOW
ELECTRIC
MOTOR
HIGH-PRESSURE
STAINLESS-STEEL TUBING
CARRIES THE WATER ANY
REQUIRED DISTANCE TO
THE CUTTING STATION.
WATER IN
SCHEMATIC OF THE INTENSIFIER SYSTEM

Figure 4.

PTP SYSTEM WITH AP RECOVERY

UNIT BASIS IS 1,000,000 POUNDS 1.3 PROPELLANT

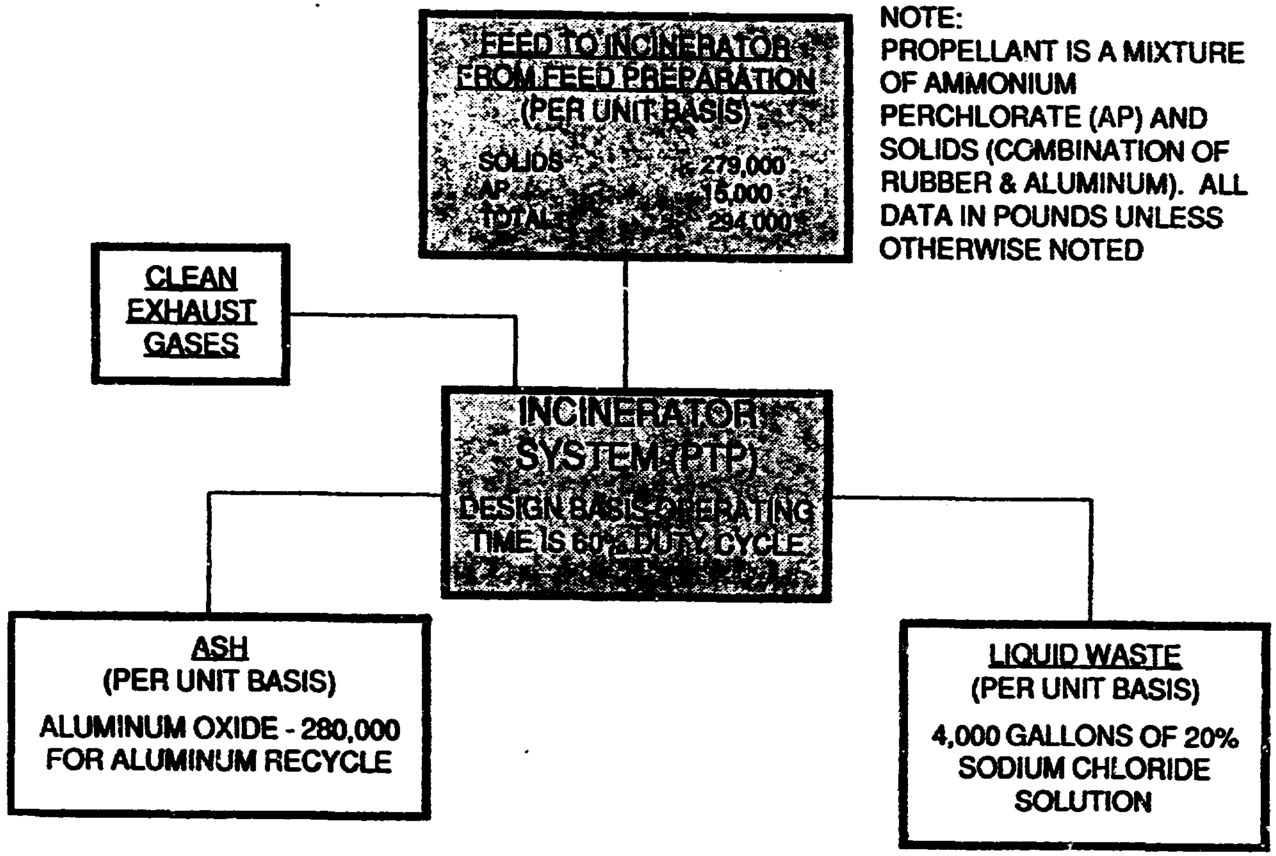


Figure 5.

Pink water has been processed through the incinerator at a rate of 5 gpm with a rotary kiln temperature of 1000 F and an afterburner temperature of 1750 F. Otto fuel incineration tests have been conducted using the rotary kiln temperature of 1600 F with an afterburner temperature of 2200° F, showing the versatility of this incineration system. Figure 6 shows the location of the incinerators relative to the Bulk Explosives Disposal Building, which could be used in the preparation of the LRM propellant slurry.

Limitations: The incinerator has been used to burn a variety of hazardous materials including explosives slurries, however, the disposal of LRM propellants slurry has not been demonstrated.

(2) Aerojet Propellant Thermal Processor (PTP) System

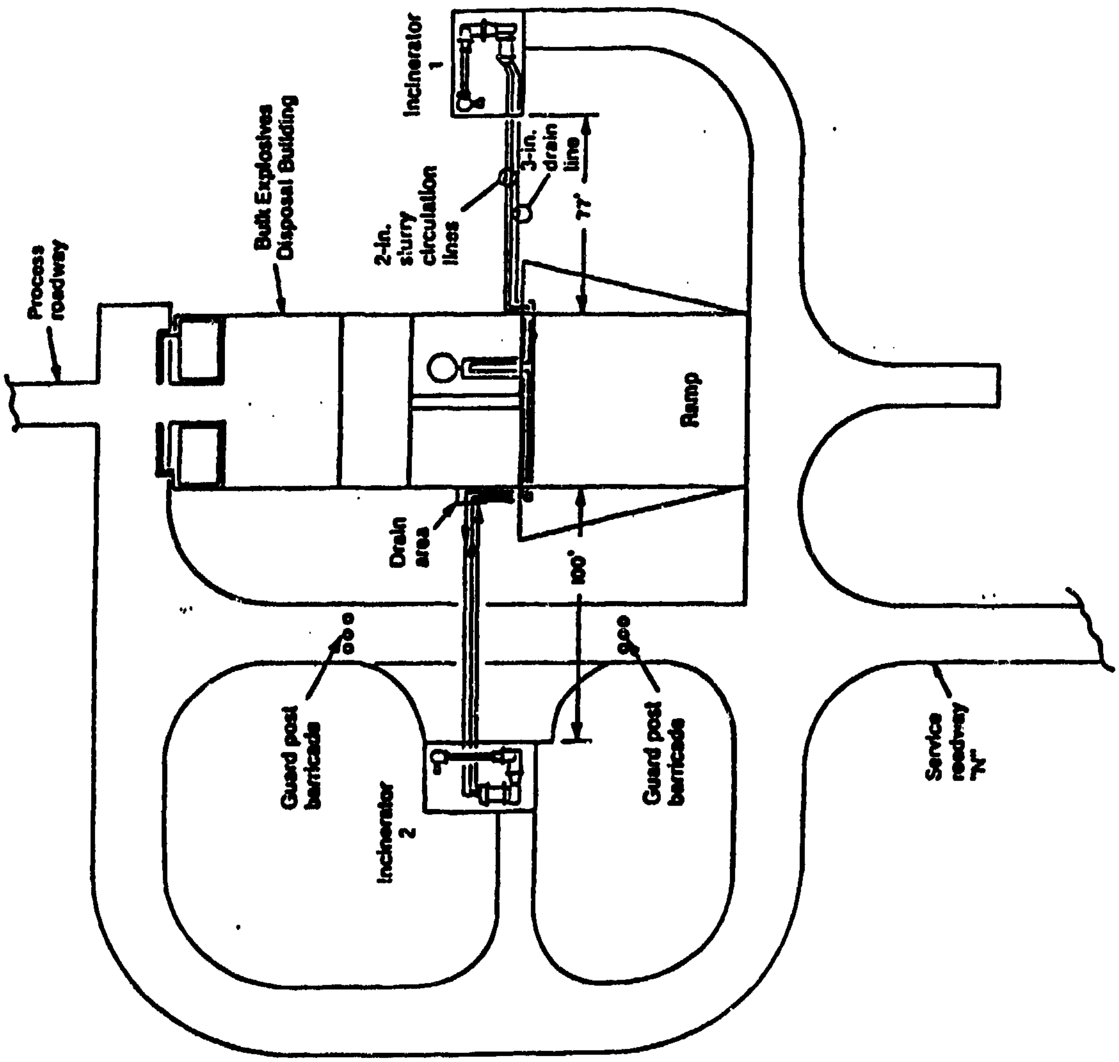
Aerojet developed a two chamber incinerator system to burn propellant residue, aluminum, binder, and 5-10 percent ammonium perchlorate, from the hogout/AP recovery operations. The initial reductive incineration is conducted at 1850° F and leaves a reclaimable aluminum. The second incineration, the oxidation process, is conducted at 2100° F to complete the combustion and destroy any remaining organics in the gaseous effluent from the initial incineration. The hot gases are cooled and scrubbed to remove particulates and hydrogen chloride gas. For every one-million pounds of class 1.3 propellant burned in the system, there will be approximately 4000 gallons of scrubber liquid waste (inorganic salts) that the Aerojet is disposing of by deep-well injection at a cost of $1.00/gallon. Figure 7 and Figure 8 show a line schematic material balance and a system schematic of the incineration process respectively.

Limitations: The existing incinerator system is now operational for the disposal of the propellant residue.

(3) Explosive Waste Incinerator (EWI) Process

The EWI, similar in design and operation to the Ammunition Peculiar Equipment (APE) 1236 Deactivation Furnace System, was developed by the U.S. Army. There are four major components; a Deactivation Furnace, a Positive Feed System, an Air Pollution Control System, and Equipment Control Panels. The pollution control system is consisted of a low temperature (1000° F to 250 F) heat exchanger, a cyclone dust collector, a baghouse, and a draft fan. There are plans to upgrade the EWI with an afterburner, a high temperature heat exchanger, and a new control system. Also, it will have a shrouded containment system similar to the upgraded APE 1236 Deactivation Furnace System. Figure 9 shows the facility layout.

Limitations: The disposal of LRM propellants has not been demonstrated. A positive propellant slurry feed system has to be developed.



ARRANGEMENTS OF INCINERATORS RELATIVE TO THE BULK EXPLOSIVES DISPOSAL BUILDING

Figure 6.

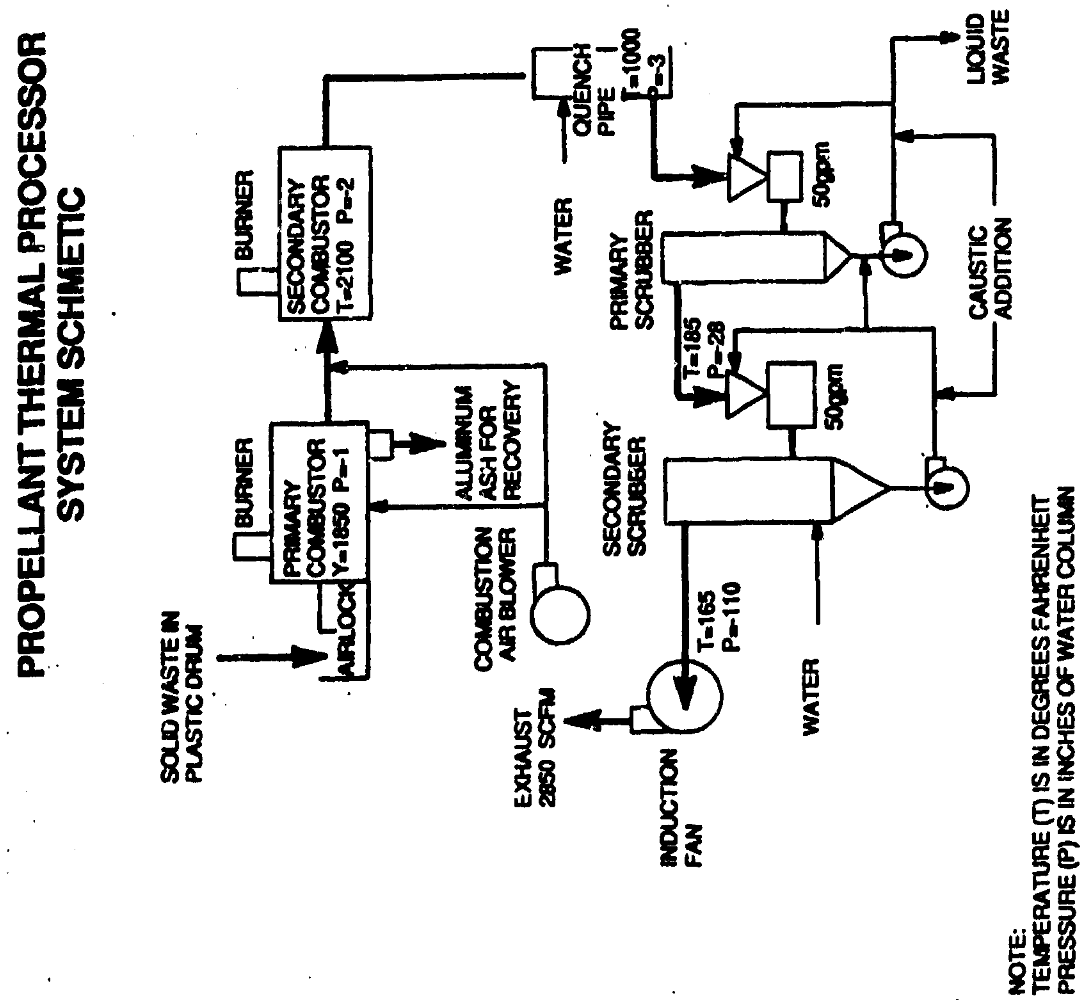

PROPELLANT THERMAL PROCESSOR
SYSTEM SCHMETIC
SOLID WASTE IN PLASTIC DRUM
AIRLOCK
BURNER
PRIMARY COMBUSTOR Y=1850 P=-1
BURNER
SECONDARY COMBUSTOR T=2100 P=-2
ALUMINUM ASH FOR RECOVERY
COMBUSTION AIR BLOWER
EXHAUST 2850 SCFM
INDUCTION FAN
T=165 P=-110
WATER
SECONDARY SCRUBBER
50gpm
T=185 P=-28
PRIMARY SCRUBBER
50gpm
WATER
QUENCH PIPE
T=1000 P=-3
CAUSTIC ADDITION
LIQUID WASTE
NOTE:
TEMPERATURE (T) IS IN DEGREES FAHRENHEIT
PRESSURE (P) IS IN INCHES OF WATER COLUMN

Figure 7.

PTP SYSTEM WITH AP RECOVERY
FEED PREPARATION FOR PROPELLANT WASTE

UNIT BASIS IS 1,000,000 POUNDS 1.3 PROPELLANT

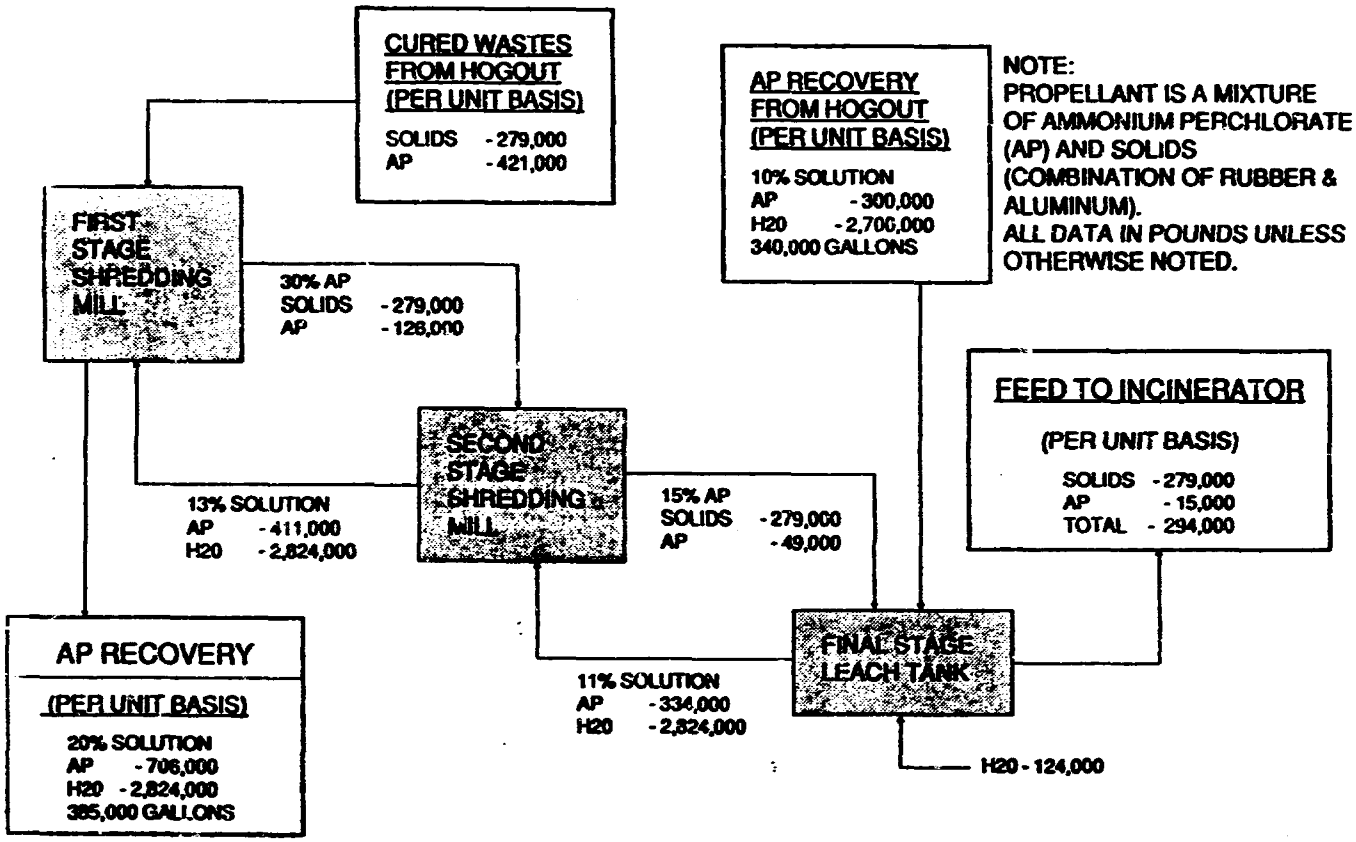


Figure 8.

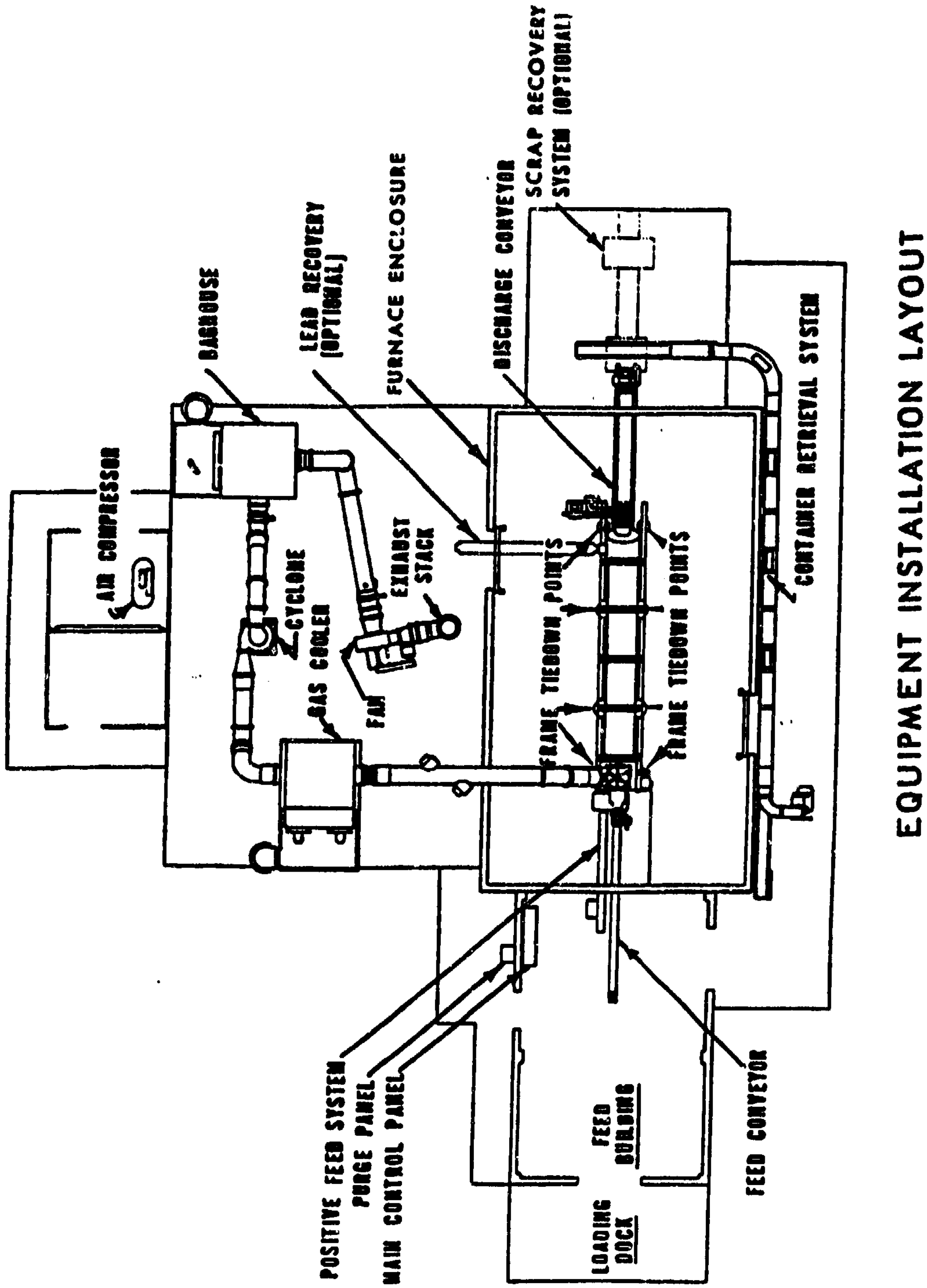

EQUIPMENT INSTALLATION LAYOUT
BAGHOUSE
AIR COMPRESSOR
CYCLONE
GAS COOLER
FAN
EXHAUST STACK
LEAD RECOVERY (OPTIONAL)
FURNACE ENCLOSURE
DISCHARGE CONVEYOR
SCRAP RECOVERY SYSTEM (OPTIONAL)
FRAME TIEDOWN POINTS
FRAME TIEDOWN POINTS
CONTAINER RETRIEVAL SYSTEM
POSITIVE FEED SYSTEM
PURGE PANEL
MAIN CONTROL PANEL
FEED BUILDING
LOADING DOCK
FEED CONVEYOR

Figure 9.

(4) Environmental Systems Company (ENSCO) Process

Environmental Systems Company (ENSCO), El Dorado, AR operates a Hazardous Waste Disposal Facility on a commercial basis. Two systems, fixed base and transportable are reviewed.

(a) Fixed Base System

The liquids wastes are pumped directly into the Thermal Oxidation Unit (TOU), a two chamber combuster, while solid wastes are fed into the two rotary kilns through a hopper/shredder/auger feed system. The kiln off-gases are passed through vertical cyclones where ash is removed and the ashless gases from the cyclone travel through a ductway to the first chamber of the TOU. The complete combustion is ensured by burning the effluent gases again in the second chamber of the TOU. In the scrubber, the gas streams are cooled to 200°F and acid gases are neutralized with a lime slurry. The gases exiting the top of the scrubber pass through the Venturi Jet for additional scrubbing to ensure removal of any remaining entrained particulates. Some of the pertinent physical combustion characteristics of the fixed based units are described as follows:

Fixed Base System	Operating Temperature	Retention Time
Rotary Kiln #1	1750-1900 F	3/4-1.5 hr (solids)
Rotary Kiln #2	1750-1900 F	1/2-2.0 hr (solids)
Primary Combustion	2200-2500 F	2.5 sec
Secondary Combustion	1800-2400 F	2.0 sec
Waste-Fired Boiler	1800-2400 F	2.0 sec

Figure 10 shows a process schematic for the "fixed base" system.

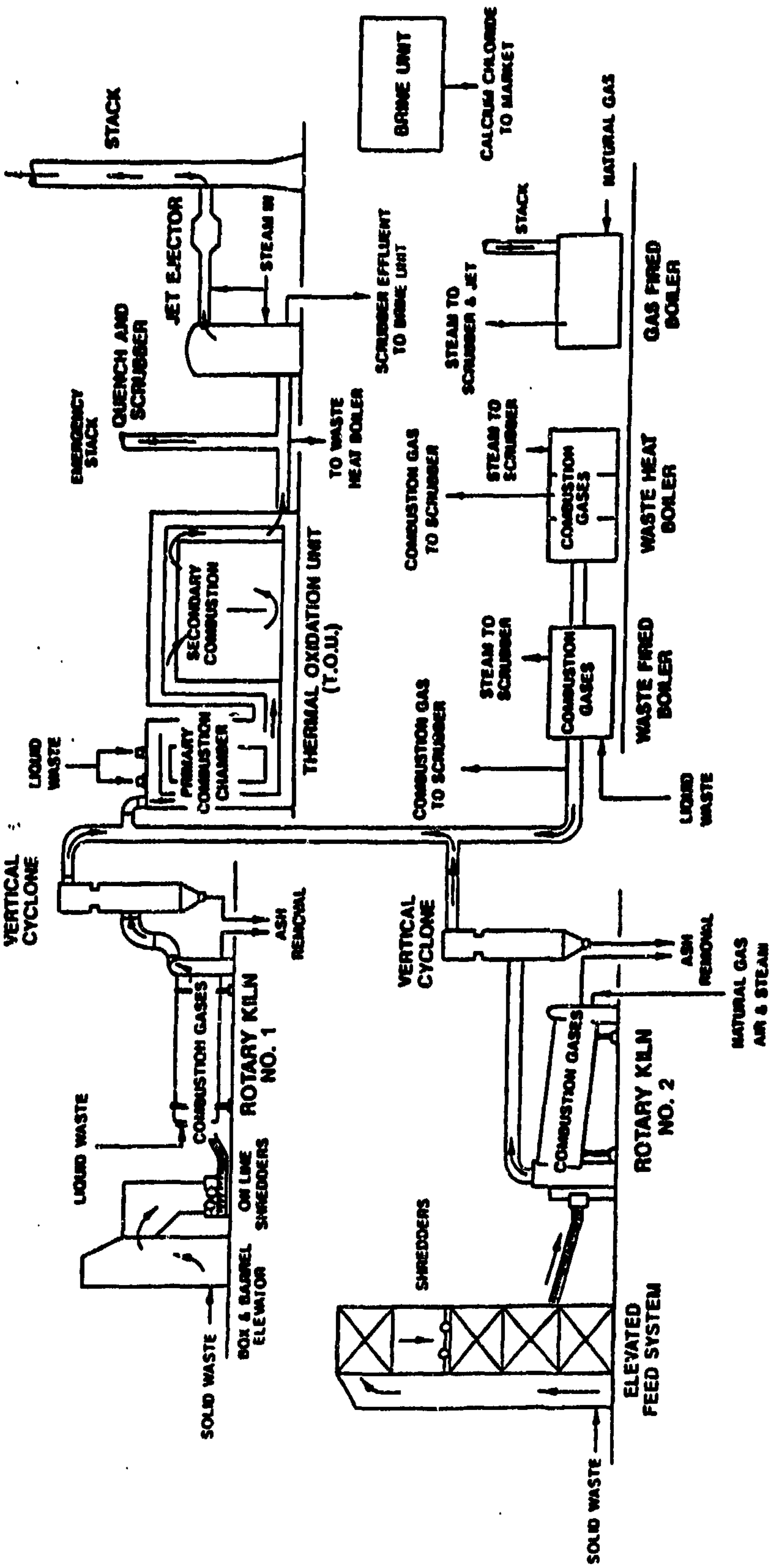
(b) Transportable System

The Modular Waste Processor (MWP) 2000 consisting of a rotary kiln, an afterburner, a waste heat recovery system, an acid gas neutralization and an air pollution control train, is a stand alone, transportable incineration system. At the ENSCO, the MWP 2000 operates independently except that it utilizes and depends on the waste receiving, the store, and scrubber brine clarifier units of the main fixed base facility. The process is similar to that of the main facility with corresponding pieces of equipment performing similar duties. The MWP 2000 processes 120,000,000 pounds/year of hazardous waste materials at an operating cost of approximately 1.00/lbs. Figure 11 shows the process flow diagram of the MWP 2000 System.

Limitations: The capability of processing energetic materials using these furnaces has not been proven.

(4) Fluidized Bed Incineration (FBI) Process

The FBI at Pine Bluff Arsenal incineration complex has a thermal



PROCESS SCHEMATIC INCINERATION SYSTEM

Figure 10.

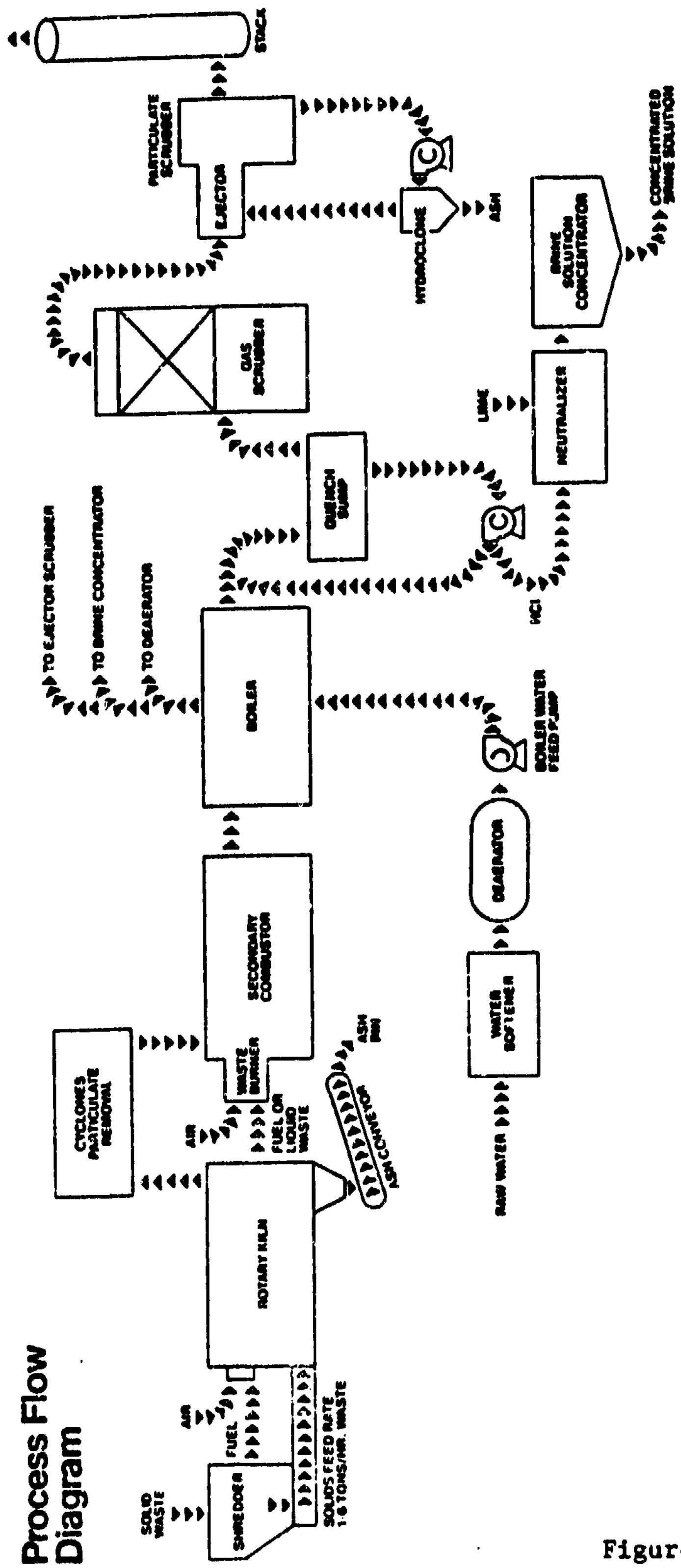

Process Flow Diagram
SOLID WASTE
SHREDDER
AIR
FUEL
SOLIDS FEED RATE 1.6 TONS/HR. WASTE
ROTARY KILN
CYCLONES PARTICULATE REMOVAL
AIR
FUEL OR LIQUID WASTE
WASTE BURNER
ASH CONVEYOR
ASH BIN
SECONDARY COMBUSTOR
RAW WATER
WATER SOFTENER
DEAERATOR
BOILER WATER FEED PUMP
BOILER
TO EJECTOR SCRUBBER
TO BRINE CONCENTRATOR
TO DEAERATOR
QUENCH SUMP
HCl
LIME
NEUTRALIZER
GAS SCRUBBER
BRINE SOLUTION CONCENTRATOR
CONCENTRATED BRINE SOLUTION
HYDROCLONE
ASH
EJECTOR
PARTICULATE SCRUBBER
STACK

Figure 11.

capacity of 26,000,000 BTU/hr. The FBI uses high velocity air to entrain solids in a highly turbulent combustion chamber. The bed media is 8 feet, expanded height, of silica sand. This thermal mass stabilizes the combustion temperature and allows for efficient heat transfer to the material being processed. Materials are fed into the FBI in liquid, slurry, or solid form. The combustion gas stream passes through a Cyclone Separator for removal of large particulates (5 microns), a gas quench tower and a variable throat wet venturi scrubber for removal of acid gases and fine particulates prior to discharge to the stack. Pine Bluff Arsenal is currently procuring a hydro-sonic scrubbing system that will remove particulates down to .02 micron size, which is well below the current environmental standards.

Limitations: The FBI technology is fully developed. The disposal of LRM propellants has not been demonstrated.

(5) Circulating Bed Combuster (CBC) Process

The Ogden Environmental Services Inc., San Diego, CA has developed a CBC which has evolved from the FBI technology. The main differences between the FBI and CBC is that the CBC has a lined cyclone separator in which the additional combustion is sustained, the larger feed materials separated and returned to the combustion chamber. The CBC uses high velocity air (14 to 20 ft/sec) to entrain and circulate solids in a highly turbulent combustion loop. The system design allows combustion along the entire length of the FBI, cyclone, and connecting loop. Due to its high thermal efficiency, the CBC is suited to treat feed with low heat content, such as contaminated soil.

Contaminated wastes are fed into the combuster at the loop seal section where it immediately mixes with hot recirculating material from the cyclone. The retention times in the combustor range from 1.5 to 2 seconds for gases to more than 30 minutes for larger feed materials (more than 1.0 inch in diameter). Hot flue gases and fly ash pass through a convective gas cooler and on to a baghouse where fly ash is removed. The clean solid such as soil in the bottom of the combustor bed is slowly removed by a water cooled ash conveyor system. Temperatures within the entire combustion loop (combustion chamber, hot cyclone, return leg) are maintained at 1800 ^{o}F. Figure 12 shows the process flow schematic.

Limitations: The technology is fully developed and operational. The disposal of LRM propellants has not been demonstrated. A propellant slurry feed system will have to be developed.

3. Past Experiments

Two technologies, reclamation and wet air oxidation, have been reviewed that may be applicable to the LRM demilitarization and disposal program.

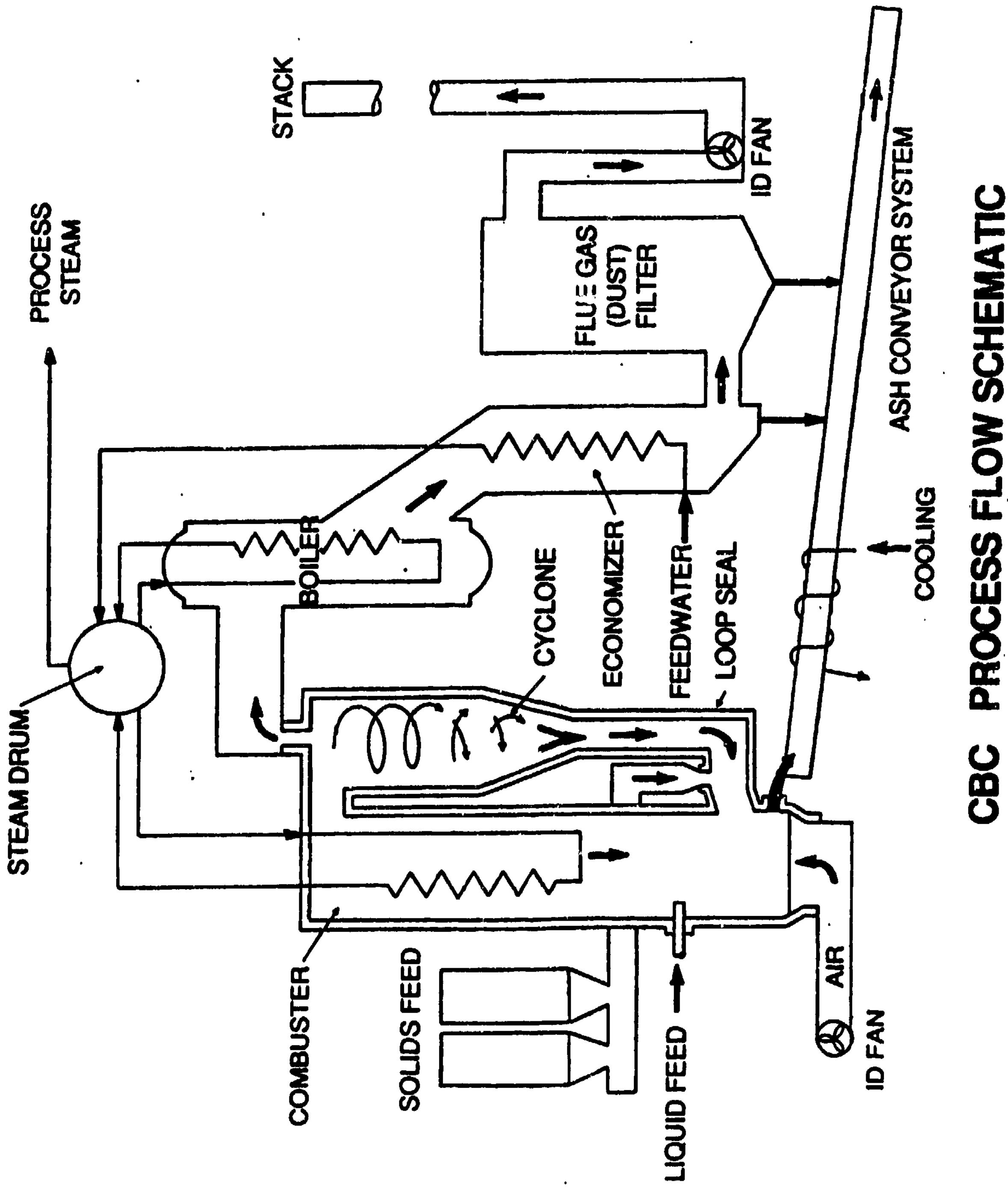

CBC PROCESS FLOW SCHEMATIC
PROCESS STEAM
STACK
ID FAN
FLUE GAS (DUST) FILTER
ASH CONVEYOR SYSTEM
STEAM DRUM
BOILER
CYCLONE
ECONOMIZER
FEEDWATER
LOOP SEAL
COOLING
COMBUSTER
SOLIDS FEED
LIQUID FEED
AIR
ID FAN

Figure 12.

a. Reclamation Technique - Hydraulic Macerator Solvation

The Thiokol Corporation, Brigham City, UT conducted a study in 1982 for the Air Force Wright Aeronautical Labs, Materials Laboratory, Wright Patterson Air Force Base (AFB), Ohio on solid propellant reclamation. The process extracts and recovers AP from the scrap propellant. Scrap propellant is charged into a hydraulic macerator where high pressure waterjets cut the propellant into small particles and extracts the AP into solution. The concentrated solution from the macerator is passed through a liquid cyclone and in-line filters to remove suspended solids and then cooled in batch crystallizers to precipitate the AP crystals. The AP crystals are separated from the cooled solution in a basket centrifuge and are recovered in a wet cake. The cooled water is reheated and recycled to the hydraulic macerator. Figure 13 and Figure 14 show a schematic diagram of the process and the hydraulic macerator, respectively.

Limitations: The through put was small. No further development is planned.

b. Wet Air Oxidation (WAO) Technique

The Navel Ordnance Station (NOS), Indian Head, MD, has investigated WAO as an alternative to open burning for the disposal of waste propellants and other energetic materials. The operation of WAO is based on an aqueous phase oxidation of energetic materials using heat and air in a high-pressure reactor. The materials most commonly oxidized in WAO are those which contain a large amount of water that cannot easily sustain combustion under conventional burning conditions. The waste sludge is ground under water to 1/4-inch size before entering the storage tank where it is preheated to $60^{o}C$ to $80^{o}C$. The feed stock is fed into the system by a positive-displacement high-pressure pump and mixed with an appropriate amount of air supplied by a compressor. The pressure of the system is maintained from 150 to 4,000 psig depending upon the fuel concentration. The mixture of air and feed stock passes through a series of heat exchangers to increase its temperature to about $200^{o}C$, the point at which oxidation will proceed spontaneously. Figure 15 shows the process schematic.

Limitations: The concentration and size of suspended solids has to be controlled for the process to function properly.

4. Emerging Technologies

Four emerging technologies, sub-critical fluids, biodegradation, super critical water oxidation, and energy recovery from controlled incineration, are selected for review as being applicable for the LRM demilitarization and disposal program.

a. Super/Sub-Critical Fluid Extraction Technique

The U.S. Army Missile Command (MICOM) Propulsion Directorate, Research

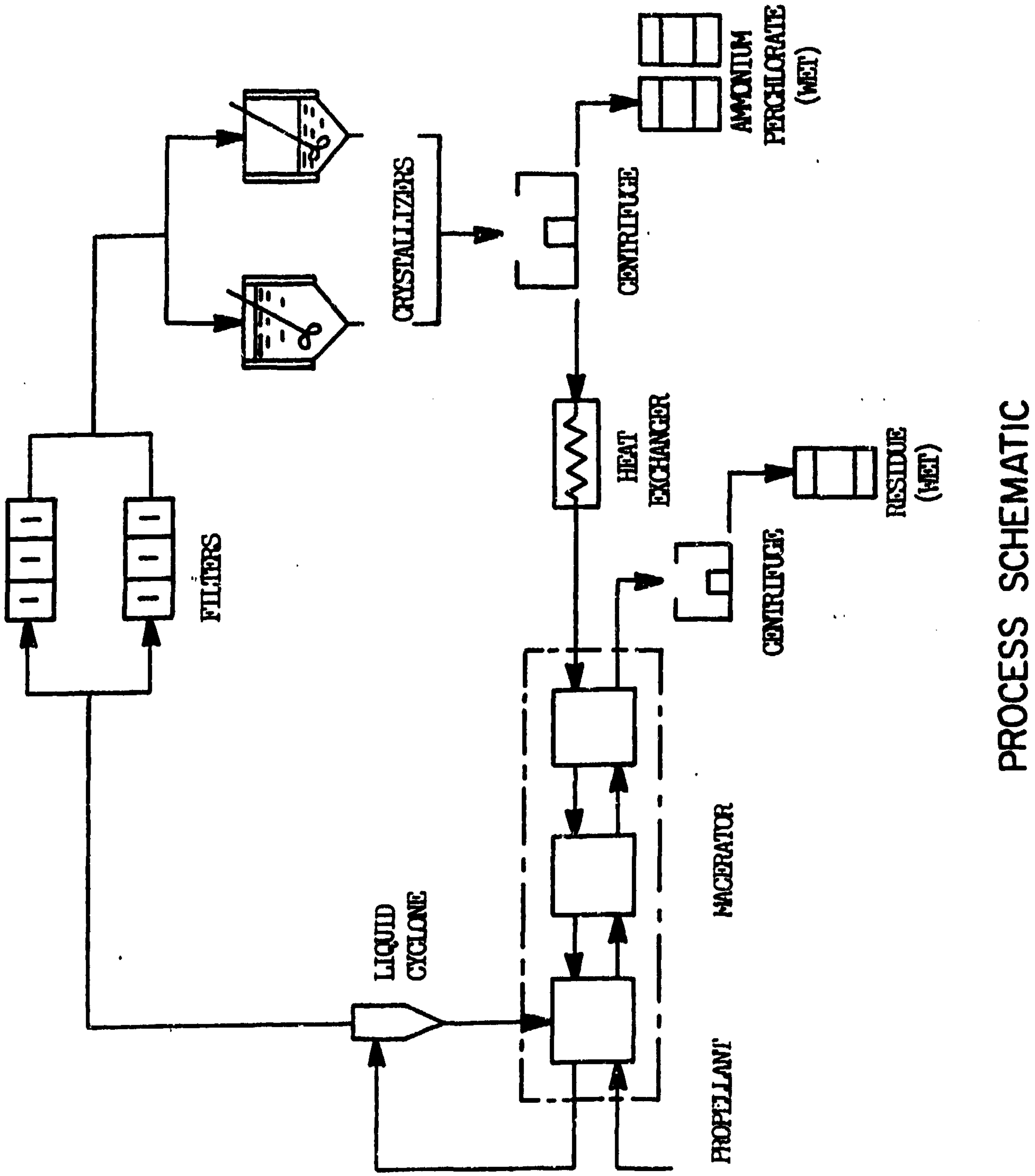

FILTERS
CRYSTALLIZERS
CENTRIFUGE
AMMONIUM
PERCHLORATE
(WET)
HEAT
EXCHANGER
CENTRIFUGE
RESIDUE
(WET)
LIQUID
CYCLONE
MACERATOR
PROPELLANT
PROCESS SCHEMATIC

Figure 13.

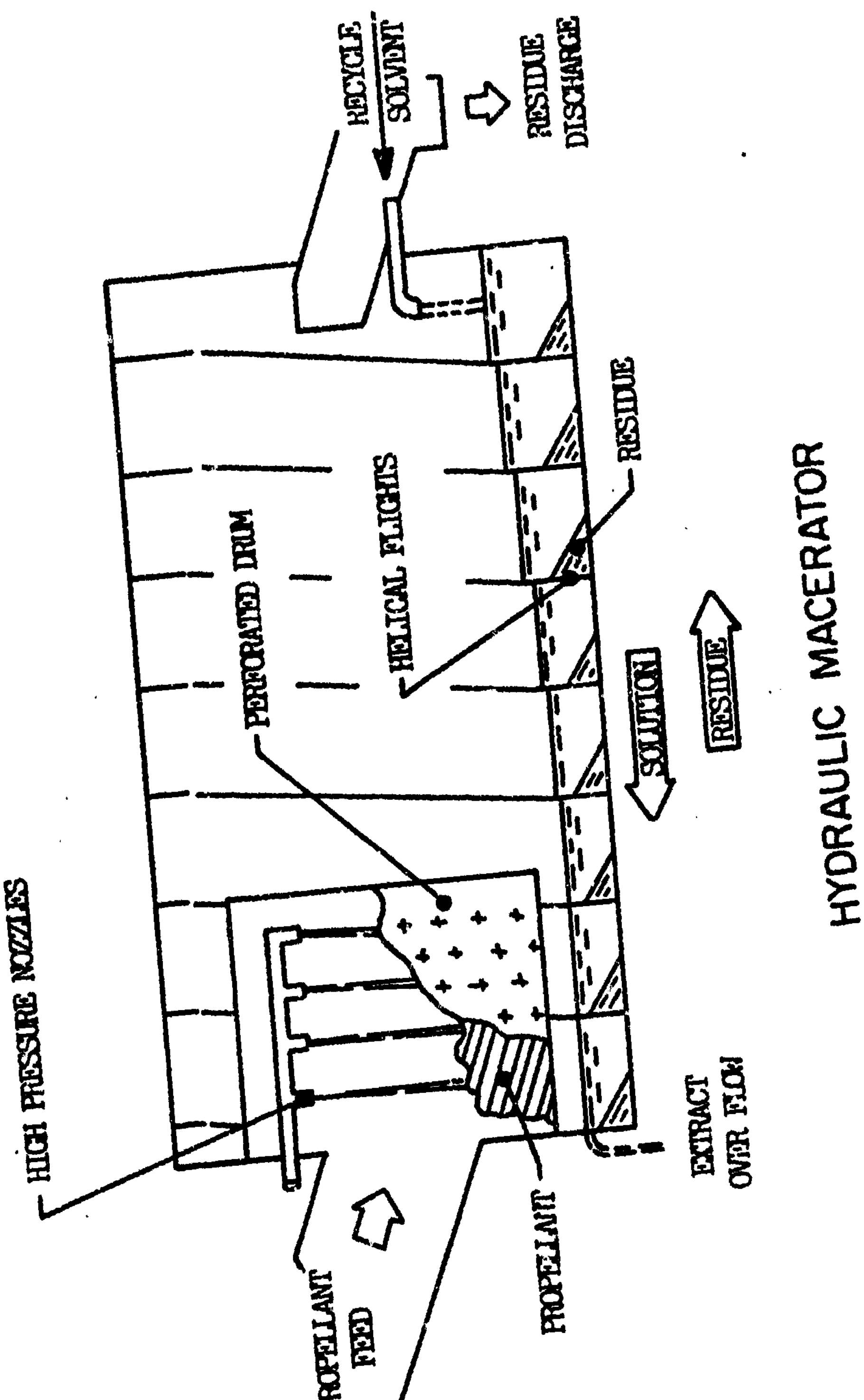

RECYCLE SOLVENT
RESIDUE DISCHARGE
PERFORATED DRUM
HELICAL FLIGHTS
RESIDUE
SOLUTION
RESIDUE
HIGH PRESSURE NOZZLES
PROPELLANT FEED
PROPELLANT
EXTRACT OVER FLOW
HYDRAULIC MACERATOR

Figure 14.

29

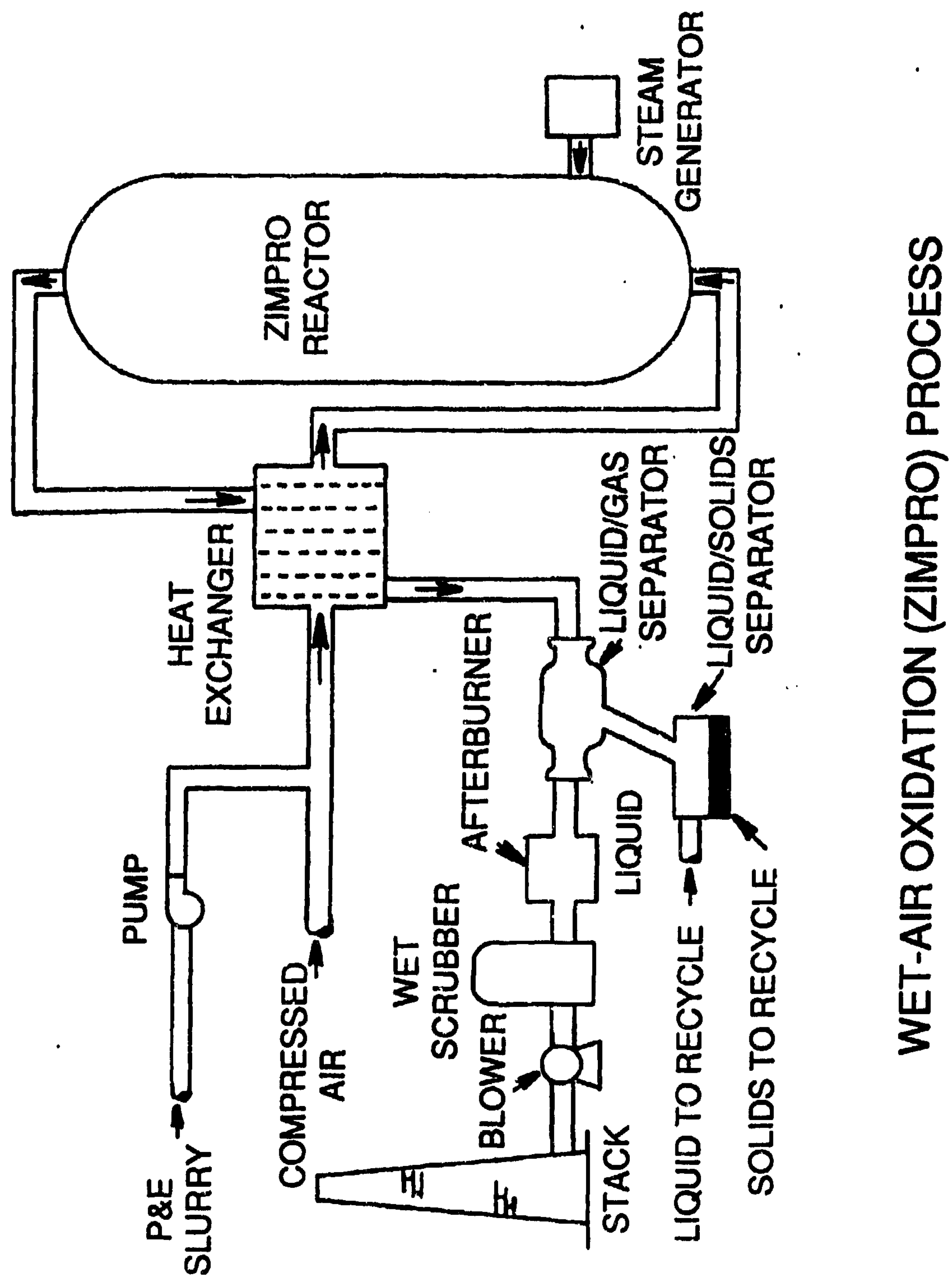

WET-AIR OXIDATION (ZIMPRO) PROCESS
ZIMPRO REACTOR
STEAM GENERATOR
HEAT EXCHANGER
PUMP
P&E SLURRY
COMPRESSED AIR
WET SCRUBBER
BLOWER
STACK
AFTERBURNER
LIQUID
LIQUID/GAS SEPARATOR
LIQUID/SOLIDS SEPARATOR
LIQUID TO RECYCLE
SOLIDS TO RECYCLE

Figure 15.

Development and Engineering Center, Huntsville, AL is conducting R&D to extract AP from the 1.3 solid propellant. This method takes advantage of the enhanced solubility characteristics of the super/sub-critical fluid and the phase transitions which occur during the compression and expansion of gases. Among the three gases, ammonia, carbon dioxide, and nitrous oxide, investigated the sub-critical liquid ammonia was found to be a super-solvent for the extraction of AP from the 1.3 solid propellant.

The rocket motor can serve as its own self-contained high pressure extraction vessel. The working solvent can be nozzle sprayed under sufficient pressure to erode and wash away exposed propellant surfaces.

Soluble propellant ingredients are extracted into the fluidized gas and separated by filtration from all undissolved materials. The dissolved propellant ingredients are recovered in a separation vessel during the liquid-to-gas pressure reduction cycle. The expanded gas, now devoid of all dissolved propellant ingredients, is filtered and re-compressed to the fluid state to complete the solvent regeneration cycle. Figure 16 shows a simple schematic diagram of the system.

Limitations: This process has been demonstrated in laboratory testing. A scaled up pilot study has yet to be proved. Continued R&D is required for final evaluation.

b. Biodegradation Technique

The Lummus Crest Inc., (LC), Bloomfield, NJ has been conducting bench scale laboratory work using White Rot Fungus (WRF) to biodegrade pink water. The process consists of first growing the WRF by bringing the microorganism into contact with a support medium, and letting the culture grow 5-10 days. The growth medium is then nitrogen starved for a period of 3-4 days. By giving the WRF only enough food to subsist, the LC has determined that the WRF culture would last 2-6 months.

The LC studied two compositions, TNT pink water at 150-220 ppm and 80°C, and RDX pink water at 20-86 ppm and 80°C. Two different mechanical devices, Rotating Biological Contactor and Packed Column Unit were used in their evaluation. The bench scale rotating biological contactor, shown in Figure 17, is a 7 inch by 20 inch horizontal cylinder divided into 4 equal compartments. It has a rotating shaft in the center with 8 cylindrical disks covered with the WRF cultures that are spaced to provide each of the 4 compartments with a pair of disks. The pink water is fed into the RBC until it is about 1/2 full and then the shaft is rotated to allow the 8 disks to alternately be wetted with pink water and then be exposed to the oxygen enriched air. Using a batch method, the LC, has successfully reduced the TNT pink water to 2 ppm in 24 hours and the RDX pink water to less than 10 ppm min 48 hours.

The bench scale packed column, shown in Figure 18, is a 5 inch by 12 inch vertical cylinder packed with plastic balls, approximately 3/8 inch in

LARGE ROCKET MOTOR DEMILITARIZATION PROGRAM
PROCESS FLOW DIAGRAM

CRITICAL FLUID EXTRACTION (CFE) PROCESS
FOR AMMONIUM PERCHLORATE MOTORS
USING LIQUID AMMONIA

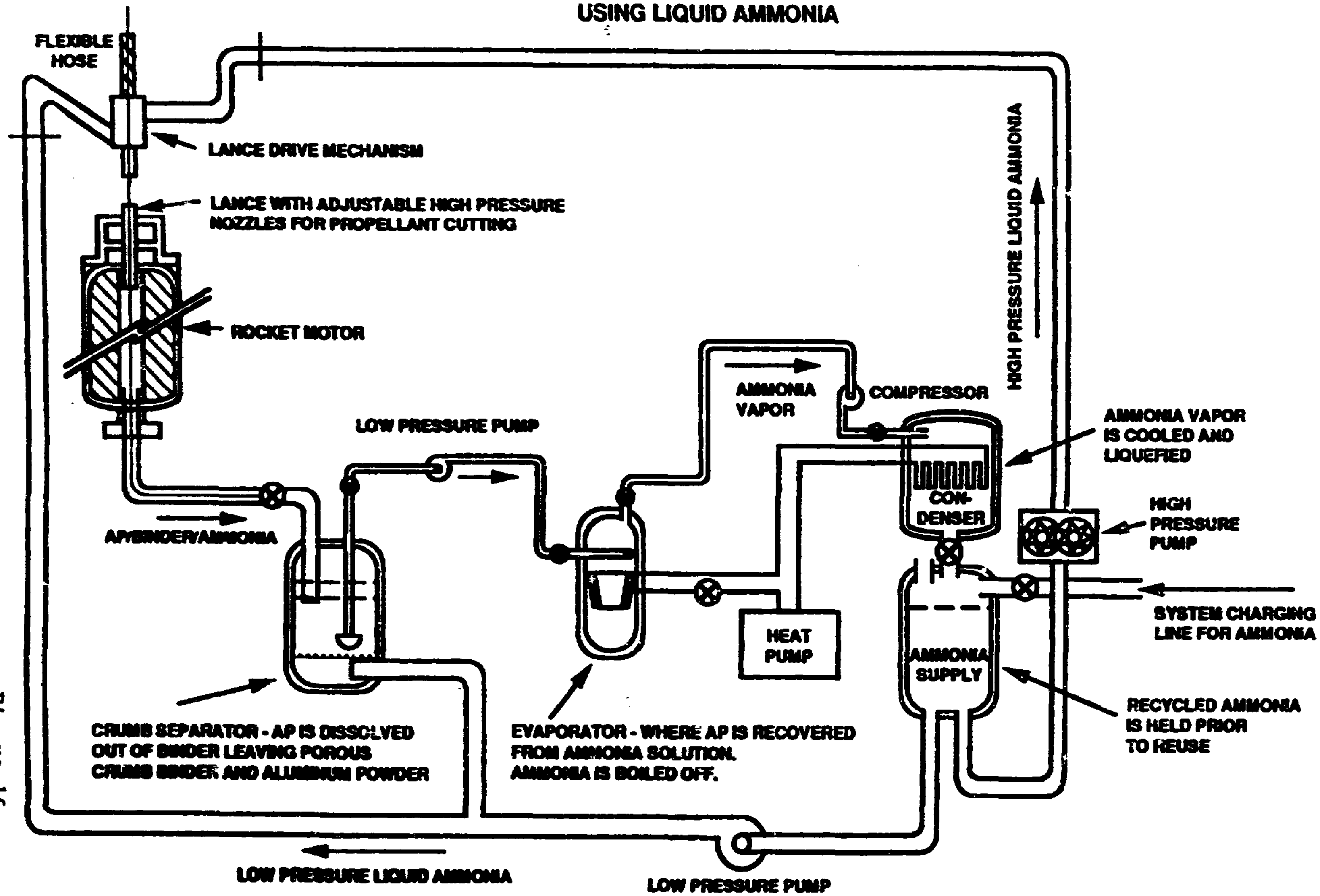
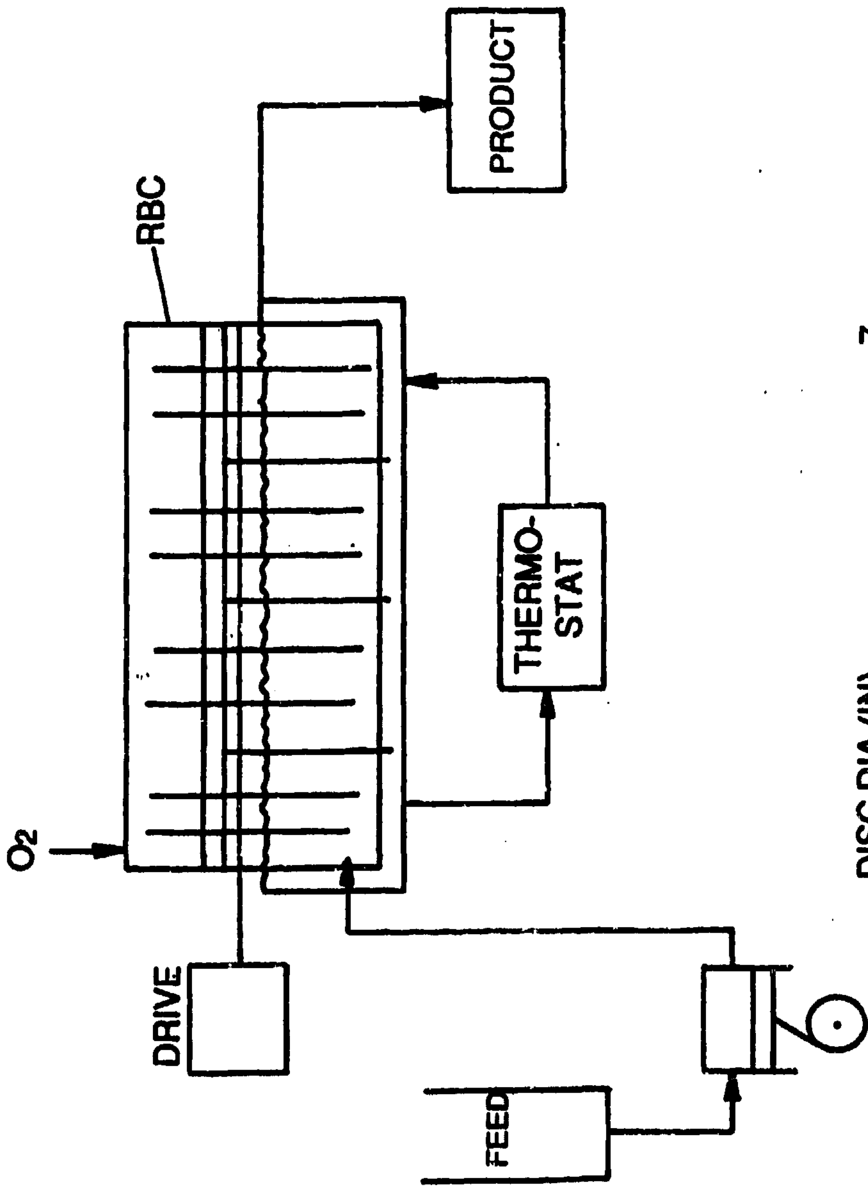


Figure 16.

RBC BENCH UNIT



DISC DIA (IN)	7
NUMBER OF DISCS	8
NUMBER OF COMPARTMENTS	4
RPM	9
TEMPERATURE (°C)	37
FEED FLOW RATE (cc/Hr)	40-85
LIQUID INVENTORY (cc)	2000

Figure 17.

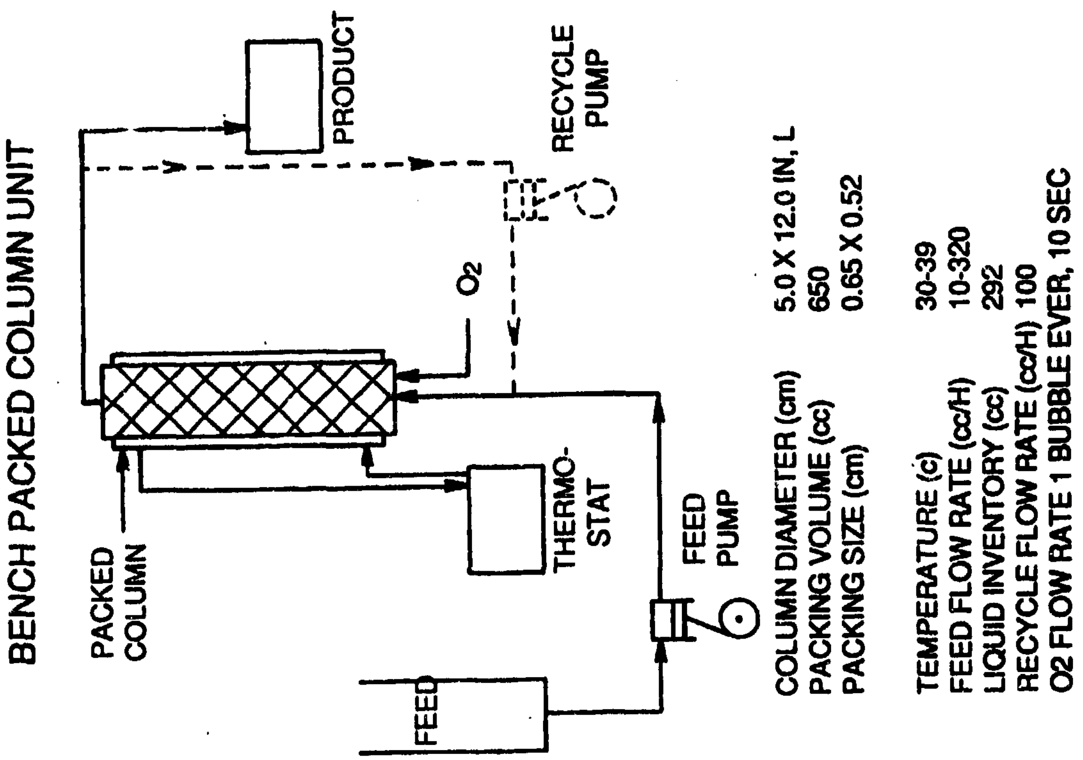

BENCH PACKED COLUMN UNIT
PACKED COLUMN
THERMO-STAT
FEED PUMP
FEED
O2
PRODUCT
RECYCLE PUMP
COLUMN DIAMETER (cm) 5.0 X 12.0 IN, L
PACKING VOLUME (cc) 650
PACKING SIZE (cm) 0.65 X 0.52
TEMPERATURE (c) 30-39
FEED FLOW RATE (cc/H) 10-320
LIQUID INVENTORY (cc) 292
RECYCLE FLOW RATE (cc/H) 100
O2 FLOW RATE 1 BUBBLE EVER, 10 SEC

Figure 18.

diameter, covered with the WRF culture. The method was tested by processing the pink water through the system at a low feed rate, and by recycling the feed material at a higher rate. Using the bench scale packed column, the LC has reduced the concentration of TNT from 100 to 20 ppm in 1 1/2 hours and to 3 ppm in 4 1/2 hours. Further experimentation is needed to confirm, (1) the activity of the WRF over an extended continuous operation with the pink water, (2) the activity of WRF with an outside carbon source and minerals, and (3) the RDX removal efficiency in a continuous operation.

Limitations: Applicability of the Lummus process for LRM demilitarization has not been determined. For explosives contaminated water (pink water), the process shows potential. The process has not been proven in scaled models. Continued R&D is required for final evaluation.

Special Note: The U.S. Air Force (USAF) Engineering and Services Center at Tyndall Air Force Base recently reported that the Manville Corporation presented preliminary evidence that development of a biological system is feasible for AP biodegradation.

c. Energy Recovery Technique

The U.S. Army Toxic Hazardous Materials Agency (USATHAMA), Aberdeen Proving Ground, MD, is developing a means to recover the energy from burning energetic materials in industrial boilers. A pilot scale (1.4 million BTU/hr) commercial boiler is in fabrication for this development. Mixtures of TNT or composition B with number 2 fuel oil and a solvent will be burned to produce steam. The process prove out will be conducted at WADF in the summer of 1990. Investigation of nitrocellulose as a supplemental fuel is also underway. Figure 19 shows a block diagram of a supplemental fuel system.

Limitations: Full scale testing is required to prove the process. The technology has potential in recovery of energy from waste energetic materials. The supplemental fuel method has not been investigated using the LRM propellants and R&D is required.

d. Oxidation Technique

The LC, Bloomfield, NJ conducted oxidation experiments, both high temperature and low temperature oxidation, on red water. The samples used for the experiments had a 14 percent dissolved substance with organic carbon content of 4 to 5 percent. For high temperature oxidation, the operating temperature was 400^{o}C with an initial oxygen pressure of 80 psig. The reaction time was less than 10 minutes with 82 percent total organic carbon destruction. For the low temperature experiment, the operation was at moderate temperature and atmospheric pressure. The reaction time was 4 hours with 92 percent total organic carbon removal.

SUPPLEMENTAL FUEL SYSTEM BLOCK DIAGRAM

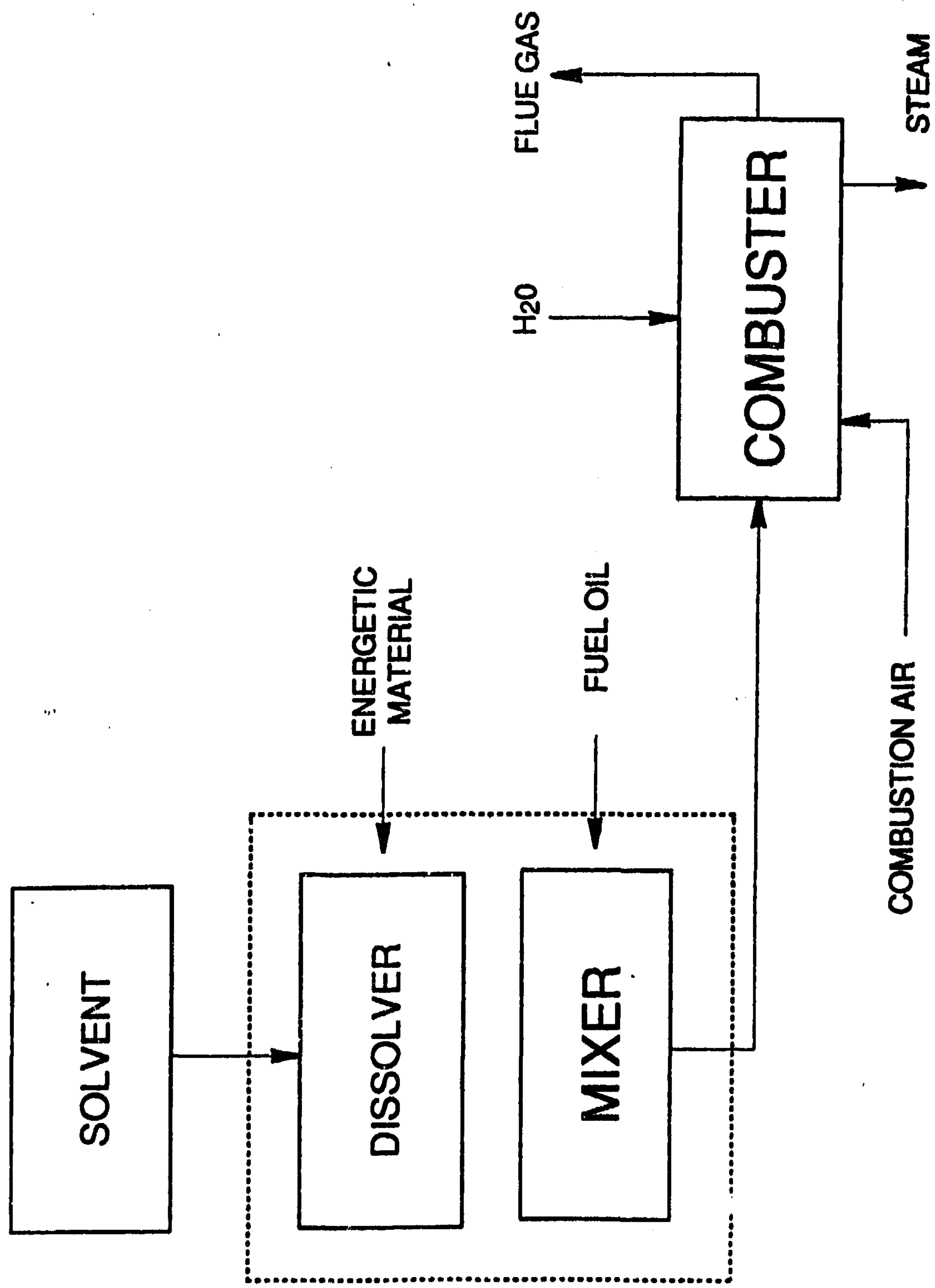


Figure 19.

Limitations: Application of the Lummus oxidation technology for the LRM demilitarization and disposal program has not been demonstrated.

Special Note: The USAF Engineering and Services Laboratory in conjunction with the Los Alamos National Laboratory, NM, and the Modell Corporation is conducting a bench scale supercritical water oxidation research to determine the feasibility of the technology for the destruction of propellants.

5. Conceptual Technology

Two technologies have been reviewed that may have potential for the LRM demilitarization and disposal program.

a. Confined Static Firing with Scrubber

The Lockheed Research Laboratory, Lockheed Missiles and Space Company, Palo Alto, CA conducted a study to determine alternate approaches to the disposal of solid rocket propellants. One concept proposed was the confined burning of the whole motor. The conceptual operation would consist of removing the nozzle from the motor case and burning the motor at ambient pressure. The effluent gas would be conducted through a large, 12 foot diameter pipe sloping downward into a water tank 40 ft deep. The gases would bubble up through the water tank through a series of perforated steel plates into a large, 60 ft high by 170 ft diameter, domed containment chamber. The scrubbed gases from this containment chamber would be conducted through a 6-7 ft diameter duct to the exhaust gas disposal equipment, which is not yet defined. Figure 20 shows a line schematic of the proposed concept.

Limitation: This technology is at conceptual stage. Estimated construction cost is over $100 million.

b. Cryogenic Fluid - Dry Washout Technique

General Atomics Technology and El Dorado Engineering jointly proposed to study the cryogenic fluid-dry washout process to remove propellant from large rocket motors. Liquid nitrogen is used as the washout medium. It is postulated that with cryo-washout there is no waste water stream that requires extensive treatment. The cryogenic fluid would be sprayed onto the surface of the propellant in much the same manner used in high pressure water washout. The cryogenic jet would embrittle the propellant and reduce its sensitivity to ignition or initiation. The embrittled propellant would be susceptible to brittle fracture with relatively small applied forces. For the most brittle propellant materials, the force of the cryogenic jet itself will likely be sufficient to erode the material. A nozzle system will be designed to deliver a high pressure cryogenic gas jet to the material surface. This approach would probably be the most efficient use of the cryogenic fluid, with little loss of liquid. If gas phase erosion is not sufficient, two-phase or liquid phase erosion may prove necessary, with some loss of excess liquid and efficiency.

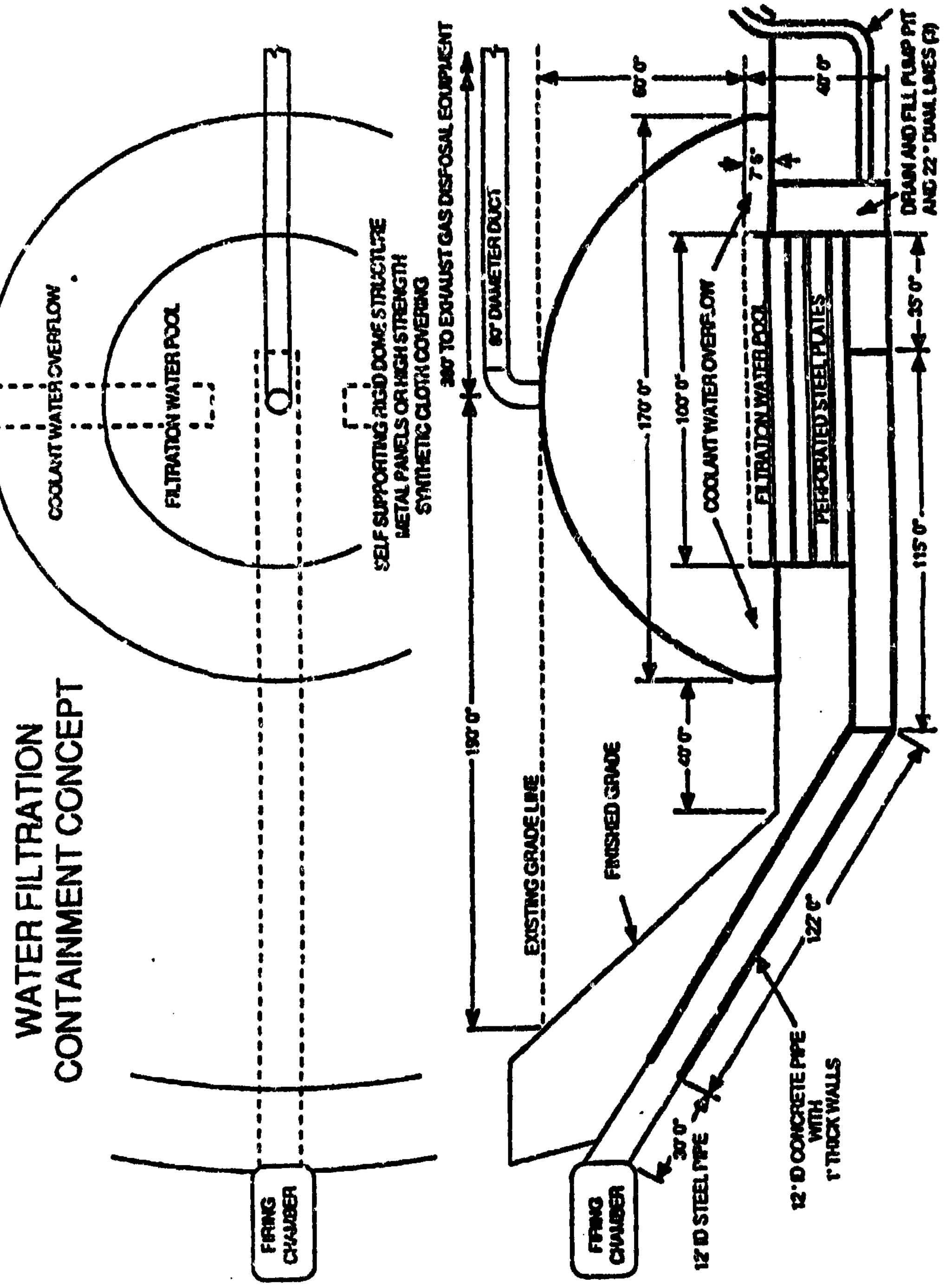

WATER FILTRATION
CONTAINMENT CONCEPT
COOLANT WATER OVERFLOW
FILTRATION WATER POOL
SELF SUPPORTING RIGID DOME STRUCTURE
METAL PANELS OR HIGH STRENGTH
SYNTHETIC CLOTH COVERING
FIRING CHAMBER
360° TO EXHAUST GAS DISPOSAL EQUIPMENT
60' DIAMETER DUCT
190' 0"
60' 0"
170' 0"
100' 0"
40' 0"
7'6"
COOLANT WATER OVERFLOW
FILTRATION WATER POOL
PERFORATED STEEL PLATES
DRAIN AND FILL PUMP PIT
AND 22" DUAL LINES (3)
35' 0"
115' 0"
EXISTING GRADE LINE
FINISHED GRADE
122' 0"
12' ID CONCRETE PIPE
WITH
1' THICK WALLS
30' 0"
12' ID STEEL PIPE
FIRING CHAMBER

Figure 20.

Limitations: The optimum flow rate and pressure of the cryogenic fluid/gas, the electrostatic discharge, and the removal efficiency would be investigated. Large quantities of nitrogen may be required for this process.

FUNDING REQUIREMENT

1. Introduction

In June 1989, the JOCG Munition Demilitarization and Disposal Subgroup provided Dr. Osterman's office a Consolidated Funding Requirement for R&D and Pilot Process Efforts for the LRM demilitarization and disposal program. The consolidated funding requirement was based on the R&D funding requests submitted by each service and the nongovernment research groups. Recognizing that some of the proposed R&D programs identified in the original consolidated funding requirement were overlapping, a more critical screening was exercised in evaluating and assessing the funding requirements for the demilitarization technology development efforts in this report. The R&D funding requirement identified in the cost analysis in this report correlates well with the funding requirements previously submitted by the services.

2. Limitations.

It is imperative and prudent to set limitations to what can be accomplished with the proposed fundings. The funding will support R&D work for LRM demilitarization and disposal, evaluate and assess to determine viability of R&D efforts, make fundings available to potential projects to further develop and conduct pilot scale operations, evaluate and assess to determine validity of pilot operation, and make recommendations for further action.

3. Discussion of Funding Requirement

The LRM demilitarization and disposal funding requirements are identified for the three major technology groups, existing, emerging, and conceptual technologies as shown in Table 1. These three main groups are further broken down into several subgroups which relate to specific processes. The funding requirements for the past experimentations are excluded from this report.

a. Existing Technologies

The existing technologies are those that could be assembled in the shortest possible time frame with a high confidence of success. These

TABLE 1 - FUNDING REQUIREMENTS FOR LRM DEMILITARIZATION/DISPOSAL PROGRAM ($MIL)

PRIORITY	PROGRAM	FY 91	FY 92	2 YEAR TOTAL
	EXISTING TECHNOLOGIES			
1	Solvation	0.600	0.650	1.250
2	Washout	3.200	3.075	6.275
3	Controlled Incineration	1.150	1.150	2.300
	EMERGING TECHNOLOGIES			
1	Reclamation	0.600	1.425	2.025
2	Controlled Incineration	0.150	0.150	0.300
3	Biodegradation	0.100	0.125	0.225
4	Oxidation	0.100	0.125	0.225
	CONCEPTUAL TECHNOLOGIES			
1	Confined Static Firing	0.250	0.500	0.750
2	Cryo-dry Washout	0.250	0.250	0.500
	OTHER	0.600	0.600	1.200
	TOTALS	7.000	8.050	15.050

Table 1

technologies have been proven by actual production test runs with full scale systems or test runs with scale model components. Limited system modification may be required of these existing components for the LRM demilitarization and disposal applications. The funding requirements for supporting R&D efforts for each technology group is given, followed by a brief description of the processes.

(1) Solvation Technique: Funding requirement is $1.25 Million. This group of technologies are those that use a liquid to extract major components of the propellant. Mechanical devices for the size reduction of propellants may be required to enhance the solvations process. A macerator and other types of size reduction mechanical devices should be investigated and evaluated for the non-water soluble, nitrocellulose/nitroglycerine propellants (1.1). The funding will also support the investigation of various liquids to establish solubilities and applicabilities in dissolving the 1.1 type propellants.

(2) Washout Technique: Funding requirement is $6.275 Million. This group of technologies are those that use some form of a liquid, usually water, under high pressure 100 to 50,000 psig to hogout the propellant from the LRM cases. Segments of the process equipment have been developed among several different firms, which if assembled in one place, could readily demilitarize the LRMs with AP composite propellant. If the waterjet washout technology (1000 lbs/hr/unit) at Thiokol was interfaced to the AP solvation reclamation and incineration technology that has been successfully demonstrated at Aerojet, it would be possible to demilitarize the LRM at a production rate in excess of 1,000,000 lbs/yr. This process can be scaled up for a greater production rate on demand. The AP and aluminium are the two major components reclaimed for recycling. Western Area Demilitarization Facility (WADF), currently in lay-away status, could accommodate the LRM demilitarization program with minimum modification. Funding will also support the proposed computer controlled waterjet washout systems similar to the one under development by the Naval Weapons Support Center (NWSC) at Crane.

(3) Controlled Incineration Technique: The funding requirement is $2.30 Million. This group of technologies are those that encompass all of the incineration processes. Funding will support development efforts for the advanced incineration techniques which will meet all environmental constraints in a cost effective manner. Currently, controlled incineration is the military's only proven method of disposing the doublebase propellants.

b. Emerging Technologies

The emerging technologies are those that are in the evolutional stages and are not currently matured enough to be used in the short term LRM demilitarization and disposal program. These technologies have shown possibilities in the laboratories and scale model testing and it is recommended that the research and development efforts be pursued at an expeditious pace.

(1) Reclamation Technique: Funding requirement is $2.025 Million. This group of technologies are those that extract valuable components from solid propellant. The Super/Sub Critical Fluid Extraction method has shown potential in the demilitarization of the LRM propellants. The AP is recovered from the solid propellant in the LRM. The residue is the aluminium powder and the binder compound in a sludge form. During the subsequent incineration of the residue sludge, the aluminium powder is recovered.

(2) Energy Recovery From Controlled Incineration Technique: The funding requirement is $0.3 Million. Incineration is mainly a destruction process. However, there is at least one known experiment conducted which recovers energy by supplementing the fuel oil with energetic materials such as waste explosives and propellants. This process has potential for extracting energy, in the form of heat, from the washed out propellants. Research effort should be pursued to develop an appropriate feed system for feeding the propellant slurry into incinerators.

(3) Biodegradation Technique: Funding requirement is $0.225 Million. This group of technologies are those that use microorganisms to decompose waste energetic material found in pink water. One technology that has shown potential is the use of White Rot Fungus to reduce the concentrations of TNT and RDX material in pink water. The biodegradation technology R&D should be supported for propellant disposal.

(4) Oxidation Technique: Funding requirement is $0.225 Million. This technology uses the induction of oxygen to speed the decomposition of energetic materials to inert chemical compounds such as carbon dioxide, carbon monoxide, nitrogen, and hydrogen. There are now three types of techniques under study, high temperature oxidation, low temperature oxidation, and wet air oxidation which show potential.

c. Conceptual Technology

(1) Confined Static Firing Technique: Funding requirement is $0.750 Million. This technique proposes the burning of LRMs into a confined chamber. Operation would consist of removing the nozzle from the LRM motor case and burning the motor at ambient pressure. The combustion gases are scrubbed by bubbling the gases through a water tank placed in a large concrete dome.

(2) Cryo-dry washout technique: Funding requirement is $.500 Million. This technology is a dry washout process in that it uses a liquid nitrogen spray to flake off the propellant directly in the LRM. The fragmented pieces of propellant will have to be further processed.

d. Other Techniques

The funding requirement is $1.2 Million. This funding is required to support development of new, innovative technology for the LRM demilitarization and disposal program.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

The Large Rocket Motor and Solid Propellant disposal inventory in the United States is steadily increasing. The rate of increases will continue, and in some instances, will be accelerating for some time. There is no single complete environmentally acceptable demilitarization technology and disposal system for the large rocket motors and propellants within the military organizations or in the industrial communities.

In March 1989, the Joint Ordnance Commanders Group (JOCG) tasked the chairman of the JOCG Munitions Demilitarization and Disposal Subgroup to develop a charter for the Joint Large Rocket Motor Demilitarization Office (JLRMDO) which will develop and implement a Department of Defense corporate Large Rocket Motor Demilitarization policy. The draft charter was presented to the JOCG at the Keyport, WA meeting in September 1989.

Nineteen large rocket motor demilitarization technologies and processes were reviewed and evaluated to determine the extent of the technical maturity and feasibility, engineering scale-up capability and process efficiency and funding required for research and development efforts.

The funding requirement to support Large Rocket Motor demilitarization technology development for FY 91-92 is $15.05 million. A two year research and development funding assignment for supporting the development efforts to investigate consolidation and expansion by the existing technology group is $9.825 Million. Funding for supporting the research and development and scale-up efforts by the emerging technology group is $2.775 Million. The funding of $2.45 million is assigned to the conceptual and other technology development efforts.

2. Recommendations

A funding of $15.05 Million for the first 2 years, FY 91 and FY 92 is recommended. This level of commitment is required to initiate a programmatic effort to support Large Rocket Motor Demilitarization Technology research and development work, support pilot scale study efforts, and conduct systematic evaluations of the validity of the research and development and the pilot study project.

It is recommended that the Large Rocket Motor Demilitarization Technology Development efforts be monitored carefully and coordinated judiciously in order to realize an expedient return for the capital investment.

It is recommended that a continued funding commitment be provided beyond the first two years to sustain the current research and development efforts and to achieve cost effective demilitarization and disposal of the Large Rocket Motors and Propellants.

REFERENCE

1. John L. Byrd, Jr. and Solim S. W. Kwak, LARGE ROCKET MOTOR DISPOSAL PROGRAM, Joint Ordnance Commanders Group (JOCG) Munitions Demilitarization and Disposal Subgroup, January 1990.

2. William Melvin, ARMY INVESTMENT PLAN FOR LRM DISPOSAL R&D PROJECT, U.S. Army Missile Command, Huntsville, AL, January 1990.

3. Mark Smith, AIR FORCE INVESTMENT PLAN FOR LRM DISPOSAL R&D PROJECTS, U.S. Air Force Engineering and Services Laboratory, Tyndall Air Force Base, FL, January 1990.

4. Dan Burch, NAVY INVESTMENT PLAN FOR LRM DISPOSAL R&D PROJECTS, Naval Weapons Support Center, Crane, IN, January 1990.

5. William Melvin, REVISED MILESTONE AND FUNDING REQUIREMENT FOR CRITICAL FLUID WASHOUT/EXTRACTION TECHNOLOGY, U.S. Army Missile Command, April 1990.

6. Dan Burch, REVISED MILESTONE AND FUNDING REQUIREMENT FOR THE NAVY LRM DISPOSAL R&D PROJECTS, Naval Weapons Support Center, Crane, IN, April 1990.

7. Leroy Throckmorton, REVISED MILESTONE AND FUNDING REQUIREMENT FOR STATIC FIRING WITH SCRUBBING, U.S. Navy, April 1990.

8. Mark Smith, REVISED MILESTONE AND FUNDING REQUIREMENTS FOR THE AIR FORCE LRM DISPOSAL R&D PROJECTS, Tyndall Air Force Base, FL, April 1990.

APPENDIX A

Consolidated Funding Requirement For Research and Development and Pilot Study for Large Rocket Motor Demilitarization

A-2

DEPARTMENT OF THE ARMY
US ARMY DEFENSE AMMUNITION CENTER AND SCHOOL
SAVANNA, ILLINOIS 61074-9639

REPLY TO
ATTENTION OF:

SMCAC-DO 15 JUN 1989

MEMORANDUM FOR Dr. Joseph V. Osterman, Director, Mission Enhancement Technologies, Office of the Director of Defense Research and Engineering, Washington, DC 20301

SUBJECT: Consolidated Funding Requirement for Research and Development (R & D) and Pilot Study for Large Rocket Motor Demilitarization

1. Reference:

a. Memorandum for Record, SMCAC-ESS, 12 June 1989, subject: Large Rocket Motor Demilitarization Program (enclosure 1).

b. Memorandum for Record, SMCAC-ESS, 13 June 1989, subject: Large Rocket Motor Demilitarization Program (enclosure 2).

c. Memorandum for Record, SMCAC-ESS, 13 June 1989, subject: Large Rocket Motor Demilitarization Program (enclosure 3).

2. The consolidated funding requirement has been identified as follows:

	Army	Navy	Air Force	Others*	Subtotal
FY 90	1.5 M	1.5 M	0.66 M	1.5 M	5.66 M
FY 91	2.0 M	2.0 M	0.95 M	2.0 M	6.95 M
FY 92	2.0 M	3.5 M	0.55 M	2.0 M	8.05 M
				Total	20.16 M

* Industry and academic research and development groups

3. Expenditure of this funding will deliver the following:

a. Make fundings available to large rocket motor demilitarization technology research and development work.

b. Evaluate and assess to determine viability of research and development work.

SMCAC-DO
SUBJECT: Consolidated Funding Requirement for Research and Development (R & D) and Pilot Study for Large Rocket Motor Demilitarization

c. Make fundings available to selected groups to further develop and conduct pilot scale study.

d. Evaluate and assess to determine validity of pilot study.

e. Make recommendation for further action.

3. Points of contact (POCs) are the undersigned, SMCAC-DO, and Dr. Solim S.W. Kwak, SMCAC-ESS, at AUTOVON 585-8901 and 585-8618, respectively.

3 Encls
as

for William T Ernst
JOHN L. BYRD, JR.
Director
Defense Ammunition Center and School

APPENDIX B

Large Rocket Motor

Demilitarization Office

Charter

JOINT LARGE ROCKET MOTOR DEMILITARIZATION OFFICE

CHARTER

27 JULY 1989

JOINT ORDNANCE COMMANDERS GROUP

MUNITIONS DEMILITARIZATION

AND DISPOSAL SUBGROUP

TABLE OF CONTENTS

CHARTER

I. DESIGNATION OF JOINT LARGE ROCKET MOTOR DEMILITARIZATION OFFICE (JLRMDO).

Pursuant to Joint Ordnance Commanders Group (JOCG) Task Directive 89-0301, Munitions Demilitarization and Disposal Subgroup, 10 March 1989, the Chairperson of the Subgroup is designated as proponent of the Charter for the JLRMDO. The JLRMDO will have the responsibility and authority to execute this Charter.

II. MISSION.

A. General: The JLRMDO will develop a Department of Defense (DOD) corporate solution for the demilitarization of large rocket motors. Large rocket motors are defined as service peculiar missile motors that are not included in the SMCA Charter. The JLRMDO will manage and coordinate the investigation, research and development (R&D), documentation, evaluation, and maintenance of the technology base to support the Large Rocket Motor Demilitarization Program. The JLRMDO mission is to develop solutions, recommendations, programs, and plans for large rocket motor demilitarization to ensure safe, economical, and environmentally acceptable demilitarization methodologies. The JLRMDO will represent and serve all Military Services, interfacing with other government agencies, academia, and industry. It will provide technology support to the Services and other participating organizations, act as a clearing house and focal point for large rocket motor demilitarization technology, and provide information for DOD program oversight to prevent duplication of effort. The JLRMDO will make recommendations for policy changes regarding the Large Rocket Motor

emilitarization Program and support budgetary requirements of the Military
Services to the Office of the Secretary of Defense (OSD). The JLRMDO will recommend policies that implement the standards and objectives of all Federal, State, and local environmental statutes impacting on the Large Rocket Motor Demilitarization Program.

B. Functions:

The JLRMDO will obtain forecast demilitarization/disposal assets, identify demilitarization capabilities, perform studies, tests, and prototype evaluations as requested. In addition, the JLRMDO will establish a focal point for coordination on interservice demilitarization efforts and support budget activities for technology development and execution of the JLRMDO program. The JLRMDO will obtain resources to support and maintain JLRMDO establishment. Typical functions include, but are not limited to:

1. Identify:

a. Short-term goals:

(1) Subpart "x" requirements of the Resource Conservation and Recovery Act (RCRA).

(2) Disarmament treaty requirements.

b. Short-term solutions: Funding sources and alternatives.

c. Long-term solutions: Institutional solutions.

2. Evaluation/Analysis/Assessment:

a. Analysis of technology (shortfalls).

b. Analysis of asset inventory.

c. Assess compatibility of long-term goals versus short-term goals.

d. Evaluate unsolicited proposals.

e. Consider, assess, and compare alternative operational approaches.

(1) Government-owned, Government-operated [GOGO].

(2) Government-owned, contractor-operated [GOCO].

(3) Contractor-owned, contractor operated [COCO]).

f. Evaluate requests for proposals (RFPs) and proposals contracts for supporting technology development.

g. Assess future demilitarization plans for new or modified rocket motors.

3. Maintain:

a. Environmental standards (including federal, state, local, and international codes and information sources).

b. Treaty agreements impacting large rocket motor demilitarization.

c. A demilitarization technology base.

4. Report/Publish:

a. Quarterly In-process Reviews (IPRs) to JOCG.

b. In-process Reviews to Joint Logistics Commanders, as required.

c. Requests for proposals.

d. JLRMDO Newsletter (technological breakthroughs, progress reports, points of contact (POCs), etc.).

e. Information/recommendations to treaty negotiators.

5. Interfaces:

a. Joint Army-Navy-NASA-Air Force (JANNAF)/Chemical Propoulsion Information Agency (CPIA).

b. Joint Ordnance Commanders Group Subgroups.

c. Environmental Agencies; all levels - federal, state, local, and international.

d. Other demilitarization groups.

e. Acedemia.

f. Industry.

g. Other governmental agencies.

6. Promote the interchange of demilitarization technology data on a national and international basis.

7. Plan for the transition or termination of the JLRMDO.

III. AUTHORITY AND RESPONSIBILITIES.

Delegation of authority to the JLRMDO is from the JOCG. The JOCG delegates the authority for monitorship of the JLRMDO to the JOCG Executive Committee. The JLRMDO is delegated the authority to work directly with OSD and Military Services in the execution of its mission. The responsibility of the JLRMDO is to develop a DOD corporate solution for the disposal of large rocket motors through the analysis of the projected workload and technologies that are applicable to the commodity.

IV. RESOURCE CONTROL.

The JLRMDO will ensure that dollar and manpower requirements to accomplish all assignments are developed and submitted IAW established DOD/JOCG manpower/funding channels and procedures. Internal operations budget of the JLRMDO is based on a fair-share approach. Resource requirements will be developed for inclusion in the Program Analysis Resources Review (PARR) for applicable target program years. Large Rocket Motor Demilitarization

Program requirements and funds are to be separately identified in budget submission by each Military Service and will be supported by the JOCG. The JLRMDO will support the defense of the budget at DOD level. Each Service retains technology development and budget execution. The Large Rocket Motor Demilitarization Program will be designated as a DOD Line Item to be developed and justified by each Service.

V. SUPPORT AND LOCATION.

The JLRMDO will be supported by a jointly staffed group of military and civilian personnel with technical and administrative expertise assigned and/or recruited from each Service to accomplish the JLRMDO mission. The organizational support structure is as follows:

A. General. The JLRMDO will be headed by a Director/GM-15/Colonel (minimum grade level) with an ammunition background. The JLRMDO will be a single element organization with no suborganizational elements.

B. Staffing Support. The U.S. Army (USA), U.S. Navy (USN), and U.S. Air Force (USAF) will each provide funding for their man-years of effort to support the JLRMDO. The JLRMDO will not be space/billet constrained. It will operate on a 'manage to payroll' principle. The U.S. Marine Corps (USMC) will provide technical support as required. Clerical support will be accomplished using temporary personnel. Service contracts will be used to procure specialized requirements.

C. Staffing Structure. The staffing will initially be 9 manyears of effort as identified below:

(1) Office Chief (GM-15 Program Manager 340-series/Military Officer 06-Rank, Ammunition Officer (not explosive ordnance disposal [EOD]).

(2) Clerical Personnel (Temporary).

(3) One USA Ammunition Missile Item Expert.

(4) One USN Ammunition Missile Item Expert.

(5) One USAF Ammunition Missile Item Expert.

(6) One Senior Research Chemist.

(7) One Chemical/Environmental Engineer.

(8) One Mechanical Engineer.

(9) One Program/Budget Analyst.

(10) One Logistics Management Specialist.

NOTE: Skills such as legal, safety, procurement, computer systems analyst, etc., will be procured on an as-required-basis.

D. Location. To be determined.

VI. ORGANIZATIONAL RELATIONSHIPS.

All DOD agencies which deal with large rocket motors and other government agencies with related interests will be participants in the JLRMDO. The JLRMDO will maintain communications with JOCG on Services' issues and programs, and will have direct access to the DOD for policy and funding. The JLRMDO will provide quarterly reports to the JOCG and progress reports to the Joint Logistics Commanders as the JOCG requires. The JLRMDO will have open access to all classified and unclassified data related to large rocket motors and will observe security/owner proprietary rights to such data. Unresolved major issues will be elevated to the JOCG Executive Committee. An executive OSD office will be assigned as the focal point for all JLRMDO actions and interfaces and is designated as Office Under the Secretary of Defense, Deputy Director Defense Research and Engineering

(Research and Advanced Technology) Environmental and Life Sciences (OUSD [R&AT] ELS). The JLRMDO has the authority to respond to OSD information needs and will inform Military Service POCs of information provided or requested. The JLRMDO interfaces and coordinates for reasons of policy, budget, technology, and operations with all related agencies. These include the Services, industry, allied nations, academia, Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), JANNAF Interagency Propulsion Committee, CPIA, Department of Energy (DOE), National Oceanic and Atmospheric Administration (NOAA), the States, State Department, OSD, Department of Defense Explosives Safety Board (DDESB), and special Project Managers (PMs).

VII. TIMEFRAME.

The timeframe for a concept discussed is shown below.

Charter Draft | Charter Staff | Authorization to Proceed

May 89 — Aug 89 — Nov 89 Brief JLC — Feb 90

Budgets - Travel
Issue - Computers
Housing - Moves
Job Descriptions
Recruit - Hire | Learning Curve Period | Execute | Termination

Feb 90 — Jun 90 — Jun 91 — Jun 93

VIII. TRANSITION AND TERMINATION.

The JLRMDO is programmed to operate 2 1/2 years after establishment. Its existence will be reviewed by the JOCG after its goals are met; i.e., establishing a corporate solution for long-range rocket motor demilitarization. When this goal is met, the JLRMDO will be terminated or will transpire into a permanent office. Termination/transition plan is required and will be developed as a task of the JLRMDO.

IX. FUNDING REQUIREMENTS.

An initial internal operations budget funding requirement is $1,000,000. This funding requirement is to be shared equally on a reimbursable basis by the USA, USN, and USAF. Each Service identified will transfer $333,000 to the JLRMDO initially for office establishment. This cost is based on location at a military installation that can provide base operations support. Base operation cost is dependent on location. The preponderance of costs are in support of research, development, test, and evaluation (RDTE) operations.

RISK MANAGEMENT-BASED APPROACH TO RANGE SAFETY

BY

LIEUTENANT COLONEL G BARKLEY
SECRETARY, AUSTRALIAN ORDNANCE COUNCIL
DEPARTMENT OF DEFENCE
CANBERRA

ABSTRACT

Many aspects regarding range safety are based on empirical or historical factors. The ever increasing public awareness of and concern regarding Defence activities, the mounting pressure upon existing range space and a more professional attitude by the Services towards maximising the safety of all aspects of munitions has contributed to an evaluation of the existing empirical range safety guidelines. A new scientific procedure for the determination of range safety criteria was developed under the auspices of the Australian Ordnance Council. An overview of this procedure is presented in this paper. Some other areas are examined, such as storage and transportation of explosives and the use of lasers.

RISK MANAGEMENT-BASED APPROACH TO RANGE SAFETY

INTRODUCTION

1. The use of a weapon of any type is always potentially dangerous, to different degrees, for those service and civilian personnel associated with the weapons use or in the vicinity of the weapons area of influence. As well as the uncertainties as to what the risks are involved, there is another factor which is the responsibility of all concerned (directly or indirectly), that is the legal 'duty of care' which mandates our involvement.

2. The current accepted and commonly used basis for determining range danger areas (two dimensions as in direct fire weapons) and danger zones (three dimensions as in air-to-ground and indirect fire weapons) is an anachronism in 1990. The current methodology implies that the range danger areas or zones are large enough to contain the potential danger from weapons use. There is no such situation however, as absolute safety on the 'safe' side of a weapons danger template or on the other side of the fence around a weapons range. What must be known is the acceptable risk a service person may be exposed to achieve the operational or training objectives as well as protecting other non-involved service and civilian persons in the vicinity. What should be remembered is that people are exposed to different risks and levels of risk every day and night, and that sometimes service persons are exposed to greater risks necessitated by the nature of their employment.

BACKGROUND

3. The current operation of the Australian Defence Force weapons ranges is based upon the implicit understanding that range boundaries are sufficiently large so as to ensure that:

   a. persons outside designated boundaries are not subjected to risk of injury or death, and that property beyond those boundaries is not damaged when firings are undertaken; and

   b. persons within designated boundaries and outside safety templates can operate and fire weapon systems, individually or in concert, with no risk of injury or death.

4. The concept thus implied is one of absolute safety based upon the use of an absolute danger area (or danger zone if danger to aircraft in the space above is also to be included).

5. In view of this situation, the Australian Ordnance Council (AOC), the Australian Department of Defence governing body charged with providing advice on Service safety matters, initiated a review of Australian range safety policies and procedures in 1984 to determine their applicability for service Defence and community needs for the present and the foreseeable future. This task was placed on the Ballistics Coordination Committee (BCC); the committee of the AOC responsible for the detailed consideration of ballistic related/range safety matters. The three sequential stages to this review were:

a. determine the basis for current range safety procedures,

b. assess their applicability to current and future needs; and

c. if found wanting, develop new scientific procedures which realistically take into account current and future Defence and community needs.

6. The AOC review identified problems with the use of this absolute safety concept, some of the more salient ones being that:

a. The assessment of many of the effects of weapon system operations, on which danger areas or zones depend, were based on ad hoc methods, personal experience and, in some instances, post accident investigation - scientific methodology has been conspicuous by its almost total absence! Many other safety doctrines were traced back to British War Office publications of circa 1900 - their relevance to present day range safety needs is questionable to say the least.

b. Measures taken to ensure safe training of Service personnel and/or operation of Service equipment had, to some extent, been over-emphasised such that the training became unrealistic and its value and effectiveness diminished.

c. Procedures used to determine danger areas or zones between Services had been inconsistent and non-uniform. It should be noted that similar situations have been acknowledged to exist in other countries' Defence Forces.

7. Clearly this was a most disturbing and unsatisfactory state of affairs in respect of range safety determination, it did not inspire confidence but rather raised the spectre of legal complications and difficulties.

8. The AOC review identified the need for a rigorous scientific basis for the determination of danger areas/zones which incorporated all significant inputs (whatever they should be), whilst acknowledging explicitly areas of uncertainty and gaps in knowledge, and which would allow range boundaries to be determined consistent with any specified level of accepted risk. In other words, replace the old 'black and white safe/unsafe, worst case' concept of absolute safety with a more realistic risk management approach based on allowing for intermediate levels of risk other than that perceived as safe/unsafe. The ability to determine levels of risk would allow more realistic training to be undertaken and/or allow the use of economically valuable land which would otherwise be contained within an existing range boundary.

NEW APPROACH TO RANGE SAFETY

Development of the New Approach

9. The Central Studies Branch of the Department of Defence was tasked by the AOC to develop a new scientific procedure for the determination of range safety criteria, deemed necessary by the AOC review. Certain of the assumptions underlying the theoretical development of a new procedure were that:

a. weapons systems perform in accordance with specifications (ie. no defects in the system),

b. normal range discipline applies, and

c. there will be no negligence on the part of any individual involved in the firing.

10. It should be noted that the research conducted and the resultant papers [1, 2 and 3] are working documents only, forming a basis for the AOC BCC to develop a Pillar Proceeding on Range Safety, which should be issued in October 1990.

11. In order to more easily understand the essentials of the theoretical model a simplified review is presented. The simplifying assumptions are:

a. the use of a flat range surface,

b. a maximum of one ricochet only, and

c. no fragmentation of the projectiles.

Methodology Overview

12. The basis of this new approach to range safety is to develop and use risk contours. To evaluate risk contours the distribution of the final impact point is required. An overview of the methodology leading to the determination of this distribution follows.

13. **Risk Contours.** A risk contour is a curve enclosing an area such that the probability (or risk) of a projectile landing outside this area (where it is assumed it could have a catastrophic effect on an individual) has a predetermined value. Hence to each level of risk that may be of interest there is a corresponding contour.

14. **Determination of Final Impact Distribution.** As it is assumed that only one ricochet is possible, we have two cases to consider:

a. the projectile flight terminates at first impact (ie. without ricochet), or

b. the projectile flight terminates at second impact (ie. after one ricochet).

15. **Impact Distribution (No Ricochet).** It is assumed that the launch distribution is known (ie. the variation in elevation angle, azimuth angle and muzzle velocity). Using this the impact distribution (ie. the variation in impact point and velocity at impact) can be determined using the projectile flight equations.

16. It can be seen that the impact distribution is completely determined by the launch distribution and flight equations.

17. **Impact Distribution (Ricochet).** The direction and speed of the projectile immediately after ricochet depends on the

direction and speed of the projectile immediately before impact. Since the distribution of the first impact (input to ricochet) has already been determined the distribution of the ricochet output (ie. the variation in direction and speed immediately after ricochet) can be found.

18. The remaining step is to determine the final impact distribution. This can be expressed in terms of the distribution of the ricochet output using the ricochet flight equations.

19. The distribution of the final impact is completely determined by the launch distribution, flight equations (for first flight and ricochet) and the conditional ricochet distribution.

20. **Final Impact.** The final impact distributions for the ricochet and no ricochet cases are now combined (using the probability of ricochet) to give the distribution of the final impact.

21. **Final Impact Point.** The distribution of the final impact point is derived from the distribution of the final impact by 'integrating out' the velocity components.

22. **Essential Inputs.** The essential inputs to the process of determining the distribution of the final impact point are:

a. Launch Distribution.

b. Flight Equations for Projectile (for first flight and ricochet flight).

c. Probability of Ricochet Given Input Vector.

d. Conditional Ricochet Distribution for the Ricochet Output Given the Ricochet Input.

23. **Issues not Included Above.** In keeping with this simple review, issues such as fragmentation, non flat ranges, non standard meteorological conditions and most importantly the risk to an individual were not discussed in this overview. However the theoretical model does provide the framework for dealing with these issues. For instance, in theory, risk contours can be determined where the risk relates not to the probability of finding a projectile or fragment in a given zone but to the risk of an individual being hit in that zone, however further work needs to be done to develop a usable methodology for the calculation of such risks. Fragmentation modelling is another area where further work needs to be done.

INTERNATIONAL REVIEW/INTEREST

24. Over the period 1987 to 1988, the AOC became aware that its concerns on range safety were shared by other non-NATO and NATO nations alike. Acquainting these nations with the AOC work elicited a favourable response and the possibility of its adoption and use. Accordingly, under the auspices of the United Kingdom Ordnance Board, the First International Conference on Range Safety was convened in London in May 1989. The objective of this conference was to subject the AOC work to international scrutiny and if acceptable, to propose its adoption as the basis for the first uniform and internationally accepted methodology for the determination of range safety.

25. At the Second International Conference on Range Safety in London in March 1990, the prevailing international views were expressed by the Vice President of the Ordnance Board in the following terms:

a. There is a need to move towards common danger area templates, particularly for the same weapon system when used in the same country; and

b. In regard to the future introduction of a probabilistic approach to range safety, there is a need to understand the risks involved and to be able to justify range areas. The risks need to be quantified and criteria for tolerable levels of risk established. This approach would enable range danger areas to be defined that take into account the nature of the environment and specified levels of protection for the public. It would also allow flexibility to make informed changes if necessary. The need for a common approach and way forward was emphasised, as was the need for the free exchange of information, collaboration and perhaps the sharing of costs on expensive trials. [4]

26. This viewpoint was endorsed by nations attending and attested to by the acknowledged legal consequences arising from failure to have such a methodology in place.

27. The tangible results arising from these two conferences were that:

a. the United States is in the process of adopting risk based management principles as standard range safety policy and practice;

b. a Memorandum of Understanding (MOU) is being negotiated between Australia, the United States and the United Kingdom for the collaborative development and implementation of the Australian methodology on risk management based range safety principles; and

c. the United States, using the Australian methodology, will be producing the first risk management based range safety criteria for 0.50 inch ammunition by September 1990.

CURRENT STATUS

28. Since the inception of the AOC work in 1984, progress has been increasingly rapid and is continuing to gain momentum. International acceptance is being progressed and further international collaboration in the development of the methodology is being negotiated by means of an MOU.

What Has Been Achieved

29. The following aspects of the scientific method have been achieved:

a. A theoretical model capable of handling many range circumstances has been developed.

b. A prototype computer program which calculates probabilities of hitting given areas on a range has been produced.

c. The theoretical model with the prototype computer program requires only short execution times.

30. At this stage, two essential aspects of the method are prohibiting it from being progressed further, namely the availability of:

a. adequate data inputs for the program, and

b. satisfactory models for ricochet behaviour and post-ricochet flight.

Future Development of the Method

31. For the future development of the method the following aspects will need to be considered [5]:

a. **Smoothing.** Investigate the theoretical and computational aspects of smoothing the raw output from the firing programs, specifically to provide a suitable method for smoothing and determine the different amounts of smoothing required.

b. **Confidence Limits and Error Analysis.** Development of appropriate techniques for conducting an error analysis and for assigning confidence limits to the probabilities or contours produced by smoothing the program outputs.

c. **Statistical Analysis of Ricochet.** Evaluation and comparison of existing statistical models of the output of ricochet with one another and available data, and possibly develop new models, in order to find a suitable representative of ricochet in the firing programs. No modelling of the mechanics of ricochet is intended: attention will be focused on statistical relationships between the outputs (such as impact speed, angles and nature of the surface) and the outputs.

d. **Sensitivity Analysis.** Extend the analyses already completed [3].

e. **Probable Longer Term Work.** The following are longer term goals:

(1) Risk definitions should be based on probability of an injury or damage.

(2) Ricochet models incorporating correct post-ricochet drag laws and the treatment of realistic range topography be developed.

RELATED AREAS FOR THE USE OF RISK-BASED MANAGEMENT

32. There is an increasing use of risk management in almost all fields where safety of personnel and materiel necessitate an informed judgement on the acceptance of potential risks offset against the benefits this method and the costs of the status quo. The knowledge and/or acceptance of risks associated with every day activities, both voluntary and involuntary and individual and societal risks, is preparing the way for the greater application of risk management methodology in the community, industry and the services. A key difficulty with a risk management method is the acceptance of

a level of risk for an activity by the appropriate authorities, with the knowledge that an incident can occur at any time, regardless of the risk level being accepted.

Explosives Activities

33. The application of risk-based management to explosives activities has been in operation in varying degrees for many years. The Swiss adopted a risk assessment method for explosive storage in the mid 1960s and other countries such as Germany, Norway and France have also adopted the method in varying degrees. The United Kingdom has been assessing for a number of years the application of risk assessment in the storage and handling of explosives as compared to the simple damage-related basis of the NATO storage rules (Q-D tables) [6].

34. It seems the largest problem in the application of this method to explosives activities is the scarcity of historical data on the levels of risk presented by explosives [6] This and other difficulties however do not overshadow the significant potential advantages in adopting a risk-based method. The main advantages are:

a. **Cost Savings** - in the more efficient use of existing explosives facilities and avoidance of unnecessary expansion.

b. **Credibility** - in the Service, government and public arena as a tool for presenting a complex technical case and because it presents risk from explosives on the same basis as the risks from more familiar and generally better understood hazards in general industry.

c. **Management Tool** - for use by all involved in explosives activities as it is based on a quantifiable method, risks are accepted and the ramifications understood or at least acknowledged including the legal 'duty of care'.

Laser Equipment

35. The application of risk-based management to the use of lasers in fire control, ranging, guidance and training systems is becoming the recognised way ahead for a number of countries, despite the fact that all national laser safety standards are based on a deterministic approach. The United Kingdom Ordnance Board Military Laser Safety Committee has adopted a risk-based method since 1988 [7] which is also being

assessed for application in Australia. Much preparatory work has already been conducted by the Australian Ordnance Council Defence Laser Safety Committee and the Defence Science and Technology Organisation [8,9] as a basis for introducing laser safety risk-based management to the Department of Defence. It is also likely that the next generation of national laser safety standards will recognise the risk-based management method and allow for its use in certain situations.[9]

CONCLUSION

36. In 1984, a new approach to the construction and use of range safety danger areas using risk-based range safety management criteria was commenced to:

a. realistically address and reconcile the conflicting operational, commercial and community pressures arising from the acquisition and/or use by the Services of ranges to satisfy training needs;

b. lead to significant savings in new Service training land requirements and/or the more effective utilisation of existing ones, whilst providing a more realistic training environment for the Australian Defence Force; and

c. replace the extant range safety determination principles (the majority of which are of unknown origin and/or validity, non-uniform and contain inherent and unquantifiable errors and therefore are legally flawed in fulfilling the Services' 'duty of care' obligations), by one based on firm and documentary scientific principles with legal validity.

37. The theoretical model provides a basis for the development of risk contours for any weapon in any terrain subject to the availability of appropriate data. And therein lies the main obstacle to its practical use in the near future, the current dearth of relevant data; for example data on launch distributions, ammunition ricochet and fragmentation, essential in any range safety work. The collation of this and other data is not an insurmountable task, it is simply a matter of commitment of time and resources and is currently being progressed jointly by Australia, the United States of America and the United Kingdom.

REFERENCES

1. A L Pope, 'A General Method of Calculating Probability-Based Risk Contours for Firing-Ranges'. Working Paper RANSAF1, Central Studies Branch, Australian Department of Defence, Canberra, 1988.

2. A L Pope, 'Practical Methods for the Numerical Calculation of Probability-Based Risk-Contours for Firing-Ranges'. Report for the Australian Ordnance Council, 1989.

3. A L Pope, 'Sensitivity of Probability-Based Risk-Contours to Variation of Parameters'. Report for the Australian Ordnance Council, 1989.

4. International (..Second..) Range Safety Conference 13-14 March 1990, Record of Activities and Decisions. Ordnance Board file reference D/OB/2200/5/2 of 2 April 1990.

5. Visit Report - 'Visit to Picatinny Arsenal 30 April - 4 May 1990' by Dr A L Pope. Presented at AOC Ballistics Coordination Committee meeting in Canberra, 29 May 1990.

6. N J M Rees and J Henderson, 'Risk Assessment in the UK MOD Explosives Activities'. Proceedings of Australian Department of Defence Australian Ordnance Council 2nd Explosives Safety Seminar, Canberra 1987.

7. Joint Service Publication 390 (UK): Military Laser Safety.

8. J A Hermann, 'Probabilistic Evaluation of Laser Hazard Zones'. MRL Report MRL-R-981, Materials Research Laboratory, Maribyrnong, 1986.

9. D R Brighton, 'Laser Safety on Ranges'. MRL Technical Report MRL-TR-90-13, Materials research Laboratory, Maribyrnong, 1990.

DEMILITARIZATION ALTERNATIVES TO OPEN BURNING/OPEN DETONATION (OB/OD)

PRESENTED BY: MR. ED ANSELL
U.S. ARMY DEFENSE AMMUNITION CENTER AND SCHOOL
Savanna, IL 61074-9639

(VG-2) There is growing concern within the U.S. Army that the Department of Defense (DOD), federal, or state environmental protection agencies may in the future, restrict or limit the practice of OB/OD of munitions and explosives. As the Single Manager for Conventional Ammunition (SMCA) field operating element, the U.S. Army Armament, Munitions and Chemical Command (AMCCOM) has the responsibility to oversee the demilitarization of the services excess and obsolete ammunition. This responsibility includes developing technology, equipment, and processes, as well as management of the demilitarization inventory. Technology funding constraints, however, have severely limited these efforts. Several independent studies over the past decade, as well as new demilitarization technology efforts, have been explored to determine if more efficient methods are available for the demilitarization of ammunition. The U.S. Army Defense Ammunition Center and School (USADACS) located in Savanna, IL was tasked to accomplish a study that identifies alternative methods or technologies to OB/OD.

The Demilitarization Technology Office, AMSMC-DSM-D, of AMCCOM has a parallel study in process at Dugway Proving Ground (DPG) that is to be used in petitioning the federal and various state environmental protection agencies (EPA) to continue OB/OD as a demilitarization method. In addition, USADACS has completed a parallel study covering large rocket motor (LRM) demilitarization. These studies will not be covered in this paper.

(VG-3) The demilitarization account, also known as the B5A account, consists of 4,476 separate national stock numbered (NSN) items. These items have been divided into 80 separate families and 14 consolidated families to assist in the comparison of technologies. The U.S. Army Defense Ammunition Center and School has developed the capability to provide detailed analysis of the inventory by various methods. Some of these methods are a direct result of the conversion of the Joint Ordnance Commanders Group (JOCG) Demilitarization/Disposal Handbook, Volume I, Demilitarization/Disposal Inventory (Orange Book) and JOCG Volume III, Reclamation of Materiels and Weights, to dBase files. This conversion provides quantifiable inventory information to perspective technology developers that was previously impossible, due to the matrix of variables such as the 16 distinct material types and 78 major fillers.

(VG-4) A historical review of the demilitarization inventory reveals that there was over 220,000 short tons of materiel in 1981. The quantity dipped to a low of 155,000 short tons during 1985. This drop was achieved through an aggressive Department of the Army (DA) funding effort. The inventory has since grown to over 200,000 short tons today. Current trends indicate that there is an annual generation of approximately 20,000 short tons.

(VG-5) Comparing the 1986 inventory with the 1989 inventory, there is an obvious drop in the quantity of smokes and dyes. This is attributed to the successful development and implementation of the white phosphorus - phosphoric acid conversion (WP-PAC) plant. There has been an increase in the quantity of munitions in the bombs, torpedoes, CBUs, depth charges, rockets and missiles, and HE-loaded projectiles.

(VG-6) The 31 December 1989 demilitarization inventory may be shown by the relationship between the explosive or reactive filler and the inert material. This type of information is necessary because the composition of filler normally drives the technology development. The quantity and type of filler often drive the technology development and could determine the possible return on investment through reclamation.

(VG-7) This same analysis may be performed not only on the entire demilitarization inventory, but may also be used to understand the material types and quantities or filler types and quantities in the individual consolidated families. An example of this is the consolidated family of HE-loaded projectiles. In this example, the materials that are most prevalent in this consolidated family are: heavy steel - projectile body, wood - packing material, light steel - cartridge case or tracer, fiber - inner container, mixed metal - fuze with booster, and brass - primer.

(VG-8) The fillers of the consolidated family of HE-loaded projectiles are more complex. They consist of single base propellant, Comp B, Comp A-3, double base propellant, triple base propellant, TNT, explosive D, tetryl, black powder, and HC smoke among others. As can be seen from the chart, the single base propellant is by far the most extensive filler in the HE-loaded projectile consolidated family at 3,400 short tons followed by Comp B at 1,576 short tons.

(VG-9) There are several factors that influence the technical solutions to the disposal of munitions in the demilitarization account. These include the planned base closures of several locations that store munitions and the retrograde of stocks from the Federal Republic of Germany (FRG). These actions may create a shortage of available storage space and will mandate an increase in demilitarization. Demilitarization by OB/OD, even if fully funded, could not dispose of all the items. There are some munitions that cannot be safely destroyed by OB/OD and must be demilitarized using other technology. These items include hand grenades, improved conventional munitions (ICMs), smokes, dyes, and pyrotechnics. Newer ammunition or ammunition that is under development by the Services may require new technology such as the copperhead or ammunition containing depleted uranium. Other factors that will influence the demilitarization of ammunition is the increased emphasis on the environment by the DOD, other governmental agencies, and various other organizations.

(VG-10) This report was accomplished in three phases. The approach to phase I was to review, compile, and maintain a database of existing studies and reports. This includes 11 previous demilitarization or disposal studies, 28 reports from the Defense Technical Information Center (DTIC) that were applicable to this study, and 60 technical reports from various sources.

Phase II consisted of on-site visits to DOD/industry/academia. Included in these on-site visits were 16 to Government facilities and 12 to industrial or academia locations. Phase III consists of analyzing the emerging technologies against the demilitarization stockpile and the needs of the technology.

(VG-11) The technologies identified have been divided into 11 categories in order to compile, evaluate, and prioritize them. These categories are: washout, meltout, reclamation, controlled incineration, disassembly, electrochemical reduction, chemical conversion, detonation chamber, super/subcritical fluid extraction, oxidation, and biodegradation. A description of each of the families and their members follows:

(VG-12) The washout family has been divided into four distinct technology groups. They are hot water, high pressure, solvent, and cryogenic dry wash. The hot water technology is comprised of two existing processes. These processes are the ammunition peculiar equipment (APE) 1300 washout plant designed by the Ammunition Equipment Directorate (AED), Tooele Army Depot (TEAD) and used for hot water washout of TNT and RDX fillers. The hydraulic cleaning system which is located at the Western Area Demilitarization Facility (WADF) is used for removing explosive D from Navy munitions. The high pressure technology group consists of two existing "hogout" processes that are used for removing ammonium perchlorate (AP) propellant from LRMs. These processes are located at the Thiokol Corporation, Brigham City, UT and Aerojet Solid Propulsion Company, Sacramento, CA. These hogout processes use a combination of solvation of the AP and high pressure waterjet erosion of the binder material to remove the propellant. A third existing hogout process is located at WADF and is designed for removal of explosive A-3 from projectiles.

An emerging high pressure washout process is the Waterjet Ordnance and Munitions Blastcleaner with Automated Tellurometry (WOMBAT). This system was developed by the University of Missouri at Rolla for the Naval Weapons Support Center (NWSC), Crane, IN. This system is designed for the removal of PBX (plastic bonded RDX) from projectiles. The process consists of an automated state-of-the-art system for maneuvering the waterjet lance through a variety of different geometries encountered inside munitions that have internal plumbing. Before this system can be put into production usage, computerized waterjet operational procedures must be developed for each type of munition and the sensitivity of the various explosive fillers to the high pressure waterjet must be determined.

(VG-13) Solvent washout is another group in the washout family. These processes are related by the fact that they all dissolve a component of the filler in order to perform removal. The toluene process was a feasibility study conducted by AED. This process used toluene to remove Comp B from projectiles. The chemical hazards and flammability of toluene has been deemed inappropriate for further studies of this solvent for this process.

The methylene chloride and methanol system was designed and tested by NWSC, Crane for use in recovering ingredients from aircraft parachute flares. The pilot plant proved successful, but has never been scaled up to an operational facility due to economic considerations. The Naval Weapons Support Center, Crane developed a similar system using water as the solvent to reclaim aluminum from photoflash cartridges; it too was never scaled up to an operational facility. A similar process has been tested using a high flash point solvent to remove and reclaim ingredients from infrared flares.

The Naval Weapons Support Center, Crane has under development two similar processes for removal of PBX fillers using a solvent. The first is a 60 percent methanol and 40 percent methylene chloride solvent blend for dissolution of the binders that are used in the PBX series of fillers. These solvents exhibit low toxicity, are reasonably priced, and have a flash point in excess of 100 degrees Fahrenheit. Bench scale testing has been completed on different PBX compositions. Bench scale and pilot plant testing, economic analysis of solvent extraction/ingredient recovery methods has yet to be accomplished.

The other effort currently underway by NWSC, Crane in conjunction with El Dorado Engineering is the solvent extraction of PBX materiels. This automated system will feature mutli-solvent storage, solvent distillation and recycling, and process water disposal. Lab scale testing has been completed on different PBXs with bench scale testing extended through Fiscal Year 1991 (FY 91).

(VG-14) A conceptual method to remove energetic materiel from projectiles and rocket motors has been proposed by General Atomics, San Diego, CA. This conceptual method involves applying a cryogenic liquid to the surface of the filler. This liquid causes the surface to cool rapidly, thus causing thermal stress in the materiel. The thermal stress will cause the material to develop fractures. Preliminary tests indicate that a mechanical method in combination with the cryogenic liquid may be necessary to remove AP propellant from the motor case.

(VG-15) The meltout family is comprised of methods that remove the energetic materiel by applying heat to the filler causing it to melt and flow out. This family consists of three discrete technologies; they are autoclave, steamout, and heating. These technologies are described further in the following text.

The autoclave process transfers heat to the meltable explosive filler by applying steam to the metal casing. In the ideal situation, the steam condensate would be kept separate from the melting explosive so that a hazardous waste is not created and the condensate could be reused. There is a full scale production autoclave facility at WADF that is in layaway. This facility was intended to be used to meltout TNT or TNT Comp B. The WADF process was initially developed by the AED at TEAD. An operating autoclave is located at Ravenna Army Ammunition Plant (RVAAP). This autoclave is older and allows commingling of the melted explosive and the condensate. The contaminated water that is produced because of this is treated on-site in a charcoal filter system prior to discharge.

Another type of meltout technology is steamout. Steamout is similar to the autoclave process, except in steamout the steam is applied directly to the explosive. This direct application of steam to the explosive is a more efficient heat transfer system than the autoclave, and thus reduces the time necessary for meltout. The direct application of steam to the explosive produces contaminated water that must be processed through a charcoal filter prior to discharge. Although this method does produce some explosive contaminated water, it produces less than the hot water washout technology.

Several steamout facilities exist in the continental United States. Two facilities where on-site visits were conducted are located at Crane Army Ammunition Activity (CAAA) and WADF. The facility at CAAA is prepared to operate, while the facility at WADF is in layaway.

Two other heating methods have been tested and produced limited success. They are induction heating and microwave meltout. Induction heating is a technique that operates on the principle of friction and eddy currents induced by an electric current. Although this method obtains the most rapid heating, it also has a high potential for creating hot spots. Microwave meltout was tested on 500- and 750-pound bombs. This technique was not considered successful due to uncontrollable heating which created hot spots within the tritonal filler.

(VG-16) The technologies grouped in the reclamation family all provide a product that may be recovered. A solvation process has been tested by Thiokol Corporation on AP propellant extracted from LRMs. The propellant is placed in a hydraulic macerator where high pressure waterjets cut the propellant into small parts and extract the AP into solution. The AP may be recovered from solution and the binder destroyed by other means. A pilot plant developed by Aerojet Solid Propulsion Company, Sacramento, CA has demonstrated that some of the components may be recovered from AP solid rocket propellant. In the process, the AP is extracted from the propellant after it is removed from the motor casing. The remaining material which consists of binder, aluminum, and a small percent of AP are incinerated in the propellant thermal processor (PTP). The initial incineration produces an aluminum ash which may be recycled. The second stage incineration is done on the gaseous effluents from the initial incineration. This combustion destroys any organics that remain from the first stage incineration. The effluent is further scrubbed to meet existing EPA regulations. The brine produced from this scrubbing is deep well injected.

The conversion technologies manufacture a marketable product from a munition filler that is considered a raw material. This process was demonstrated by NWSC-Crane using red phosphorus as the raw material and converting it to phosphoric acid. There is a production facility at CAAA which converts white phosphorus (WP) to phosphoric acid. The WP to phosphoric acid conversion (WP-PAC) plant incinerates the raw material WP in a modified AFE 1236 to form phosphorus pentoxide. The phosphorus pentoxide is drawn through a hydration system where it is combined with water to form phosphoric acid. This process has been vary successful in reducing the amount of WP in the demilitarization inventory.

There are two emerging recovery technologies in the reclamation family. These technologies are both under development by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). The first process involves reuse/reblending of single-, double-, or triple-based propellants as an alternative to thermal destruction. This technique processes the propellant for reintroducing into the production process. The process involves grinding the waste propellant under water and drying it for reintroducing into an existing propellant production line. Laboratory scale and preliminary cost analysis have been conducted with pilot scale demonstration to be conducted during FY 91-92.

The other emerging recovery technology that USATHAMA has demonstrated on a pilot scale is the use of explosives as a supplemental fuel. This process involves dissolving TNT or Comp B in toluene and combining this solution with No. 2 fuel oil so that the concentration of explosive is from 5 to 15 percent by weight. This solution is then used as a fuel to fire an industrial type boiler for production of steam.

(VG-17) The controlled incineration family is comprised of processes that destroy the propellant, explosive and pyrotechnic (PEP) filler or contamination by incineration. Some of the processes are similar and may differ only in the ancillary equipment that feeds the incinerator or treats the effluent. Other processes may be limited to treatment of PEP contaminated material.

The flashing chamber system located at WADF, was designed to decontaminate large items. This system has since been converted to the hot gas decontamination test facility.

The APE 1236 deactivation furnace was designed by AED. The furnace consists of a 4-section rotary kiln and is used for incineration/destruction of small arms, primers, and items with minimal explosive content. The APE 1236 furnace is undergoing an upgrade to bring it into compliance with applicable environmental regulations. This upgrade includes a modified feed system with automatic feed cutoff, afterburner, high/low temperature heat exchangers, centrifugal dust collector (cyclone) baghouse, draft fan, and exhaust stack. The rotary kiln will be completely shrouded to capture any fugitive emissions and process them through the afterburner. When the upgrade is completed, there will be 14 locations that will operate this incinerator. The other locations that did not receive the upgrade on their APE 1236 furnaces may continue to operate, but will not be allowed to process ammunition that is designated as hazardous waste.

The deactivation furnace located at Pine Bluff Arsenal (PBA) is a modified APE 1236. The modification done in-house consists of a feed system with automatic feed cutoff and shrouded rotary kiln. The exhaust gases are directed to a central afterburner and air pollution control system. There are plans to add a hydrosonic scrubbing system to the central air pollution control system.

The APE 2210 deactivation furnace located at WADF is a two rotary kiln system. The rotary furnace lead item system is intended for deactivation of small caliber ammunition equipped with lead projectiles. The rotary furnace detonating items system is intended for deactivation of larger detonating items equipped with non-lead projectiles. These systems are currently undergoing modification to comply with environmental regulations.

The explosive waste incinerator (EWI) was developed by AED and is a rotary kiln system designed to incinerate quantities of up to 5 pounds of bulk explosives or propellant. The EWI has a positive feed system and a pollution abatement system which consists of an indirect, low temperature heat exchanger; a cyclone dust collector; baghouse; draft fan; and, exhaust stack. There are plans to upgrade the EWIs with an afterburner, high temperature heat exchanger, and a new control system. The retort will be shrouded to contain fugitive emissions similar to the APE 1236 deactivation furnace system.

The contaminated waste processor (CWP) was developed by AED for incineration of explosive contaminated packing material or decontamination of metal parts. The CWP is a 'car bottom' type incinerator which has a movable hearth. There are two sizes of CWPs; the small unit is batch fed using a 4-foot by 8-foot basket. The large unit can be operated in a continuous mode by processing the material through a shredder system and then feeding it into the fire chamber through a series of doors. Both systems are equipped with air pollution abatement equipment that consists of a dilution air damper, low temperature heat exchanger, dust collector, bag house, draft fan, and exhaust stack.

The car bottom furnace located at PBA is a commercial incinerator that is used for the incineration of PEP contaminated material or decontamination of metal parts. This incinerator may be batch feed or operated in a continuous mode by addition of material through a door on the side of the furnace.

(VG-18) The flashing furnace at WADF is designed to heat moderate sized ammunition components to a temperature where any residual energetic material is decomposed or burned. The furnace is large enough to accommodate four skids at a time. The skids are moved through the furnace by means of a walking beam conveyer.

A rotary kiln type incinerator located at WADF can be used to incinerate explosive slurries and Otto fuel. This incinerator differs from the standard APE 1236 in that it has a refractory liner which is unsuitable for use with items that detonate. Another refractory lined rotary kiln incinerator is located at ENESCO, El Dorado, AR. This incinerator is used to destroy EPA classified hazardous wastes, including PCBs.

The chain grate incinerator at PBA is used for incinerating contaminated packing materials, munitions hardware, and decontaminating scrap metal. The material to be treated is pulled into the fire chamber by means of a movable chain grate assembly. The emissions from the incinerator are processed through the facilities central afterburner.

The fluidized bed incinerator (FBI) at PBA has a thermal capacity of 26 million BTU/hr. The FBI uses high velocity air to entrain solids in a highly turbulent combustion chamber. The bed media is 8 feet expanded height of silica sand. This thermal mass stabilizes the combustion temperature and allows for efficient heat transfer to the material being incinerated. The process material must not be explosives, but can be smokes, dyes, riot control agents, or other material in liquid, slurry, or solid form.

Another closed incinerator that was examined was the circulating bed combustor (CBC) operated by Ogden Environmental Services, Inc. This system is similar to the FBI and is used mainly for decontamination of soil contaminated with hazardous wastes. This system differs from the FBI in that it has provisions for continuous removal of incinerated soils.

The air curtain incinerator located at PBA is a commercially available unit that is used for size reduction of non-PCP treated wood, paper, and scrap material. It consists of a burning chamber and a blower system that generates a 'curtain of air' across the top of the pit. This air curtain entrains the effluent from the combustion process and circulates it back into the flame.

The air control incinerator is under development by Los Alamos National Laboratory (LANL) under contract with NWSC, Crane. The incinerator is designed to incinerate toxic/carcinogenic materials such as organic dyes that are contained in some colored smoke compositions. The incinerator will be a scaled-down model of the LANL incinerator that was used to incinerate samples of Army and Navy smokes. A new feed module system has been constructed and tested using a slurry made from Navy flare composition.

(VG-19) Plasma heating systems convert electricity into heat by ionizing gases and can operate with almost any gas including air, argon, helium, hydrogen, carbon dioxide, or methane. Plasma arc torches are available in many configurations from low power convertible torches, to high power systems suitable for large volume raw municipal waste treatment plants. These torches may routinely create temperatures that range from 7,000 to 12,000 degrees Fahrenheit. They have been proposed by Mason & Hanger National Inc. as an incineration method for use in demilitarization operations. This incineration method may be usable when developed for destruction of smokes, dyes, pyrotechnics, and riot control agents.

Static firing of LRMs may be considered another form of controlled incineration. The Thickol Corporation has been contracted by MICOM to dispose of Pershing 1A and II rocket motors at Longhorn Army Ammunition Plant (LHAAP). This process is accomplished by using two test stands to restrain the motors for subsequent functioning. This method has no provisions for capturing the effluent for treatment prior to release to the environment; therefore, it may not be a viable alternative in the future.

As an alternative to static firing the LRMs, Lockheed Missiles & Space Company has proposed a technique for capturing and treating the effluent that is dispersed into the atmosphere. This process consists of removing the nozzle assembly of the LRMs and burning the motor at ambient pressure. The effluent gases would be bubbled up through a 40-foot tank of water that contains a series of perforated steel plates into an enclosed chamber. The gases from this chamber would be passed through a duct to air emissions control equipment that has not been identified.

(VG-20) The disassembly family contains processes that will reduce the size of the munition or will expose the PEP filler for further processing. A process of this nature must be accomplished prior to most other processing and generally does not destroy any of the hazardous characteristic of the filler. For instance the TNT explosive filler must be exposed before a meltout operation may be performed. The following processes are examples of disassembly technology:

Laser grooving is a technology that has been proposed by the AED at TEAD. This process would involve using a laser to score the projectile case at its major diameter. This would create a circular weakened groove which in combination with a tearing/breaking process would bisect the case to expose the filler. This filler would then be exposed for further processing such as washout or meltout.

Waterjet cutting or waterjet abrasive cutting has been demonstrated by Program Manager for Ammunition Logistics (PM-AMMOLOG). They demonstrated that a 105mm fuzed projectile may be rendered safe by remotely severing the fuze using an abrasive waterjet. Equipment similar to that used by PM-AMMOLOG is manufactured by Flow International. Their ultra-high-pressure intensifier pump pressurizes water up to 55,000 psig and forces it through a nozzle as small as 0.004 inches in diameter which generates a high velocity waterjet with speeds of up to 3,000 feet per second. This waterjet can cut a variety of non-metallic materials. To cut metallic or hard materials such as metal plates, ceramics, or glass, an abrasive is entrained into the waterjet to enhance the cutting capability.

An emerging disassembly technology is cryofracturing that is under development by General Atomics, San Diego, CA. This technology may prove capable of exposing the filler in difficult or dangerous to disassemble munitions. The cryofracture process involves cooling a munition in a bath of liquid nitrogen at cryogenic temperatures. At this temperature, the heavy steel projectile body becomes brittle, and if subject to pressure of a 1,000-ton press, it will shatter, thus exposing the contents. The shattered munitions can subsequently be treated by another technology to complete the demilitarization process. The process has been successfully demonstrated on simulated filled chemical munitions.

(VG-21) Electrochemical reduction is a very selective process in its application. This process has been demonstrated in the demilitarization of lead azide. In this process, a quantity of bulk lead azide is dissolved in a 20 percent sodium hydroxide solution. The solution is then circulated into a larger tank where two electrodes have been positioned. Application of an electric current to the electrodes causes the lead to plate out where it may be removed. This process does produce a sludge material which also must be disposed of.

The neutralization process in the chemical conversion family is limited in use to acidic or basic fillers. This process has been demonstrated for disposal of bulk FS smoke. The FS material is slowly added to a rapid flow of water. The diluted solution is then allowed to mix with lime slurry in a water cooled four million gallon tank to dissipate the heat that is generated.

S-cubed, San Diego, CA constructed a six-foot diameter steel sphere for total containment of explosives detonation experiments. This sphere will fully contain a detonation of up to 100 pounds of C-4 explosive. For charges of 20 pounds or more, the steel sphere is filled with coke which acts as a heat-sink material.

A promising process that is emerging is the use of super/sub-critical fluids that is under development at MICOM for the removal of propellants from LRMs. This process takes advantage of the enhanced solubility characteristics of super/sub-critical fluids and the liquid-to-gas phase transitions which occur during the compression or expansion of all gases. This process may be used for other fillers; however, further study is needed to determine the appropriate super/sub-critical fluids. The fundamental operation principle of this system is similar to that which occurs in a refrigeration system. Soluble propellant ingredients are extracted into the fluidized solvent and separated by filtration from all undissolved materials. The dissolved propellant ingredients are recovered down stream in a separation vessel during the liquid-to-gas pressure reduction cycle. The expanded gas now devoid of all dissolved propellant ingredients is filtered and re-compressed to the fluid state to complete the solvent regeneration cycle.

(VG-22) The oxidation family consists of an emerging high/low temperature oxidation process for red/pink water. This process is under development by Combustion Engineering, Bloomfield, NJ. The scale model will treat less than 10 gallons per minute of red/pink water at an operation temperature of approximately 400 degrees Celsius with a 10-minute retention time. Laboratory work is in process.

The biodegradation family consists of two processes: Degradation of explosive waste by micro-organisms and white rot fungus. Lawrence Livermore National Laboratory, Livermore, CA is examining the feasibility of using micro-organisms to degrade HE contaminated water and soils. Preliminary results indicate that micro-organisms are capable of degrading RDX under aerobic conditions. Work is in process to determine the optimum conditions for HE degradation.

Lummus Crest Inc., a subsidiary of Combustion Engineering, Bloomfield, NJ, has done laboratory work on a process to biodegrade pink water. The active portion of the system consists of a packed column unit or rotating biological contractor upon which a white rot fungus culture has been grown. In the laboratory work, the pink water is continually circulated through the system. Combustion Engineering has successfully reduced, using a batch test method, the TNT concentration in pink water to 2 ppm in 24 hours and the RDX concentration in pink water to less than 10 ppm in 48 hours. This process may have an application in treating waste water effluent from washout or steamout operations.

(VG-23) Volume II is titled 'Demilitarization Alternatives to Open Burning/Open Detonation - Technology Compilations Project Number DEV 12-88' and contains a compilation of all the technologies investigated thru April 1990. There are no doubt technologies being pursued which have not been brought to our attention. To remain informed of new developments in this area, we would like to be made aware of any efforts that are being undertaken. If there is a written report, they may be sent to the following address:

Director
U.S. Army Defense Ammunition Center and School
ATTN: SMCAC-DES (Ed Ansell)
Savanna, IL 61074-9639
Phone (815) 273-8928

Volume III is titled 'Appendixes' and include the following:
a. Bibliography of 99 separate reports
b. Points of contact at 28 locations/agencies visited
c. Applicable demil/disposal regulations

d. Listing of current demilitarization Depot Maintenance Work Requirements (DMWRs) cross-referenced to DODIC

e. Brief description of currently available ammunition peculiar equipment (APE) and new APE programed for FY 90-92

f. Listing of current demilitarization/disposal capabilities at DOD installations worldwide

Volume I containing recommendations for technology funding is "For Official Uses Only." Volumes II and III will be available through the DTIC when released.

VG-1

DEMILITARIZATION ALTERNATIVES TO OPEN BURNING/OPEN DETONATION (OB/OD)

PRESENTED BY: MR. ED ANSELL
U.S. ARMY DEFENSE AMMUNITION CENTER AND SCHOOL

Encl 2

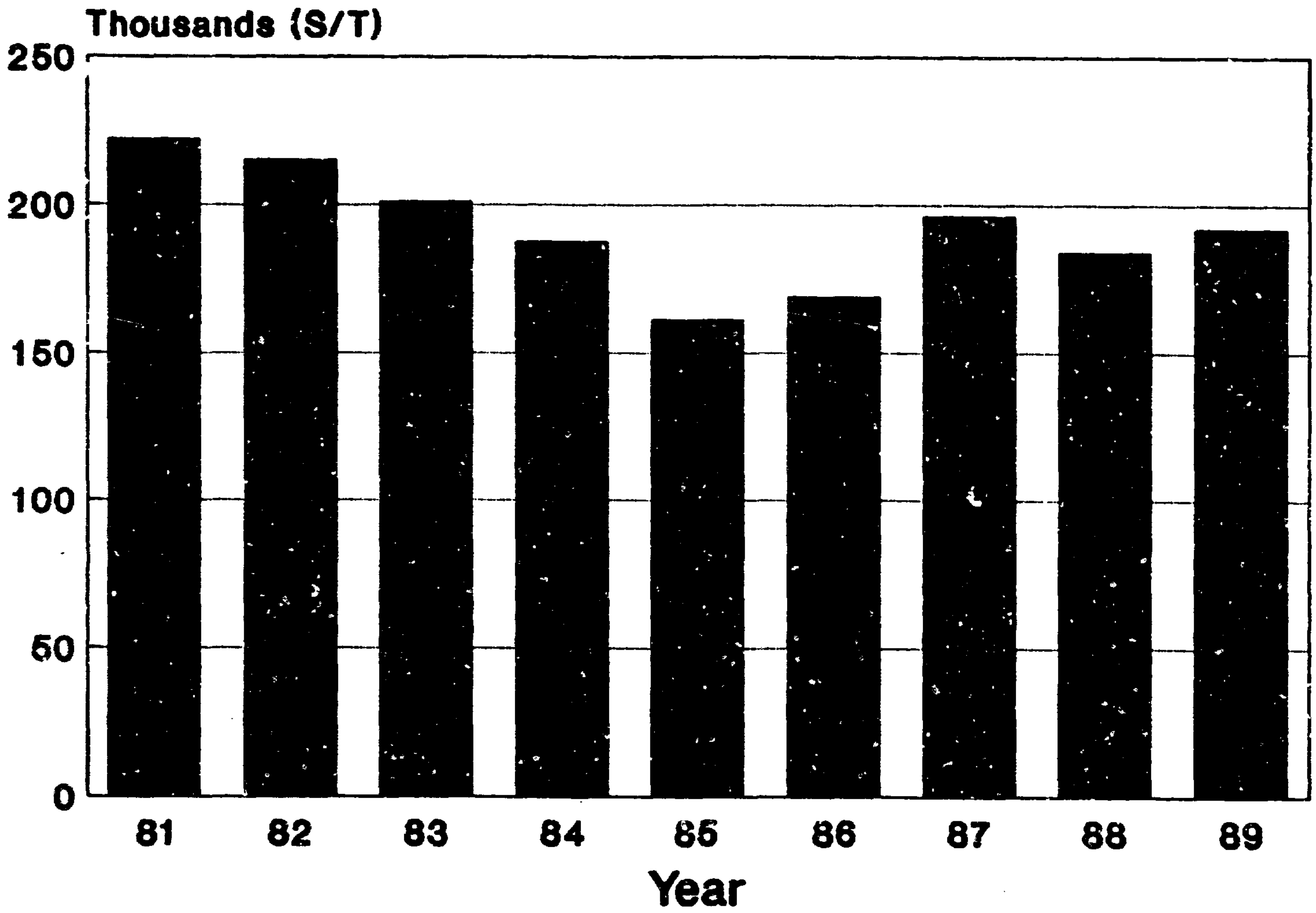
BACKGROUND

- ARMY AND SINGLE MANAGER CONTINUE TO RELY UPON OB/OD AS PRINCIPAL DEMIL METHOD
- USADACS FUNDED BY AMCCOM OCT 88 TO ACCOMPLISH STUDY THAT IDENTIFIES ALTERNATIVE METHODS (TECHNOLOGY)
- AMCCOM HAS A PARALLEL STUDY IN PROCESS AT DUGWAY TO QUANTIFY ENVIRONMENTAL IMPACT OF OB/OD
- USADACS HAS A PARALLEL STUDY IN PROCESS COVERING LARGE ROCKET MOTOR (LRM) DEMIL THAT HAS BEEN BRIEFED AT THE JOINT LOGISTICS COMMANDERS (JLC) LEVEL

CURRENT DEMIL STOCKPILE (PROBLEM)

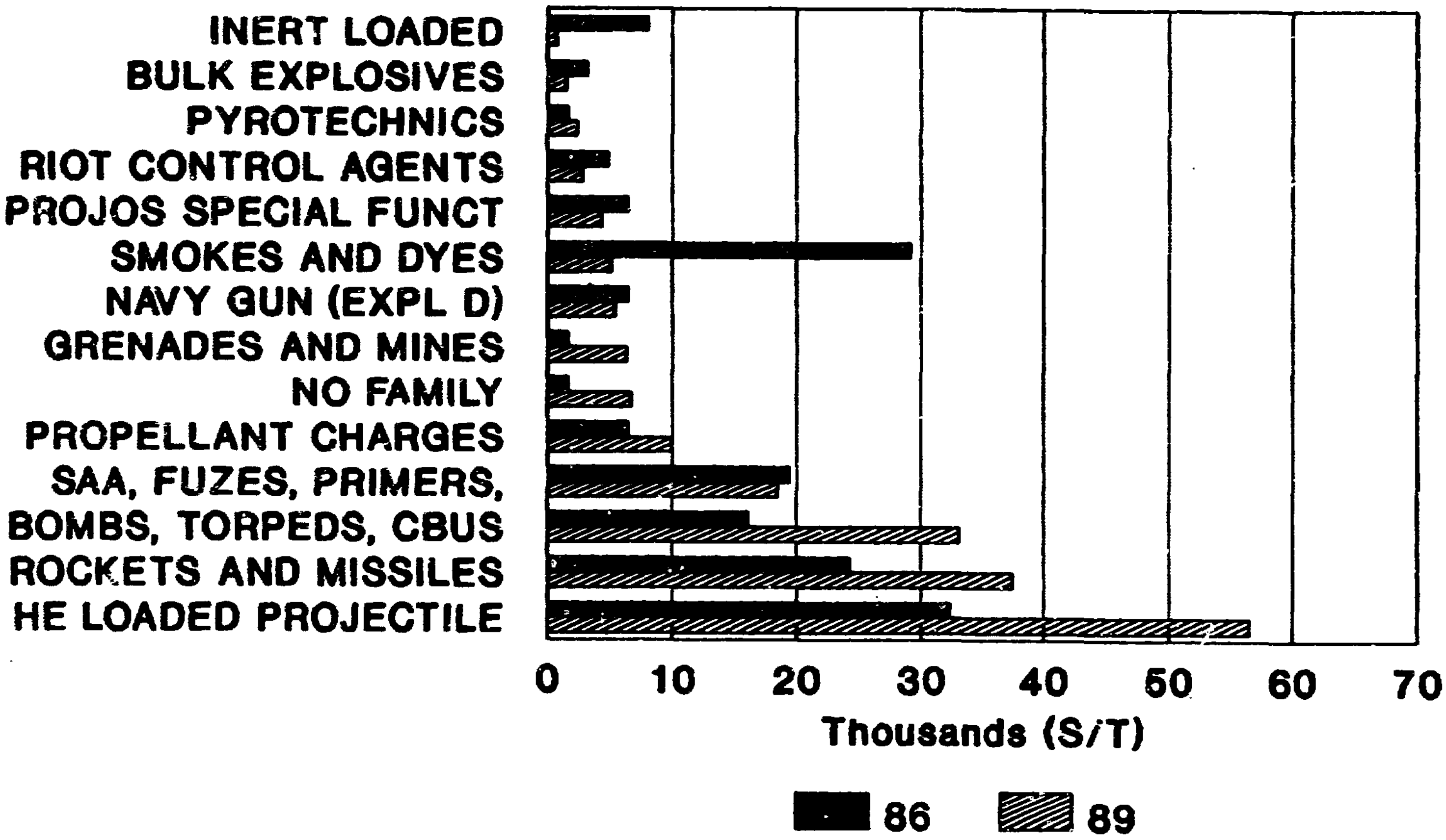
- 4,476 SEPARATE NSNs IN "ORANGE BOOK"
- 80 SEPARATE "FAMILIES" OF AMMUNITION
- 16 DISTINCT MATERIEL TYPES
- 78 MAJOR FILLERS

9 YEAR TREND



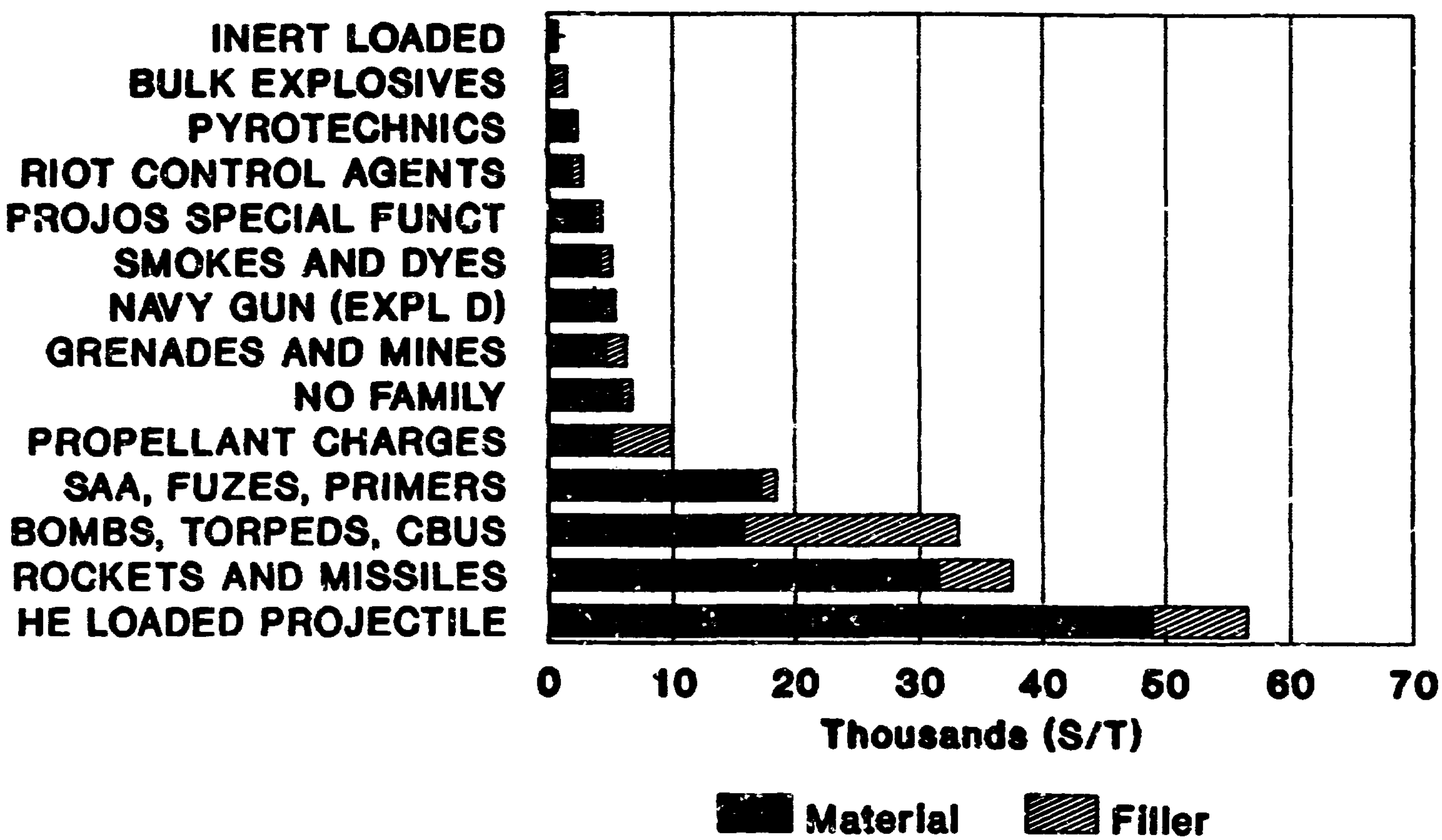
Source-JOCG Demilitarization / Disposal Handbooks

DEMIL INVENTORY BY CONSOLIDATED FAMILY 1986 VS 1989



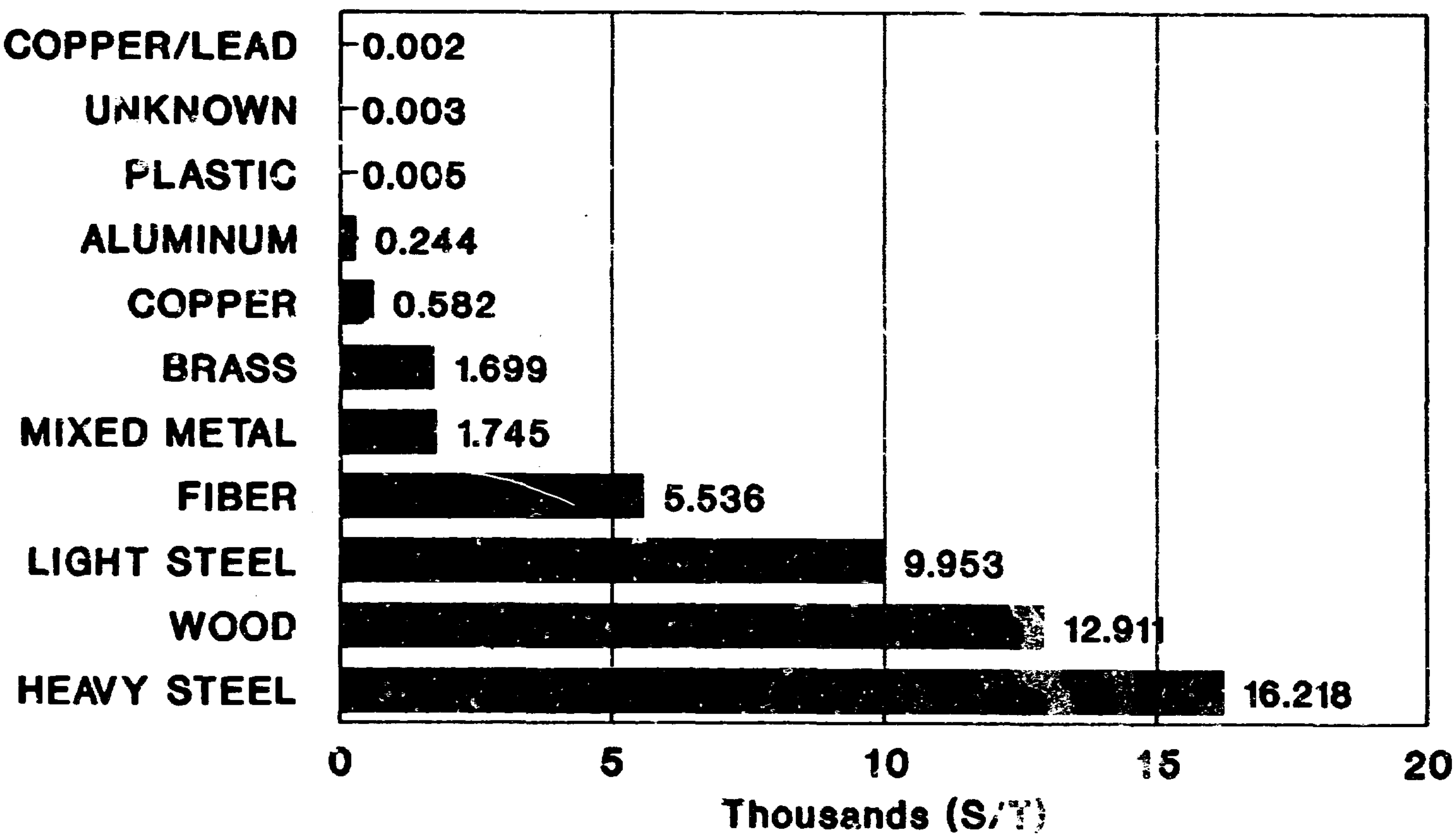
Source-JOCG Demilitarization / Disposal Handbook 31 Dec 86 & 31 Dec 89

31 DEC 89 DEMIL INVENTORY
(By Consolidated Family)



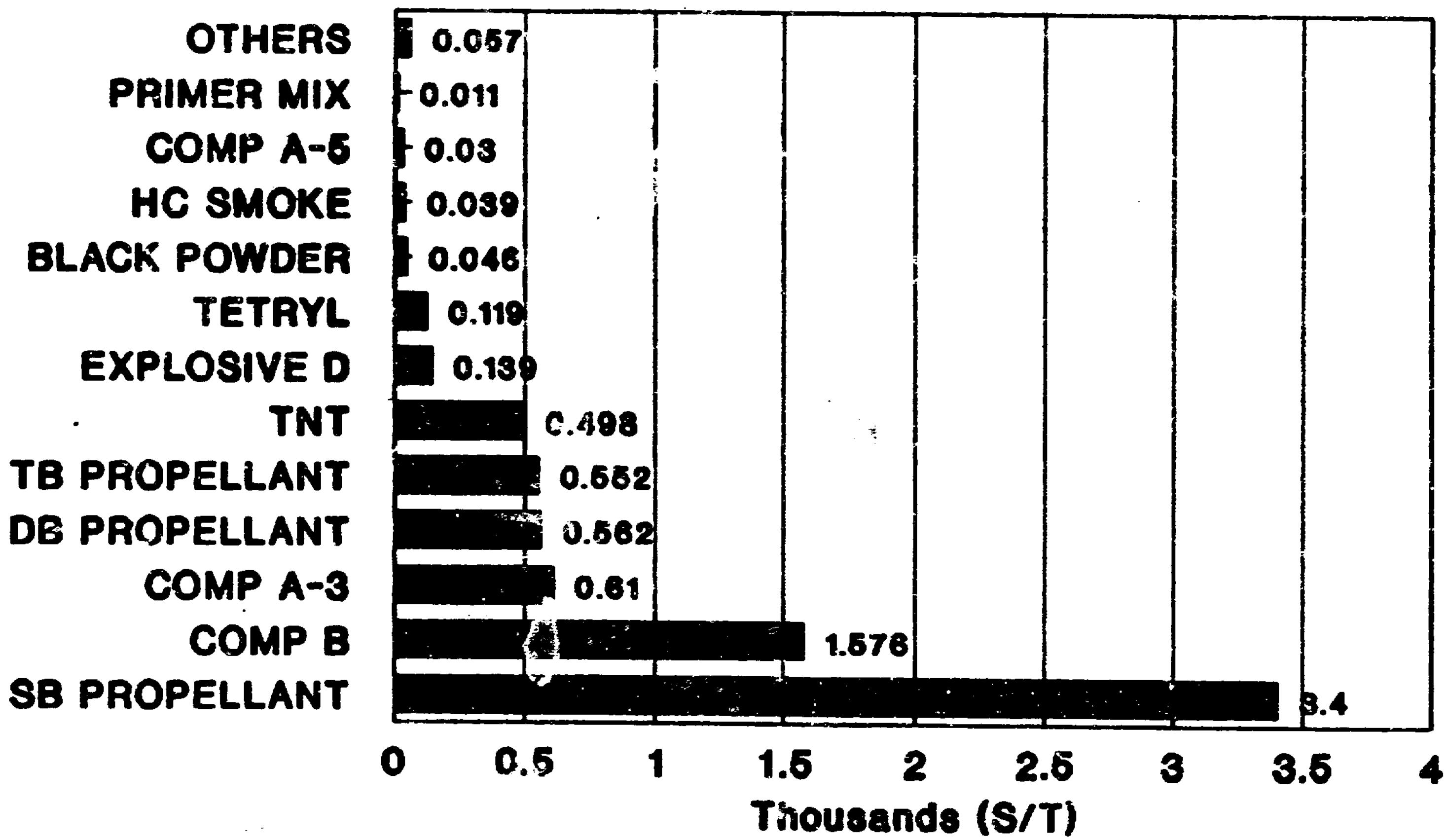
Source–JOCG Demilitarization / Disposal Handbooks Volume I and Volume III

31 DEC 89 DEMIL INVENTORY FOR THE FAMILY OF HE LOADED PROJECTICLES (By Material)



Source-JOCG Demilitarization / Disposal Handbooks Volume I and Volume III

31 DEC 89 DEMIL INVENTORY FOR THE FAMILY OF HE LOADED PROJECTILES (By Filler)



Source-JOCG Demilitrization / Disposal Handbooks Volume I and Volume III

EMERGING IMPACTS THAT REQUIRE IMMEDIATE TECHNICAL SOLUTIONS

- BASE CLOSURES AND RETROGRADE OF STOCKS FROM FRG WILL MANDATE INCREASED DEMIL
  - OB/OD (IF FUNDED) CANNOT DEMIL ALL ITEMS
  - HAND GRENADES/ICMs/SMOKES/DYES/PYROTECHNICS REQUIRE NEW TECHNOLOGY
- NEWER AMMUNITION (COPPERHEAD/DU ROUNDS) WILL ALSO REQUIRE NEW TECHNOLOGY
- DOD HAS INCREASED EMPHASIS ON ENVIRONMENT
  - INCLUDING OB OF SINGLE/DOUBLE BASE PROPELLANT

STUDY APPROACH

- REVIEW, COMPILE, AND MAINTAIN DATABASE OF EXISTING STUDIES/REPORTS INCLUDING:
  - 11 PREVIOUS DEMIL DISPOSAL STUDIES
  - 28 DTIC REPORTS APPLICABLE TO THIS STUDY
  - 60 TECHNICAL REPORTS FROM VARIOUS SOURCES
- ON-SITE VISITS TO DOD/INDUSTRY/ACADEMIA INCLUDING:
  - 16 GOVERNMENT
  - 12 INDUSTRY AND ACADEMIA
- RATE/RANK 28 TECHNOLOGIES (53 SEPARATE DESCRIPTIONS) AGAINST NEED/RISK/COST (RETURN ON INVESTMENT)

ALTERNATIVE FAMILIES TO OB/OD

- WASHOUT
- MELTOUT
- RECLAMATION
- CONTROLLED INCINERATION
- DISASSEMBLY
- ELECTROCHEMICAL REDUCTION
- CHEMICAL CONVERSION
- DETONATION CHAMBER
- SUPER/SUBCRITICAL FLUID EXTRACTION
- OXIDATION
- BIODEGRADATION

WASHOUT FAMILY

HOT WATER:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
WASHOUT PLANT (APE 1300)	LBAD	AED	TNT/RDX FILLERS	EXISTS
HYDRAULIC CLEANING SYS	WADF	AMCCOM	EXPLOSIVE D	EXISTS

HIGH PRESSURE:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
"HOGOUT"	THIOKOL	THIOKOL	LRM PROPELLANT	EXISTS
"HOGOUT"	AEROJET	AEROJET	LRM PROPELLANT	EXISTS
"HOGOUT"	WADF	AMCCOM	EXPLOSIVE A3	EXISTS
WOMBAT	UNIV OF MO-ROLLA	UNIV OF MO-ROLLA	PBX FILLERS	EMERG ING

WASHOUT FAMILY (CON'T)

SOLVENT:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
TOLUENE	AED	AED	COMP B EXPLS	TRIED
METHYLENE CHLORIDE METHANOL	NWSC, CRANE	NWSC, CRANE	A/C PARACHUTE FLARES	TRIED
WATER	NWSC, CRANE	NWSC, CRANE	PHOTOFLASH CTG	TRIED
BLEND	NWSC, CRANE	NWSC, CRANE	IR FLARES	TRIED
BLEND	NWSC, CRANE	NWSC, CRANE	PBXN-3,4,5 & 6	EMERG ING
BLEND	NWSC	NWSC, CRANE & EL DORADO ENG, INC.	PBX FILLERS	EMERG ING

WASHOUT FAMILY (CON'T)

CRYOGENIC DRY WASH:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
CRYOGENIC FLUID	GENERAL ATOMICS	EL DORADO ENGR, INC.	EXPLOSIVES & PROPELLANTS	CONCEPT

MELTOUT FAMILY

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
AUTOCLAVE:				
STEAM	AED	AED	TNT OR TNT COMP	TRIED
STEAM	WADF	AMCCOM	MELTABLE EXPLS	EXISTS
STEAM	RVAAP	RVAAP	MELTABLE EXPLS	EXISTS
STEAMOUT:				
STEAM	CAAA	CAAA	MELTABLE EXPLS	EXISTS
STEAM	WADF	AMCCOM	MELTABLE EXPLS	EXISTS
HEATING:				
INDUCTION	AED	AED	MELTABLE EXPLS	TRIED
MICROWAVE	AED	AED	TRITONAL FILLER	TRIED

RECLAMATION FAMILY

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
SOLVATION:				
WATER	THIOKOL	THIOKOL	LRM AP PROPELLANT	TRIED
WATER	AEROJET	AEROJET	LRM AP PROPELLANT	EXISTS
CONVERSION:				
HEAT AND SCRUBBING	NWSC, CRANE	NWSC, CRANE	RP TO PHOSPHORIC ACID	TRIED
HEAT AND SCRUBBING	CAAA	AMCCOM	WP TO PHOSPHORIC ACID	EXISTS
RECOVERY:				
REUSE/ REBLENDING	USATHAMA	USATHAMA	WASTE PROPELLANT PROPELLANT REUSE	EMERG-ING
ENERGY	USATHAMA	USATHAMA	SUPPLEMENTAL FUEL	EMERG-ING

CONTROLLED INCINERATION FAMILY

INCINERATORS:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
FLASHING CHAMBER SYS	WADF	AMCCOM	LARGE ITEM	TRIED
DEACT (APE 1236)	AED	AED	SMALL ARMS, ETC.	EXISTS
DEACT (APE 1236 MODIFIED)	PBA	PBA	SMOKES/DYES, ETC.	EXISTS
ROTARY (APE 2210)	WADF	AMCCOM	SMALL ARMS, ETC.	EXISTS
EXPLOSIVE WASTE INCIN-ERATOR (EWI)	AED	AED	EXPLOSIVE WASTE	EXISTS
CONTAMINATED WASTE PROCESSOR (CWP)	AED	AED	CONTAMINATED WASTE	EXISTS
CAR BOTTOM	PBA	PBA	CONTAMINATED WASTE, ETC.	EXISTS

CONTROLLED INCINERATION FAMILY (CON'T)

INCINERATORS (CON'T):

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
FLASHING FURNACE (WALKING BEAM)	WADF	AMCCOM	METAL PARTS	EXISTS
ROTARY KILN	WADF	AMCCOM	EXPL SLURRIES OTTO FUEL	EXISTS
ROTARY KILN	ENSCO	ENSCO	CONTAMINATED WASTE	EXISTS
CHAIN GRATE	PBA	PBA	CONTAMINATED WASTE	EXISTS
FLUIDIZED BED INCINER-ATOR (FBI)	PBA	PBA	SMOKE & DYES IN SLURRIES	EXISTS
CIRCULATING BED COMBUSTOR (CBC)	OES	OES	CONTAMINATED SOIL, ETC.	EXISTS
AIR CURTAIN BURNER	PBA	PBA	SIZE REDUCE SCRAP	EXISTS
AIR CONTROL INCINERATOR (ACI)	NWSC & LANL	LANL	SMOKES & DYES	EMERG-ING

CONTROLLED INCINERATION FAMILY (CON'T)

INCINERATORS (CON'T):

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
PLASMA ARC INCINERATOR	HUNTSVILLE, AL	MASON & HANGER NATL INC	SMOKES & DYES, PYROTECHNICS, & RIOT CONTROL	EMERG- ING
STATIC FIRING	LHAAP & MICOM	MICOM	PERSHING IA & II AND SRM	EXISTS
STATIC FIRING	LOCKHEED	LOCKHEED	LRM	CONCEPT

DISASSEMBLY FAMILY

CUTTING:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
LASER GROOVING	AED	AED	METAL REMOVAL	TRIED
WATERJET (EOD)	PM-AMMOLOG	PM-AMMOLOG	METAL CUTTING	EXISTS
WATERJET ABRASION	KENT, WA	FLOW INT.	METAL CUTTING	EXISTS

CRYOFRACTURE:

CRUSHING	SAN DIEGO, CA	GEN ATOMICS	METAL/FILLER EMBRITTLEMENT	EMERG-ING

ELECTROCHEMICAL REDUCTION FAMILY:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
ELECTRO-CHEMICAL REACTION	SVADA	MASON-HANGER	LEAD AZIDE	EXISTS

CHEMICAL CONVERSION FAMILY:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
NEUTRALIZATION	PBA	AMCCOM	FS DISPOSAL	EXISTS

DETONATION CHAMBER FAMILY:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
STEEL SPHERE	SAN DIEGO	S-CUBED	EXPLOSIVE CONTAMINANT	EXISTS

SUPER/SUB-CRITICAL FLUIDS FAMILY:

PROCESS	LOCATION	TECH AGENCY	LOCATION	TECH STATUS
AMMONIA	MICOM	MICOM	LRM AP PROPELLANTS	EMERG-ING

OXIDATION FAMILY:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
HIGH/LOW TEMP	BLOOMFIELD, NJ	COMBUSTION ENGINEERING	RED/PINK WATER	EMERGING

BIODEGRADATION FAMILY:

PROCESS	LOCATION	TECH AGENCY	APPLICATION	TECH STATUS
DEGRADATION BY MICRO-ORGANISMS	LIVERMORE, CA	LAWRENCE LIVERMORE LABS	RDX, HMX CONTAMINATED SOIL	EMERG-ING
WHITE ROT FUNGUS	BLOOMFIELD, NJ	COMBUSTION ENGINEERING	PINK WATER	EMERG-ING

CURRENT STATUS OF REPORT

- VOLUME II, TITLED "DEMILITARIZATION ALTERNATIVES TO OPEN BURNING/OPEN DETONATION - TECHNOLOGY COMPILATIONS PROJECT NUMBER DEV 12-88" IS CURRENTLY BEING PRINTED

- VOLUME III, TITLED "APPENDIXES," WHICH INCLUDES THE FOLLOWING IS ALSO BEING PRINTED:

  - BIBLIOGRAPHY OF 99 SEPARATE REPORTS
  - POCs AT 28 LOCATIONS/AGENCIES VISITED
  - APPLICABLE DEMIL/DISPOSAL REGULATIONS
  - LISTING OF CURRENT DEMIL DMWRs CROSS-REFERENCED TO DODIC
  - BRIEF DESCRIPTION OF CURRENTLY AVAILABLE AMMUNITION PECULIAR EQUIPMENT (APE) AND NEW APE PROGRAM (FY 90-92)
  - LISTING OF CURRENT DEMIL/DISPOSAL CAPABILITIES AT DOD INSTALLATIONS WORLDWIDE

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THE INTERNAL BLAST WAVE PRODUCED IN A CLOSED RANGE BY A 155mm HOWITZER GUN

Y. Kivity, RAFAEL Ballistics Center, Haifa, Israel.

and

D. Palan, PALAN CONSULTING ENGINEERS, Luxembourg.

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ABSTRACT

This work is concerned with the internal air blast resulting from firing a 155mm Howitzer gun in a closed test range. The range is about 260 meters long and has a typical cross-section of 5x6 meters. Various openings in the range are closed by steel doors. A good estimate of the dynamic load on the doors is critical for their proper design, and is the main objective of the present study.

The pressure loading on the walls is calculated using a numerical hydrodynamic code. The problem is formulated as a quasi one-dimensional flow in a variable area duct. The initial conditions of the flow at the muzzle gun position are derived from a simplified model for the mixing of the hot combustion products of the propellant and a finite mass of the ambient air. In addition, two-dimensional calculations were carried out to get more detailed distributions of the pressure loading at the target end and at the firing arena. It is found that reflected overpressure levels of about 35 KPa (≈5 psi) are attained for typical periods of about 100 ms.

1. INTRODUCTION

Safe testing of large caliber guns and ammunition in the open field requires a large area to be closed as a precaution against the various hazards associated with the firing. An alternative approach would be to conduct the testing within a closed structure. Such a structure will have to withstand the dynamic blast loading generated by the gun. In particular, the loading on various doors in the structure is required as an input for their design.

The present paper deals with the internal blast loading generated in a closed firing range by a 155mm Howitzer gun. The main structure of the range is essentially a long tunnel extending for about 260m, with internal cross-sectional dimensions of 5m wide and 6m high. The range includes two firing chambers along the tunnel, having slightly larger cross-sections, and a target chamber which is designed to contain all possible effects of rounds hitting the target or chamber.

The blast wave produced in a closed structure due to an energy burst is significantly different from the blast wave in a free air, when long times are considered. This is so because the walls of the structure reflect the incident wave, and thus contain the energy to a confined space. As a result the pressure levels and impulses in a closed structure may be much higher than the corresponding ones for the free blast wave.

In the closed proof range described above the energy containment effect is even more severe due to the tunnel-like geometry of the structure. This geometry forces the blast wave to move in one direction, thus focussing the momentum of the blast in the longitudinal direction. As a result, the decay of blast peak pressure with distance is much slower than in the spherical case. Baker [1] quotes Lindberg and Firth who studied blast wave propagation for three different symmetries: plane, cylindrical, and spherical. The results show very clearly that in the region where the spherical wave decays with the third power of distance, the plane wave decays only with the first power.

In the present work, the blast wave propagation is calculated using the hydrodynamic computer code SCALE. This code can handle a time dependent two-dimensional compressible flow and its dynamic interaction with a thin shell structure. In the present case, due to the elongated shape of the proo range, a quasi one-dimensional approximation was found adequate for studying the gross behavior of the blast. To get more details of the loading on the target end, a full two-dimensional model was employed. Examples of detailed calculations for blast waves from high explosive charges may be found in references [2] and [3].

The paper includes several preparatory sections to establish the validity of the calculations. Section 2 describes the model for the initial muzzle blast. Section 3 gives the details of the numerical solution. Section 4 discusses the propagation of a blast wave in a long tunnel. A parametric study of the initial muzzle blast effect on the wall load is given in section 5, and the convergence of the numerical scheme is demonstrated in section 6.

Sections 7-10 deal with the loading on the doors. Section 7 gives the one-dimensional solution for a variable cross section range, with emphasis on the target end. In Section 8 a more detailed two-dimensional calculation for the target end is given. In Section 9 the load on the firing chamber door is obtained. Finally, Section 10 treats the effect of venting from the firing chamber door, simulating a firing with an open door.

2. MUZZLE BLAST MIXING MODEL

Following the exit of the projectile from the muzzle, the hot combustion products of the propellant eject out in the form of an energetic stream which mixes with a large mass of the ambient air. The mixing process is very complex, and its determination would require significant computational and experimental efforts [4]. In the present investigation, however, we are interested in the flow at large distances from the mixing region, and therefore it suffices to consider only an average state of the mixing region. The averaged flow variables of the mixture will serve as initial conditions for the blast wave calculation.

It will be assumed that the total energy of the propellant E is divided into three main parts: Kinetic energy of the projectile, Kp, kinetic energy of the combustion gases, Kc, and internal energy of the combustion products, Uc, so that

$$E = Kp + Kc + Uc$$

In the above energy balance several energy losses were neglected, namely, frictional losses to the barrel, heat losses to the barrel and projectile, and other minor losses such as energy needed for spinning the projectile. All these losses are included in U, in order to obtain a conservative estimate of the blast energy. For convenience, the kinetic energy components will be represented as fractions of the total propellant energy:

$$Fp = Kp/E \;, \quad Fc = Kc/E$$

The combustion products are assumed to mix with a finite volume of the ambient air, V, such that the internal energy and momentum of the mixture are conserved in the process. This results in the following relations for the mixture average properties:

$$M = Mc + Ma \quad ; \quad d = M/V$$

$$U = Uc + Ua \quad ; \quad e = U/M$$

$$W = Mc/M\ Wc \quad ; \quad Kc = \tfrac{1}{2}\ Mc\ Wc^2$$

Here M,U and W are the mixture mass, internal energy and velocity, respectively; d and e are the density and specific internal energy of the mixture. The pressure is determined by d and e using the equation of state (ideal gas, with specific heat ratio equal to that of air). The indices c and a refer to combustion products and air, respectively.

For a given propellant mass and energy, one has to specify Fp, Fc and the air volume V in order to close the model. Krier and Adams [5] give a typical energy balance for large caliber guns, which shows that Fp is around 0.32. Fc is more difficult to estimate, since the kinetic energy of the gases leaving the barrel varies with time. A representative average value of this velocity is the projectile velocity. Assuming that the combustion products have a uniform velocity enables to determine Fc. As an example, assume a propellant mass of Mc=10Kg, combustion products velocity Wc = 1000 m/s, the kinetic energy Kc is then =5 MJ. To detrmine the total propellant energy one needs the propellant specific energy Q. Reference [6] gives typical values of the propellant impetus in the range F=1.0-1.1 MJ/Kg. To be on the safe side, the larger value of 1.1 MJ/Kg is adopted. The specific energy of the propellant Q is found from the relation [7]

$$Q = F/(\tau - 1)$$

Here τ is the ratio of specific heats of the combustion products. For the 155mm charge τ=1.24. Therefore:

$$Q \approx 4.6 \text{ MJ/Kg}$$
$$E = Mc\ Q = 46 \text{ MJ}$$
$$Fc = Kc/E \approx 0.11$$

The remaining parameter in the model is the volume of the air that mixes with the combustion products. It will be assumed that V is the volume of the cell in the computational mesh that represents the muzzle region. The actual value depends on the particular choice of the mesh. In the uniform cross-section study V was in the range 40-60 cubic meters. In the variable cross-section V was about 100-250 cubic meters.

3. NUMRERICAL SOLUTION

The hydrodynamic calculation was carried out using the computer program SCALE. This program is based on numerical schemes employed in well known hydrocodes such as SALE [8], DISCO [9] and PISCES [10]. The air was represented as an ideal gas with a specific heat ratio of 1.4. For the preliminary study of the uniform cross-section range, the computational mesh consisted of a column of equally spaced grid points, representing a column of air in the tunnel-like range. The length of this column was divided to 70 cells of 3.33 m each. The air is assumed to be initially at standard conditions and at rest, except in one cell which represents the muzzle blast field. In that cell, the initial conditions of density, pressure and material velocity were taken according to the mixing model which was described in the previous section. The boundary conditions were taken as rigid wall at both ends of the column.

4. UNIFORM CROSS-SECTION RANGE

The uniform cross-section range is regarded as a simple model for studying the main features of the blast waves. The main tunnel section of the proof range, with a cross-section of 5x6 meters, is represented as a circular tube with a radius of 3.09 m. (Fig.1). The tube is 235 meter long, with the target end at the Z=-200 m coordinate, and the firing chamber door at Z=+35. The gun muzzle is located at the origin (Z=0). For this case the entire energy of a 10 Kg propellant was assumed to be converted to internal energy of the combustion products (Fc=Fp=0).

The blast field evolution in time is shown in Figs.2-7 by the pressure distributions in the tube, and by pressure time histories at two locations, Figs.8-9. All the figures show overpressure normalized by standard atmospheric pressure.

At t=0 the high pressure at Z=0 gives rise to two shock waves moving in opposite directions away from Z=0. The backward facing shock (i.e. the wave moving towards the firing chamber door) hits the door at t≈75 ms, and is amplified due to reflection at the closed end. Fig.2 shows clearly the reflected shock with an overpressure of about 0.75. At the same time the wave facing the target end has progressed about 35 m and has an amplitude of about 0.37. At t=200 ms (Fig.3), both waves have progressed further towards the target, while their amplitude has decayed to about 0.25. Fig.4 shows the distribution at t=550 ms, when the leading shock has just hit the target end. Due to reflection, the leading shock amplitude is about 0.4, or about twice that of the shock behind it. Fig.5, at t=800 ms, shows the two reflected waves now moving back towards the firing chamber, with an amplitude of ≈0.15. Subsequent distributions show the waves moving further, with some more decay of their peaks (Fig.6, t=1150 ms), and after reflection from the firing chamber end (Fig.7, t=1500 ms).

Figs.8-9 show pressure time histories at two locations. Fig.8 gives the pressure at the firing chamber door. The backward shock wave arrives at t≈40 ms and reaches its peak due to reflection at t≈75 ms. The finite rise time is a result of the numerical scheme which smears the shock discontinuity over a finite number of grid cells. The overpressure remains close to zero until the arrival of the two shock waves (described earlier) after reflection from the target end (t≈1150 ms). A more interesting pressure time history is shown in Fig.9 for the target end. It shows two peaks, amplified by reflection to an amplitude of about 0.4.

5. EFFECT OF MIXING MODEL PARAMETERS

The mixing model of section 4 assumes that the momentum of the combustion products is imparted to the entire mixture. Although this is a plausible assumption in the average sense. its accuracy can not be taken forgranted. Since an accurate description of the mixing process is outside the scope of the present work, a short parametric study of the effect is given.

For the parametric study the following values are assumed:

Total propellant energy:	$E = 46$ MJ
Projectile kinetic energy fraction:	$Fp = 0.30$
Volume of air in the mixture:	$V = 60$ cu.m.

Four cases were calculated, with Fc = 0, 0.1, 0.2 and 0.6. The results of these calculations are summarized in Table 1. Fig.10 shows the overpressure time history at the target end for Fc=0. The peaks are 0.33 and 0.29. These values are lower than those of Fig.9 since in the present case with Fp=0.3 there is less energy available to the mixture. The following Fig.11 for the extreme value of Fc=0.6 shows a consistent trend of an increase in the first peak and a decrease in the second peak. The sum of the two peaks is almost constant, as is evident from Table 1.

TABLE 1
Peaks of the Normalized Overpressure as Function of the Combustion Products Kinetic Energy

Fc	First Peak	Second Peak	Sum
0	0.33	0.29	0.62
0.1	0.37	0.25	0.62
0.2	0.39	0.24	0.63
0.6	0.42	0.15	0.57

It may be concluded from these results that the gas kinetic energy may increase the peak pressure by about 27%. In section 2, Fc was estimated as 0.11. One may take Fc=0.1 as a working approximation and expect the model variation to be within ±13% of the calculated figure.

6. NUMERICAL CONVERGENCE

The numerical scheme used in the SCALE code employs the artificial viscosity method for treating shock wave discontinuities in the flow. As a result both shock level and steepness depend on the mesh size. The numerical results presented above were obtained for a mesh of 70 cells. A question arises as to how far are these results from the theoretical limit of the solution when the number of cells is very large.

To test the convergence of the numerical solution a representative case was calculated with an increasing number of mesh cells, N. The peak pressure at the target end is given in Table 2 for three cases: N=70,100 and 150. The variation of the peak overpressure at the target end was then plotted against δ=100/N, where δ represents the cell size. Fig.12 shows the overpressure as function of δ^2. From this plot it is clear that the solution is converging linearly with δ^2 as the number of cells increases. The theoretical limit may be obtained by extrapolation to δ=0. The limit value of the overpressure is 0.303. This value is about 22% over the N=70 calculation. In addition to the increase in the peak values, a measurable increase in the wave steepnes with N was also noticed, by inspection of the pressure time history for the three cases. (Not included in the paper).

In what follows, the computations will be carried out with a moderate value of N (≈80) and then a "correction factor" will be applied to obtain the theoretical converged value.

TABLE 2
Peaks of the Normalized Overpressure as Function of the Number of Mesh Cells in the Calculation

N	Peak	δ=100/N	δ^2
70	0.2474	1.43	2.04
100	0.2768	1.00	1.00
150	0.2910	0.667	0.44

7. VARIABLE CROSS-SECTION RANGE

The final evaluation of the loads in the firing range were obtained with a variable cross-section model. In this quasi one-dimensional model the variation in cross-sectional area must be continuous. The actual discontinuous changes were therefore replaced by gradual variations of the area, as shown in Fig.13. The parameters of the problem were as follows: The propellant mass was taken as 9.8 Kg. In view of the discussion of section 7, Fc was taken as 0.1. Fp was taken as 0.30, (a more conservative value than indicated in [5]), and the specific propellant energy Q was taken as 4.6 MJ/Kg, according to the estimate of section 4. The number of computational cells was 80.

The pressure load time history at the target end is shown in Fig.14. The peak normalized overpressure is 0.19, with a pulse duration of about 100 ms. The first peak is immediately followed by a second peak of almost the same level, and a similar pulse duration. Both the peak level and pulse duration depend on the computational cell size. According to the analysis of section 6, the converged peak value should be about 20% higher, i.e. ≈0.23. A further increase of the peak value by about 13% follows from the analysis of section 5, so that the estimate for the maximum load becomes ≈0.26.

Another factor that affects the blast peak levels is the position of the muzzle within the range. The actual gun muzzle is located about 12.5m from the firing chamber end. However, the "center" of the muzzle blast may be a few meters away from the muzzle end, due to the motion of the combustion products. The nominal case quoted above assumed that the initial blast mixture occupied the space in the firing chamber between 12.5m to 14.5m from the chamber end. To assess the effect of the initial location of the muzzle blast, four cases were calculated, with varying position of the initial blast energy source. From the results of these calculations it was concluded that an additional factor should be applied to the peak load. This factor was estimated as ≈1.17, which brings the load estimate from the former figure of 0.26 to ≈0.30.

To sum up, the calculated loads should be amplified due to three effects: (a) numerical convergence (≈20%), (b) kinetic energy of propellant gas (≈13%), and (c) blast energy position (≈17%).

An additional factor that could affect the load on the target end door is local two-dimensional flow, resulting from the geometry at the target end. This effect will be discussed in the next section.

8. TWO-DIMENSIONAL EFFECTS AT TARGET END

The flow at the target end requires special attention because the geometry deviates from the assumed cross-section uniformity. The shock wave which approaches the target end is almost planar, but the abrupt change in cross-section causes the wave to diffract. (Fig.15). The resulting curved shock propagates further into the target chamber, eventually reflecting from the walls. Although the diffraction weakens the shock, the subsequent reflections strengthen it, and it is difficult to estimate the net result without an appropriate two-dimensional calculation.

A two-dimensional calculation was carried out for the generic shape shown in Fig.15. The computational grid is shown in Fig.16. The flow was started assuming an oncoming plane shock front with a normalized peak overpressure of 0.15, decaying exponentially with time. The resulting flow field at selected times is shown in Figs.17. The velocity vector plot clearly show the diffraction of the wave and its interaction with the walls.

The pressure time histories at four locations are shown in Fig.18. The selected locations are indicated in Fig.15 by the numbers 2,4,5 and 6. Point 2 represents an almost undisturbed one-dimensional geometry. Points 4,5 and 6 represent typical positions at the target end door.

The curves indicate that peak pressure in excess of 0.3 are attained. The 0.3 level corresponds to ordinary reflection of a normal weak shock wave from a rigid wall. In fact the peak value at point 2 (Fig.18) is 0.29, as expected for this point, where the wave behaves locally as a plane wave. For the other locations, reflections contribute to higher peak values, about 0.35 for the three locations at the side wall with the door. (points 4,5 and 6). The two-dimensional effect for this case can be summed up by saying that an extra amplification of the peak occurs, from 0.3 to 0.35.

The calculated case is believed to be a conservative model of the actual geometry, and therefore the normalized peak overpressure of 0.35 should be considered an upper bound.

9. BLAST LOAD ON FIRING CHAMBER DOOR

The one-dimensional approach to the blast field within the proof range enables one to obtain cross-section averages of the flow variables. However, the averaged quantities are meaningful only at large distances from the energy source. The flow field in the vicinity of the muzzle is fully three dimensional, due to the complex wave reflections and refractions in the firing chamber. Nevertheless, an upper bound on the pressure load at the firing chamber door will be obtained, based on the one-dimensional model and known data on spherical blast waves from explosions.

The pressure time history at the door end predicted by the one-dimensional model is shown in Fig.20. The peak of the normalized overpressure is about 0.2, with a duration of about 40 ms. Applying a correction for numerical convergence brings the peak to ≈0.24. This figure constitutes the one-dimensional estimate.

An upper bound on the pressure peak may be obtained by taking the energy burst as a spherical explosion. The muzzle blast energy is equivalent to that of a 7 Kg TNT charge, assuming Fp=0.3. One finds for the normalized reflected overpressure from a 7 Kg charge at a distance of 12.5m a value of ≈0.47, using either tabulated data ([1], p.158) or the blast wave curves in well known manuals. This peak should be taken in conjunction with the load duration found from the one-dimensional model, despite the fact that the duration of the corresponding spherical blast would be much lower. It is believed that this definition of the load is on the safe side and thus a more elaborate two-dimensional calculation is not necessary.

10. VENTING FROM FIRING CHAMBER

It is well known that venting can alleviate the loads produced in closed structures by explosive blasts. However, the effectiveness of venting depends on the vent size and on the geometry of the structure.

The closed proof range has a large 5mx6m door at the end of the firing chamber. The effect of operating the range while this door is left open is examined in this section.

The computational model used for the closed end was modified at the firing chamber end (Fig.13). First, the cross-sectional area was reduced to the door opening. Second, the boundary condition at the end was modified to allow for the air to flow out of the opening, with an applied pressure equal to the ambient pressure. The resulting pressure time history at the target, Fig.21, is significantly different from the corresponding one for the closed end (Fig.14): It has only one significant peak as opposed to the double peaks in the closed end pressure pulse. The first peak is followed by a weak peak and a rather strong negative pressure. This negative phase is a result of the pressure rarefaction at the open end. However, from the practical view point the opening of the door does not reduce the design loads since the peak values are about the same, with a similar pulse duration.

11. SUMMARY AND CONCLUSIONS

The pressure loads inside a closed proof range resulting from the firing of a 155mm Howitzer (charge 10) were calculated using a computer code for unsteady compressible flow, and a simple model for the muzzle blast. It was found that the loading at the target end has a peak overpressure of the order of 0.35, with a pulse duration of over 100 ms. For the load at the firing chamber door, an upper bound on the peak of ≈0.47 was estimated from data on spherical explosions, with a pulse duration of ≈40 ms, based on the one-dimensional model.

Several factors that affect the calculated peak overpressure were discussed and estimated, namely:

- Effect of combustion products kinetic energy.
- Effect of numerical convergence.
- Effect of muzzle blast initial location.
- Two-dimensional effects of shock reflection at the target end.

The loads were found to have typical pulse duration of 40-100 ms. Since the loads are to be applied to structures having natural vibration periods of the same order of magnitude, the dynamic response of the structures must be considered.

REFERENCES

[1] Baker, W.E.: "Explosions in Air", University of Texas Press, p.18-21 (1973).

[2] Kivity, Y. and Feller, S.: "Blast Venting from a Cubicle", Proceedings of the 22nd DoD Explosives Safety Seminar, Anaheim, California, Aug. 1986.

[3] Kivity, Y. and Kalkstein, A.: "Blast Wave Penetration into Cubicles". Proceedings of the 23rd DoD Explosives Safety Seminar, Atlanta, GA., Aug. 1988.

[4] Gladstone, D.H. et al.,: "Studies of the Intermediate Ballistics of a Recoilless Rifle", Proceedings of the 7th Symposium on Ballistics, The Hague, The Netherlands, 1983.

[5] Krier, H. and Adams, M.J., in "Interior Ballistics of Guns", Edited by Krier and Summerfield, p.9, Table 1 (1979).

[6] Stiefel, L., in "Interior Ballistics of Guns", Edited by Krier and Summerfield, p.310, Table 2 (1979).

[7] Heiney, K.O., in "Interior Ballistics of Guns", Edited by Krier and Summerfield, p.90, eq. 6, (1979).

[8] Amsden, A.A., Ruppel, H.M., and Hirt, C.W.: "SALE : A Simplified ALE Computer Program for All Speeds", LA-8095 Report, Los Alamos National Lab. (1980).

[9] Kivity, Y., and Golan, D.: "Response of an Imbedded Reactor Containment to Explosive Blast Loading", Proceedings of the 5th Confer. on Structural Mechanics in Reactor Technology, (SMIRT-5), Berlin, W. Germany (1979).

[10] Hancock, S.L.: "PISCES 2DELK Theoretical Manual", Physics International Company, San Leandro, CA. (1985).

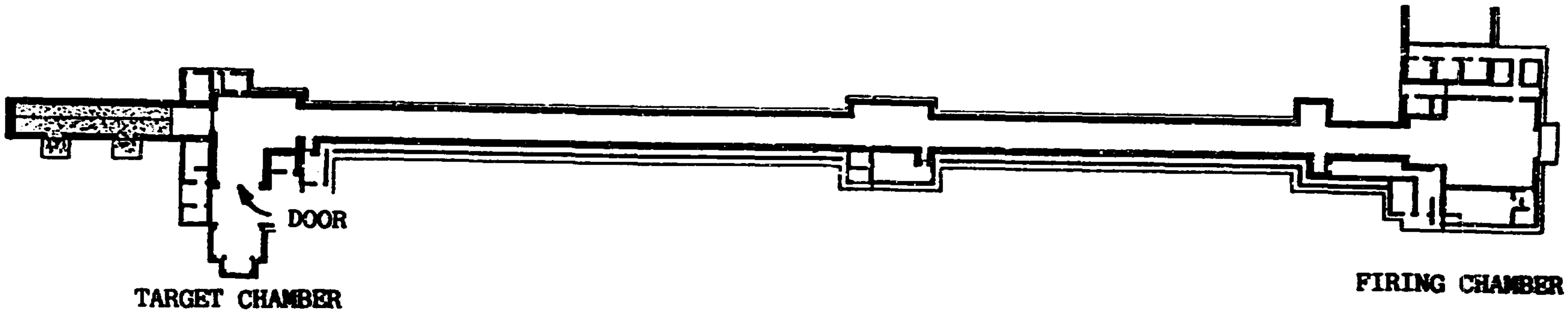

FIGURE 1a: SCHEMATIC OF THE FIRING RANGE

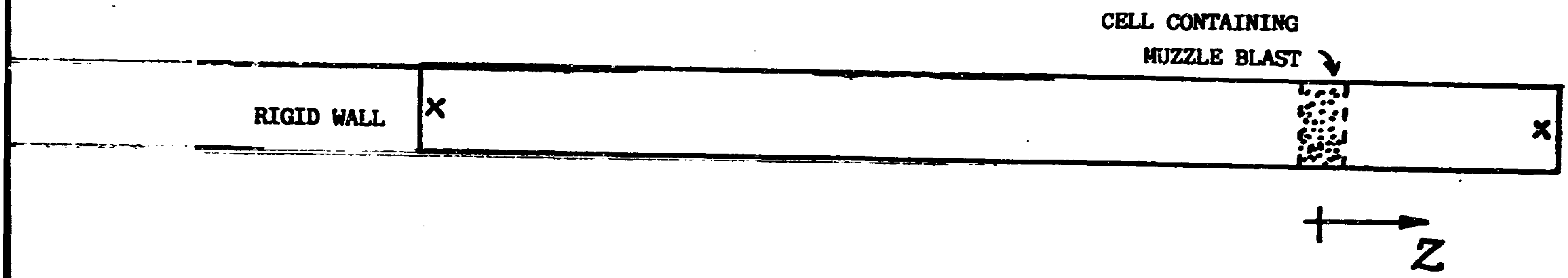

FIGURE 1b: THE COMPUTATIONAL MESH FOR THE UNIFORM CROSS-SECTION RANGE.

X - LOCATION OF PRESSURE TIME HISTORY PLOT

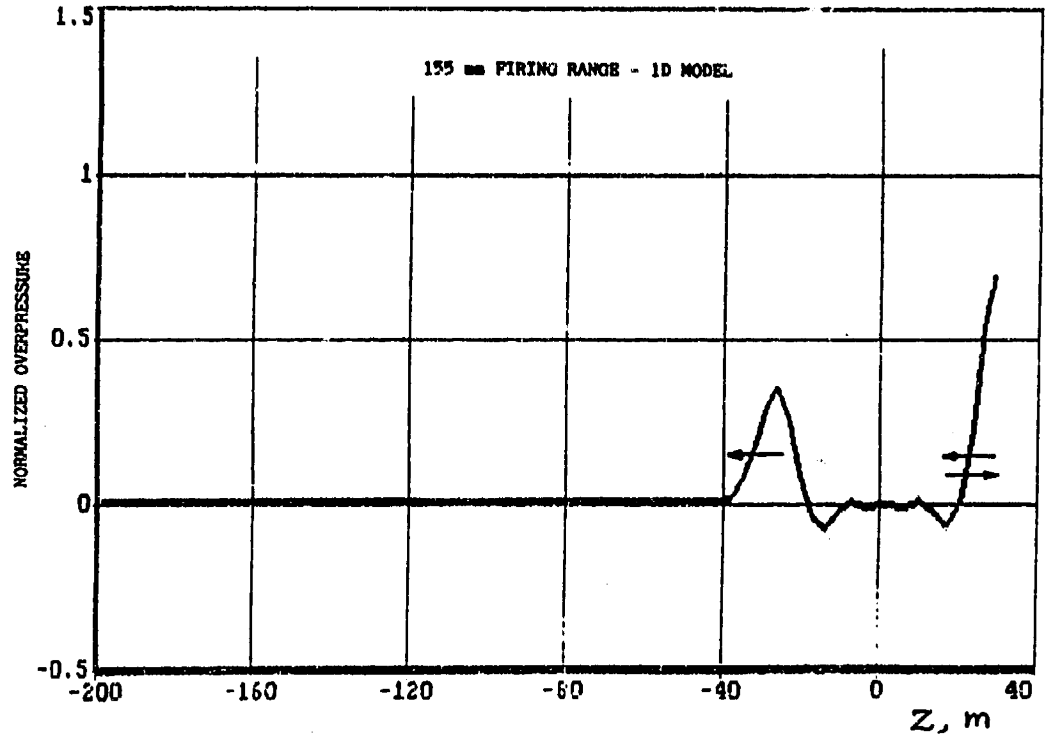

FIGURE 2: NORMALIZED OVERPRESSURE PROFILE AT TIME = 75 MS. (UNIFORM CROSS-SECTION RANGE).

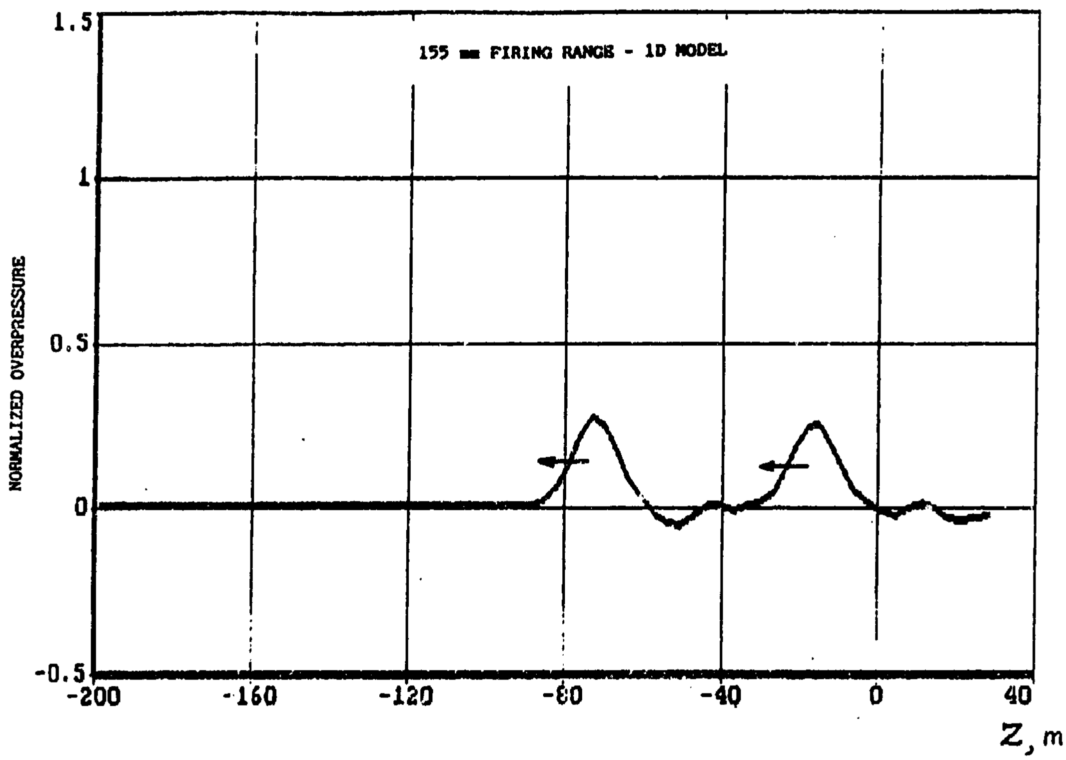

FIGURE 3: NORMALIZED OVERPRESSURE PROFILE AT TIME = 200 MS. (UNIFORM CROSS-SECTION RANGE).

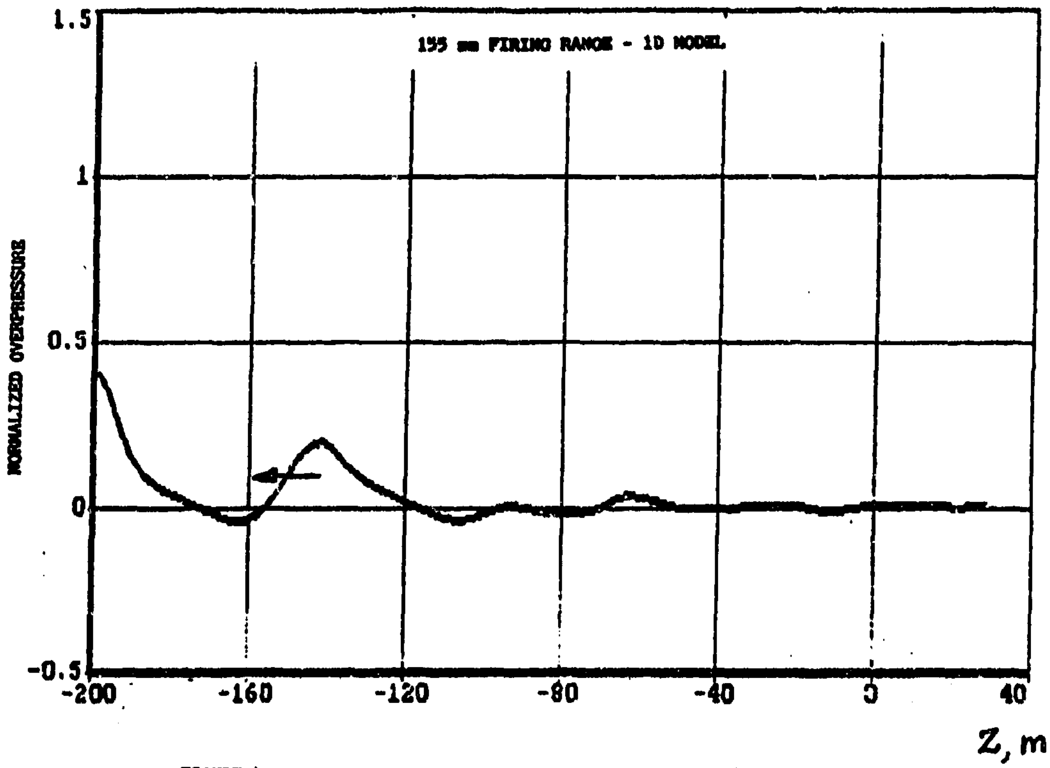

FIGURE 4: NORMALIZED OVERPRESSURE PROFILE AT TIME = 550 MS. (UNIFORM CROSS-SECTION RANGE).

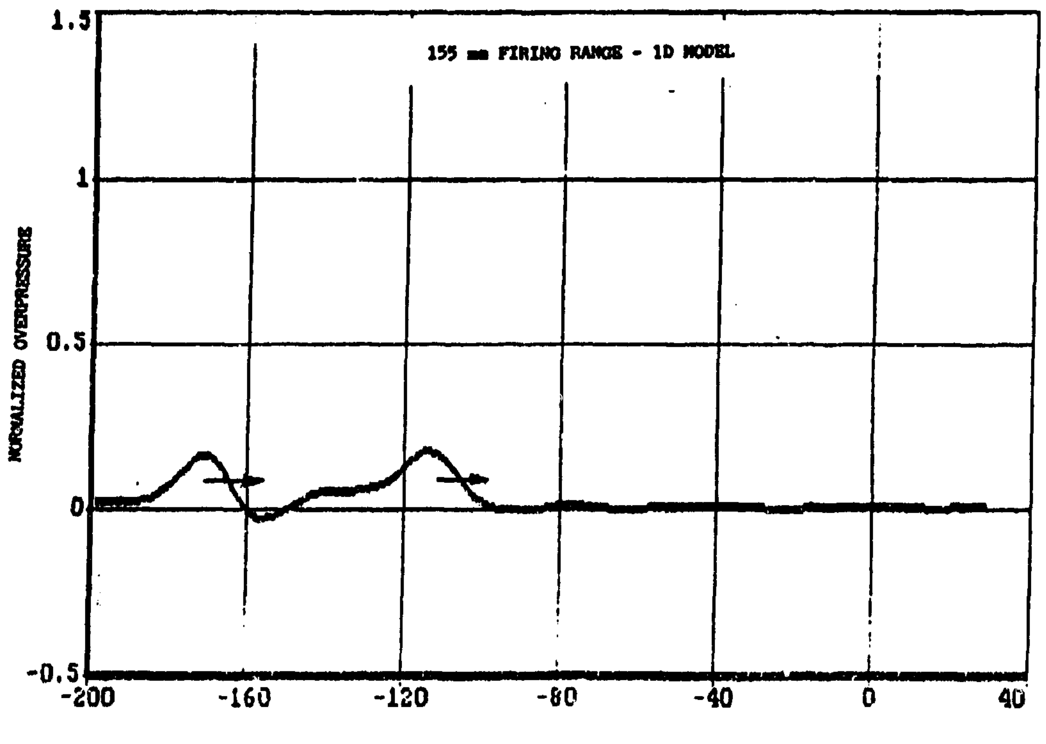

FIGURE 5: NORMALIZED OVERPRESSURE PROFILE AT TIME = 800 MS. (UNIFORM CROSS-SECTION RANGE).

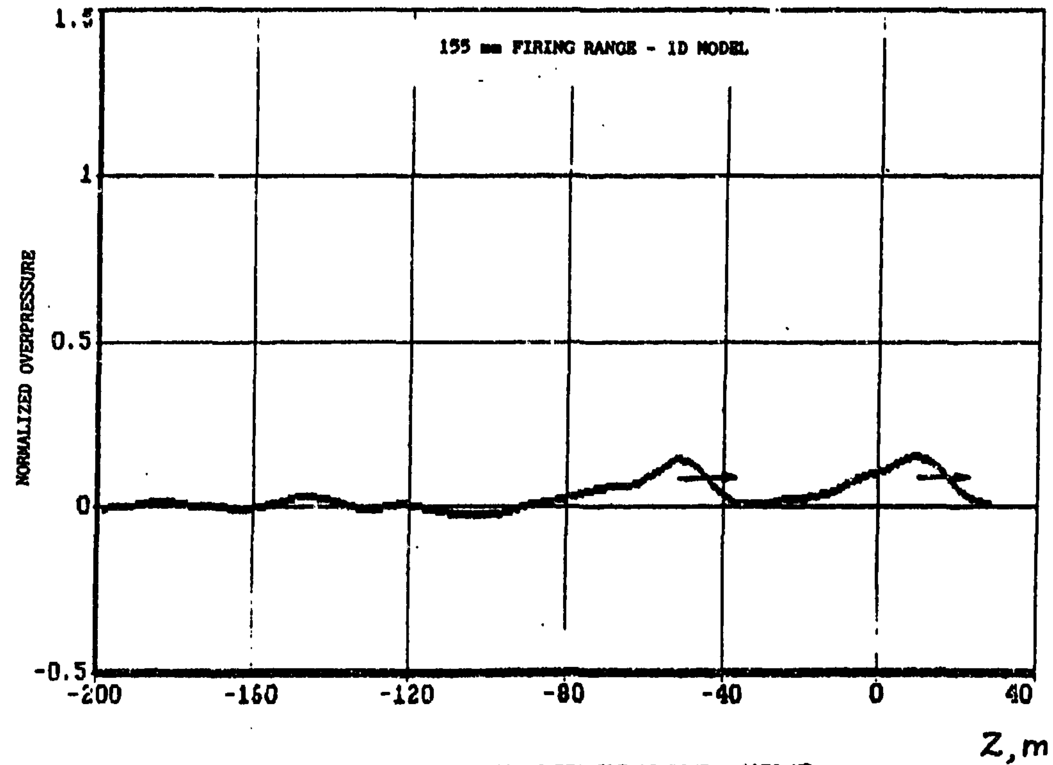

FIGURE 6: NORMALIZED OVERPRESSURE PROFILE AT TIME = 1150 MS.
(UNIFORM CROSS-SECTION RANGE).

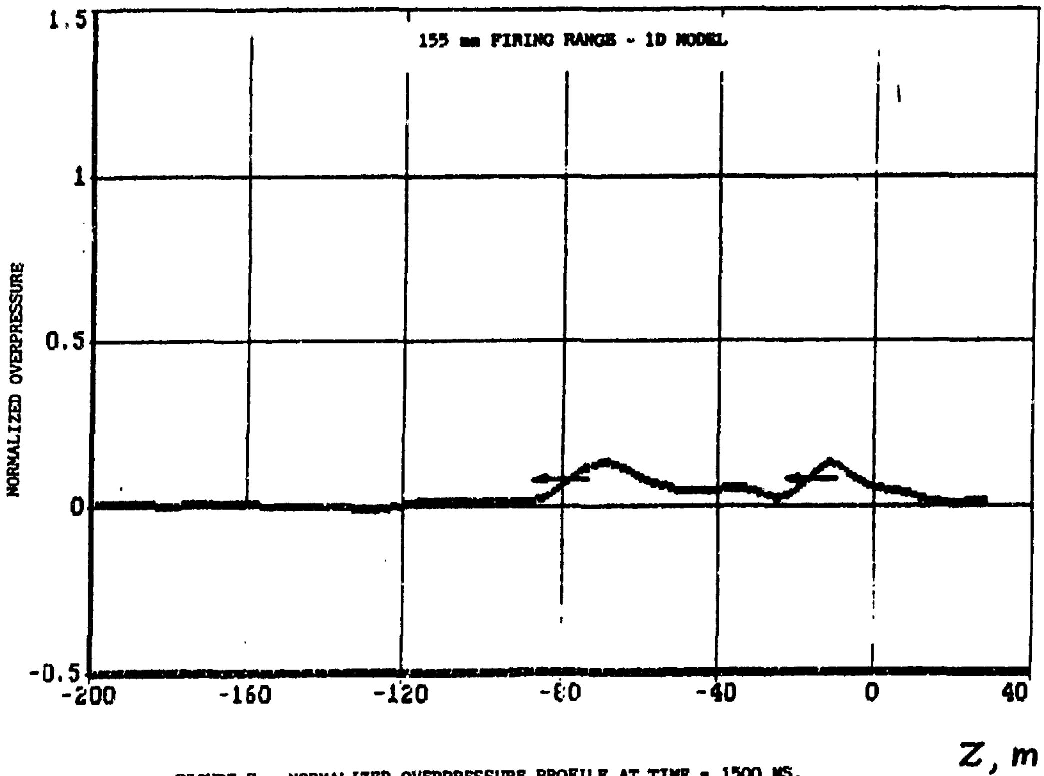

FIGURE 7: NORMALIZED OVERPRESSURE PROFILE AT TIME = 1500 MS.
(UNIFORM CROSS-SECTION RANGE).

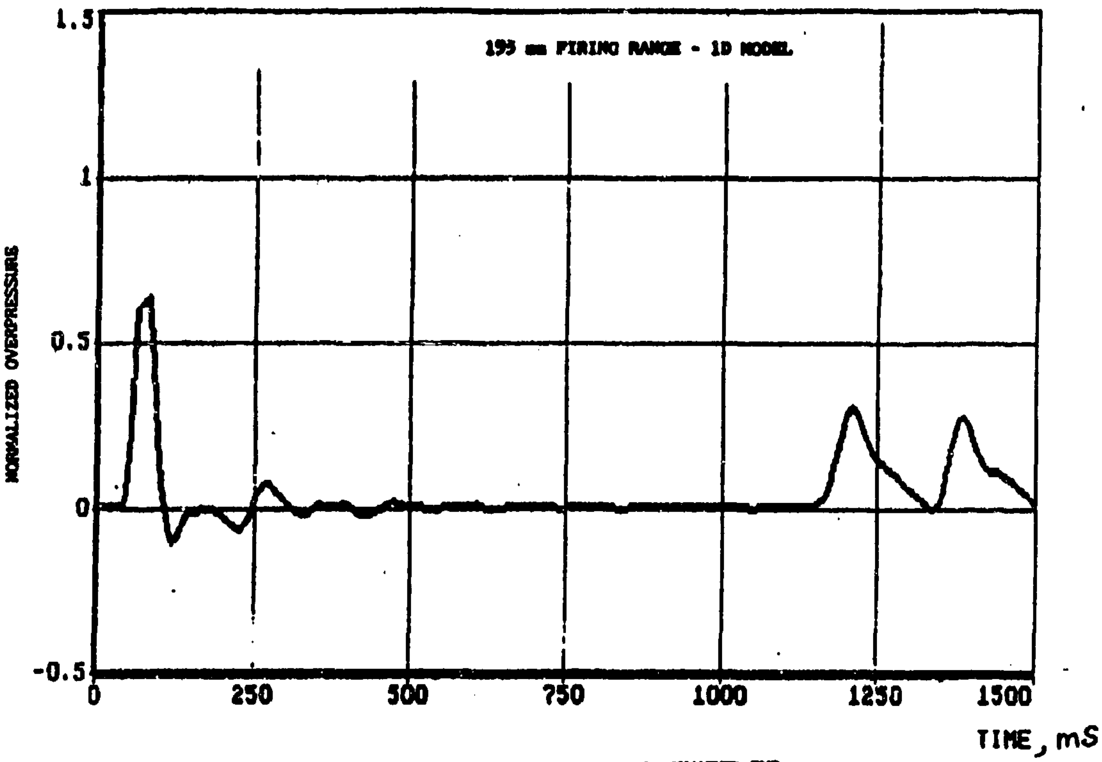

FIGURE 8: PRESSURE TIME HISTORY AT THE FIRING CHAMBER END.
(UNIFORM CROSS-SECTION RANGE).

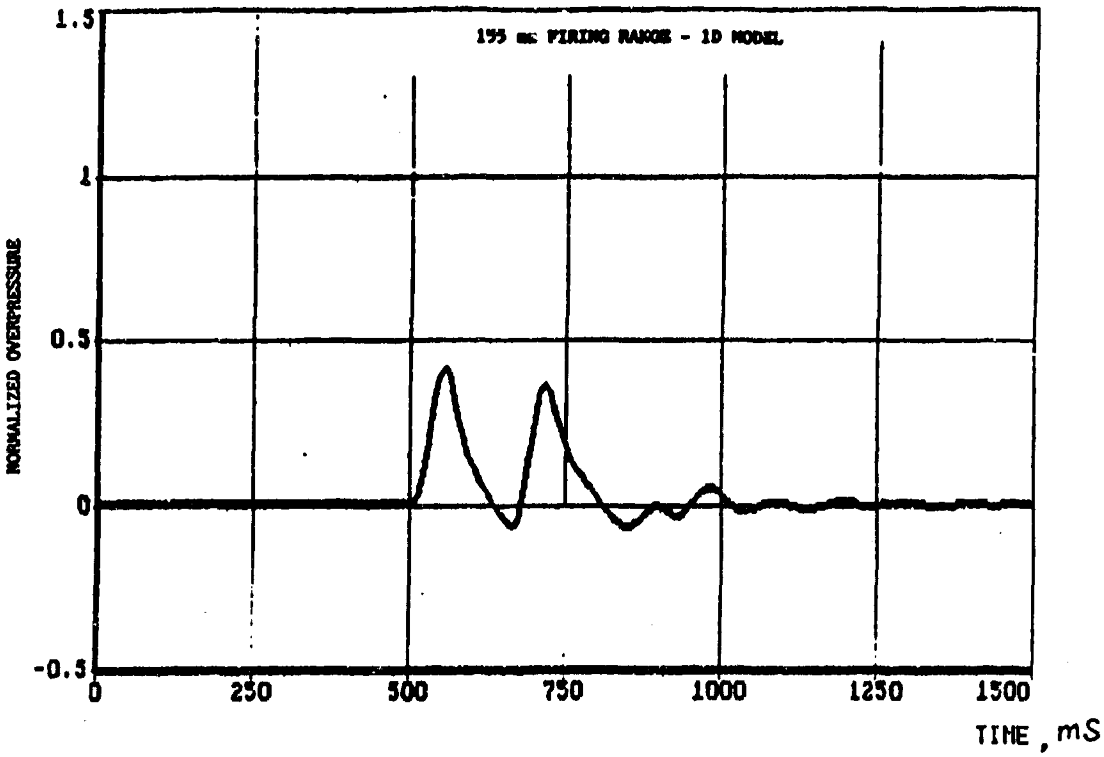

FIGURE 9: PRESSURE TIME HISTORY AT THE TARGET END (Z = -200).
(UNIFORM CROSS-SECTION RANGE).

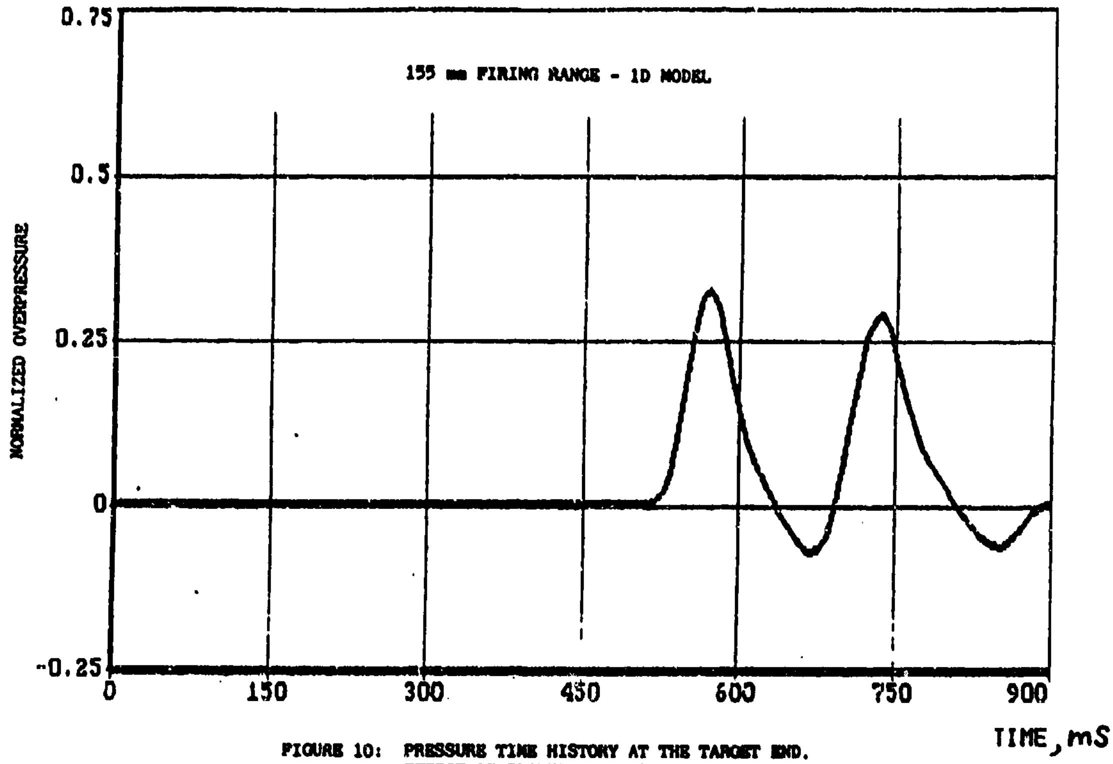

FIGURE 10: PRESSURE TIME HISTORY AT THE TARGET END.
EFFECT OF PROPELLANT GAS KINETIC ENERGY.
Fp = 0.30 ; Fc = 0.

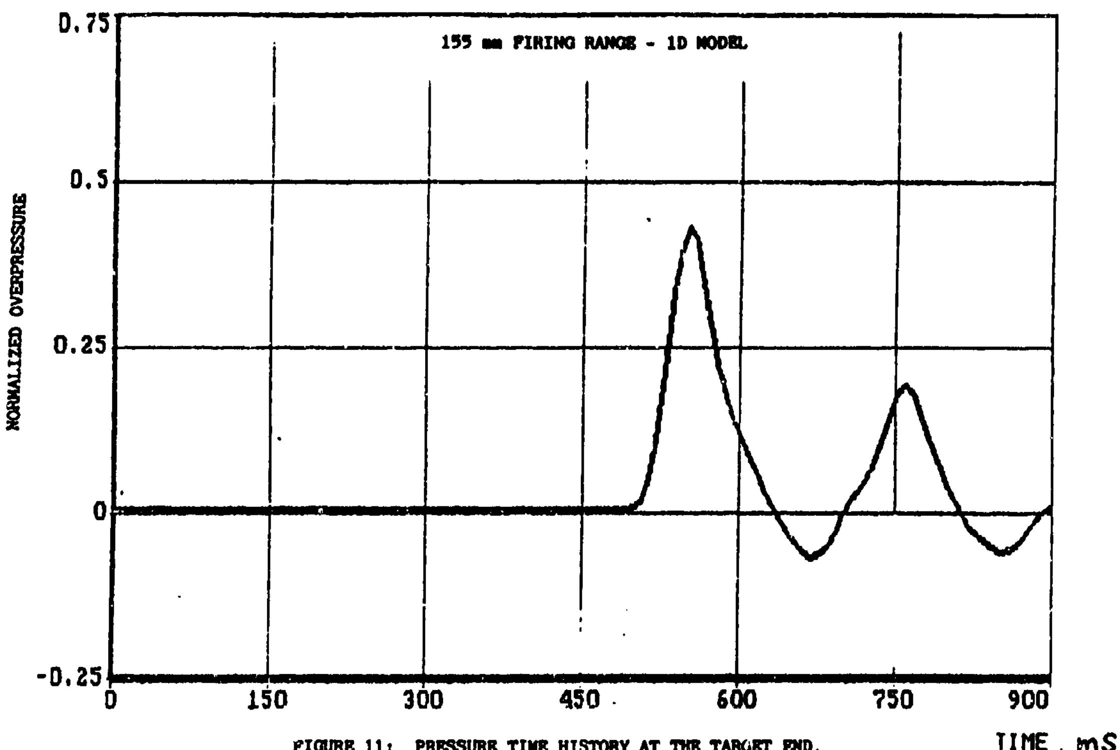

FIGURE 11: PRESSURE TIME HISTORY AT THE TARGET END.
EFFECT OF PROPELLANT GAS KINETIC ENERGY.
Fp = 0.30 ; Fc = 0.6

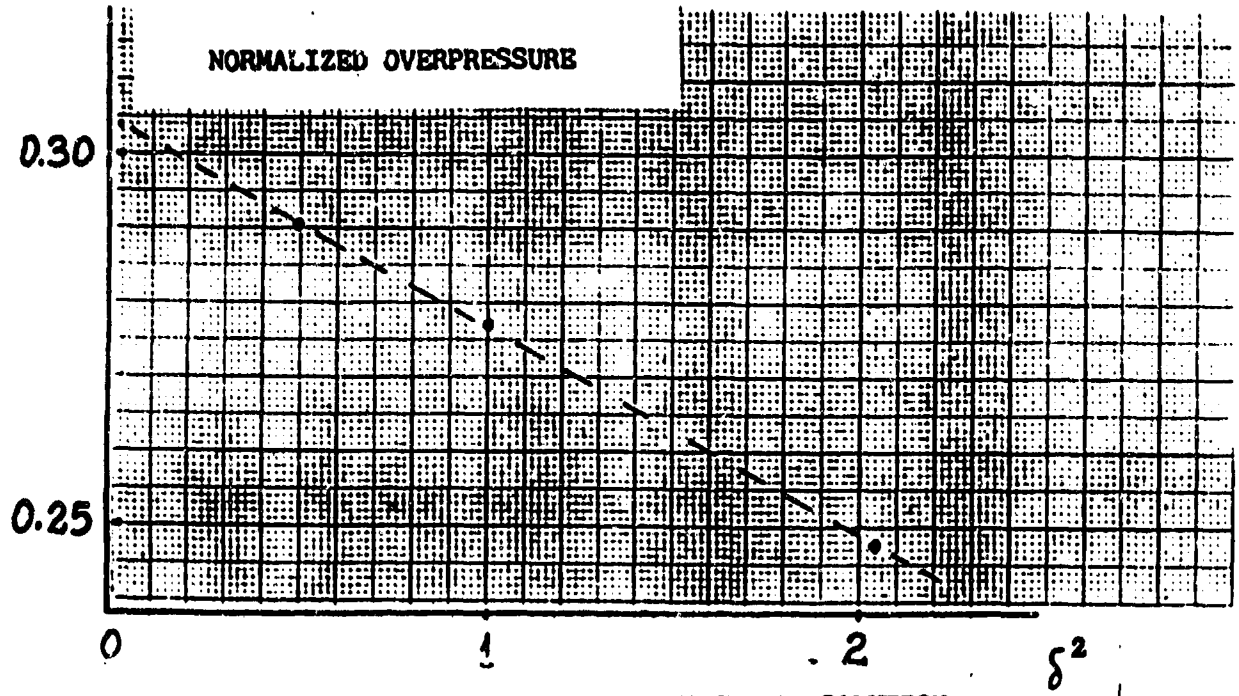

FIGURE 12: CONVERGENCE OF THE NUMERICAL SOLUTION.
N = NUMBER OF GRID CELLS; δ = 100/N.

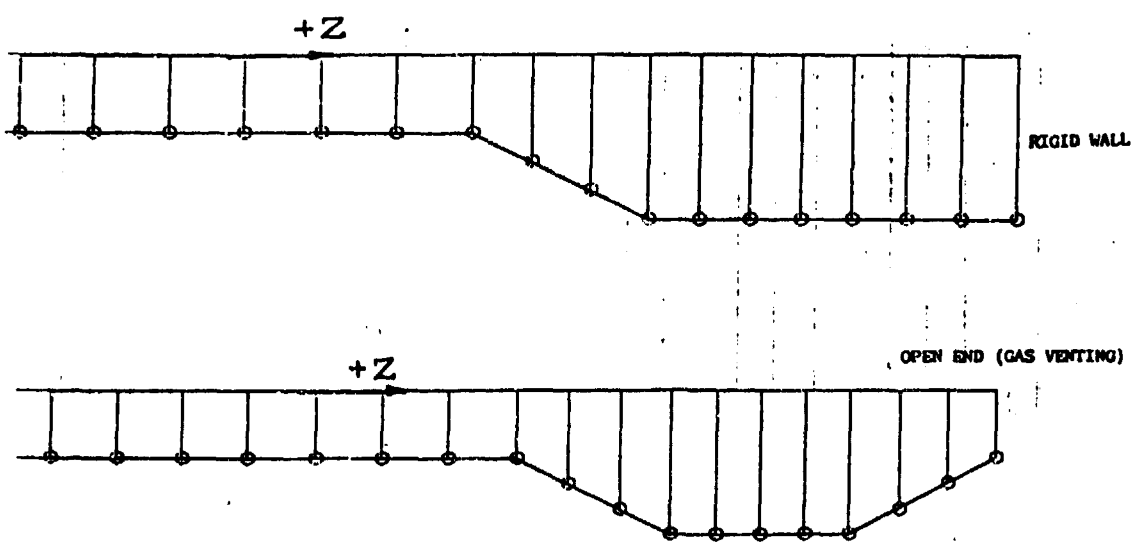

FIGURE 13: THE MESH FOR THE VARIABLE CROSS-SECTION RANGE.
TOP: FIRING CHAMBER DOOR CLOSED (NO VENTING).
BOTTOM: FIRING CHAMBER DOOR OPEN (WITH VENTING).

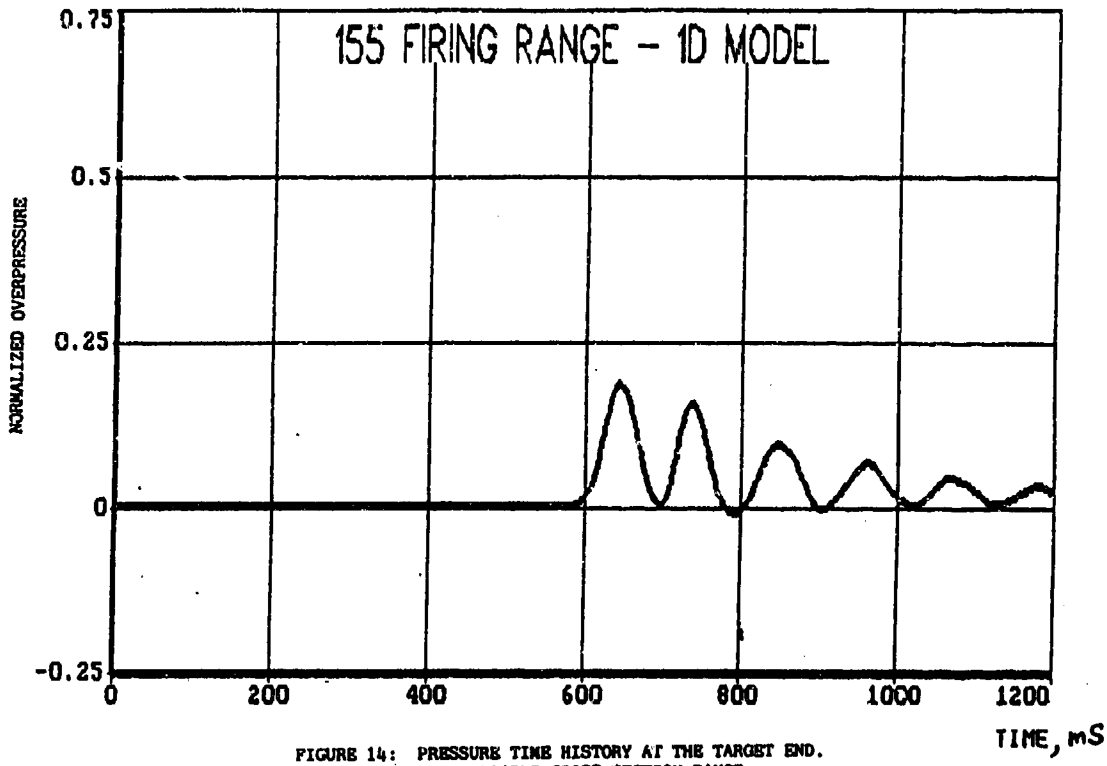

FIGURE 14: PRESSURE TIME HISTORY AT THE TARGET END.
VARIABLE CROSS-SECTION RANGE.
$F_p = 0.30$; $F_c = 0.1$

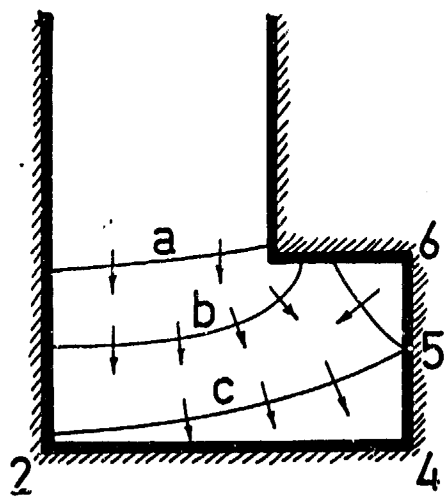

FIGURE 15: SCHEMATIC OF WAVE PROPAGATION IN THE TARGET CHAMBER.

THE CURVED LINES INDICATE THE SHOCK FRONT AT VARIOUS TIMES. (TIME INCREASES FROM a TO c) NUMBERS INDICATE LOCATIONS OF PRESSURE TIME HISTORY PLOT.

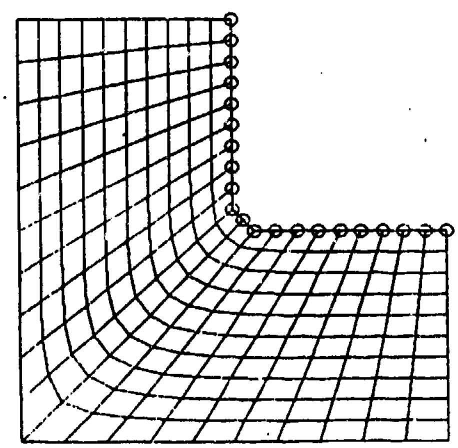

FIGURE 16: THE COMPUTATIONAL MESH FOR THE TWO-DIMENSIONAL CALCULATION. (TARGET END SIMULATION).

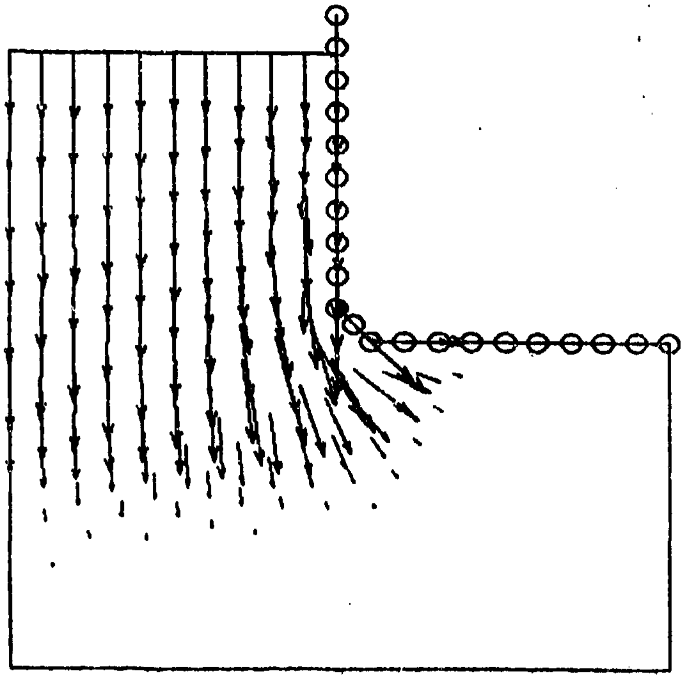

FIGURE 17a: VELOCITY VECTOR PLOT AT TIME=20 MS.
(TARGET END SIMULATION).

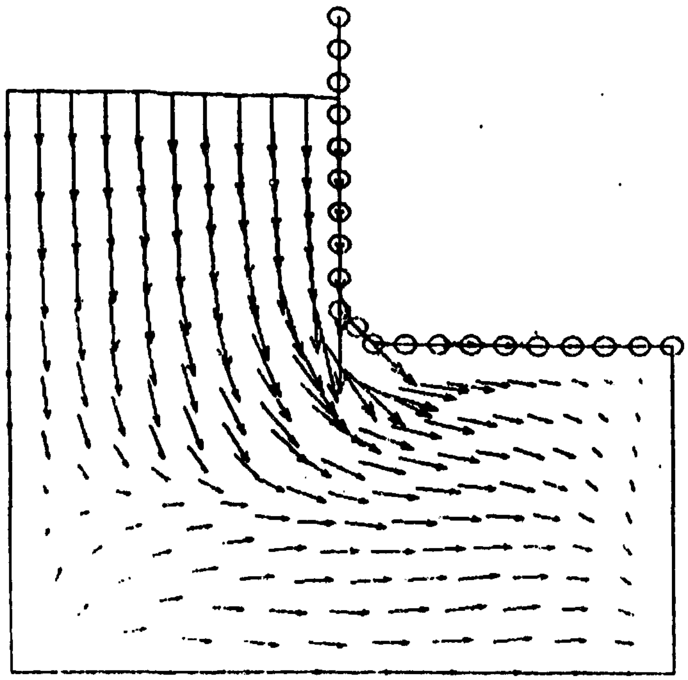

FIGURE 17b: VELOCITY VECTOR PLOT AT TIME=40 MS.
(TARGET END SIMULATION).

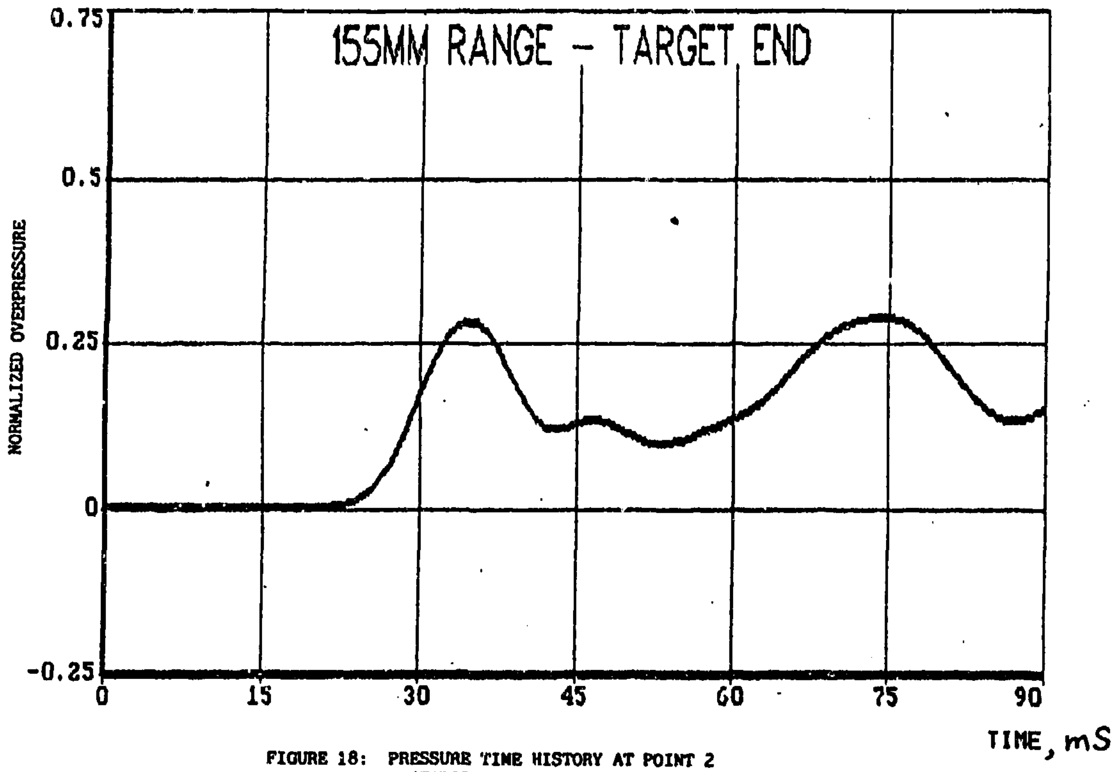

FIGURE 18: PRESSURE TIME HISTORY AT POINT 2
(TARGET END 2D SIMULATION)

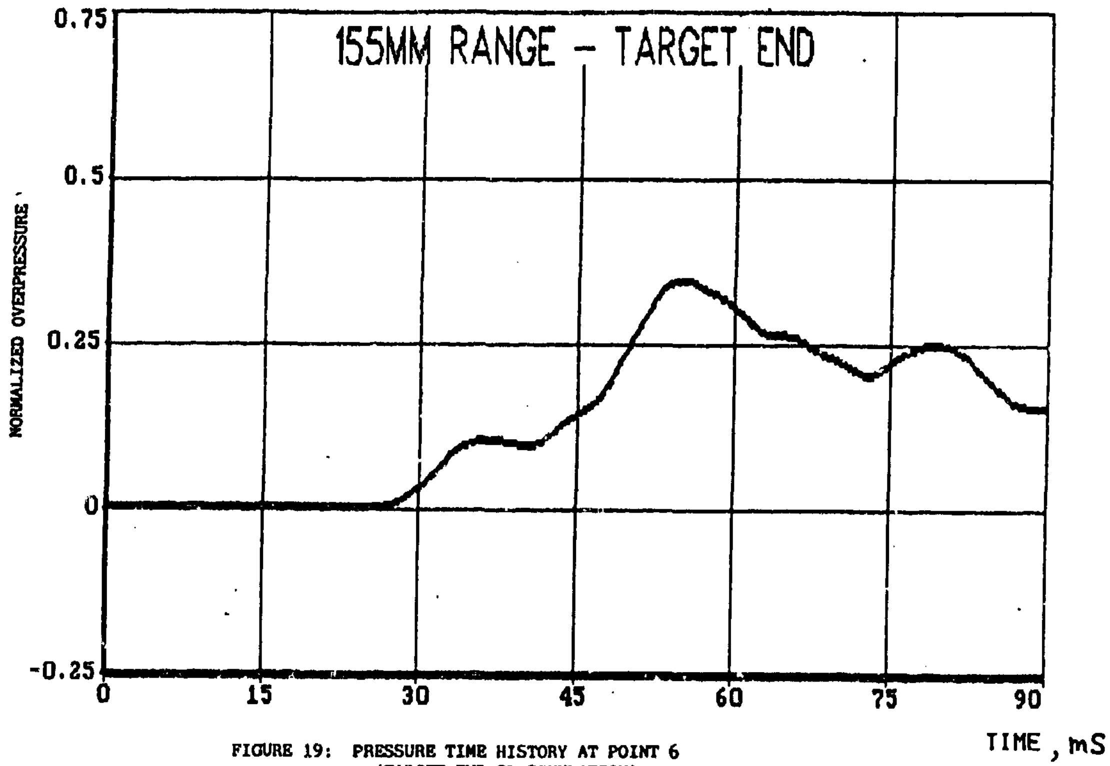

FIGURE 19: PRESSURE TIME HISTORY AT POINT 6
(TARGET END 2D SIMULATION)

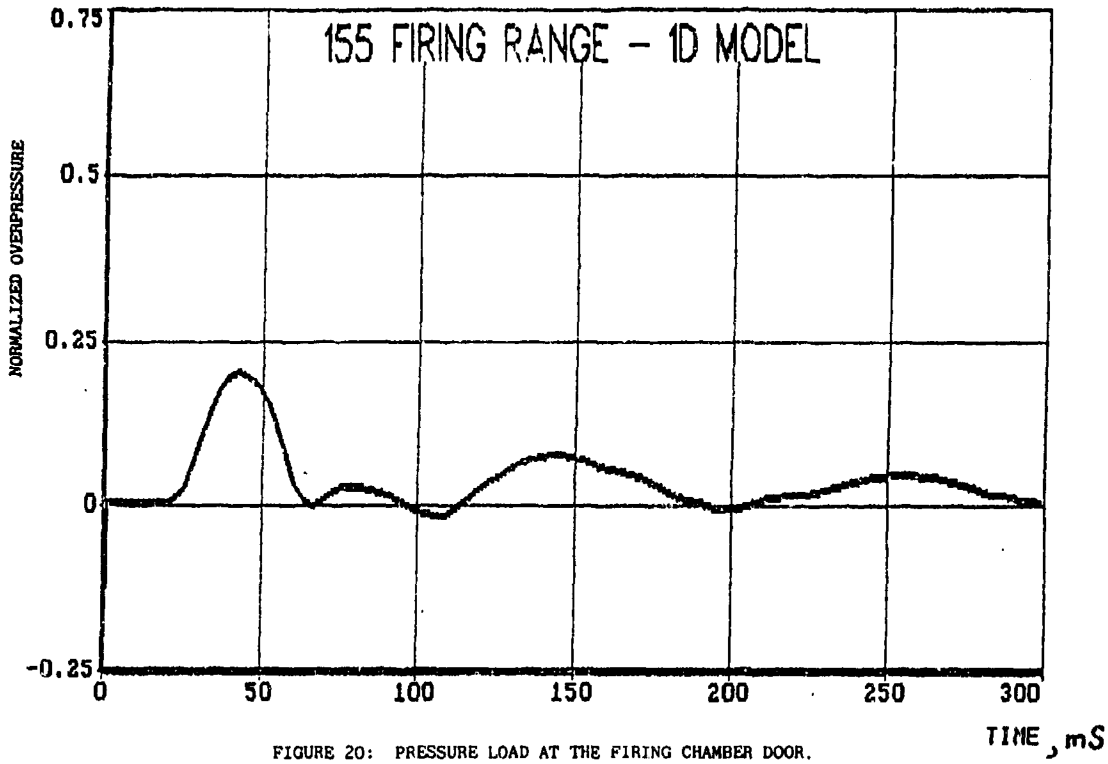

FIGURE 20: PRESSURE LOAD AT THE FIRING CHAMBER DOOR.
VARIABLE CROSS-SECTION RANGE.
Fp = 0.30 ; Fc = 0.0

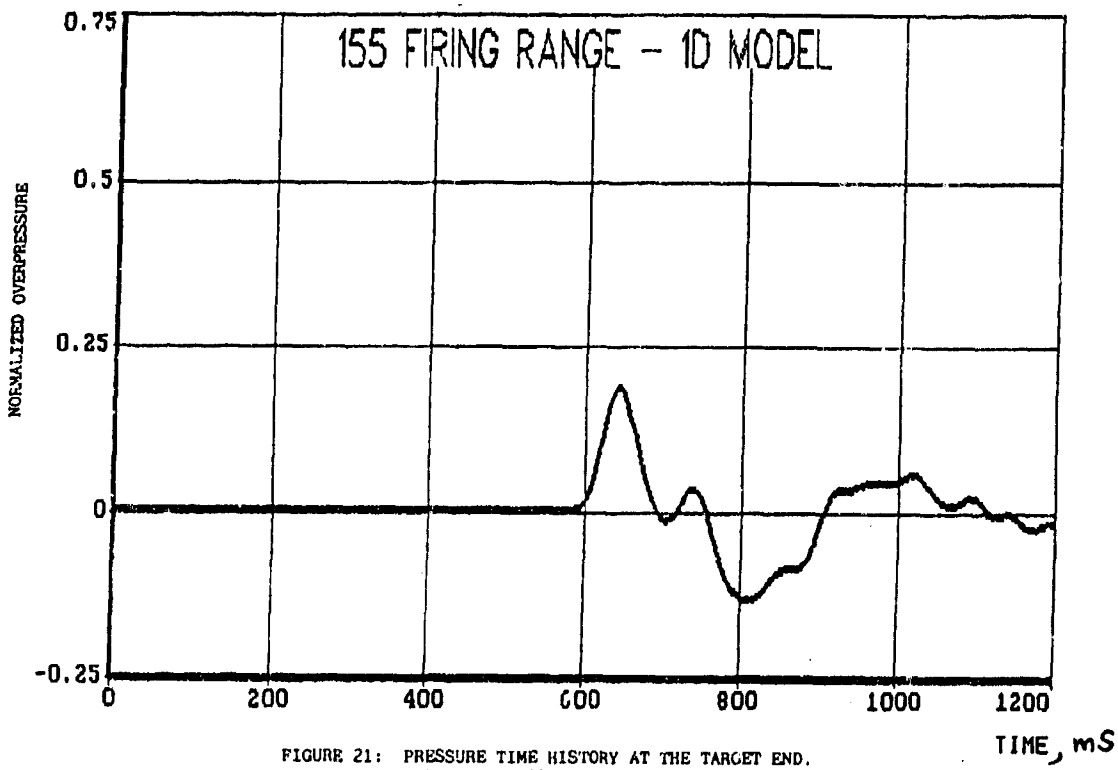

FIGURE 21: PRESSURE TIME HISTORY AT THE TARGET END.
VARIABLE CROSS-SECTION RANGE, WITH VENTING.
Fp = 0.30 ; Fc = 0.1

SAFETY WINDOW SHIELD TO PROTECT AGAINST EXTERNAL EXPLOSIONS

by

R. L. Shope and W. A. Keenan
Naval Civil Engineering Laboratory
Port Hueneme, CA 93043

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ABSTRACT

This paper describes the conceptual design, predicted performance, and development plan for a new design concept being developed by the Naval Civil Engineering Laboratory for safety windows in both new and existing buildings. The concept, named the safety window shield, protects the building interior against effects from accidental explosions outside the building, including blast overpressures, fragments, and debris. Instead of transferring window loads to the exterior wall, the shield transfers the applied window loads to the wall-ceiling and wall-floor joints where the building is inherently strong. This vastly reduces collateral building damage and the probability of structural collapse from an explosion. The acquisition, installation, and maintenance costs make the shield an economical, reliable, and effective way to increase the safety of personnel in buildings from accidental explosions associated with ammunition logistics.

The design concept is a polycarbonate shield mounted in a steel frame suspended immediately behind the window opening from steel cables connected to the ceiling and floor. Energy absorbers and lead mass concealed inside the frame control dynamic response of the shield to an explosion. The cables restrain the shield in a blocking position behind the window opening to protect the building interior during the critical time when blast overpressures, casing fragments, glass shards, and debris act on the window.

1.0 INTRODUCTION

1.1 PROBLEM

Terrorist bombings directed against U.S. facilities and accidental explosions from ammunition logistics have prompted a need for ways to upgrade buildings to protect inhabitants from explosions. Historical records of explosions show that inhabitants are most vulnerable to explosion effects that enter interior spaces through windows, as illustrated in Figure 1-1.

The threats from explosions include blast overpressures, flying debris, glass shards, and fragments entering the building through windows. The concept of a safety window shield evolved as a means to defeat these threats in both new and existing buildings.

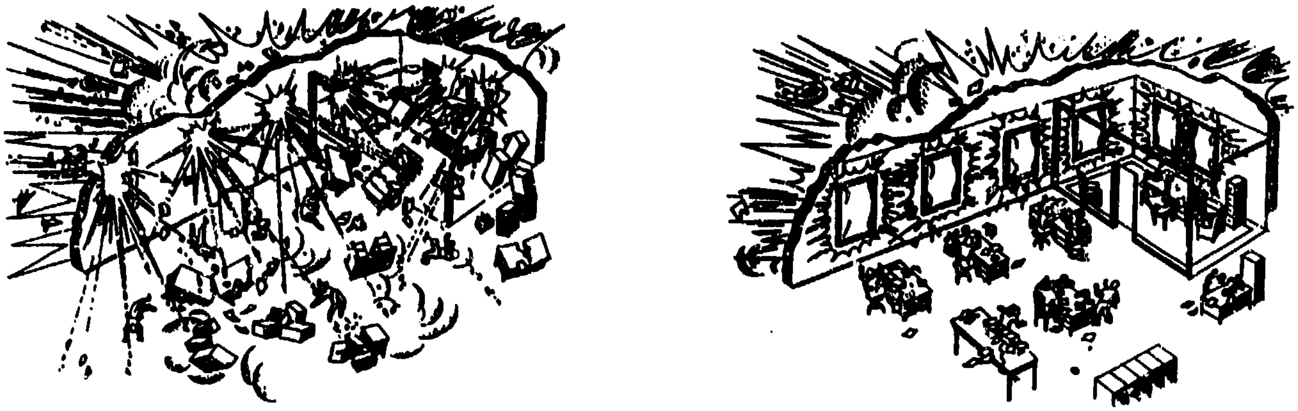
The common approach to protect against explosion effects is to install a hardened window and frame. While this approach will protect the building interior, there are several disadvantages. The principal disadvantage is that the blast loads applied to a hardened window are transferred directly to the adjoining wall. This vastly increases collateral damage to unhardened buildings which, in turn, increases the probability of structural collapse. Also, hardened windows are very expensive and time consuming to install, especially in existing buildings. Further, blast hardened windows are permanent modifications which cannot be easily altered to accommodate a change in the threat level. In most buildings, hardened windows provide neither a practical nor affordable solution for life safety.

1.2 SOLUTION

The safety window shield is a polycarbonate panel mounted in a steel frame which is suspended immediately behind the window opening from steel cables connected to the ceiling and floor, as illustrated in Figure 1-2. An explosion outside the building destroys the conventional glass window covering the opening and directly loads the shield. The cables restrain the shield in a blocking position behind the window opening to protect the building interior during the critical time when blast overpressures, casing fragments, glass shards, and debris try to enter through the window openings. Blast, fragment, and debris loads applied to the shield are transferred by the cables to the wall-ceiling and wall-floor joints where buildings are inherently strong. This vastly reduces collateral building damage and the probability of structural collapse from the explosion.

1.3 SCOPE

The safety window shield can be designed to defeat a variety of threats, including blast overpressures from explosions, flying debris and fragments, small arms fire, electronic surveillance, and forced entry. However, this paper deals primarily with the theory and design for a safety window shield to protect interior spaces from external explosions.



(a) No safety window shield

(b) Safety window shield behind each window

Figure 1-1. Life safety in buildings with and without safety window shields.

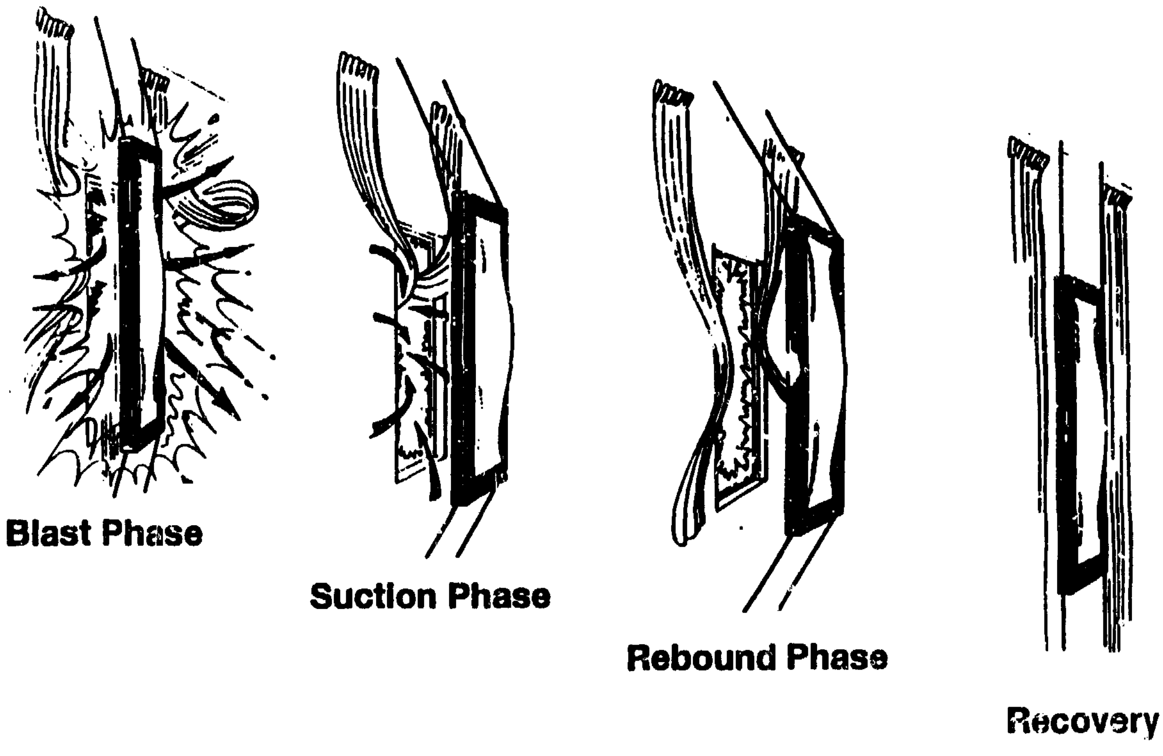


Figure 1-2. Dynamic response of shield to external explosion.

2.0 SAFETY WINDOW SHIELD

2.1 THREAT

The design threat is an explosion outside the building. Design parameters are the TNT equivalent weight of the explosion, the location of the explosion relative to the window opening, and the number, mass, and velocity of fragments and debris striking the window opening.

2.2 FUNCTION

Safety window shields are installed on the interior of the building, directly behind the window openings. The shields block threats from entering the building. A typical safety window shield is shown in Figures 2-1 through 2-S. The major components of the system are a polycarbonate glazing panel, a tubular steel frame that holds the glazing, four cables which suspend the shield behind the window opening, energy absorbers inside the vertical rails of the frame, and lead ballast inside the horizontal rails of the frame.

The safety window shield protects inhabitants by remaining in a blocking position behind the window opening during the critical time when blast overpressures, fragments, and debris try to enter the opening. When an explosion occurs, the shock wave arrives at the building, strikes the window, and reflects back. The result is an instantaneous rise in pressure on the window. This blast load easily fails the window glass and causes the shield to displace horizontally into the room. This movement creates a vent area around the shield for blast pressures to enter the room. However, this vent area is small compared to the area of the window opening. Consequently, the pressures escaping into the room are greatly reduced. In addition to reducing overpressures, the shield acts as a barrier to reduce the number of fragments, debris and glass shards entering the room.

2.3 COMPONENTS

2.3.1 Glazing

The glazing is a thin panel of polycarbonate material, such as Lexan. Both faces of the polycarbonate are covered with a commercial film to inhibit environmental degradation of the glazing. The glazing is mounted in a steel frame and held in place by bolts uniformly spaced along the perimeter of the glazing. The length and width of the glazing are equal to those of the window opening. The stress-strain characteristics of the polycarbonate, shown in Figure 2-6, allow the glazing to absorb the blast energy by work done in the form of strain energy associated with large inelastic deflections of the glazing acting as a tensile membrane.

2.3.2 Frame

The frame supports the polycarbonate glazing and is made up of standard AISC tubing. The horizontal and vertical members of the frame are welded together. A glazing boot made up of steel plates is welded to the tubes to hold the polycarbonate panel in place, as shown in Figure 2-7. The boot is lined with a uroprene gasket that develops friction forces to resist pull-out of the polycarbonate as it undergoes large membrane deflections.

2.3.3 Cables

Four cables hold the shield in position immediately behind the window opening as shown in Figure 2-1. Two cables are connected to the wall-ceiling joint and two cables are connected to the wall-floor joint, as shown in Figure 2-8. The other ends of the cables are attached to the pull-rods in the energy absorbers, as shown in Figure 2-4. The cables are pretensioned to restrain the shield flush against the interior face of the wall. Additional cables can be installed in vertical mullions to accommodate wide windows.

2.3.4 Energy Absorbers

Four energy absorbers are concealed inside the steel frame tubing, one near each end of the two vertical rails, as shown in Figures 2-2 and 2-3. The energy absorber is a series of aluminum honeycomb blocks threaded onto a steel rod. Each block is sandwiched between a steel bearing plate and a steel resisting plate. The bearing plates are connected by ring keys to the rod. The resisting plates are connected by shear pins to the steel tubing. Tension in the rod causes compression in the honeycomb blocks.

Any shield motions produce tension in the top and bottom cables which, in turn, produces tension in the rod of each energy absorber. Significant shield motions produce cable tension forces sufficient to crush the honeycomb blocks.

A typical stress-strain curve for the aluminum honeycomb material is shown in Figure 2-5. This material can be obtained with crushing strengths ranging from 15 to 10,000 psi. Once the material reaches its crushing strength, it will undergo large inelastic strains with no significant increase in stress until it locks up at strains exceeding 75 percent. It is evident from Figure 2-5 that the crushable material can dissipate a large amount of energy.

2.3.5 Ballast

Ballast, in the form of lead beads, is packed into the space inside the top and bottom horizontal rails of the frame, as shown in Figure 2-7. The lead ballast increases the total mass of the system which, in turn, reduces the horizontal shield displacements, thus reducing the peak blast overpressure inside the room. In addition to reducing shield displacements, the ballast can be proportioned between the top and bottom rails so as to minimize the rigid body rotation of the shield. Reducing the rotation limits the amount of debris allowed to enter the room.

2.3.6 Cable Anchors

The cables are threaded through holes drilled in the floor and ceiling, as illustrated in Figure 2-8. A standard cable connector, such as a lead-filled wedge sleeve, anchors the cable to the back face of the floor and ceiling. A steel anchor plate is used to safely distribute the cable forces into the structural floor/ceiling system. The shield is drawn against the wall by pretensioning the cables before the connectors are fastened to the cables.

2.4 PERFORMANCE OBJECTIVES

The shield design should consider the following performance objectives for life safety of inhabitants:

- Limit the peak incident blast overpressures inside the room
- Limit the number of fragments and debris entering the room
- Limit the maximum horizontal displacement of the shield into the room

Typical safety thresholds are as follows:

- Overpressure. The peak incident blast overpressures inside the room shall not exceed 1.2 psi at a point 8 feet behind the window opening and 5 feet above the floor.
- Fragments. No more than one bomb fragment shall enter the room through the window opening with an energy content exceeding 58 ft-lbs. No debris and glass shards shall perforate the glazing. However, in no case shall the penetration resistance of the glazing be required to exceed that of the adjoining wall.
- Displacements. The maximum horizontal displacement of the shield into the room shall not exceed 12 inches.

2.5 INSTALLATION

2.5.1 Security Film

For maximum shield effectiveness, the glass in the window behind the shield is covered with a thin layer of plastic security film. This film binds the glass shards together, thereby reducing the number and lethality of glass shards entering the room.

2.5.2 Air Gap

The effectiveness of the shield in mitigating peak blast overpressures entering the room increases with the air gap distance, defined as the distance from the face of the glass window to the face of the shield. The blast wave must accelerate the mass of the broken window glass and move it through the air-gap distance before the glass shards and trailing blast wave can strike the shield. During this time interval, the blast overpressures outside the building are decaying. This decay reduces the peak blast overpressures trying to enter the room around the shield.

The air gap also serves to prevent degradation of the polycarbonate due to ultra violet rays from sunlight.

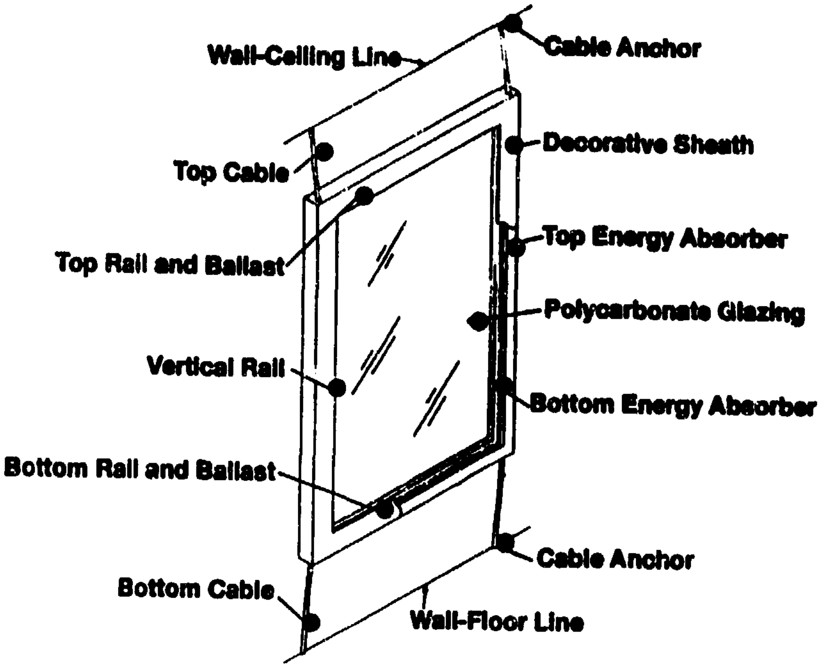


Figure 2-1. Shield components.

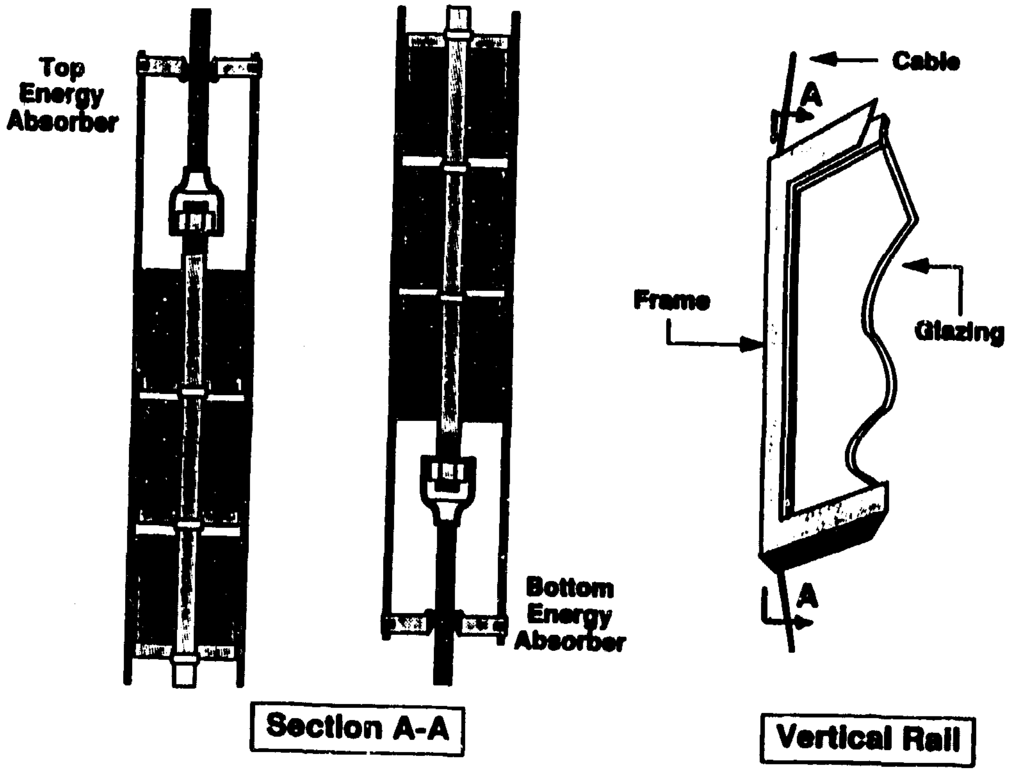


Figure 2-2. Cables and energy absorbers.

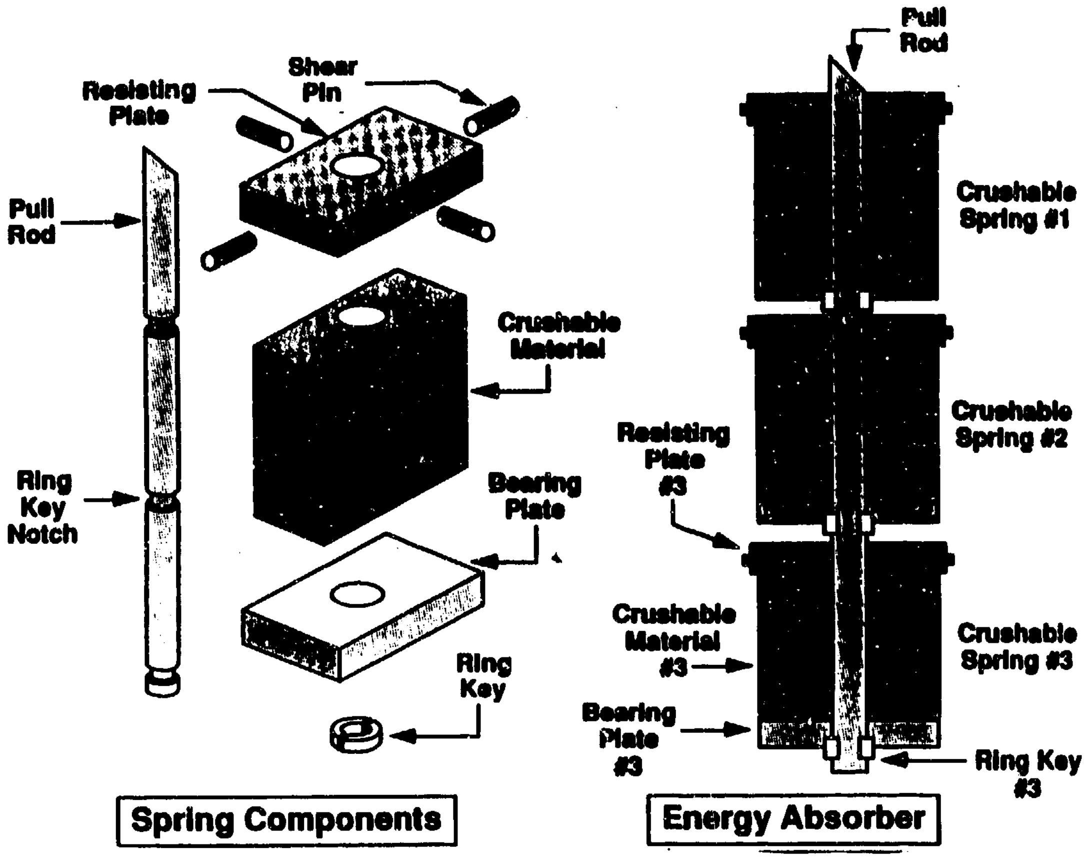


Figure 2-3. Energy absorber components.

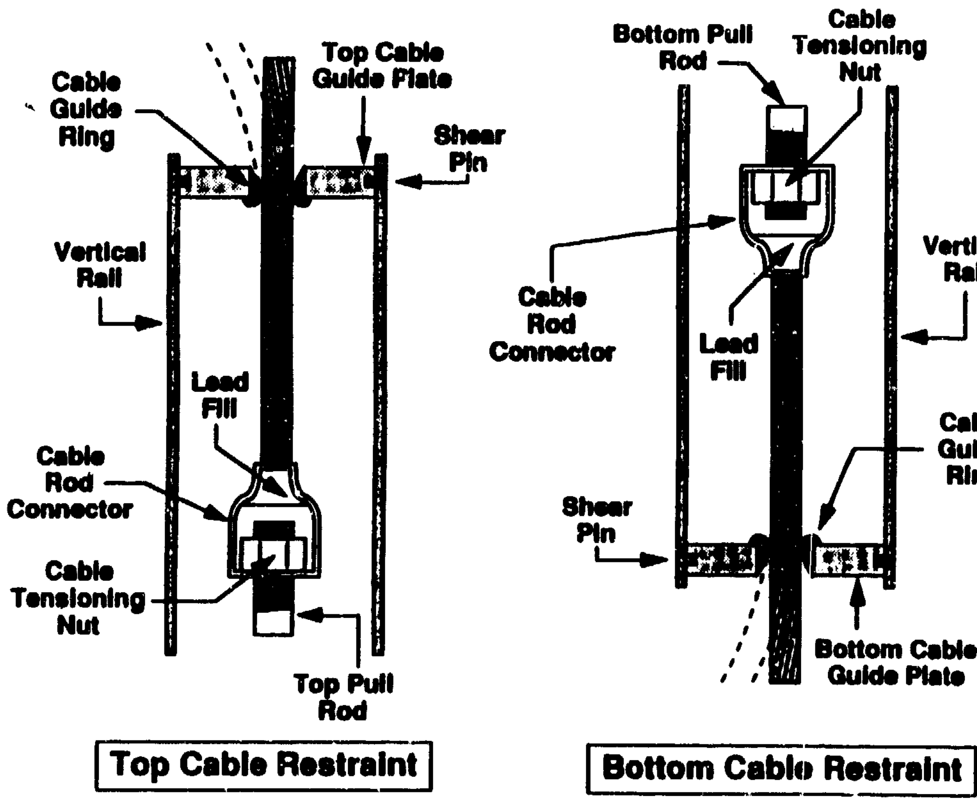


Figure 2-4. Cable restraint system.

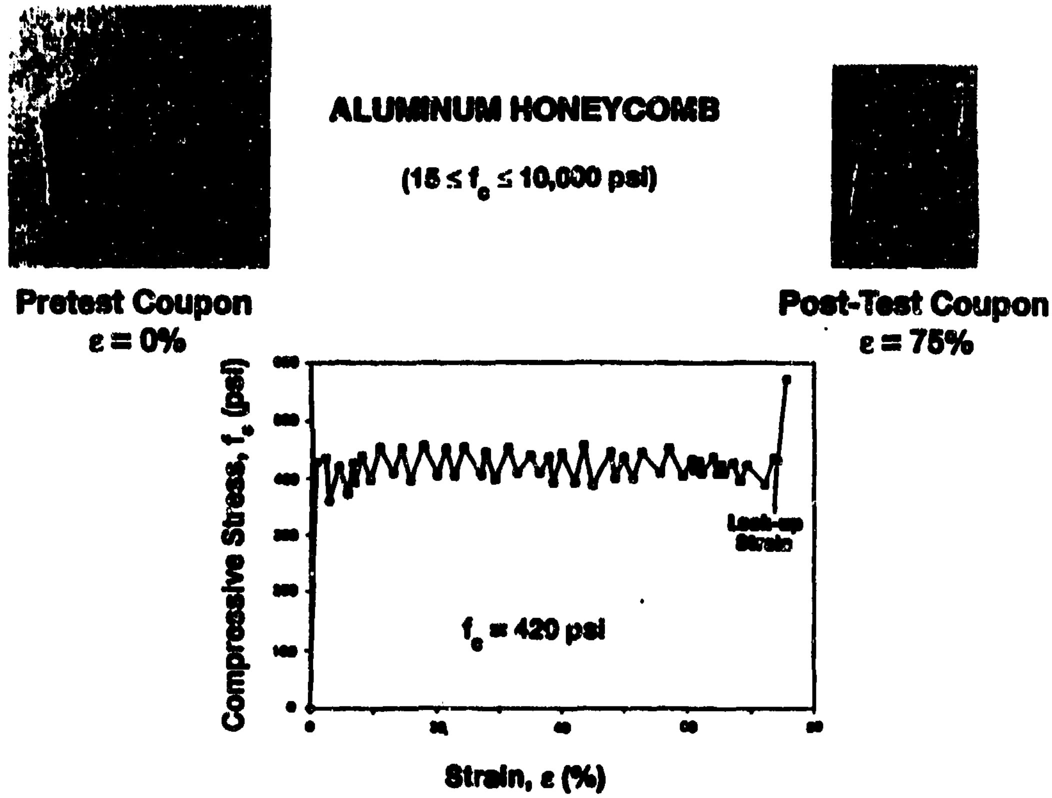


Figure 2-5. Stress-strain characteristics of aluminum honeycomb material.

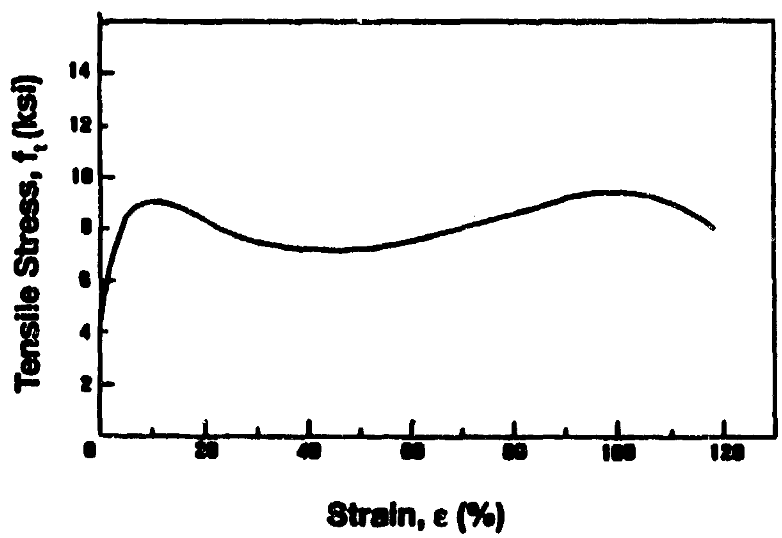


Figure 2-6. Stress-strain characteristics of polycarbonate glazing.

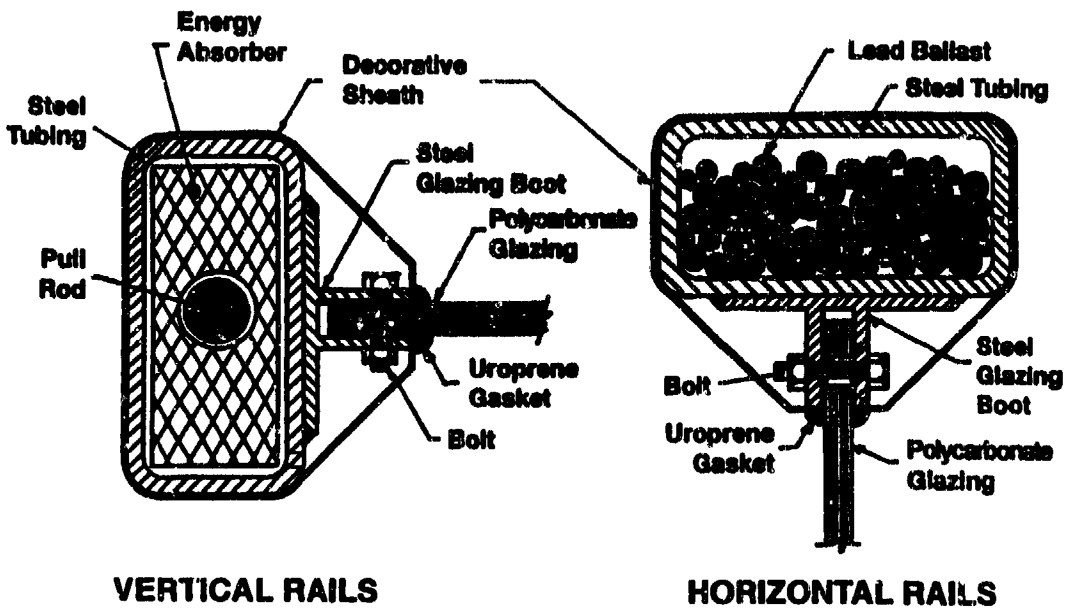


Figure 2-7. Rails, boots, ballast, energy absorbers, and glazing for shield.

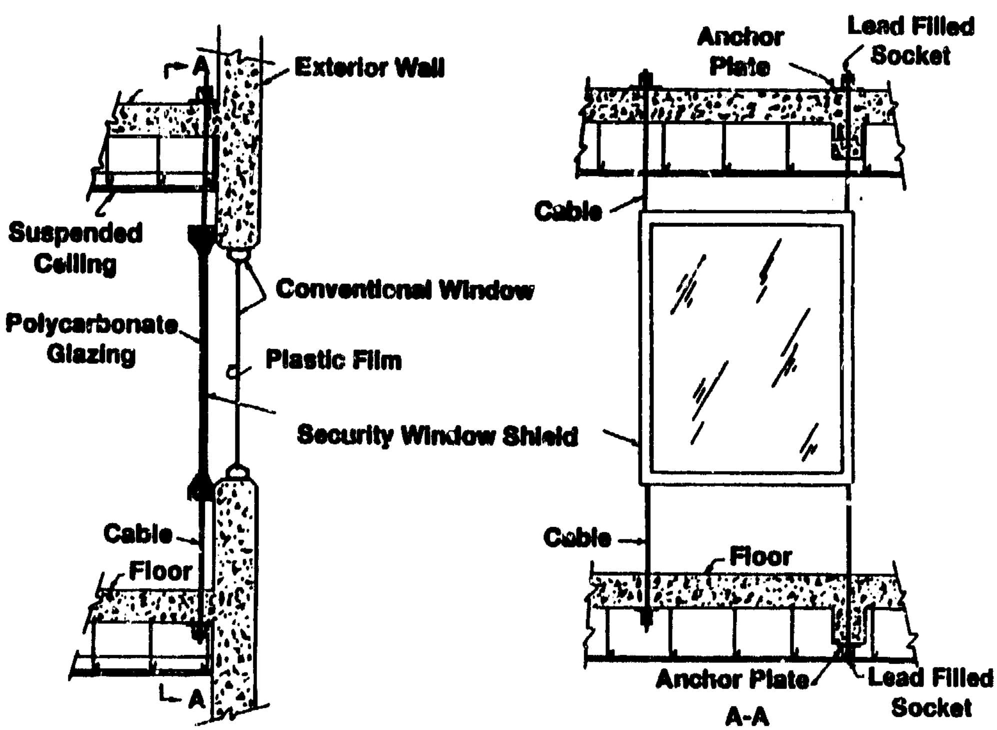


Figure 2-8. Safety window shield installed in reinforced concrete building.

3.0 THEORY

3.1 BLAST OVERPRESSURES

Consider a building subjected to the blast overpressure from a hemispherical, surface burst explosion. The blast overpressure is a function of time, the charge weight, and the standoff distance from the building to the charge. Given the charge weight, W, and the standoff distance, R, the NAVFAC P-397 Manual (Ref 1) can be used to find the peak reflected pressure, P_r, the reflected impulse, i_r, and the positive duration of the pressure, T_o. The time history of the overpressure is defined as follows (Ref 2):

$$P_e(t) = P_r \left(1 - \frac{t}{T_o} \right) e^{-\beta_L t/T_o} \qquad (3.1)$$

Equation (3.1) is plotted in Figure 3-1.

The decay factor, β_L, in equation (3.1) is a constant. The value of β_L depends on the reflected impulse, i_R, which is the area under the pressure-time curve shown in Figure 3-1 or:

$$i_r = \int_{t=0}^{t=T_o} P_e(t) \; dt$$

Substituting equation 3.1 and solving for β_L,

$$\beta_L = \left[\frac{P_r T_o}{i_r} \left(e^{-\beta_L} + \beta_L - 1 \right) \right]^{1/2}$$

Rearranging terms,

$$C_1 \beta_L^2 - e^{-\beta_L} - \beta_L + 1 = 0 \qquad (3.2)$$

where $C_1 = \frac{i_r}{P_r T_o}$

The Bisection method (Ref 3) is used to solve equation (3.2). It can be shown that for the possible range of C_1, the value of β_L will range from 0 to 50. Thus, the Bisection method of root solving should be implemented over a range of β_L from 0 to 50 where there is only one root other than the trivial root at $\beta_L = 0$.

3.2 DISPLACEMENTS

3.2.1 Window Glass

In most cases, the shield will be installed behind an existing glass window with an air gap between the glass and the polycarbonate. The glass will have little resistance to the blast overpressures. Therefore, this resistance is assumed to be zero, regardless of the glass thickness. However, the glass will have significant mass such that at any time t,

$$P_e(t) = m_{G1}\, a_{G1}(t)$$

where $P_e(t)$ = external blast overpressure applied to the glass, psi

m_{G1} = unit mass of the glass panel, lb-msec^2/in^3

$a_{G1}(t)$ = acceleration of the glass at time t, in/msec^2

Substituting equation (3.1) for $P_e(t)$,

$$a_{G1}(t) = \frac{P_r}{m_{G1}} \left(1 - \frac{t}{T_o} \right) e^{-\beta_L t/T_o} \qquad (3.3)$$

By integrating equation (3.3), the velocity, $V_{G1}(t)$, and displacement, $X_{G1}(t)$, of the glass shards are,

$$V_{G1}(t) = \frac{P_r}{m_{G1}} e^{-\beta_L t/T_o} \left[\frac{-T_o}{\beta_L} + \left(\frac{T_o}{\beta_L^2}\right) \left(\frac{\beta_L t}{T_o} + 1\right) \right] + C_2 \qquad (3.4)$$

$$X_{G1}(t) = \frac{P_r T_o}{m_{G1} \beta_L^2} e^{-\beta_L t/T_o} \left[T_o - t - \frac{2 T_o}{\beta_L} \right] + C_2 t + C_3 \qquad (3.5)$$

where

$$C_2 = \frac{-P_r}{m_{G1}} \left[\frac{-T_o}{\beta_L} + \frac{T_o}{\beta_L^2} \right]$$

$$C_3 = \frac{-P_r}{m_{G1}} \left[\frac{T_o^2}{\beta_L^2} - \frac{2 T_o^2}{\beta_L^3} \right]$$

The glass must travel a distance d_{G1} before it strikes the shield. The time required for the glass to impact the shield, t_{im}, can be determined by letting $X_{G1}(t) = d_{G1}$ in equation (3.5) and solving for t_{im}. An effective way to find t_{im} is to repeatedly solve equation (3.5), increasing the value of t each time by adding a small time increment, δt. The procedure is stopped when $X_{G1}(t) \geq d_{G1}$ and the current value of t is taken as t_{im}.

The glass shards strike the shield at time t_{im} and impart an initial velocity, V_i. For conservation of momentum at time $t = t_{im}$,

$$V_i = \frac{W_{G1} V_{G1}(t_{im})}{(W_{G1} + W_s)} \qquad (3.6)$$

where W_{G1} = total weight of the glass panel, lb

W_s = total weight of the shield, including frame, energy absorbers, and ballast, lb.

$V_{G1}(t_{im})$ = glass velocity at time t_{im} determined from equation (3.4), in/msec.

3.2.2 Shield

Once the glass shards and trailing blast wave strike the shield, the shield begins to displace into the room. This displacement is assumed to result from rigid body motion of the shield, with no deformation of the steel frame and the polycarbonate glazing. The error associated with this assumption is conservative since plastic deformations in the glazing and frame will absorb additional energy from the blast.

Figure 3-2 shows the shield at some time during the loading phase. At any time, t, the position of the shield can be defined by three variables:

X_G = horizontal displacement of centroid of shield, in.

Y_G = vertical displacement of centroid of shield, in.

α_G = rotation of shield about centroid of shield, radians.

A free body diagram of the shield is shown in Figure 3-3. The forces acting on the shield are the resultant horizontal and vertical pressure forces, $F_h(t)$ and $F_v(t)$, the sum of the forces in the top and bottom cables, T_1 and T_2, the total weight of the shield, W_s, and the ballast in the top and bottom horizontal frame rails W_1 and W_2.

From the free body diagram in Figure 3-3, dynamic equilibrium of the forces require:

For $\Sigma F_x = 0$:

$$m_s \ddot{X}_G = F_h(t) - T_1 \sin \theta - T_2 \sin \beta \qquad (3.7)$$

where $F_h(t) = P_e(t) A_s \cos \alpha_G$

A_s = Area of shield, in^2

For $\Sigma F_y = 0$:

$$m_s \ddot{Y}_G = F_v(t) + T_1 \cos \theta - T_2 \cos \beta - W_s - W_1 - W_2 \qquad (3.8)$$

where $F_v(t) = P_e(t) A_s \sin \alpha_G$

For $\Sigma M_G = 0$:

$$I_G \ddot{\alpha}_G = (T_1 \sin \theta) (\frac{h_f}{2} \cos \alpha_G) - (T_1 \cos \theta) (\frac{h_f}{2} \sin \alpha_G)$$

$$- (T_2 \sin \beta) (\frac{h_f}{2} \cos \alpha_G) - (T_2 \cos \beta) (\frac{h_f}{2} \sin \alpha_G)$$

$$+ W_1 (\frac{h_f}{2} \sin \alpha_G) - W_2 (\frac{h_f}{2} \sin \alpha_G) \qquad (3.9)$$

where from the displaced geometry shown in Figure 3-2:

$$\sin \theta = \frac{X_{o1} + X_1}{Y_1} = \frac{(X_{o1} + X_1)}{[(X_{o1} + X_1)^2 + K_1^2]^{1/2}} \qquad (3.10)$$

$$\cos \theta = \frac{K_1}{Y_1} = \frac{K_1}{[(X_{o1} + X_1)^2 + K_1^2]^{1/2}} \qquad (3.11)$$

$$\sin \beta = \frac{X_{o2} + X_2}{Y_2} = \frac{(X_{o2} + X_2)}{[(X_{o2} + X_2)^2 + K_2^2]^{1/2}} \qquad (3.12)$$

$$\cos \beta = \frac{K_2}{Y_2} = \frac{K_2}{[(X_{o2} + X_2)^2 + K_2^2]^{1/2}} \qquad (3.13)$$

and

$$X_1 = X_G - \frac{h_f}{2} \sin \alpha_G \qquad (3.14)$$

$$X_2 = X_G + \frac{h_f}{2} \sin \alpha_G \qquad (3.15)$$

$$Y_1 = h_1 + \frac{h_f}{2} - \frac{h_f}{2} \cos \alpha_G - Y_G \qquad (3.16)$$

$$Y_2 = h_2 + \frac{h_f}{2} - \frac{h_f}{2} \cos \alpha_G + Y_G \qquad (3.17)$$

Substituting equations (3.10) through (3.17) into equations (3.7) through (3.9) and integrating, expressions are obtained for the shield displacements X_G, Y_G, and α_G.

Now, expressions are needed for the cable forces T_1 and T_2 in terms of X_G, Y_G, and α_G. As the shield displaces into the room, the cables will deform elastically. This deformation, as well as the cable force, will increase until the plastic springs begin to crush. Once crushing occurs, the cable forces remain constant and the crushable material deforms uniformly and plastically.

In the elastic range of response, the total tension force in the top cables, T_1, and the total tension force in the bottom cables, T_2, are derived from the initial and displaced shield geometry (Figure 3.2) and the known stress-strain properties of the cables.

$$T_1 = A_{c1} E_{c1} \frac{\left[(X_{o1}^2 + h_1^2)^{1/2} - Y_1 \right]}{(X_{o1}^2 + h_1^2)^{1/2}} \qquad (3.18)$$

$$T_2 = A_{c2} E_{c2} \frac{\left[(X_{o2}^2 + h_2^2)^{1/2} - Y_2 \right]}{(X_{o2}^2 + h_2^2)^{1/2}} \qquad (3.19)$$

where A_{c1} = sum of the cross-sectional areas of the top cables, in^2.

A_{c2} = sum of the cross-sectional areas of the bottom cables, in^2.

E_{c1}, E_{c2} = modulus of elasticity of the top and bottom cables, respectively, psi

X_{o1}, X_{o2} = horizontal distance from the inside face of the wall to point where the top and bottom cables enter the frame, respectively, in.

h_1, h_2 = vertical distance from the top of the frame to the ceiling and from the bottom of the frame to the floor, respectively, in.

Y_1, Y_2 = deflected length of the top and bottom cables, respectively, in.

The force in the cable cannot exceed the sum of the resisting forces of the springs, $N_s f A_{cm}$, as shown in Figure 3-4. In the plastic range, $f = f_{cm}$ and the maximum forces in the top and bottom cables are:

$$T_1 = N_1 N_{s1} f_{cm1} A_{cm1} \tag{3.20}$$

$$T_2 = N_2 N_{s2} f_{cm2} A_{cm2} \tag{3.21}$$

where N_1, N_2 = number of top and bottom cables, respectively

N_{s1}, N_{s2} = number of springs in each top and bottom energy absorber, respectively

f_{cm1}, f_{cm2} = crushing strength of a single spring in a top and bottom energy absorber, respectively, psi

A_{cm1}, A_{cm2} = cross-sectional area of a single spring in a top and bottom energy absorber, respectively, in^2

By equating the force in the cables to the force in the energy absorbers, the stress in each spring of a top energy absorber, f_1, and a bottom energy absorber, f_2, is:

$$f_1 = \frac{A_{c1} E_{c1} \left[(X_{o1}^2 + h_1^2)^{1/2} - Y_1 \right]}{N_1 N_{s1} A_{cm1} (X_{o1}^2 + h_1^2)^{1/2}} \tag{3.22}$$

$$f_2 = \frac{A_{c2} E_{c2} \left[(X_{o2}^2 + h_2^2)^{1/2} - Y_2 \right]}{N_2 N_{s2} A_{cm2} (X_{o2}^2 + h_2^2)^{1/2}} \tag{3.23}$$

The force in the top cables, T_1, is defined by equation (3.18) when $f_1 \leq f_{cm1}$, and is defined by equation (3.20) when $f_1 > f_{cm1}$.

The force in the bottom cables, T_2, is defined by equation (3.19) when $f_2 \leq f_{cm2}$ and is defined by equation (3.21) when $f_2 > f_{cm2}$.

The three dynamic equilibrium equations (3.7) through (3.9) can be solved by using a method of direct integration called the Newmark - β method (Ref 4). The Newmark - β method divides the problem into intervals of time, δt, and performs a step-by-step integration procedure to solve for the displacements, velocities, and accelerations at each time step. The general procedure is as follows:

1. Assume values of the accelerations $\ddot{X}_G$, $\ddot{Y}_G$, and $\ddot{\alpha}_G$ at the end of the time interval.
2. Compute the velocities and displacements at the end of the time interval for each of the degrees of freedom (X_G, Y_G, α_G) using the following equations:

$$V_{n+1} = V_n + (1 - \mu) a_n \delta t + \mu a_{n+1} \delta t$$

$$X_{n+1} = X_n + V_n \delta t + (0.5 - \beta) a_n \delta t^2 + \beta a_{n+1} \delta t^2$$

where $\mu = 0.5$ and $\beta = 0.25$. The terms a_{n+1}, V_{n+1} and X_{n+1} are the acceleration, velocity and displacement at the end of the time interval and a_n, V_n, and X_n are the acceleration, velocity, and displacement at the end of the previous time step.

3. Solve equations (3.7) through (3.9) for a new set of accelerations ($\ddot{X}_G$, $\ddot{Y}_G$, $\ddot{\alpha}_G$) at the end of the time interval.

4. Compare the computed accelerations with the assumed accelerations. If they are within a given tolerance, go on to the next time step. If not, take the computed accelerations as the assumed accelerations and repeat steps 2 through 4 until the accelerations converge.

Step 1 of the Newmark - β method begins at time $t = t_{im}$ when the displacements, velocities, and the cable forces are known. The accelerations are computed directly from equations (3.7) through (3.9). These accelerations are then used as the assumed accelerations for the next time step, $t = t_{im} + \delta t$. In succeeding time steps, the assumed accelerations are equal to those at the end of the previous time step.

The Newmark - β method is unconditionally stable if $\mu = 0.5$ and $\beta = 0.25$. However, convergence problems do occur if the time step $\delta t > 1.0$ millisecond.

3.2.3 Glazing

Theory for dynamic response of the polycarbonate glazing neglects the response of the steel frame supporting the glazing. This assumption is conservative and introduces only slight error because the glazing typically reaches its maximum deflection before the steel frame has undergone significant deflections.

Consider the glazing to be an elastic plate simply supported on non-moving supports. Assuming a single-degree-of-freedom (S.D.O.F.) model for the plate and summing the forces acting normal to the plate,

$$P_e(t) - R(z) - 2\,p \sqrt{K_{Lm}\, K(z)\, m}\;\; \dot{z}(t) = K_{Lm}\, m\, \ddot{z}(t) \qquad (3.24)$$

where $P_e(t)$ = reflected blast overpressure-time history given by equation (3.1), psi

p = percent of critical damping

$K_{Lm} = K_m / K_L$

K_m = mass factor for the equivalent S.D.O.F. model

K_L = load factor for the equivalent S.D.O.F. model

$K(z)$ = elastic stiffness of the glazing at deflection z, psi/in.

m = unit mass of the polycarbonate glazing, lb-msec^2/in^3.

$z(t)$ = displacement relative to frame at center of glazing at time t, in.

Accounting for the tensile membrane and bending behavior of a simply supported, thin plate, the resistance of the glazing, $R(z)$, is (Ref 5):

$$R(z) = \frac{\pi^6 D}{16\, b^4} \left[z\,(1+\phi^2)^2 + \frac{3\,z^3}{4\,h^2} \left[(3-\mu^2)\,(1+\phi^4) + 4\,\mu\,\phi^2\right] \right] \qquad (3.25)$$

where z = displacement at center of glazing, in.

h = thickness of glazing, in.

b = length of the short span of glazing, in.

D = flexural stiffness of glazing, $E\,h^3 / 12(1-\mu^2)$, psi-in^3

E = elastic modulus of glazing, psi

ϕ = ratio of short span to long span of glazing

μ = poisson's ratio.

The displacement, velocity, and acceleration of the polycarbonate glazing can be computed at each time step by using the Newmark - β method discussed earlier (Ref 4). In the application of the Newmark - β method, the glazing stiffness, $K(z)$, is estimated by:

$$K(z) = \frac{(R_{n+1} - R_n)}{(z_{n+1} - z_n)} \qquad (3.26)$$

3.3 INTERNAL OVERPRESSURES

A measure of the shield's effectiveness is the reduction caused by the shield in the peak blast overpressures inside the building. The interior blast overpressure, $P_i(t)$, is (Ref 6):

$$P_i(t) = P_{so}(t) \left[0.65 \ (R / D)^{-1.35} \right] \qquad (3.27)$$

where $P_{so}(t)$ = the incident blast overpressure outside the building at time t, psi

R = horizontal distance from shield to the point of interest inside room, in.

$D = (a \ b)^{1/2}$, no shield over window opening, in.

$D = [2 \ X_G(t) \ (a + b)]^{1/2}$, with shield over window opening, in.

a = height of window opening, in.

b = width of window opening, in.

$X_G(t)$ = horizontal displacement at mid-height of the shield at time t, in.

3.4 ANCHORS

As shown in Figure 2-8, the cables are anchored to the floor and ceiling by attaching the ends of the cables to a bearing plate. In the case of a concrete slab, the maximum allowable cable force, F_c, based on the allowable shear capacity of the slab (Ref 7) is:

$$F_c = \phi \ 4 \sqrt{f'_c} \ b_o \ d \qquad (3.28)$$

where ϕ = 0.85 = ACI strength reduction factor for shear

f'_c = ultimate compressive strength of concrete, psi

d = effective depth of slab, in.

b_o = effective perimeter of the bearing plate, equal to the plate perimeter plus 3d, in.

3.5 COMPUTER PROGRAM

The program SHIELD has been developed to analyze the response of a safety window shield to an external explosion (Ref 8). The program is written in FORTRAN 77 and can be executed on any computer that has a FORTRAN compiler. The program computes the following:

- Blast overpressure outside building
- Displacements, velocities, and accelerations of shield
- Displacement of polycarbonate glazing relative to frame
- Forces in top and bottom cables
- Blast overpressure at point five feet above the floor and any distance inside the room
- Strains in crushable springs
- Displacements, velocities, and accelerations of the glass window

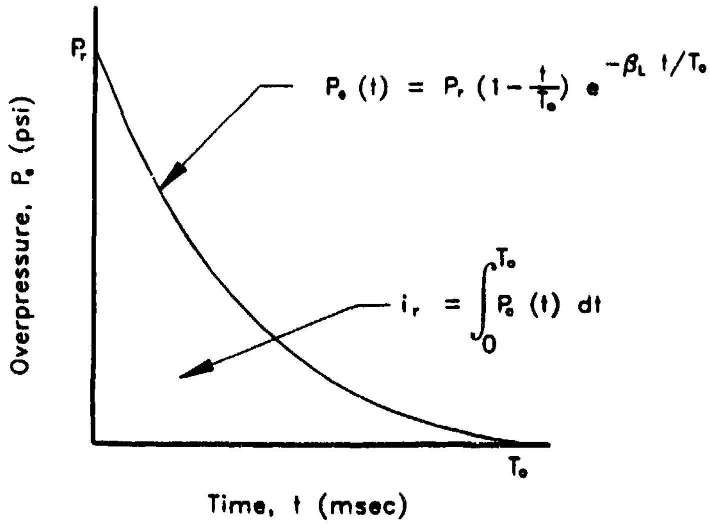


Figure 3-1. Blast load applied to shield.

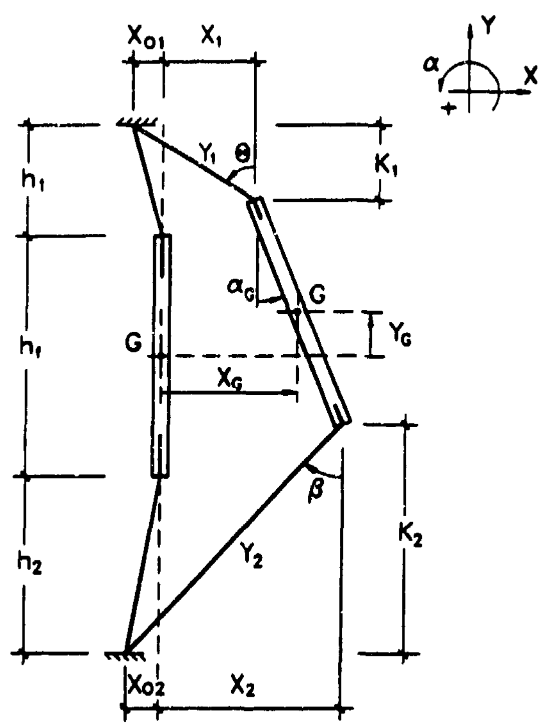


Figure 3-2. Definition of geometric parameters for displaced shield.

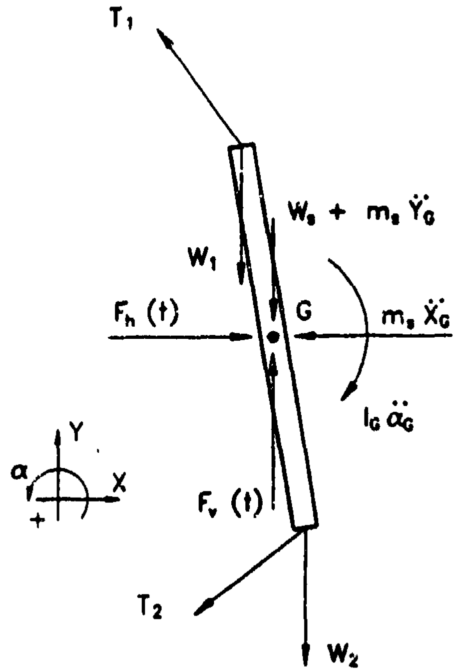


Figure 3-3. Free body diagram of shield.

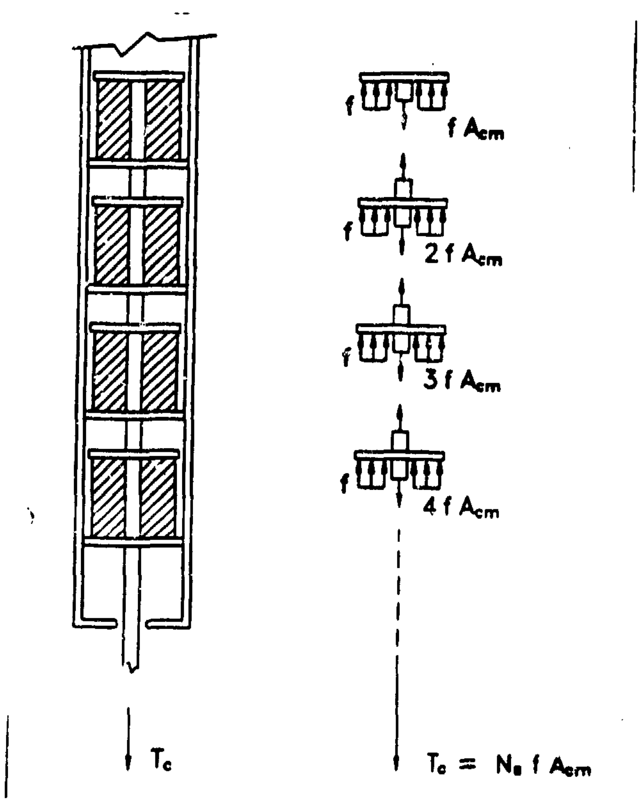


Figure 3-4. Forces applied to energy absorber.

4.0 DESIGN EXAMPLE

4.1 PROBLEM DEFINITION

4.1.1 Explosive Threat

The window is exposed to the blast environment from the detonation of a 1000 pound TNT hemispherical charge. The explosion is a surface burst located 100 feet from the face of the building. According to the NAVFAC P-397 Manual (Ref 1), the maximum reflected overpressure is 24 psi and the duration of the positive pressure phase is 26 msec.

4.1.2 Window Characteristics

The window opening is 6'-0" high and 3'-6" wide. The bottom of the opening is three feet above the floor. The top of the opening is two feet below the ceiling. The window glazing is a single panel of 3/16 inch glass coated with a security film. The air gap between the glass and the shield is 4 inches.

4.1.3 Performance Objectives

The maximum allowable overpresssure inside the room at a point located 8 feet behind the shield is 1.2 psi. The maximum allowable displacement of the frame into the room is 12 inches. Safety from debris and fragments is not considered in this design example.

4.2 SHIELD DESIGN

4.2.1 Glazing

The shield glazing is 3/8 inch thick polycarbonate. The polycarbonate has a yield stress of 9,500 psi, a modulus of elasticity of 345,000 psi, and a rupture strain of 80 percent.

4.2.2 Frame

The frame is made up of 4-inch by 4-inch AISC steel tube sections with a wall thickness of 3/16 inches. The total frame weight is 249 pounds.

4.2.3 Cables

The cable diameter is 1/2 inches. The cables have an allowable design stress of 100,000 psi and an elastic modulus of 13 x 10^6 psi. The lengths of the top and bottom cables are 2'-0" and 3'-0", respectively.

4.2.4 Energy Absorbers

Each energy absorber consists of one block of aluminum honeycomb, 4 inches in height with a cross sectional area of 10 in^2. The crushing strength of the material is 2052 psi. The maximum allowable strain of the honeycomb material is 70 percent.

4.2.5 Ballast

The top and bottom rails each contain 50 pounds of ballast in the form of lead beads.

4.3 PREDICTED PERFORMANCE

4.3.1 Displacements

Figure 4-1 shows the time history of the external blast overpressure, the displacements at the top, bottom and mid-height of the shield, and the displacements at the center of the glazing relative to the frame. At time t = 4 msec after the blast wave reaches the building, the glass shards and blast wave strike the shield. The shield continues to displace after the end of the loading phase and reaches a maximum displacement of 11.7 inches at time t = 39 msec. This displacement is less than the allowable and occurs at the bottom rail where the restraining cables are the longest. Note that the polycarbonate glazing reaches a maximum displacement of 4.3 inches before the blast overpressure has decayed to zero and long before the frame has reached its maximum displacement.

4.3.2 Internal Overpressure

Figure 4-2 shows the time history of the internal overpressures with and without the shield at points 4 and 8 feet inside the room. The maximum internal overpressure at 8 feet is 1.9 psi without the shield. With the shield in place, however, the maximum overpressure is 0.3 psi. Therefore, the shield reduces the internal blast overpressure by 84 percent, well below the allowable 1.2 psi.

4.3.3 Anchor Force

The maximum anchor force needed to restrain the cables depends on the response of the energy absorbers. For an energy absorber with one spring, the maximum cable force is the cross-sectional area of the crushable material multiplied by its crushing strength. In this example, the maximum cable force is F_c = 2050 psi x 10in^2 = 20,520 pounds in each cable. For a 6-inch concrete slab, this requires a 4 by 8 inch anchor plate to limit the shear stress in the slab.

4.3.4 Effectiveness

The shield reduces the peak blast overpressure at a point 8 feet inside the room from 1.9 psi to 0.30 psi, or 84 percent. This reduction in overpressure demonstrates the effectiveness of the shield in ensuring the life safety of inhabitants.

4.4 PARAMETER SENSITIVITY

4.4.1 Ballast

Shield performance is improved by adding ballast to the top and bottom rails of the frame. Figure 4-3 shows the effect of ballast on the maximum shield displacement and peak blast overpressure inside the room.

4.4.2 NRA Factor

The NRA factor is equivalent to the maximum cable force and is defined as the product of the number of blocks of crushable material, N, the resistance or crushing strength of the material, R, and the cross sectional area of the material, A. Figure 4-4 shows the effect of the NRA factor in controlling displacements. It should be noted that the maximum internal pressures are not effected by the NRA factor because the peak overpressure inside the room typically occurs long before the springs begin to crush.

4.4.3 Explosive Weight

The shield can effectively defeat the threats from explosions for a broad range of explosive weights. As shown in Figure 4-5, the shield maintains a high level of effectiveness in reducing the peak blast overpressures inside the room for bomb weights up to 2000 pounds TNT for a fixed standoff distance of 100 feet from the building.

4.4.4 Air Gap

The air gap between the safety window shield and the glass window will vary depending on the building wall thickness and the location of the glass window. Figure 4-6 shows the internal peak blast overpressures at a point 8 feet inside the room for air gap distances ranging from 0 to 40 inches. Note that the internal peak blast overpressure is reduced dramatically in thick-wall buildings that provide large air gap distances.

4.4.5 Anchor Detail

The energy absorber constant or NRA factor dictates the maximum cable force. Figure 4-7 shows the maximum value of the NRA factor to prevent shear failure in a reinforced concrete slab, as a function of slab thickness and anchor plate dimensions.

4.4.6 Number Windows

Figure 4-8 shows the blast overpressure-time history inside a room with 1 to 4 windows. This figure illustrates the capability of the shield to limit the blast overpressures in rooms with multiple windows.

4.5 PROTOTYPE DESIGN

4.5.1 Design Drawings

A typical prototype design for a safety window shield is shown in Figures 4-9 through 4-13. This particular design will be used to test and evaluate the window shield concept and to validate design criteria and computer programs.

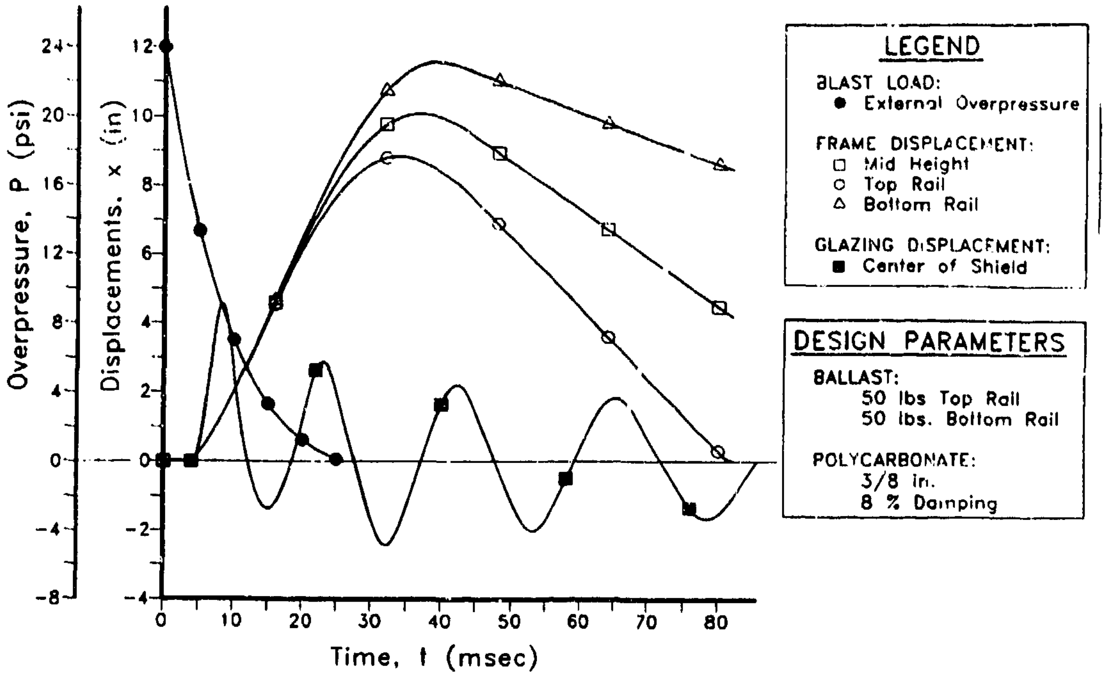


Figure 4-1. Time history of external blast pressure and displacements of frame and glazing.

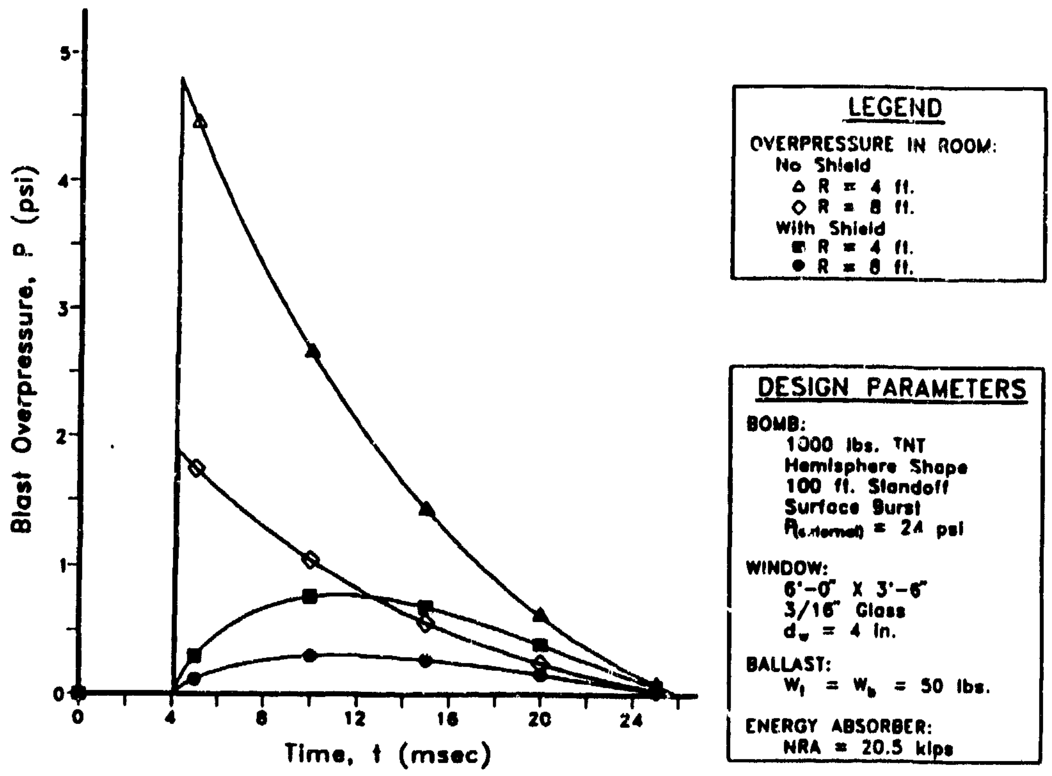


Figure 4-2. Time history of blast pressures inside room with and without shield.

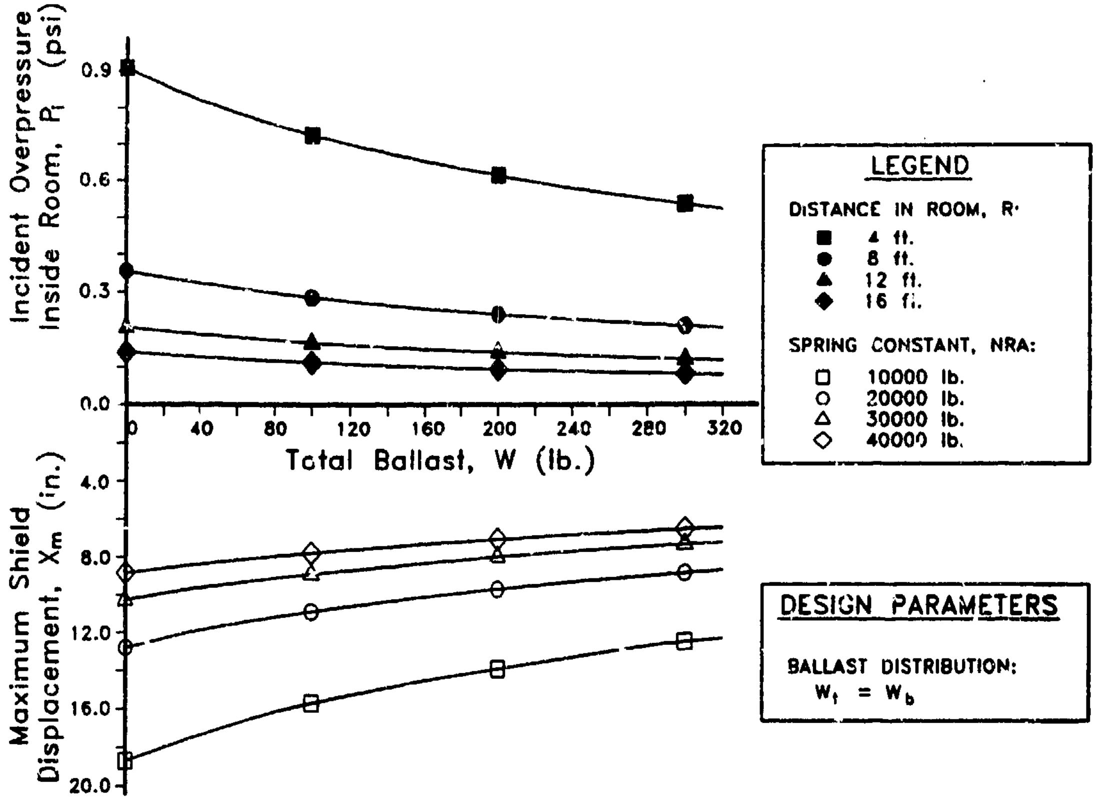


Figure 4-3. Effect of ballast on maximum shield displacements and peak room pressures.

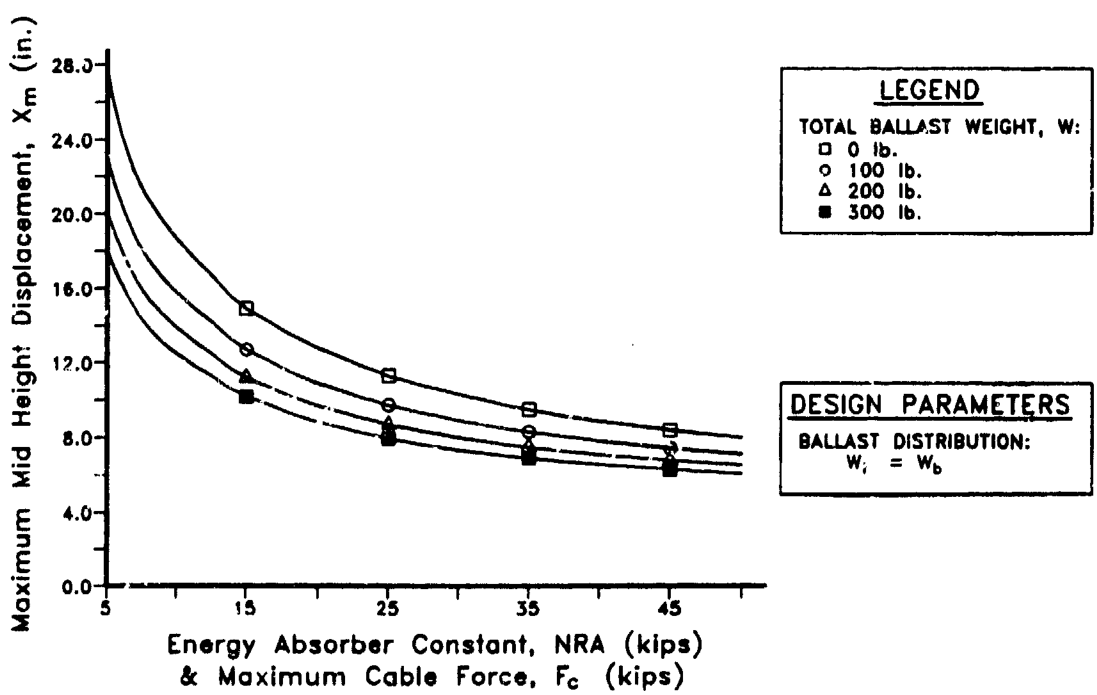
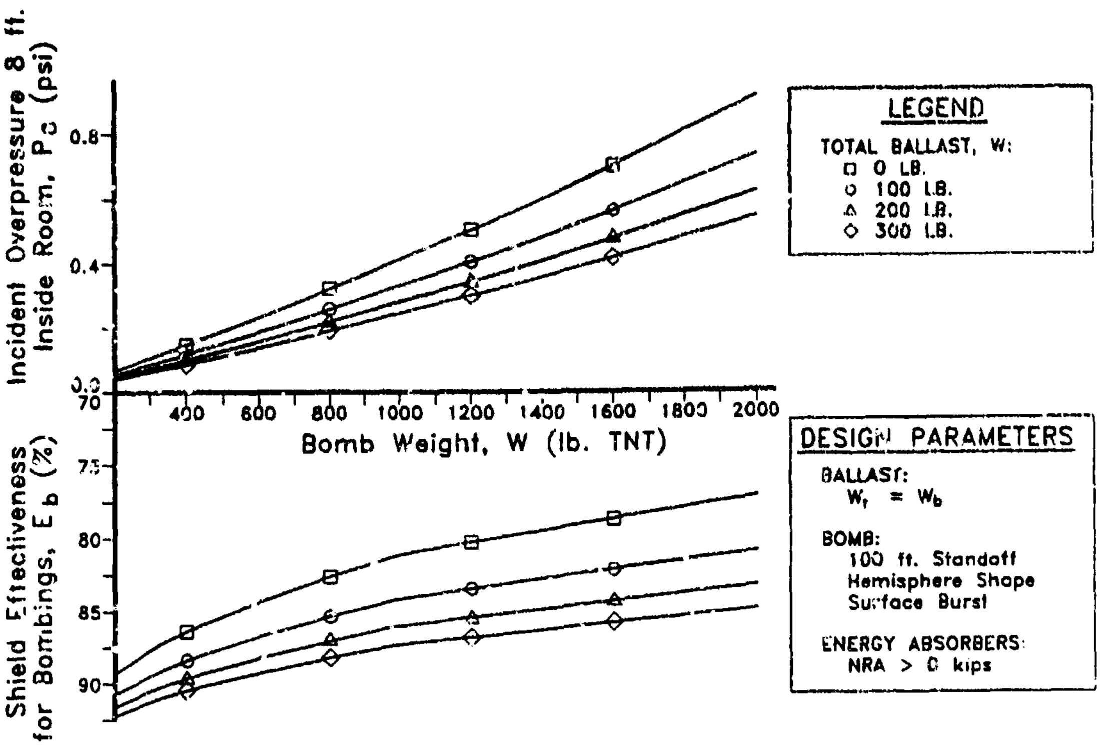


Figure 4-4. Effect of energy absorber characteristics on maximum shield displacement.



$$E_b = \left[\frac{P_8\,(\text{no shield}) - P_8\,(\text{with shield})}{P_8\,(\text{no shield})}\right] \times 100$$

Figure 4-5. Effect of explosive weight on peak room pressures and maximum shield displacements.

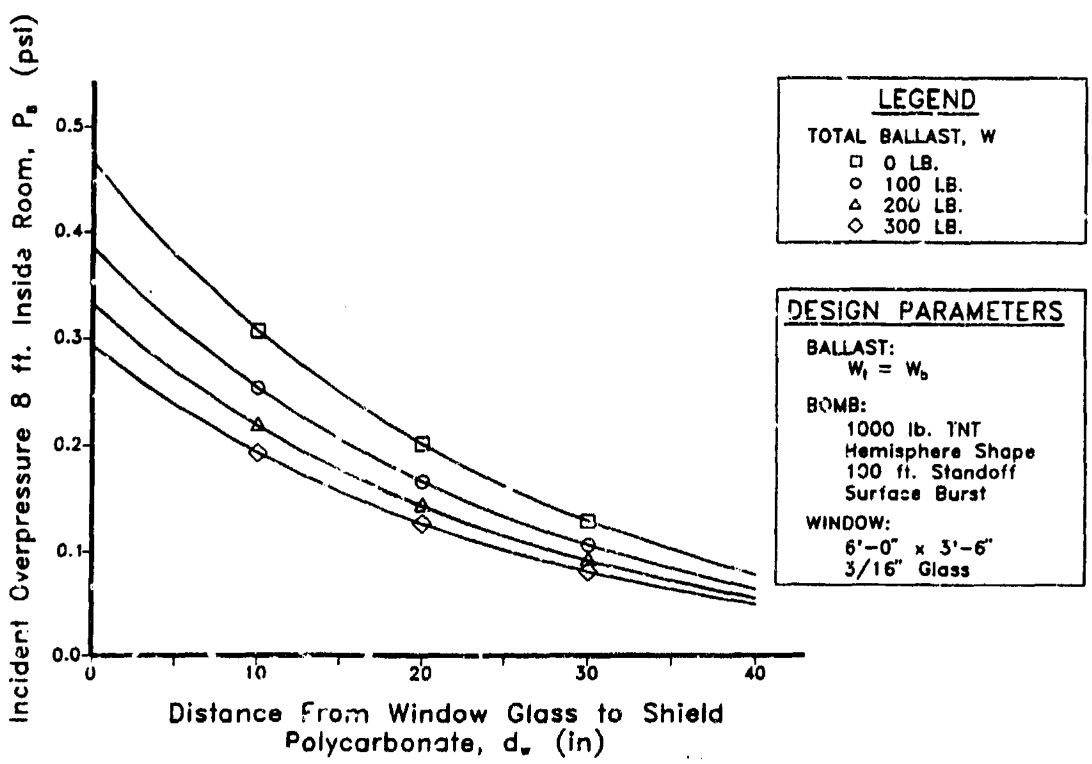


Figure 4-6. Effect of air gap distance between window and shield on peak room pressures.

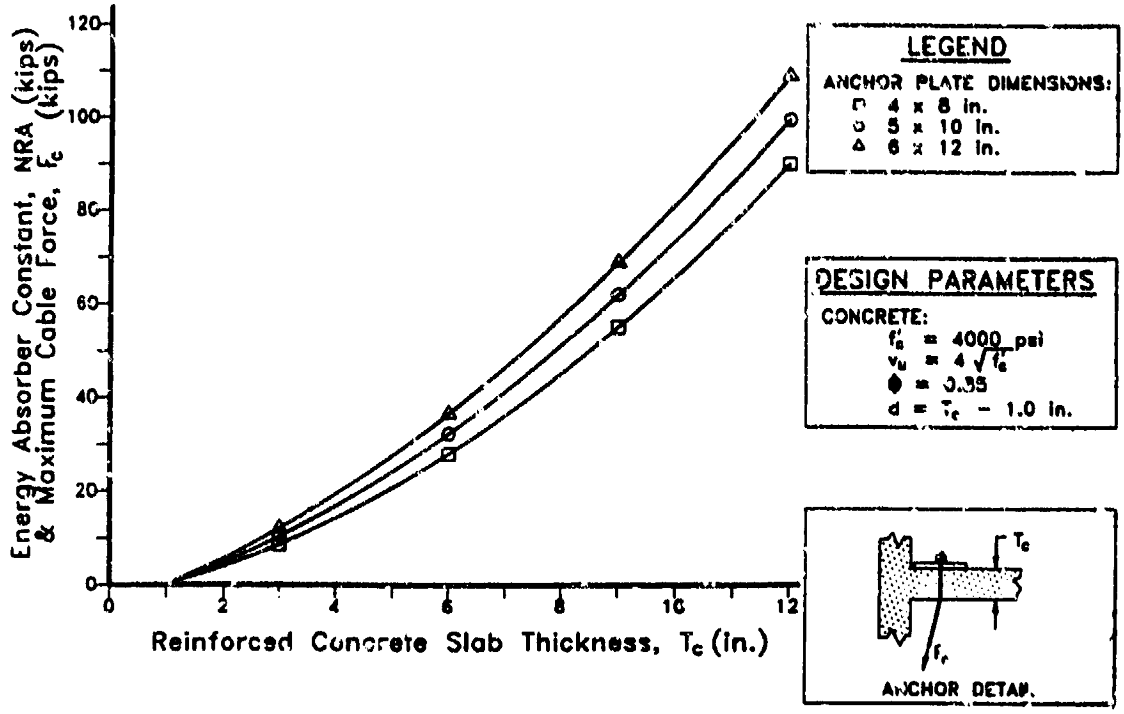


Figure 4-7. Effect of anchor plate dimensions and slab thickness on capacity of cable anchors.

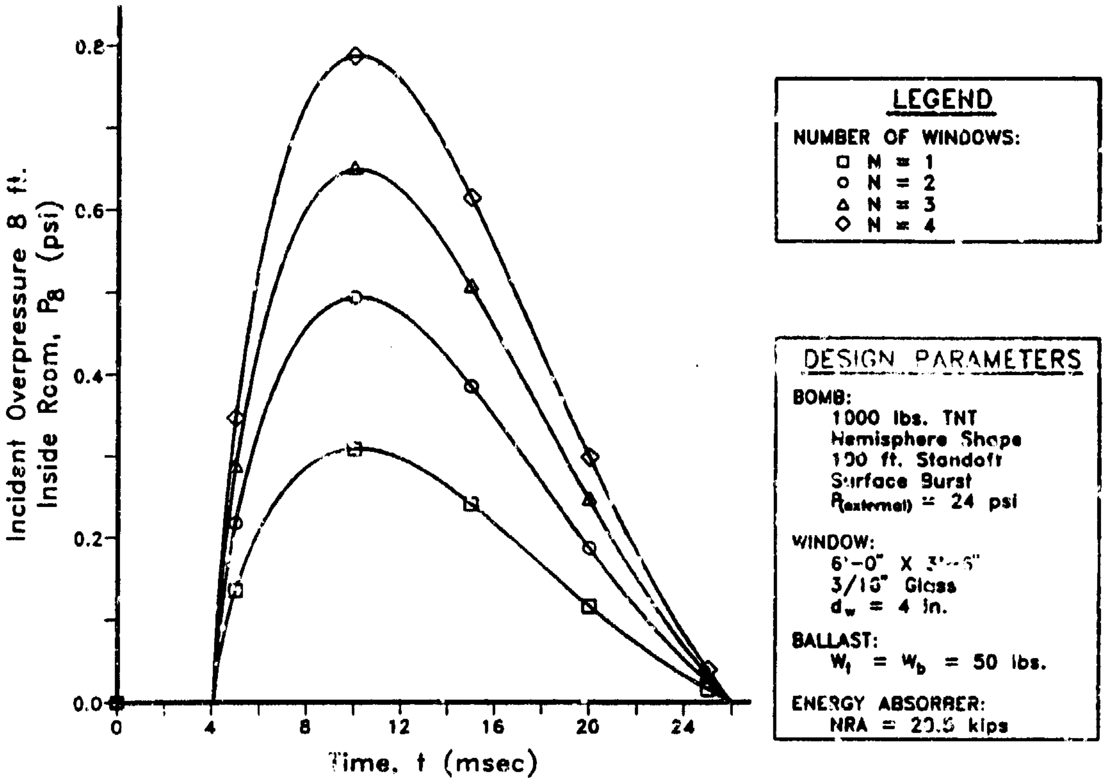


Figure 4-8. Effect of number of windows on room pressures.

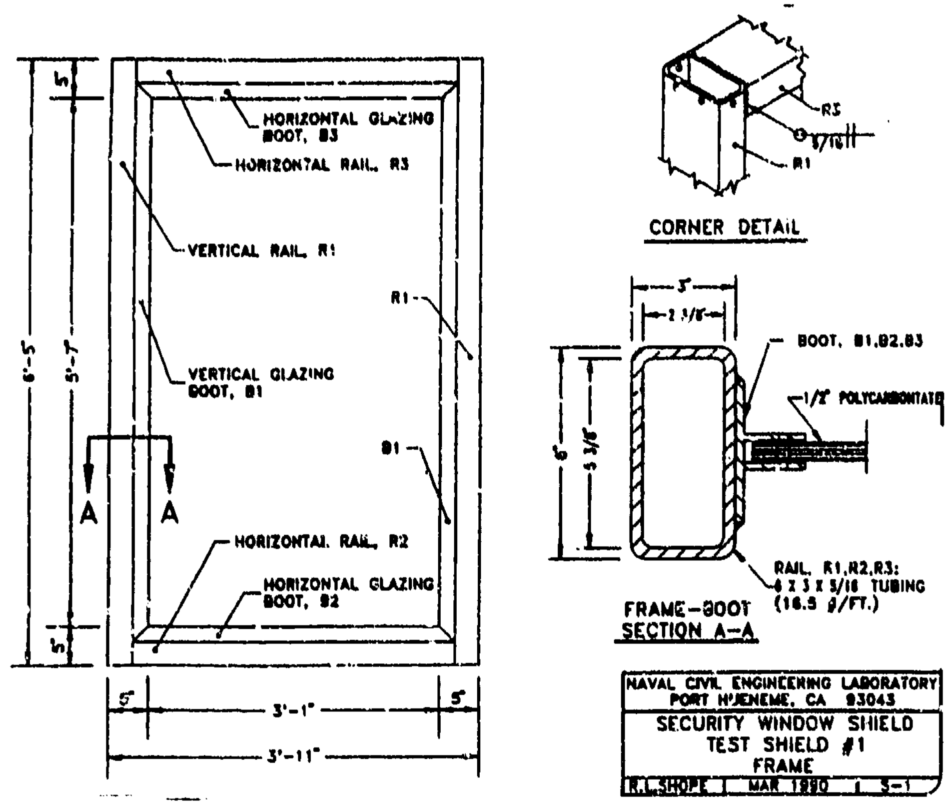


Figure 4-9. Prototype design - frame details.

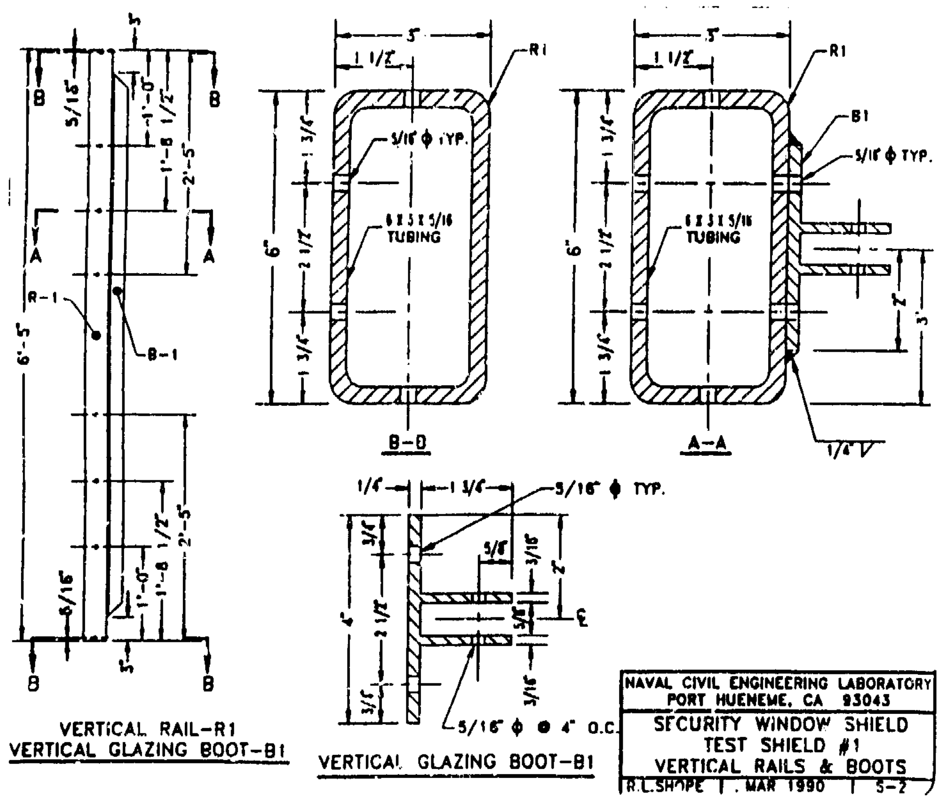


Figure 4-10. Prototype design - vertical rails and boots.

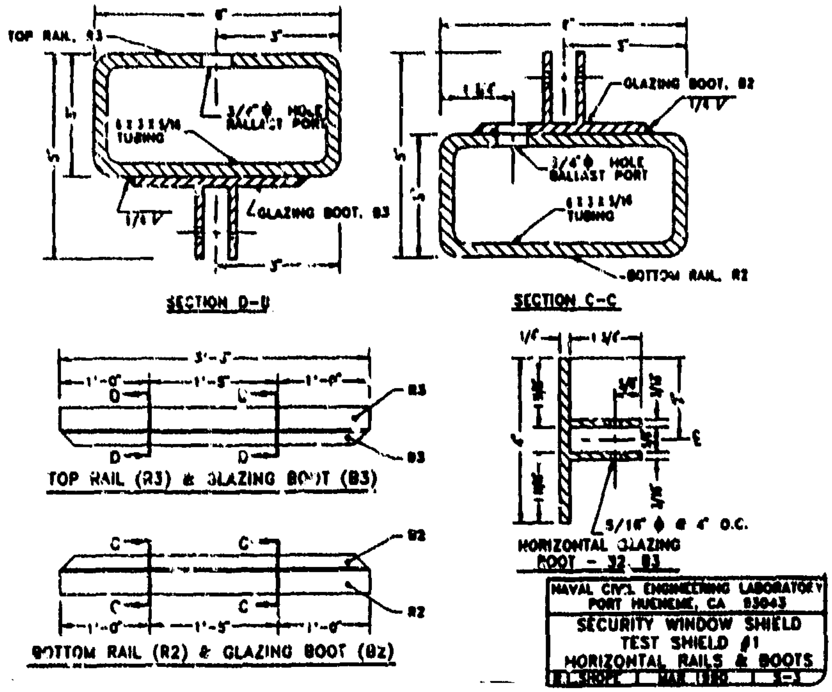


Figure 4-11. Prototype design - horizontal rails and boots.

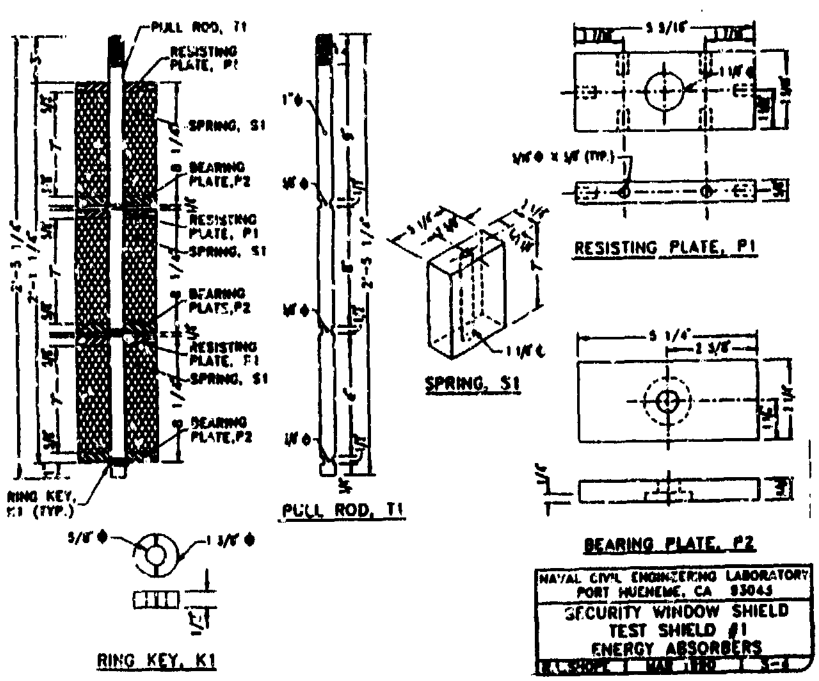


Figure 4-12. Prototype design - energy absorbers.

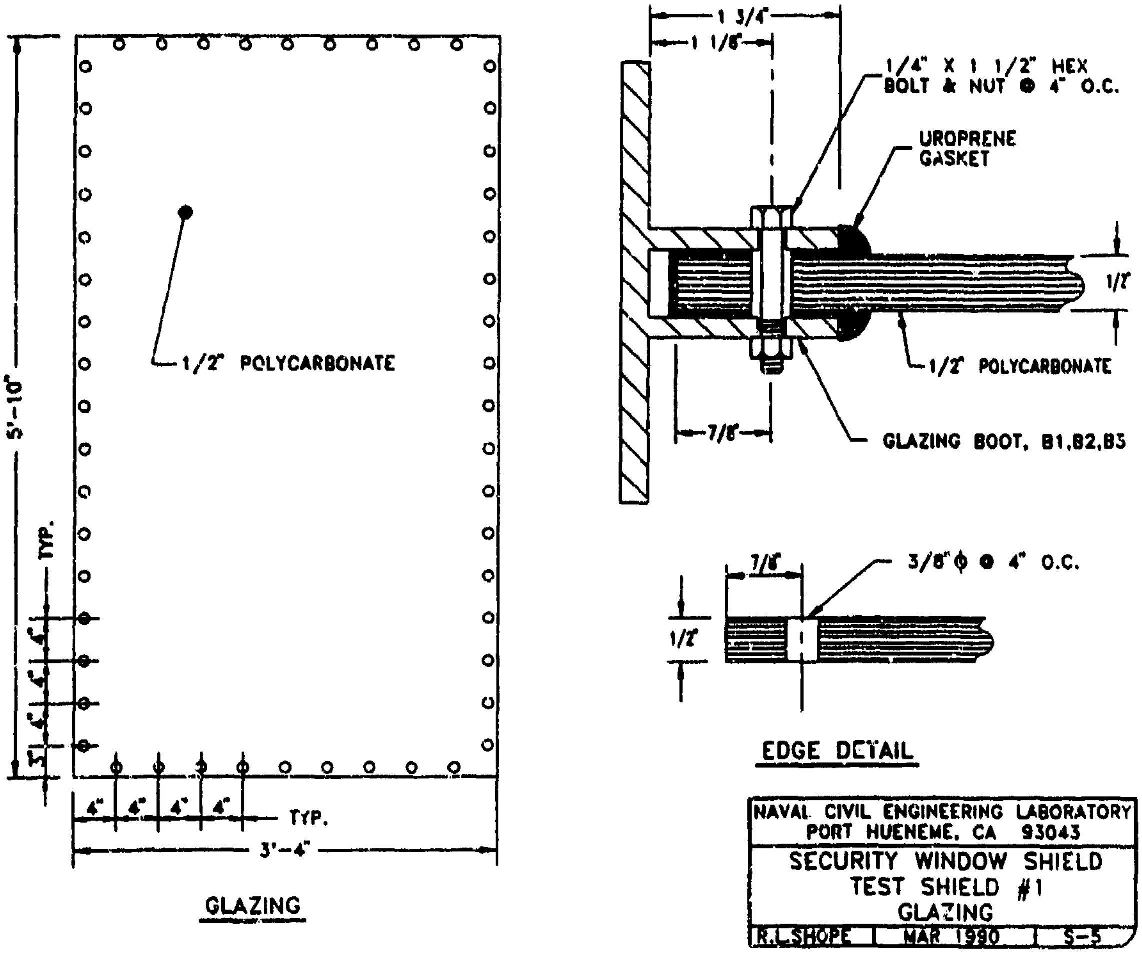


Figure 4-13. Prototype design - polycarbonate glazing.

5.0 BENEFITS

5.1 LIFE SAFETY

The shield substantially improves the safety of inhabitants against glass shards, bomb fragments, debris, and blast overpressures. The concept is universally applicable to any size explosion and window opening.

5.2 LOW COLLATERAL DAMAGE

The shield provides a major reduction in collateral building damage and the probability of structural collapse from an explosion outside the building by transferring applied window loads to the wall-ceiling and wall-floor joints where the building is inherently strong.

5.3 RAPID AND SIMPLE TO INSTALL

The shield is installed by merely drilling four holes (two in the ceiling and two in the floor) and attaching standard cable terminals. The existing window and surrounding wall remain undisturbed.

5.4 UNIVERSALLY APPLICABLE

The shield can be installed in both new and existing buildings made from any type of construction, such as concrete, steel, and masonry.

5.5 ACCOMMODATE CHANGES IN THREAT LEVEL

After the shield is installed, it can be upgraded to accommodate a higher threat level. In addition to permanent deployment, the shield can be quickly installed and removed to offer protection against fluctuating threat levels encountered at U.S. facilities worldwide.

5.6 LOW ACQUISITION AND MAINTENANCE COSTS

Since the shield is made up entirely of commercially available components and installation requires no changes to the existing wall or window, it is an economical alternative to blast "hardened" windows. Also, there are no special or unique maintenance duties to be performed on the shield.

6.0 DEVELOPMENT PLAN

6.1 WORK BREAKDOWN STRUCTURE

Development of the safety window shield is divided into six phases: Conceptual Design, Feasibility Analysis, Test and Evaluation, Prototype Design, Pilot Deployment, and Acquisition. The work breakdown structure for each phase is shown in Figure 6-1.

6.2 CURRENT STATUS

The Conceptual Design and Feasibility Analysis phases, as well as portions of the Test and Evaluation phase, are completed, as shown in Figure 6-1.

7.0 REFERENCES

1. Naval Facilities Engineering Command. NAVFAC P-397 Manual: Structures To Resist the Effects of Accidental Explosions, Vol.II: Blast, Fragment, and Shock Loads, December, 1986, p.31.

2. U.S. Army Corps of Engineers, Design of Structures to Resist the Effects of Atomic Weapons, EM 1110-345-413, July, 1959, p.15.

3. Hornbeck, R.W., Numercial Methods, Prentice-Hall, Englewood Cliffs, New Jersey, 1975, pp.65-66.

4. Newmark, N.M., "A Method of Computation for Structural Dynamics," American Society of Engineers, Vol 127, Part I, 1962, pp.1406-1435.

5. Bares, R., Tables for the Analysis of Plates, Slabs, and Diaphrams Based On Elastic Theory, Bauverlag, Wiesbaden, Germany, 1969, pp.501-507.

6. Drake, J.L. and J.R. Britt, "Propagation of Short Duration Air Blast Into Protective Structures," Proceedings of the Second Symposium on the Interaction on Non-Nuclear Muntions With Structures, Panama City Beach, FL, April,1985.

7. American Concrete Institute, "Building Code Requirements for Reinforced Concrete," ACI 318-83, Detroit, MI, 1984.

8. Naval Civil Engineering Laboratory, Technical Memorandum TM-51-90-17 "Theory and User's Manual: Computer Program for Dynamic Response of a Security Window Shield," R.L. Shope and J.R. Bogle, Port Hueneme, CA, September 1990.

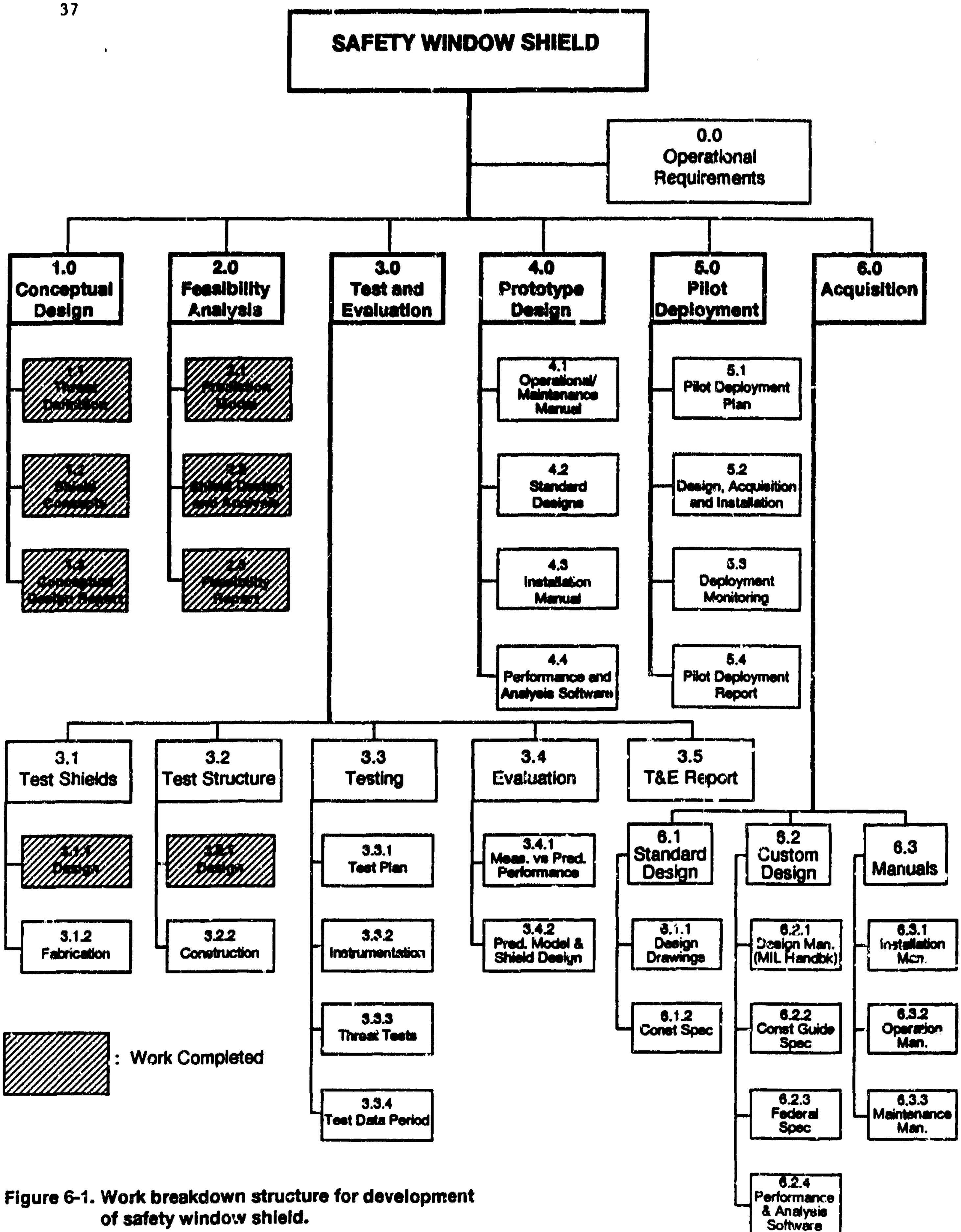


Figure 6-1. Work breakdown structure for development of safety window shield.

STRENGTHENING STRUCTURAL ELEMENTS FOR EXISTING EXPLOSIVE FACILITIES TO REDUCE THE RISKS TO ADJACENT INSTALLATIONS

Reuben Eytan
Eytan Building Design Ltd.
Tel Aviv, Israel

ABSTRACT

The paper describes different strengthening methods for structural elements of existing explosive facilities, designed by the author in various projects worldwide and aimed to reduce the risks to adjacent installations.

The strengthening measures include shielding external walls, strengthening of existing walls, additional internal walls, strengthening of existing ceilings and provision of different cover layers on existing ceilings.

The assessment of the risks to people in the vecinity of the explosive facility from the different effects induced by an internal explosion and the risk reduction by the additional strengthening measures, using our in-house computer programs, are described.

The cost-effectiveness of the strengthening measures and the definition of the optimal set of measures in real projects are discussed.

INTRODUCTION

Lately, large numbers of existing explosive facilities, which were initially located at safe distances from adjacent inhabited buildings, public roads and other installations, are presenting increased risks to their surroundings.

The increased risks result from one or several of the following factors :

a. The larger amounts of explosives stored, manufactured, processed, maintained, etc.

b. The building of adjacent installations closer to the explosive facility perimeter (under different types of waivers, due to political, municipal or local population pressures, etc.).

c. The threat of sabotage from terrorist attacks.

In order to reduce the risks to adjacent facilities several concepts may be implemented, such as :

a. Strengthening of the buildings, installations, etc. located at short distances from the explosive facility.

b. Providing shielding barriers between the explosive facility perimeter and the surrounding installations.

c. Strengthening the components of the explosive facility.

In our extensive practical experience we have found that in most of the real situations it is prefered to strengthen the components of the existing explosive facility. In this paper, the subject of strengthening structural elements for existing explosive facilities to reduce the risks to adjacent installations is addressed.

RISKS TO ADJACENT INSTALLATIONS

The risks to adjacent installations are induced by the following effects of an explosion in the existing facility :

a. Blast following an internal explosion.

b. Fragments from different types of ammunition.

c. Direct hits of projectiles activated in the explosive facility.

d. Debris of structures, equipment, etc. thrown at the surroundings by an internal explosion.

e. Thermal effects - high temperatures, fire, etc.

f. Toxic gases propagating from different types of chemical materials in the explosive facility.

Although the above effects result in damages to property : structures, equipment, stored materials, etc. it is normally the possible injuries of people which present the overiding criterion for expressing risk.

The risk to people adjacent to the explosive facility can be assessed and quantified by using risk assessment procedures. We are using a set of computerized risk analysis codes, developed in-house, which calculate the expected level of injuries to people from all the above listed effects of an explosion.

The relative probability of occurance for the different effects is also taken into account as well as the details of the explosive facility, the site topography and the surrounding installations characteristics.

For an analyzed explosive facility, with it's defined surroundings, the result of the risk assessment analysis is expressed in percentages, relative to 100%, when the risk refers to injuries to people.

METHODS OF STRENGTHENING EXISTING EXPLOSIVE FACILITIES

As previously mentioned, the prefered way of reducing the risks to installations adjacent to explosive facilities is to strengthen the existing facility components.

The methods of strengthening are generally as follows :

a. Shielding external walls.

b. Strengthening existing walls.

c. Additional internal walls.

d. Strengthening existing ceilings.

e. Cover layers on existing ceilings.

Shielding external walls

The provision of shielding external walls surrounding the existing explosive facility is often applied due to the minimal disturbances to the functioning of the installation.

The shielding external walls are provided as close as possible to the existing facility walls, leaving the smallest required space for maintenance purposes.

The requirements for the shielding external walls result from their optimal efficiency in stoping fragments, debris and flying projectiles and subsequently determine the wall characteristics : height, width, layout.

The constrains for the shielding external walls are normally related to their foundations, to the utilities running around the existing facility and to the functional requirements in the area close to the existing walls.

The protective trend is to provide shielding external walls as high as possible; however the practical height of the walls is established considering all the site constraints.

The shielding walls most often used are made of reinforced concrete, concrete-soil-concrete and other soil-filled elements as well as earth embankments of different shapes.

The design of the shielding external walls must accomodate requirements related to aesthetics, sufficient provision of air and light, psychological effects on personnel and other functional aspects.

Although the implementation of new shielding external walls cannot please everyone, it is possible to reach an acceptable solution which combines the maximal protection, providing the best risk reduction, with the minimal disturbance to the facility structures and functioning.

Strengthening existing walls

In many existing installations, due to the space constraints, instead of providing new external shielding walls it is only feasible to strengthen the existing external walls of the facility.

Strengthening existing walls made of concrete, masonry, blocks, etc. can be achieved by several methods :

- increasing the wall thickness by additional reinforced concrete.

- adding to the existing wall steel plates on one or both sides with adequate anchoring connections.

- using soil fill to upgrade the existing wall to a sandwich-type construction.

- using soil embankments on the outside as part of the facility landscaping.

The risk reduction to adjacent installations is achieved by the strengthened existing walls especially for the effects of blast, fragments and debris.

Additional internal walls

One of the most effective ways to reduce the risks to adjacent installations is to significantly contain the expansion of the internal explosion from one exploding item to the others.

This can be achieved by the provision of additional internal walls which prevent as much as possible sympathetic detonations.

These internal walls are designed for extreme explosion effects and for local failure, ensuring, however, that sympathetic explosions are prevented. In order to achieve maximal ultimate resistance and energy absorbtion capability special walls have been developed, basically consisting of several layers : concrete-steel, steel-concrete-steel, concrete-soil-concrete, etc.

The layered walls have proven very efficient as internal sympathetic explosions preventing barriers, especially in view of the space constraints related to adding walls in an existing facility, as well as the required wall foundations and minimal disturbance to the existing structural elements.

Strengthening existing ceilings

Besides wall strengthening it is often required to reduce the amount of debris by strengthening existing ceilings.

However, this method must be first carefully checked for feasibility and cost-effectiveness.

When the risk reduction to adjacent installations by the strengthening of existing ceilings proves worthwhile, the methods used include :

- additional reinforced concrete.

- additional steel plates, adequately anchored in the existing ceiling.

- upgrading the ceiling to a layered structure with the prefered solution of concrete-air-concrete.

The extreme solution is the provision of a completely new ceiling covering the existing one without any connections to it.

Cover layers on existing ceilings

In many existing installations it is feasible to add different cover layers on existing ceilings to reduce the amount of debris. The most widely used material is soil and it has proven very cost-effective providing that the existing ceiling can withstand the dead loads.

For installations including protective requirements for external attacks by conventional weapons and/or terrorist explosive charges the implementation of cover protective layers-burster layer and absorbtion layer-is often used. These protective layers. when adequately designed, can also effectively reduce the amount of debris from the existing ceilings. However, care must be taken to use such protective layers configurations which will not inadvertly increase the risk of debris (for example the use of rocks as burster layer).

ASSESSMENT OF RISK REDUCTION DUE TO THE STRENGTHENING MEASURES AND THEIR COST - EFFECTIVENESS

The assessment of the reduced risk to people in the vecinity of the explosive facility due to the implementation of different strengthening measures is performed by considering their respective lowering of the explosion effects. Our computer programs use our practical experience and databases on the performance of all types of protective measures, for reducing conventional weapons effects and allow the close-to-reality assessment of the reduced risk.

The costs of the different protective measures are related to their respective reduction in risk capability and then cost-effectiveness diagrams are ploted enabling the definition of the optimal solution.

As an example, in a real project the cost-effectiveness of different strengthening measures was found to be as follows :

- For the existing facility, the risk to people in adjacent buildings outside the perimeter was found to be 100%, meaning that people would be injured beyond the admisible limits by one or several effects of an internal explosion.

- The risk reduction capability of different strengthening measures was assessed to be 20%, 35%, 50% and 70% for strengthening existing ceilings, strengthening existing walls,providing external shielding walls and additional internal walls, respectively.

- The costs of the additional strengthening measures were assessed to be 40%, 20%, 15% and 30%, (% of the value of the existing structure), respectively.

- The optimal cost-effective solution was therefore the provision of shielding external walls.

Obviously, several protective measures can be implemented and the optimal combination of measures should be defined by similar risk-cost effectiveness considerations.

CONCLUSIONS

The assessment of risk to adjacent installations from an internal explosion, the risk reduction by different strengthening measures in the existing facility and the respective cost-effectiveness can be established using computer-aided analysis procedures based on practical experience and engineering judgement.

We have applied the described procedures and concepts to many existing explosive installations, worldwide, and have been able to define the optimal combination of strengthening measures on a project-to-project basis.

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REFERENCES

R. Eytan, "Design of Layered Structures Against Conventional Weapons", paper presented at the International Conference on the Interaction of Non-Nuclear Munitions with Structures, Panama City Beach, Florida, April 1985.

R. Eytan, "Optimal Design of Ammunition Storage Facilities to Withstand Conventional Weapons Effects", paper presented at the Twenty-Second Explosives Safety Seminar, Anaheim, California, August 1986.

R. Eytan, "Optimal Design of Ammunition Facilities for Conflicting Requirements of Survivability and Safety", paper presented at the Twenty-Third Explosives Safety Seminar, Atlanta, Georgia, August 1988.

R. Eytan, "Analysis of Observed Effects of Terrorist Atttacks on Real Structures", paper presented at the ASCE Specialty Conference on Structures for Enhanced Safety and Physical Security, Arlington, Virginia, March 1989.

M. and R. Eytan, "Practical Experience in the Design and Construction of Rapid Pre-Engineered Hardened Structures", paper presented at the Fourth International Symposium on the Interaction of Non Nuclear Munition with Structures, Panama City Beach, Florida, April 1989.

THE APPLICATION OF LIGHTNING DETECTION AND WARNING SYSTEMS WITHIN THE EXPLOSIVES SAFETY ENVIRONMENT

Mr. William C. Geitz and Mr. William H. Highlands
Atmospheric Research Systems, Inc.
Palm Bay, Florida 32905, USA

Mr. Jack McGinnis
Naval Surface Warfare Center
Dahlgren, Virginia 22448-5000, USA

ABSTRACT

Lightning has always posed a serious threat to the manufacture, transport, storage and handling of explosives. In recent years, technological progress and advancements in communications systems have increased the availability of various types of lightning detection and warning systems for use within the explosives community.

The use of these systems, which detect the presence of, or potential for, cloud-to-ground lightning, is exposing personnel to one of the most complex elements of atmospheric physics. Armed with this "scientific data", engineers and managers are expected to make the right decision all of the time, decisions that have a significant impact on personnel safety, productivity, and the material and operational readiness of a command. It is a fact of life that the data they are dealing with is not perfect, can be misinterpreted, and in many cases can cause false alarms, which can undermine user confidence in the system and slow response/reaction to future warnings.

The intent of this paper is to make the reader aware of technologies in the realm of lightning detection and system application to the every day operation of the explosives arena. In addition, an objective approach in developing a generic baseline for readiness and warning procedures is offered.

1.0 Introduction

The enormous amount of time, effort and funds expended in implementing lightning protection actions within the manufacturing and storage arenas is an essential part of a common goal, which is the safeguarding of ordnance, people and facilities.

In most cases, protection is primarily orientated toward survivability of the ordnance and the material condition of the facilities in which the explosive material is manufactured and/or stored. However, when considering the purpose for which the ordnance is intended, and the processes involved in the manufacturing and delivery of the material, the need for lightning detection and warning should be given a priority equal to that which is given protection efforts.

As is well known, the mission of the Department of Defense (DOD) is to safeguard our country's interests, support and/or assert foreign policy. This mission places the DOD in only one of two positions at any one time. That is, war or preparation for war.

Whether the requirement for ordnance are from a ship about to withdraw United States civilians from a troubled country or from an artillery unit about to conduct a readiness and training exercise, it is important that the goods be delivered intact and in a timely manner. If an accident occurs, the DOD not only looses expensive and hard to replace resources, both manpower and material, but it must also deal with a significant leadtime in effecting their respective replacements. Meanwhile, a the warfighting ability of a combat unit is degraded. In addition to the material loss, we all too frequently loose valuable, highly skilled and experienced people who are hard to replace. While not ignoring the emotional issues that accompany such a loss, it is important to keep in mind that it is very time consuming to train replacements.

Today we are at peace, for the most part, and as history has shown time and time again, with peace comes budget reductions. What is happening within our present day political and military environment is not a new wave of policy. As in the past, it will take large amounts of money, perseverance, and strong management to sustain the DOD so it can adequately serve as a deterrent to foreign powers, and quickly respond to a threat if one arises.

It is a fact of life that during the transport, loading, manufacturing and unloading of explosives, the specter of danger is more critical than at any other time. This is when people are directly involved in a hands-on manner. During such evolutions important management decisions must be made that will have an impact on productivity, mission accomplishment and personnel safety.

In the past, common sense and in many cases a "lets play it safe" attitude, has been the rule of thumb. In the majority of cases the job was done. However, in an environment of limited material and personnel resources, increased operating costs and occasional pressure from management, there is strong potential for people to take risks or to be less attentive to detail for the sake of getting the job done quickly. While some people may dispute this claim, they may want to check with their service's safety center and see how many vehicle, ship and aircraft accidents have identified "get-home-itis", "meet schedule", or "lack of attention to detail" as significant contributing factors.

The intent of this paper is to make the reader aware of technologies in the realm of lightning detection and system applications in the every day operations of the explosives arena.

2.0 Understanding Thunderstorms and Lightning

Prior to discussing lightning detection technology, it is important that the reader gain a basic understanding of, and respect for, lightning phenomena and the threat it poses.

Generally speaking, when identifying people with lightning, there are two groups. The first group consists of people who either fear lightning or ignore it. It is estimated that this group represents up to 80% of the people whose work is directly affected by lightning. The second group consists of people who accept the phenomena as a fact of life and through their understanding of it, react to its presence in a flexible and effective manner.

In the following paragraphs we will attempt to help the first group reader better understand what thunderstorms and lightning are all about. Regarding the second group, the information will provide a different perspective and expose them to some new theories about thunderstorms and lightning. As previously stated, the overall goal is to increase the reader's knowledge of the subject so their ability to orchestrate a flexible and effective response to the threat is enhanced.

2.1 Thunderstorm Origins

The most realistic method of categorizing thunderstorms is to label them as either Synoptic or Air Mass. Synoptic thunderstorms are those which are directly or indirectly generated by major storms or weather systems such as fronts, low pressure systems, and tropical cyclones (hurricanes and tropical storms). On the other hand, air mass thunderstorms are most commonly seen as individual or groups of cells that form in the summertime throughout the 50 states.

2.2 Synoptic Thunderstorms

These thunderstorms usually involve a broad area and demonstrate some consistency as to their movement and intensity. Some storms may be embedded in large areas of cloudiness, as with a warm front, while others will form a distinct line as seen with the typical cold front or with feeder bands spiraling around a hurricane.

In most cases, the most intense synoptic thunderstorm is the type associated with squall lines that are spawned by fast moving cold fronts. These squall lines develop anywhere from 150 to 300 miles in advance of the front, and the thunderstorms associated with them move very rapidly (35 to 60 knots). In some cases, the tops of these storms may extend 10 miles into the atmosphere.

Usually, these types of storms produce severe weather such as wind speeds in excess of 50 knots, large hail, tornadic activity and frequent lightning. One advantage, when dealing with this type of thunderstorm, is that it can be predicted with a high level of accuracy. This capability provides people with a reasonable amount of leadtime to take precautions to reduce the level of avoidable damage, and plan for its consequences, prior to the arrival of the severe weather.

The National Weather Service (NWS) and most services of the DOD have policies that address severe thunderstorms as a singular threat.

2.3 Air Mass Thunderstorms

As noted above, these will normally be generated by the heat of the day and involve either individual or groups of cells. When addressing a group of cells, the most common types are clusters or lines. A good example of a cluster is the large area of activity that develops over the Ocale Forest in North Central Florida. On the other hand, good examples of the line type can be seen along the sea-breeze boundary of the Gulf Coast and in the Southwest U.S. and the piedmont area of the Carolinas where mountains are present.

Under normal conditions, there is a high measure of predictability regarding air mass storms. In most cases, the only day to day change that may take place is their direction of movement, which is affected by the wind field in the upper atmosphere, or the exact location where they form.

There are times when conditions over a certain area are enhanced by converging wind fields or systems in the upper atmosphere. When this occurs, the storms tend to be more extensive in the area they affect and at times take on a very violent character. The biggest problem with this type of storms, in relation to the explosives arena, is the fact that they can develop rather quickly within a sensitive area and produce a first strike hazard with little or no advance warning. In some cases, overhead development of the storms is common, especially if large concrete or forested areas are present.

2.4 The Basic Elements

To have a thunderstorm, you must have a lifting action, moisture and hydroscopic-nuclei. The lifting action may be caused by heated air rising from the surface of the earth, while the source of moisture may be from an ocean, lake or be present in the upper atmosphere. Hydroscopic-nuclei is the critical element since the water droplets must have something to which they can attach themselves. Common nuclei are salt particles, sand, industrial airborne wastes and volcanic ash.

In most cases when dealing with synoptic thunderstorms, the necessary elements are readily present. However, in the case of an air mass situation, many thunderstorms never mature. This is caused by the absence of sufficient moisture or a strong low level wind field that shears the cell apart and cuts off or distorts the lifting mechanism.

2.5 Stages of a Thunderstorm

A typical thunderstorm involves three stages; 1) Cumulus, 2) Mature, and 3) Dissipation. In most cases, the time it takes a thunderstorm to complete all three stages is less than two (2) hours. The reader must keep in mind that with the exception of the cumulus stage, the stages of a storm will normally have no direct relation to its severity or the amount and type of lightning it will produce. For convenience, the term "cell" will be frequently used to address individual thunderstorms.

2.5.1 Cumulus Stage

This stage is recognizable by the puffy white clouds that form. The cell feeds on the warm moist air from below, but as it builds into the atmosphere, it also begins to draw energy from the surrounding air.

During the cumulus stage, all currents within the cell are upward and as the cell builds further into the atmosphere, some downdrafts begin to form in the higher portion of the cloud, which is normally above the freezing level. If the elements sustaining the cell persist, then it will continue to grow. However, if any one of the elements is weakened, the cell will release its moisture and be classified as only a rainshower.

2.5.2 Mature Stage

During this stage well defined downdrafts begin to develop within the cell. This action further increases the vertical development of the cell. As the cell continues to grow, an anvil will gradually develop (normally above 23,000 feet), the cloud mass takes on a more ominous character as its moisture content increases, and lightning begins. By definition, a cell is considered to have fully matured when precipitation falls from the base and reaches the ground. Prior to the onset of rain, a first gust front signals the release of the cold dry air that has developed within the cell.

This primary downdraft travels outward in all directions from the cell and is at its greatest extent along the cell's axis of movement. The first gust front will normally extend 15 miles ahead of the cell and as far as 5 miles in other directions. Wind speeds in excess of 100 knots have been recorded with these first gust fronts.

Most people are familiar with the change in wind direction and speed, and the rapid cooling associated with this event. It is also important to note that at this time there is a significant increase in lightning activity. Once a cell has matured, it will not develop any further.

2.5.3 Dissipation Stage

During this stage all motion within the cell is downward. Lightning is still active during the early part of this stage; however, as the rain subsides, the lightning will taper off and the wind will gradually abate. At this point many people will disagree that they have frequently encountered situations where the wind, lightning and rain have persisted for many hours from one cell. To take the reader one step further and also address this issue, lets take a look at a fourth stage of the thunderstorm.

2.5.4 Re-Development Cycle

As mentioned in the discussion of the mature stage, there is a release of cold air from the cell. While this air travels outward from the mother cell it is warmed and picks up moisture. In addition, by its motion, contact with the ground and the heating that takes place, it begins to rise and turn in a cyclonic (counter-clockwise) trajectory and thus has strong potential of developing into a new cell. This re-development cycle is most common with synoptic thunderstorms, but is not uncommon in an air mass situation.

These new cells will usually develop ahead of or slightly behind the mother cell. In most cases people will not be able to differentiate the new cells from the old ones because they will frequently become embedded within the residual cloud mass generated by the old cell. While the NWS has the advantage of modern weather radars to detect this cycle, a good thumb rule for the layman is that if during the dissipation a secondary area of strong winds is encountered, then it should be assumed that a new cycle is in progress.

2.6 Thunderstorm Categories

The NWS only addresses two categories; Thunderstorms and Severe Thunderstorms. By definition a severe thunderstorm must produce wind gusts of 50 knots or greater, and hail if present, that is 3/4-inch in diameter or greater. If conditions are less than these, then the system is just classified as a thunderstorm. In some cases wind damage can be used to classify a storm as severe.

It is also important to note that lightning frequency and flash flooding are not criteria for severe thunderstorms. While tornadoes are normally associated with severe thunderstorms, they are treated as a separate issue when it comes to issuing warnings or watches.

2.7 The Lightning Profile

The atmosphere in its normal state has a positive charge, while the earth holds a negative one. The presence of a thunderstorm will induce a mixture of charges within the cell, while the surface under and around the cell will gradually assume a positive charge. Further, an increase in the potential charge in the electrical field between the earth's surface and the thunderstorm cloud mass will also take place. For the most part, lightning activity takes place during the mature and dissipation stages of the thunderstorm. Since the most dangerous form of lightning is the cloud-to-ground discharge, a detailed discussion on the processes involved in this phenomena is provided.

A cloud-to-ground lightning discharge is made up of one or more intermittent partial discharges. The total discharge whose time duration is of the order of 0.5 seconds, is called a flash; each component discharge, whose luminous phase is measured in tenths of milliseconds, is called a stroke. There are usually three or four strokes per flash, the strokes being separated by tens of milliseconds. Often lightning as observed by the eye appears to flicker. In these cases the eye distinguishes the individual strokes which make up a flash.

Each lightning stroke begins with a weakly luminous predischarge, the leader process, which propagates from cloud-to-ground and which is followed immediately by a very luminous return stroke which propagates from ground-to-cloud. It has been found that the electrostatic field takes about seven (7) seconds to recover to its predischarge value after the occurrence of a lightning flash at a distance beyond 5 Km, but when the flash is very near, the recovery time may be different due to the presence of space charge. In both cases, regeneration of the field takes place exponentially.

2.7.1 Stepped Leader

The usual cloud-to-ground discharge probably begins as a local discharge between the positive charged region in the cloud base and the negatively charged region above it. This discharge frees electrons in the negative region which were previously immobilized by attachment to water or ice particles. The free electrons overrun the positive region, neutralizing its small positive charge, and then continue their trip toward the ground, which takes about 20 milliseconds (msec). The vehicle for moving the negative charge to earth is the stepped leader which moves from cloud-to-ground in rapid luminous steps that are about 50 meters in length. Each leader step occurs in less than a microsecond, and the time between steps is about 50 microseconds.

2.7.2 Return Stroke

When the stepped leader is near ground, its relatively large negative charge induces large amounts of positive charge on the earth beneath it and especially on objects projecting above the earth's surface. Since opposite charges attract each other, the large positive charge attempts to join the large negative charge, and in doing so initiates upward-going discharges. One of these upward-going discharges contacts the downward-moving leader and thereby determines the lightning strike point.

When the leader is attached to ground, negative charges at the bottom of the channel move violently to ground, causing large currents to flow at ground and causing the channel near ground to become very luminous. The channel luminosity propagates continuously up the channel and out the channel branches at a velocity somewhere between 1/2 and

1/10th the speed of light. The trip between ground and cloud takes about 100 microseconds. When the leader initially touches ground, electrons flow to ground from the channel base and as the return stroke moves upward, large numbers of electrons flow at greater and greater heights. Electrons at all points in the channel always move downward, even though the direction of high current and high luminosity moves upward.

It is the return stroke that produces the bright, visible channel. The eye is not fast enough to resolve the propagation of the return stroke, or the stepped leader preceding it, and it seems as if all points on the channel become bright simultaneously.

After the first return stroke is complete, more charge may be made available to the top of the ionized channel and a dart leader will then pass down this branchless channel to the ground, once more depositing negative charge. A second return stroke then passes up the channel. The process may continue several times in a fraction of a second.

2.7.3 Bolts From The Blue

In a reverse pattern we can view the anvil and its positive charge which extends over a section of earth where the ground is still in a state of negative charge. It is not unusual for the anvil to have a base 25,000-30,000 feet above ground level. When considering the distance involved, it is not unusual to see strong discharges with this type of lightning. These cloud to ground strokes are frequently called "Bolts from the blue", since in some cases they will strike in a clear area many miles from the cell. There have been reports of these lightning strokes occurring up to 30 miles away from the main cell, and producing voltages in excess of 150K/amps.

During the dissipation stage the anvil will gradually disperse and break away from the main cell and therefore, will loose its ability to produce lightning. It must be remembered that if a redevelopment cycle is in progress, the lightning will also run in a cycle with little or no noticeable break in activity.

3.0 Detection and Warning Technologies

3.1 Principals of Operation

A TOA Lightning Position and Tracking System network consists of three to six receivers each, connected by a dedicated full duplex terrestrial data link to a central analyzer (CA) (Fig. 1). At each antenna site, there are two simple whip antennas (1.2 to 5.0 meters in height). One antenna receives LORAN-C signals, while the second monitors the electric field. These have no special siting requirements, and can be placed in the vicinity of metal objects, other conductors, or atop conventional buildings. No alignment checks or frequent periodic maintenance is necessary.

The electronics at each site include a lightning strike detector and a timing signal generator synchronized to within a few hundred nanoseconds of the output of the timing signal generator at each of the other respective locations. Electric field measurements in the 2 to 500 KHz range are sampled continuously. A very specific wave form is associated with the lightning return stroke. The electromagnetic pulse emitted by the strike is assumed to originate at a point perhaps 100 meters above the attach point to the earth's surface. The timing of the peak of the wave form is ascertained within a few hundred nanoseconds.

A minimum of three stations must detect the strike in order for a location to be calculated. For a three station solution, the central analyzer solves the complex spherical hyperbolic explicit non-interactive equations necessary for stroke location. The data is output in latitude and longitude coordinates. Custom built ARSI hardware allows for extremely fast hardware trigonometric calculations, as a software approach would not allow the multiple return stroke location ability that is an LPATS characteristic. LPATS can monitor the individual return strokes in a multiple lightning flash only 15 milliseconds apart, discriminating more than 50 strikes per second (a rate unlikely to be approached in nature).

For the operational location of lightning cloud-to-ground strokes, there are essentially two acceptable approaches: 1) magnetic direction finding (MDF) [1], and 2) time-of-arrival (TOA) [2]. The MDF technique has been in widespread operational use since the late 1970s. While it certainly represents a major advancement over the highly limited lightning detection capabilities of past systems, MDF systems are subject to problems of site errors due to 1) maintaining exact antenna orientation, and 2) the presence of metal in buildings, buried cables, and other similar obstacles [3] Darveniza and Uman, 1983. As noted by Pierce [4].

A time-of-arrival (TOA) method is by far the most accurate way of fixing the source of an individual spheric. It is also, understandably, the most elaborate and expensive. TOA systems are less subject to errors than are cross-loop techniques. Polarization errors are effectively non-existent; site errors are very small. However, if the potential accuracy of the TOA system is to be realized and confusion between separate atmospherics is to be avoided, interstation timing of approximately 10 microseconds is required. This implies the installation of accurate time standards at each station."

Since these assessments were made, there has been a dramatic revolution in microelectronics, resulting in the availability of low cost receivers for easily available timing signals (such as LORAN-C), obviating the need for such expensive timing sources as atomic clocks. A four station prototype TOA network was designed by Atlantic Scientific Corporation and established over the Florida peninsula in the spring of 1982. Earlier papers by Bent, [2] [5] and Lyons and Bent [6] has described the basic system operations and presented initial examples of data collected by operating networks covering the U.S.

This paper will summarize the techniques that are currently being employed to display and interact with this newly available data base, as well as present representative case studies obtained from operational networks. At this time, there are many on-line users for LPATS data including television and radio stations, utilities, military bases, and industrial facilities.

3.2 Reported Results (TOA)

Theoretical accuracy analysis and academic discussion of error sources are interesting, but the bottom line is actual, demonstrated performance. In this section, we present data captured from an operating system which will add credibility to the claims and analysis of highly accurate lightning stroke positional data.

The major problem with trying to assess the accuracy performance of any lightning tracking system is the absence of absolute ground truth data. ARSI has wrestled with this problem for years, and the outcome of any LPATS vs. actual assessment effort could be challenged to some degree because of shortcomings in the reference data (i.e., ground observer judgements, inadequate statistics, etc.).

One of the best techniques has proven to be the comparison of fixes from two independent, differently located networks. Good fix agreement generally must mean that both networks are highly accurate, but disagreements convey no information as to which net is inaccurate or why. This technique is also really useful only when both nets cover the same area with the same degree of theoretical accuracy and detection efficiency, which is a rare situation.

Fortunately, a method has been reported by one LPATS customer that is elegant in its simplicity and also extremely difficult to take issue with Dr. M.J.G. Janssen has recently reported [7] on the performance of the Dutch system owned and operated by KEMA (the Dutch power utility). His method was based on the fact that a high object will have a large attractive radius, and if the lightning fix data base is examined in the area around such and object, there should be an obvious concentration of fixes. Knowing the true latitude/ longitude of the object and comparing against the centroid of the fix concentration then should give a measure of the mean system accuracy in that location. Not only does this technique expose systematic (mean) error, but the spread in the fix concentration gives an indication of the random error.

Figure 5 is extracted from Dr. Janssen's paper. The distribution of strokes grouped into 100-meter x 100-meter bins is shown relative to a 300-meter tall tower. The average error is on the order of 300-meters, with no clean distinction between random and systematic components. This compares very favorably with the best-case accuracy of about 200-meters predicted in Figure 6 for random error only. Of course, Figure 6 is not the Dutch network, but the 200-meter figure represents about the best average figure than can be expected from a TOA network regardless of configuration. Note the obvious absence of strokes at larger radii from the tower.

Intrigued by this method of assessing accuracy, ARSI performed a similar analysis of the November, 1988-September, 1989 data base archived from the Florida LPATS network (owned and operated by ARSI) with very interesting results. Figure 6 shows a theoretical accuracy analysis of the Florida net, plus the receiver locations. The circle shows the location of the three towers illustrated in Figure 7. Figure 8 shows the plot of all strokes found within the general vicinity of the towers (located within the squares). Three fix groupings are highly obvious and are certainly strikes to the towers. Tower 1 had 36 strikes, tower 2 had 24 strikes, and tower 3 had 56 strikes. Figures 9 and 10 are blow-ups for better resolution, with a 200-meter x 200-meter grid superimposed. It is obvious that there is a southwest mean error of about 500 meters and a random error on the order of 200 meters or less (the average random error from the fix groupings centroid is much less). Comparing with Figure 6, we expect a random error of about 200-meters average. This is excellent confirmation of the analytical predictions and lends credibility to the random timing error figure used to produce the analytical results.

Careful examination of the 500-meter systematic offset error produced no obvious explanation. There were no significant errors in site coordinates (measured using GPS) and no error in the calculation of timing propagation offset correction factors. Further investigation finally revealed the source of the error to be primarily due to absence of provisions in the central software to account for the fact that the earth is an oblate spheroid rather than a perfect sphere.

An oblate spheroid has a polar radius shorter than the equatorial radius; therefore, by using Helmert's iterative solutions for goodetic distances, it was found that the fixes moved 450 meters to the northeast if the earth's oblate characteristic was properly accounted for! This corrects 90 percent of the systematic offset error and renders it of less significance than the small random error. It is not likely that oblate corrections would render systematic errors less than the random error in the typical case. But, this example, based on real unprocessed data, effectively illustrates the inherent capability of the LPATS TOA system.

3.3 The Video Information System (VIS)

LPATS users do not need to purchase, maintain, or operate a lightning detection network. Rather, much in the manner of a dial-up radar service, users may subscribe to a data service provided by an operating network. At this time, the most commonly used device to acquire LPATS data is the Video Information System (VIS).

The VIS consists of a standard XT, AT, or a 386 personal computer with a minimum of one disk drive, enhanced graphics adaptor, monitor and keyboard (Figure 2). A VIS software package is loaded into the PC which provides the user with a visual workstation to observe the lightning within the area of interest and make decisions based on the data provided.

The lightning data displayed on the VIS equipment may be received by various means which include satellite broadcast, dial-up or dedicated telephone lines. Typical data receipt times vary according to the communications medium employed but normally no more than a 5 second delay between a stroke occurrence and data receipt can be expected. Figure 3 is a typical user station setup when lightning position data is received via satellite communications.

With systems installed throughout the U.S , national data is now available to any user who desires this large data base. However, smaller areas are available for those who's interest is limited to a local area. Figure 4 shows typical data areas available.

4.0 Types of Data and Their Effectiveness

When discussing this area, consideration must be given to the type of data, its timeliness, the manner in which it is displayed, and the ability of the end-user to manipulate and interpret the information. In addition, there must be some sensitivity given to the issue of alarms and the advantages and drawbacks of using such devices.

4.1 Types of Data

There are two types of data, realtime or aged data that represents lightning events that are or have taken place, and data that provides advance warning of the threat of lightning. Since timeliness will be discussed below, the focus at this point will be directed towards only the types of data and related pro and con issues.

4.1.1 Lightning Events

This data is frequently used to monitor the progress and/or progression of thunderstorm areas, both air mass and synoptic, respectively. The biggest advantage gained from this data is that the user can normally gain a better feel for the thunderstorm pattern and in most cases (if the software will support the effort) ascertain the trajectory and speed of the thunderstorm cell(s). The most critical drawback of such a system is that lightning must already be taking place.

While advanced systems are capable of displaying lightning occurrences in a matter of seconds after the event takes place, they cannot provide full protection from the first stroke emanating from a local air mass storm. While many may perceive this as an acceptable trade-off when considering the overall benefit gained from the entire system, people dealing with evolutions involving explosives and personnel safety issues cannot afford to treat such a risk as acceptable. To compensate for this weakness in is advisable to include some form of advance warning system within the lightning detection system configuration.

4.1.2 Lightning Potential Instrumentation

The most common technology utilized to detect potential for lighting strikes is that which is normally found in an electric field mill. In the past their has been some serious concern regarding the application of such systems since many view them as being prone to false alarms, and many production orientated people are hesitant to respond to an alarm that is initiated at a preset value that someone else claims is ideal to optimize system application.

In most cases, the field mill's reputation for false alarms is unfair since most of the time such determinations are based on observations obtained through application of non-scientific procedures. These procedures include the good old count the seconds between the lightning flash and the thunder to estimate the distance to the storm.

In all fairness, one must consider the fact that a realistic detection range for a field mill is normally less than five (5) miles, and at least 40% of the time, thunder associated with lightning is not heard by the people affected by it due to various atmospheric abnormalities such as sound focusing.

Recently, a comparison was conducted by ARSI whereby data from an electric field mill was compared directly with realtime lightning stroke data for the same location. As shown in Figure 11, the electric field mill was sensing the electric field in excess of 2,000 Vm at least five minutes prior to any lightning strike occurring within a 10 mile range (Point 1). In addition, the field mill shows at least 15 minutes of warning for a strike that occurred at a distance of less than 5 miles from the field mill site (Point 2). Of particular interest are the field changes that occur when lightning strokes take place nearby, as can be seen at points 1 and 2, and between points 3 and 4.

4.2 Timeliness of Data

There are only two categories of data that fall within this area, realtime and other than realtime. When viewing the application of the data within the explosives environment, it is obvious that realtime data, whether it be from a detection or warning system, is the only acceptable source of data that should be considered. The only value other than realtime data may offer is assistance during the investigation following a mishap. However, new software designs support archive and replay requirements.

4.3 Data Display

With the advent of high speed computers and enhanced video systems requirements for various capabilities within such media are numerous and varied. In general, there are two basic types, the Pavlovian Response and Graphic Map.

4.3.1 The Pavlovian Response

This basically entails a flashing lights, bells and whistles scenario that is designed to generate a response of sorts from the user. The most common display used is one that involves a pie shaped circle that will change color based on the number of flashes/strokes detected within a particular slice.

Some serious drawbacks from such a display include insensitivity to the storm's direction and speed, and the stage of development involved. In addition, many times such systems are advertised as providing the user with storm severity, which is normally determined by the number of strokes that occur within a given timeframe. This latter claim may be true in some cases; however, there is no scientific proof to support such a claim, and as stated earlier, lightning frequency is not a consideration with regard to storm severity.

The bigger drawback of such a display is the fact that the user never gets a feel for patterns associated with the storm, and is placed in a position that any action must be tied to the appearance of a color pattern and/or some form of alarm device, either audio and/or visual. This scenario creates problems that can impact on productivity and reduce user confidence. For example, many alarm events may later be ruled as false, and the user is forced into a position where they must wait for an alarm to occur before any action can be taken.

4.3.2 Graphic Map

Such a display provides an ideal picture of conditions to users since they can readily observe the storm's trajectory, lightning density, relative location and facilitate cell/area speed computation. In essence, the user is able to gain a "feel" for the storm(s) which can greatly assist in formulation of a decision as to whether a threat is present or not.

Through the use of various landmark features on the display the user can effectively apply the data to the other variables that are involved in making a decision as to what action should be taken to deal with the threat.

4.3.3 Data Manipulation

Most software packages are menu driven user friendly and include a basic screen display that is either generic to system users, or tailored to specifically meet both generic and unique needs. In addition, they will also include additional features that the operator can use to enhance and/or manipulate the displayed data. Some features that are common to most systems include zoom, time lapse and data looping.

Some of the more sophisticated user-friendly packages may include user programmable features that include alarm areas, movable windows, integration of field mill data, alternate map set-ups, range and bearing determination, predefined displays, and greater control of map and display features, titles and color coding. All of these elements further enhance the potential for accurate and effective interpretation by layman.

5.0 Integration With Heavy Weather Procedures

The key to optimizing the integration of data from lightning detection and warning systems is to identify; 1) vulnerable areas, 2) the level of intensity that will affect the particular area(s), 3) required action(s) and their impact on operations/productivity/safety, 4) communicating threat information; 5) personnel training, and 6) on-going program evaluation.

5.1 Identifying Vulnerable Areas

To adequately accomplish this element, all levels of the organization must evaluate the impact of lightning activity on their material facilities, standard operating procedures, personnel safety, and support facilities such as medical, recreational and security services. All elements within the organization's structure should be involved and individual assessments should not be assigned a priority or specific value at this point in time. In addition to routine issues, consideration should also be given to non-recurring activity such as construction work done by non-government contractors, open houses and sporting events.

Examples of areas to be addressed include the impact on power to critical systems such as EMCS transportation, inspection and handling of material, and public works evolutions and other facilities management related actions.

5.2 Level of Intensity Determination

The purpose of this phase is to establish the minimum threshold for each vulnerable element where conditions will produce injury, damage or an unacceptable environment. When determining a threshold value for any particular element it is important that you continue to treat each one as a separate entity and once again, refrain from assigning priorities. A good example of a result gained from such as evaluation would be the realization that it may be more important to monitor lightning near power lines that feed a computer center, rather than monitoring activity at the center itself.

5.3 Actions and Their Impact

One of the more difficult phases, it is important that while addressing the issues of action and impact, realistic approaches and honest evaluation prevail. At this point another element must be considered and that is for every action there will be a required response. The feasibility of executing the response and its initial acceptance by the responsible manager must also be an issue. This element will be critical in the future since it will impact directly on feedback during lessons learned reviews and improve the end user's overall perspective when dealing with an occasional false alarm.

While at this point one should still refrain from assigning priorities, it is important that flexibility be inserted within the individual actions and impact elements that are identified. This can be accomplished by listing in order, from the lowest to most severe, the actions that are required and the related impact on operations. In this way, analysis of the overall picture can result in a program containing flexibility factors that will limit to a major extent the impact on productivity and time-management without compromising the goal of the action.

Example:

Take for instance a fuel farm that is very active during the daytime and is closed after normal working hours. The minimum action identified for the facility is that personnel are notified in advance that based on local forecasts, thunderstorms can be expected in the area during the next six (6) hours, but based on existing data, none are expected within the next hour. Based on an initial condition of readiness (lowest), the only impact on operations would be for personnel to review what actions they will be required to take should the next level of readiness be issued.

The next level of readiness might inform the facility that data patterns indicate they can expect a lightning hazard within the hour. This action should induce a response that would include actions such as stowing loose articles, securing sensitive equipment that is not being used, review of any planned evolutions that could be restricted by the phenomena, and review of actions that should be taken should a warning be issued and which personnel will be responsible for executing the actions. As you can see at this point, the impact is still kept at a minimum.

When the data indicates that the highest level of readiness must be implemented, then such an action should be identified as a "WARNING". In this case, lets say the "WARNING" calls for lightning within 15 minutes (we'll assume the storm is within 10 miles), and the required action is to secure operations, have personnel seek shelter, take other systems off-line that could be affected, and notify responsible authority that actions are complete. At this point the impact is at its greatest in that the facility was functional to the maximum allowable until there was no choice but to shut down. However, as you can readily see, the overall impact on the fuel farm's mission was significantly reduced, which is a result of the flexibility factor.

At this point, it should be noted that another critical element that is needed to effectively analyze the impact on a particular mission area is to conduct a periodic review of lessons learned and modify the basic plan as needbe. This element is discussed later in this section.

5.4 Program Set-Up

When every area has been evaluated and the actions and their impact identified, it is time to analyze the data and assign priorities. These priorities should fit into one of the following categories; 1) Major (work stoppage/extreme danger/severe damage), 2) Moderate (reduced operations/little or no safety issues/minimum potential for damage, and 3) Minor (generally no impact of any consequence.

In setting-up the implementing procedures it is advisable to use a sequence of numbered "conditions of readiness" (COR) to mark the advent of the threat, and only apply the title of "WARNING" when the threat is real and actions of the highest impact are required. Experience has shown that development of sub-conditions of readiness (i.e. 1A, 1B, etc.,) tend to cause confusion in the long run.

When issuing CORs or warnings it is important to identify a time-frame for which the action is valid. As a minimum this time-frame should span at least one hour. In addition, where feasible, setting of CORs should be done in advance of the start point of the effective period. While extensions of CORs and warnings should be permitted, this type of action should be limited to two. Once two extensions have been used, then the issuing authority should be required to reevaluate the situation and issue a new COR or warning. The new action should go into effect at the termination time of the last extension.

Example:

*At 1005, conditions indicate that a COR must be issued to provide a low grade alert to activities regarding the anticipated development of thunderstorms during the early afternoon. The following COR is typical of what should be promulgated to supported activities:

Set Thunderstorm Condition II effective from 1030 to 1630 local time.

Narrative: Patterns indicate that thunderstorm activity, accompanied by strong winds and lightning is expected within the next six hours, but not within the hour

*At 1340 a review of the situation indicates that the storms are developing as forecast and data shows that the movement of the cells is such that they will affect all or part of the facility within the hour and patterns indicate that the activity could last for a few hours.

Set Thunderstorm Condition I effective from 1400 to 1600 local time.

Narrative: Present conditions indicate thunderstorms, accompanied by strong winds and lightning, can be expected within the hour.

*At 1430 the thunderstorm patterns are approaching the maximum acceptable range where action of the highest nature must be implemented. A statement is included within the Condition I procedures which tells people they must be ready to implement "WARNING" related actions on short notice. Therefore, for record purposes, the warning base time will be the time at which the first notification action is taken, and the effective time for people notified will be the time of notification. It is also determined that conditions will last for approximately 1 1/2 hours.

Set Thunderstorm Warning effective upon receipt until 1600 local time.

Narrative: Thunderstorms, accompanied by strong winds and lightning, are eminent.

5.5 Communicating the Threat

The most critical element, it is essential that methods used to implement warnings/CORs utilize the fastest means possible, be reliable, and involve a medium that permits clear and concise transfer of information and guidance. In addition, it is equally important that an alternate or duel medium be identified. An example would to use an auto-dial phone system as the prime method and as a back-up, sound an audible alarm to alert the people involved. Some locations, such as NAS Pensacola, utilize a paging (beeper) system as a prime means of passing an alert, while other activities use them as a back-up..

Another element regarding communications is to keep to a minimum, the number of personnel to be contacted by the responsible authority. Notification of units that have no critical need for immediate notification should be left to a higher level within their organization. For example, it is more realistic to call recreational services and pass the word about lightning so they can notify the pools, golf courses, and other facilities under their control. On the other hand, it would be more realistic to directly contact the fuel farm then to pass the data via another office since a delay could have a serious impact.

In addition, the information passed should be kept to a minimum and only relate to the issue. This will reduce potential for confusion. A call sheet should be developed for each phenomena (i.e. thunderstorms, high winds, etc.,) and the activities listed should be listed an order of priority that is relative to the phenomena. For example, while the fuel farm may be high on the thunderstorm list, it would be at a lower level on the high winds list.

5.6 Personnel Training

There should be three separate levels of training; 1) evaluation of data and the subsequent setting of CORs and warnings, 2) data dissemination, and, 3) execution of procedures and subsequent reporting of readiness attainment.

People tasked with making the final decision to set a COR or warning must have adequate knowledge of the phenomena involved to qualify their actions and in some cases actually conduct the evaluation of data. Therefore, training for these individuals should be tailored to the minimum requirements necessary to perform the action, and include pre-seasonal reviews of ty[illegible] weather patterns and related CORs and warnings, and [illegible] an annual re-certification.

It should be noted that in most cases, even at locations where a weather office is located, the weather activity can only recommend an action. The overall responsibility and authority to set a COR or warning still rests with the senior official in charge of the host activity. At best, personnel from the weather office should be utilized to train the people who will authorize the setting of the COR or warning.

Personnel involved with the dissemination or receipt of the COR and warning data must have a basic understanding of the types of CORs and warnings and the related phenomena. In addition, they must also be intimately aware of the importance of record keeping and their responsibility, if applicable, to pass the data, in a timely and concise manner, to others within their organization. In most cases, an effective pre-qualification program and the in-house training program will readily meet the need.

When viewing the issues of taking action and reporting attainment of a readiness level, it is obvious that training regarding such items should be an integral part of the in-house training program and listed occasionally within documents such as a plan of the day or safety notice.

5.7 On-going Program Evaluation

Such a program is the most critical element in any weather related COR/warning related program. For the most part one can anticipate that at least 80% of the initial program will adequately satisfy overall needs and goals and that some adjustments will be required within the remaining areas of the plan.

It is important that when implementing the initial plan a moratorium of 3 to 6 months be put into place that restricts changes to the plan unless they are critical in nature and correct documented deficiencies that cannot be tolerated for the duration of the period. This limitation will provide users with an opportunity to live with the system and therefore force them to work with what they have for a while. The long term gain from such a policy will be that for the most part, changes that are recommended after the moratorium will normally include an adequate level of supporting documentation, and lack emotion.

Another sound forum that will improve the effectiveness of the plan is the conduct of Lessons-Learned Meetings during which new ideas, mistakes made and new requirements driven by mission change(s) are actively discussed. The results of such gatherings can significantly reduce the administrative cost and manhours expended in the preparation, evaluation and implementation of changes/updates to the basic plan.

6.0 Conclusion

While the information and ideas expressed above may not provide a solution to a specific problem, they do provide an initial point from which an effective program can be developed which will adequately solve most of the day-to-day problems that consume enormous amounts of time and money.

The key point is that by better understanding the phenomena and its impact, and dealing with it head-on through use of adequate equipment and a flexible plan, a significant improvement in your overall operation and the safety environment of your personnel can be realized.

REFERENCES

[1] Krider, E.P., R.C. Noggle, and M.A. Uman, 1976: A Gated, Wideband Magnetic Direction Finder for Lightning Return Strokes. J. Appl. Meteor., 15, 301-306.

[2] Bent, R.B., P.W. Casper, T.H. Scheffler, and R. Leep, 1983: A Unique Time-of-Arrival Technique for Accurately Locating Lightning over Large Areas.

Reprints, Fifth Symposium on Meteorological Observations and Instrumentation. Toronto, AMS, 505-511.

[3] Horner, F., 1954: Influence of Buried Conductors on Bearings. Wireless Engineer, 30, p. 186, 191.

[4] Pierce, E.T., 1982: Spherics and Other Electrical Techniques for Storm Investigations. In, Thunderstorms: A Social, Scientific, and Technological Documentary, Vol. 3, E. Kessler, Ed., USDOC, NOAA, U.S. Gov. Printing Office, 135-148.

[5] Bent, R.B., W.F. Highlands, and W.A. Lyons, 1984: Description and Theoretical Evaluations of LPATS (Lightning Position and Tracking System) to Monitor Lightning Ground Strikes Using a Time-of- Arrival (TOA) Technique. Preprints, Seventh Int. Conf. on Atmospheric Electricity, AMS, Albany, 317-324.

[6] Lyons, W.A., and R.B. Bent, 1983: Evaluation of the Time-of-Arrival (TOA) Technique for Real-Time Ground Strike Measurements Using the Lightning Position and Tracking System (LPATS). Preprints, 13th Conf. on Severe Local Storms, AMS, Tulsa, 37-40.

[7] Janssen, M.J.G., "The LPATS 111 System in the Netherlands - Critical Evaluation of the Results" Proc. International Conf. on Lightning and Static Electricity, September, 1989.

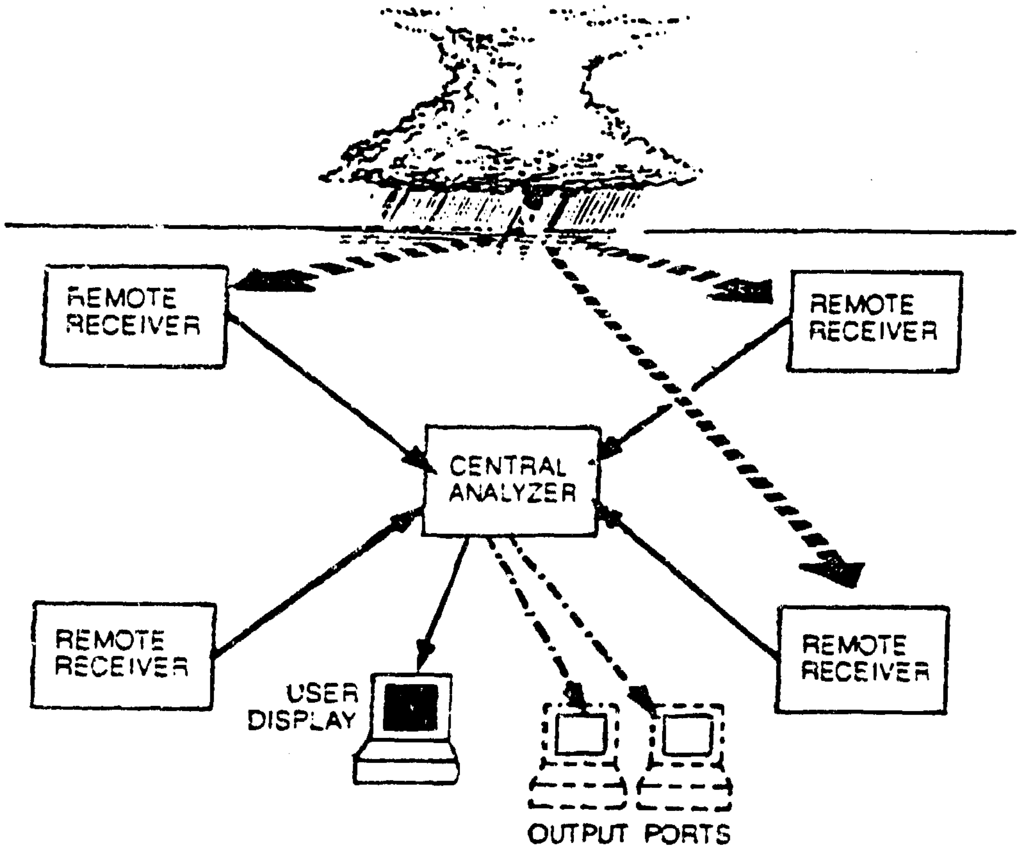


Figure 1

The LPATS system consists of three or four remote receivers that monitor lightning stroke characteristics over a wideband frequency range. Each receiver obtains the data from a small vertical antenna. Waveform analysis is performed in the receiver, and pertinent information is passed over the telephone or microwave links to a central analyzer. The central analyzer then computes the strike location. This information is time tagged and made available to several output ports for communication to a monitor.

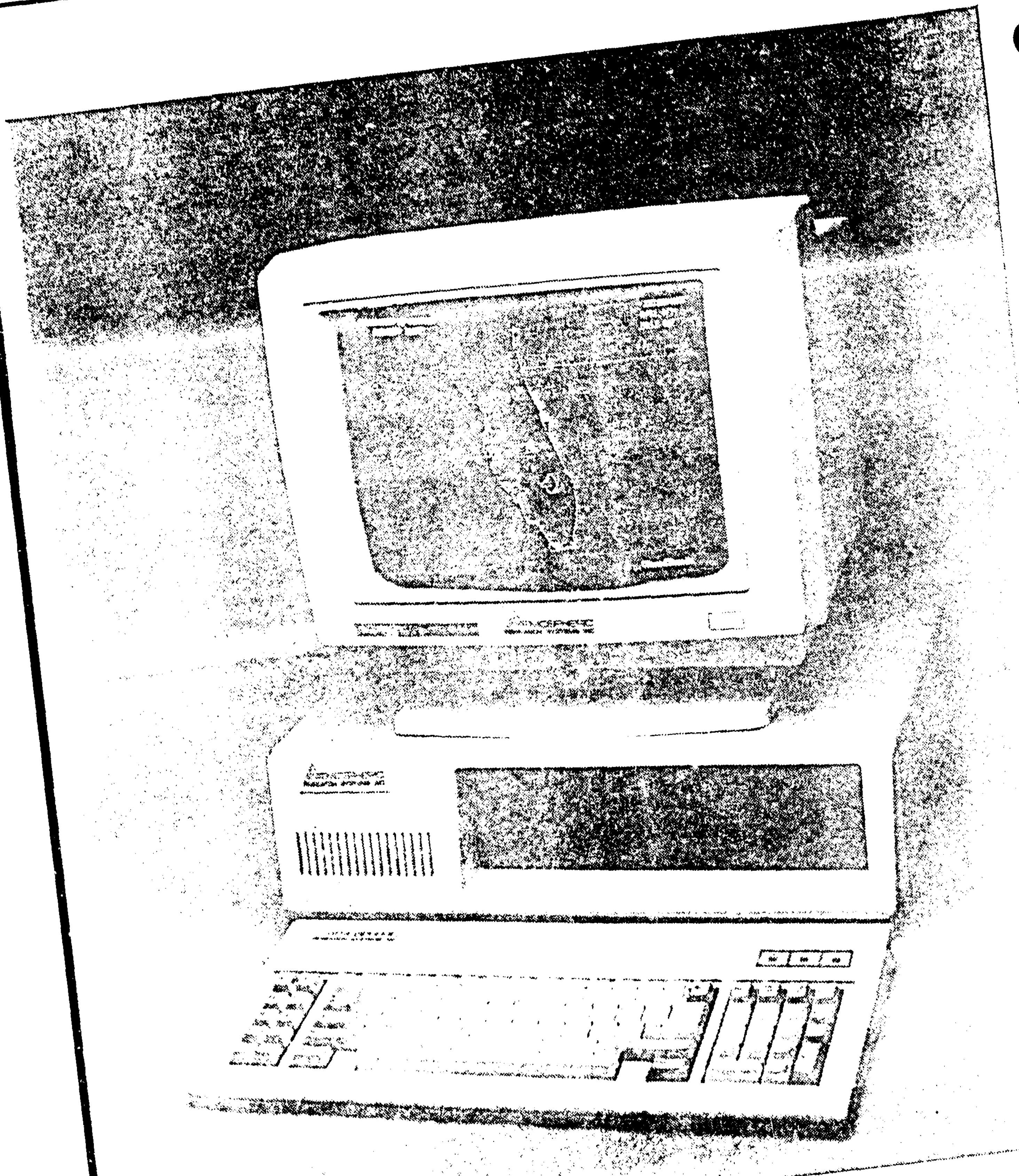


FIGURE 2

VIDEO INFORMATION SYSTEM HARDWARE

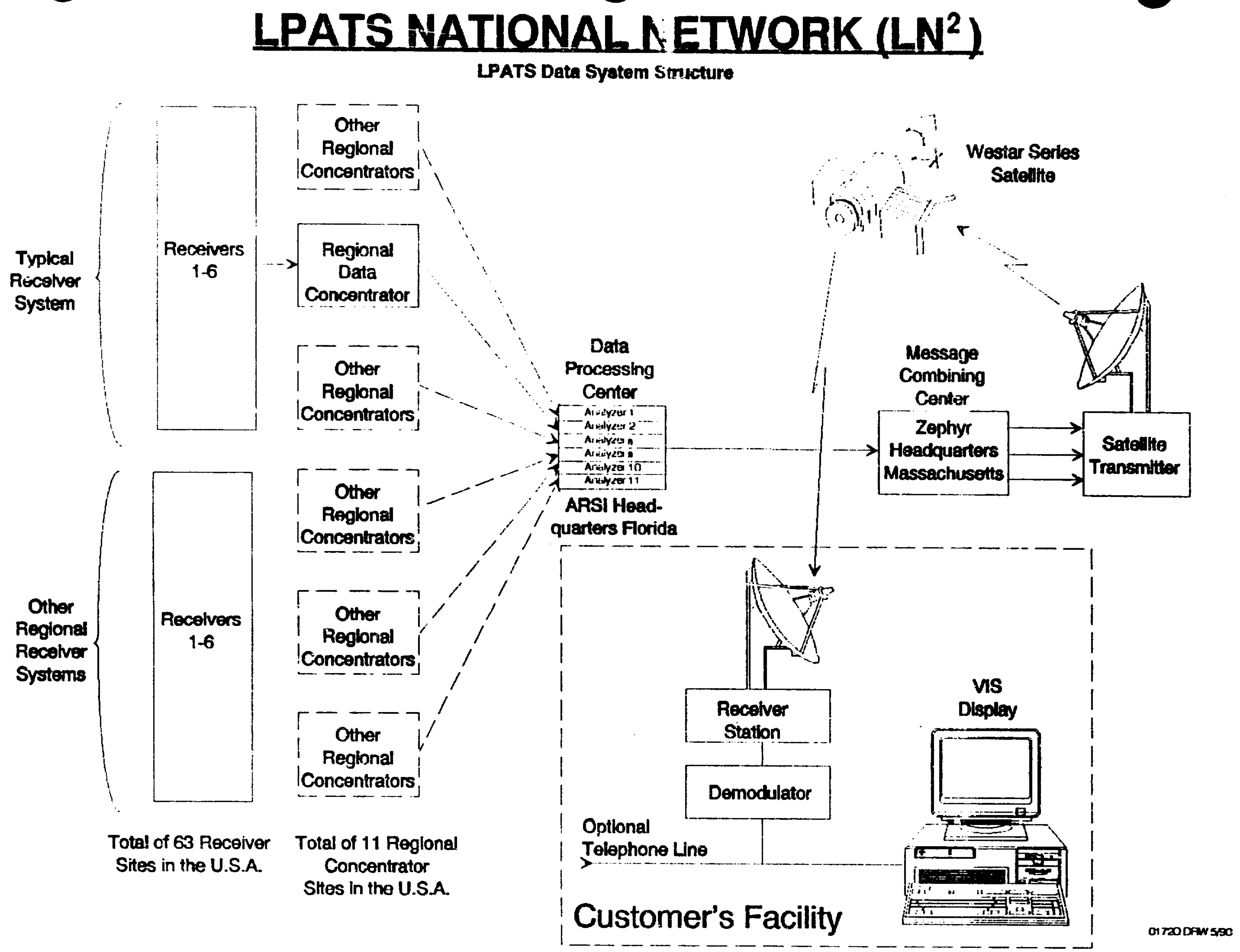
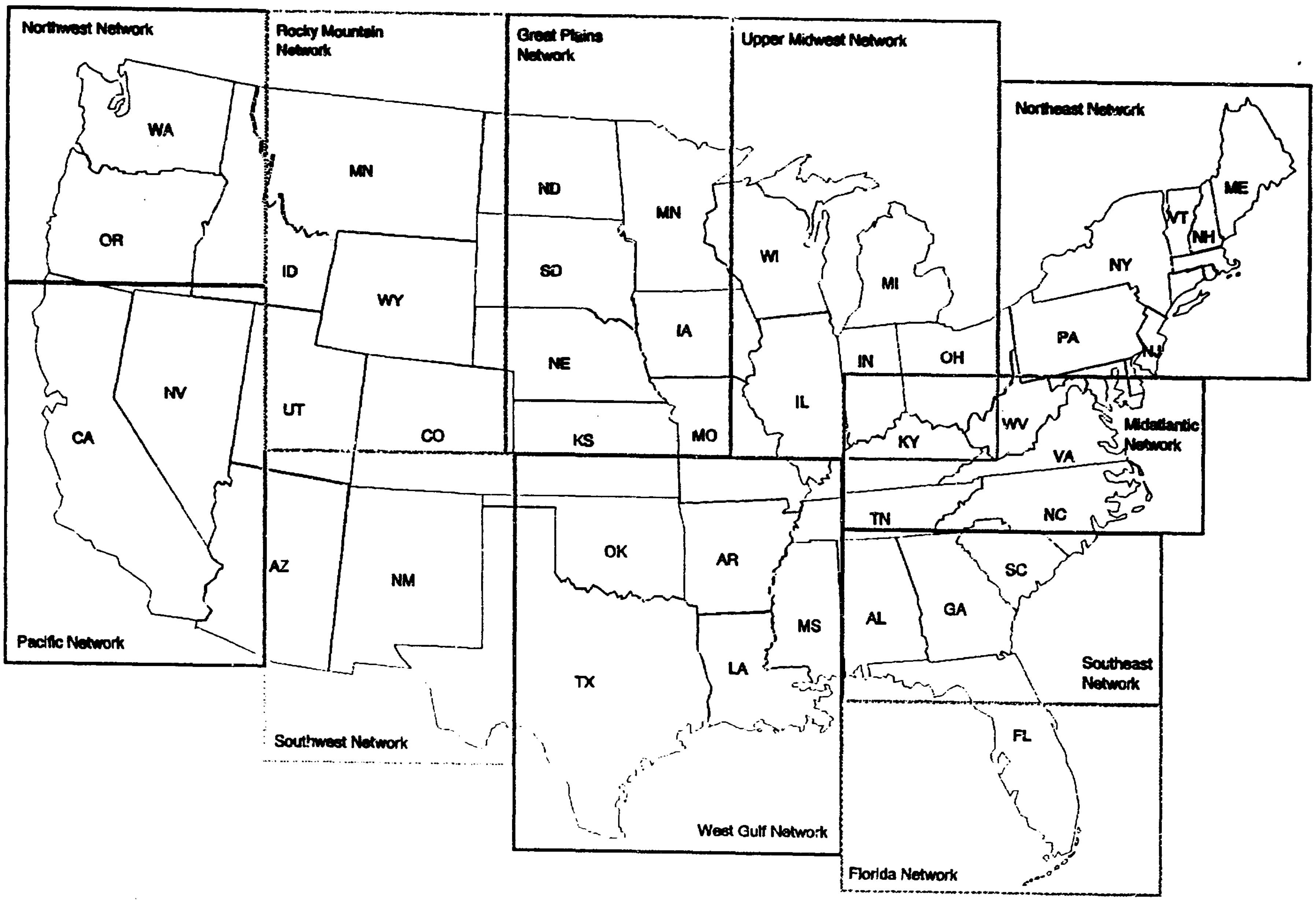

LPATS NATIONAL NETWORK (LN²)
LPATS Data System Structure
Typical Receiver System
Other Regional Receiver Systems
Receivers 1-6
Receivers 1-6
Other Regional Concentrators
Regional Data Concentrator
Other Regional Concentrators
Other Regional Concentrators
Other Regional Concentrators
Other Regional Concentrators
Total of 63 Receiver Sites in the U.S.A.
Total of 11 Regional Concentrator Sites in the U.S.A.
Data Processing Center
Analyzer 1
Analyzer 2
Analyzer 10
Analyzer 11
ARSI Head-quarters Florida
Westar Series Satellite
Message Combining Center
Zephyr Headquarters Massachusetts
Satellite Transmitter
Receiver Station
Demodulator
Optional Telephone Line
VIS Display
Customer's Facility
01720 DRW 5/90

FIGURE 3



LPATS National System: Regions

FIGURE 4

01510 DRW 4/90

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	0	0	0	0	0
0	0	0	0	6	2	0	0	0	0
0	0	0	0	2	5	0	0	0	0
0	0	0	2	0	0	0	0	0	0
0	0	0	0	3	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

4474 4472 4470 4468 4466

1315 1317 1319 1321 1323 1325

FIGURE 5

Recorded strokes in 1988 around a 300 m high TV-transmission tower. The number of strokes in each cell has been given (cell size is 100 m * 100 m).

Florida - 5 Receiver Analysis

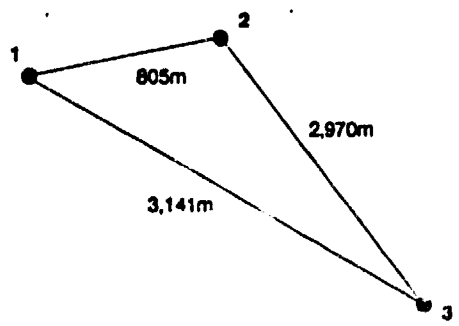
4.31	4.81	5.08	8.23	12.8	9.66	8.31	5.85	3.71	2.48	2.06	1.91	1.88	1.92	2.00	2.13	
2.86	2.89	3.05	3.32	4.93	7.52	8.32	3.49	1.87	1.48	1.34	1.34	1.39	1.48	1.61	1.76	31
2.00	1.86	1.79	1.67	1.90	5.37	4.62	1.33	0.94	0.88	0.90	0.96	1.06	1.17	1.31	1.48	
1.47	1.28	1.12	0.93	0.74	0.62	[illegible]	0.58	0.52	0.57	0.64	0.72	0.83	0.96	1.10	1.27	30
1.16	0.96	0.79	0.64	0.44	0.31	0.26	0.30	0.35	0.41	0.48	0.57	0.68	0.81	0.96	1.13	
0.97	0.79	0.63	0.50	0.35	0.23	0.21	0.23	0.28	0.33	0.40	0.48	0.59	0.72	0.87	1.04	29
0.87	0.76	0.55	0.43	0.32	0.21	0.18	0.19	0.24	0.29	0.35	0.43	0.54	0.67	0.82	1.00	
0.84	0.66	0.52	0.40	0.31	0.19	0.18	0.18	0.21	0.27	0.33	0.41	0.52	0.66	0.82	1.00	28
0.86	0.60	0.53	0.41	0.32	0.20	0.19	0.20	0.23	0.27	0.33	0.42	0.54	0.68	0.85	1.06	
0.93	0.75	0.59	0.46	0.36	0.23	0.19	0.20	0.21	0.28	0.36	0.46	0.60	0.76	0.96	1.18	27
1.06	0.89	0.72	0.58	0.44	0.20	0.22	0.20	0.20	0.24	0.42	0.57	0.74	0.94	1.16	1.40	
1.34	1.14	0.97	0.83	0.66	0.46	0.39	0.21	0.20	0.32	0.64	0.88	1.09	1.31	1.54	1.79	26
1.58	1.39	1.47	1.18	0.91	0.73	0.62	0.41	0.39	0.78	1.40	1.70	1.87	2.09	2.31	2.51	
1.84	1.66	1.51	1.40	1.20	1.03	0.95	0.89	0.39	1.57	2.11	2.39	2.56	2.72	2.93	3.20	25
2.19	2.32	1.90	1.83	1.60	1.47	1.46	1.64	1.75	2.36	3.37	3.40	3.60	3.63	3.76	3.97	

-85 -84 -83 -82 -81 -80 -79 -78 -77

FIGURE 6

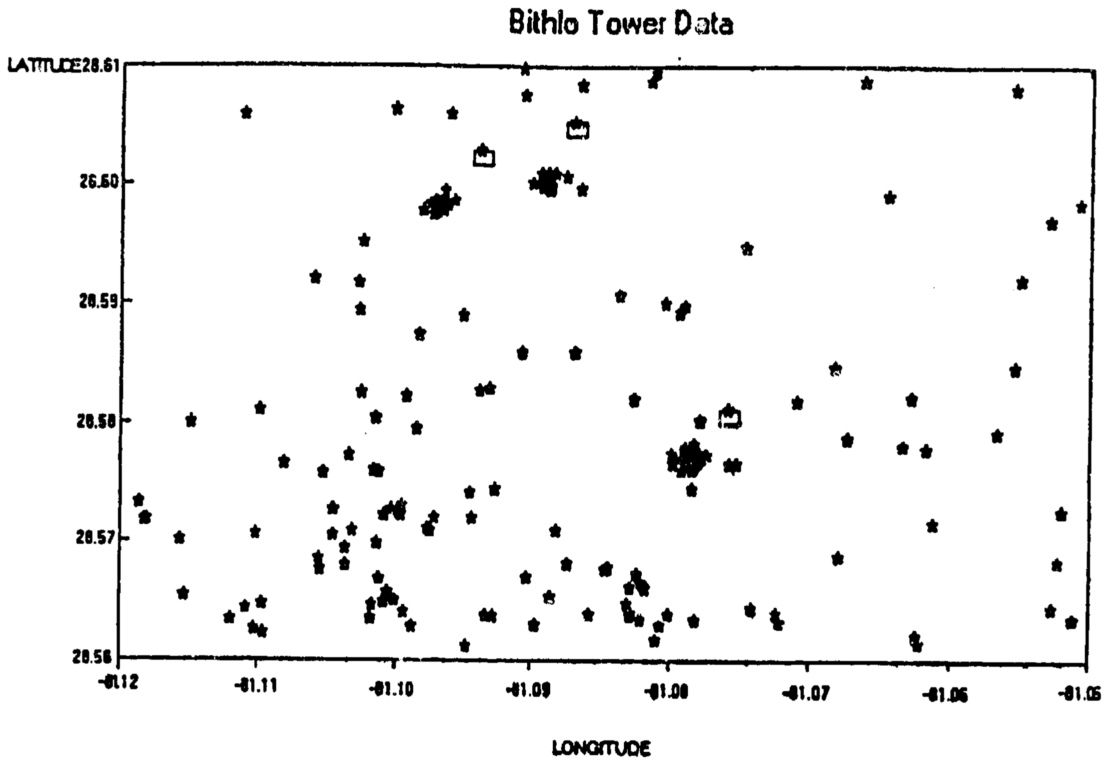
LPATS ACTUAL PERFORMANCE

Lightning Strikes to Three Radio/TV Towers at Bithlo (near Orlando, Florida U.S.A.)



TOWER NO.	LATITUDE	LONGITUDE	HEIGHT
1	28.6022°	81.0937°	1,800 ft. (549m)
2	28.6047°	81.086[illegible]°	1,420 ft. (433m)
3	28.5805°	81.0756°	1,609 ft. (490m)

FIGURE 7



Bithlo Tower Data
LATITUDE
28.61
28.60
28.59
28.58
28.57
28.56
-81.12
-81.11
-81.10
-81.09
-81.08
-81.07
-81.06
-81.05
LONGITUDE

FIGURE 8

LPATS ACCURACY DATA

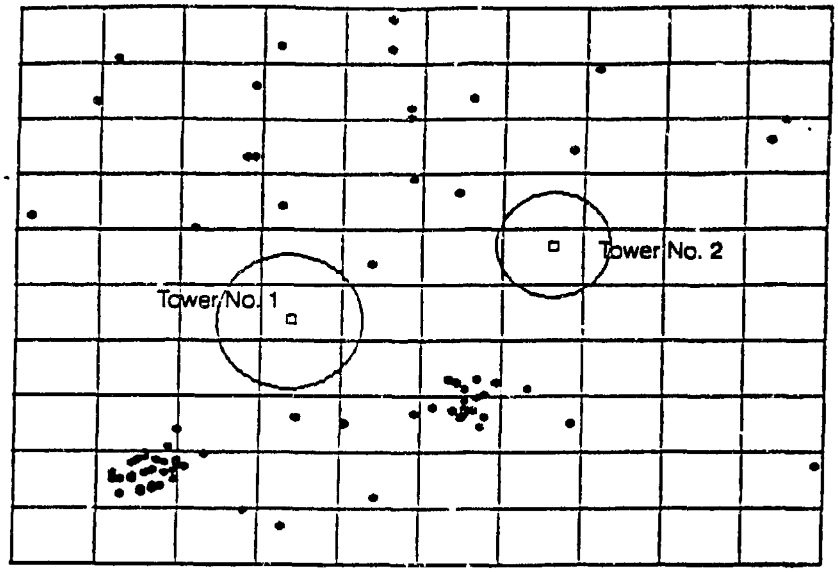


FIGURE 9

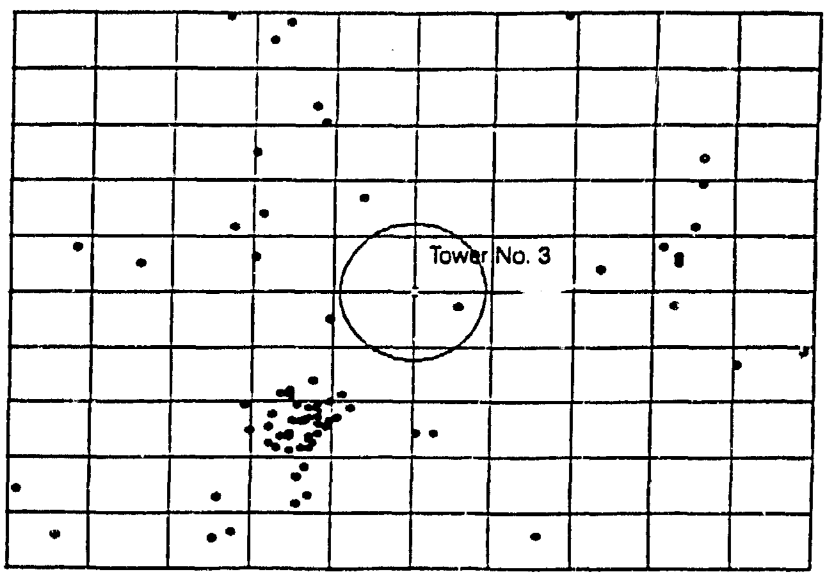
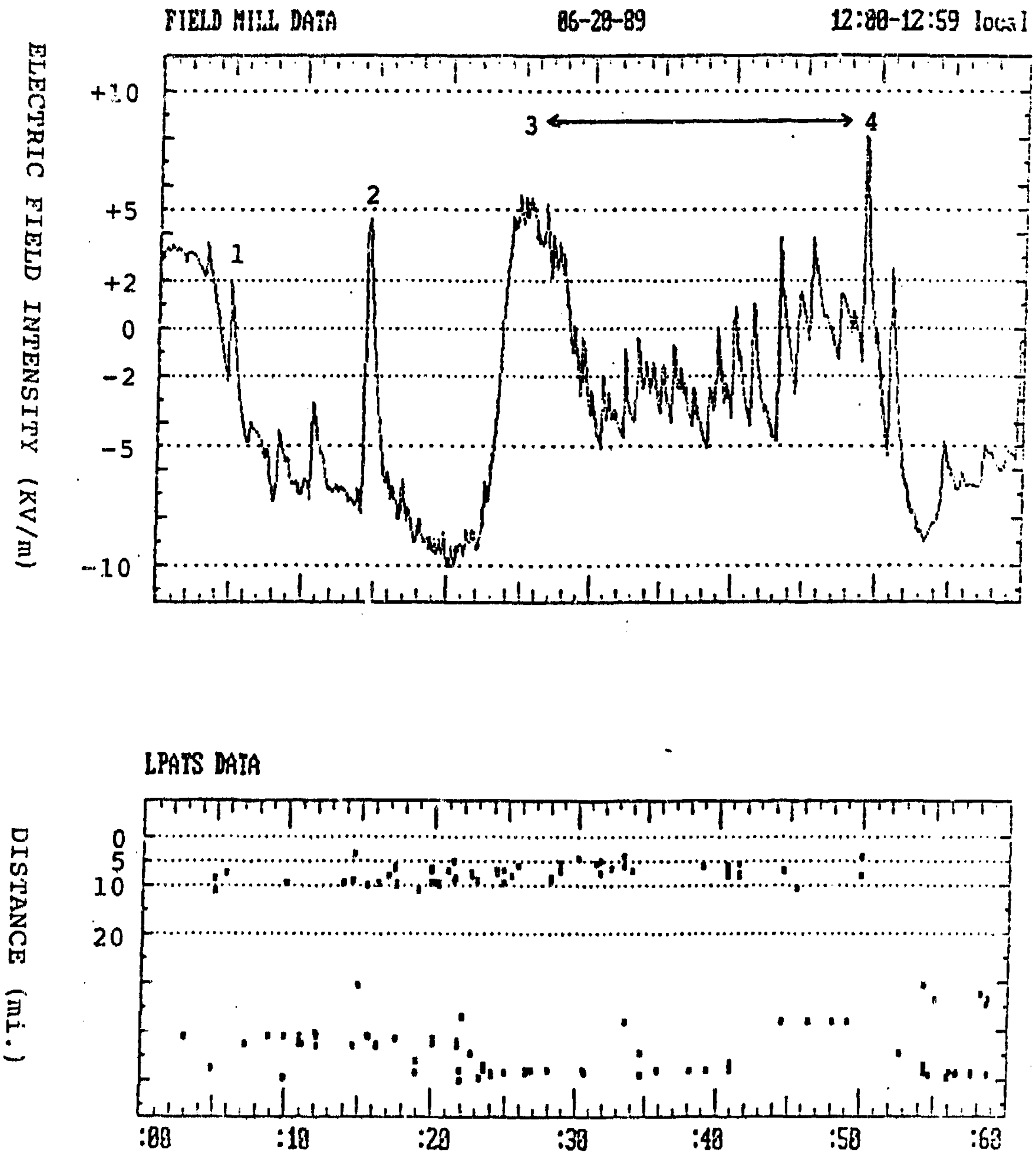


FIGURE 10

Grid size: 2 km x 2 km

Cell size: 200m x 200m

TYPICAL ELECTRIC FIELD MILL DATA
DURING LIGHTNING ACTIVITY



2350 Commerce Park Drive N.E., Palm Bay, Florida 32905 U.S.A.
phone (407) 725-8001 FAX (407) 725-7918 TELEX 755959

FIGURE 11

EVALUATION OF LIGHTNING HAZARDS TO MUNITION STORAGE HANDLING, AND MAINTENANCE FACILITIES WITH THE USE OF ADVANCED METHODS FOR SOLUTIONS OF MAXWELL'S EQUATIONS *

By

Richard S. Collier
Rodney A. Perala

Electro Magnetic Applications, Inc.
12567 W. Cedar Drive, Suite 250
Lakewood, Colorado 80228-2091
(303) 980-0070

ABSTRACT

Munition storage, handling, and maintenance facilities consist of a variety of structures. They include buried rebar re-enforced concrete walled igloos of several types, as well as above ground buildings. One of the safety hazards of concern is the protection of these munitions from the effects of lightning. These structures are electromagnetically complex, because they consist of a variety of inhomogeneous materials (e.g., concrete with rebar) which may be either conducting or partially conducting. In addition, the structures usually have metallic penetrations such as electrical cables or plumbing, as well as a lightning protection system including an earth ground of some type.

The objective of this paper is to describe how the lightning hazards to such structures can be evaluated using advanced formulations of Maxwell's Equations. The method described is the Three Dimensional Finite Difference Time Domain Solution. It can be used to solve for the lightning interaction with such structures in three dimensions and include a considerable amount of detail.

Examples of lightning strikes to buried igloos and above ground buildings will be presented. The physical details which are included in the models are discussed. The results include the voltages and currents induced on conductors which penetrate the facility, as well and the internal electric and magnetic fields. Possibilities for internal arcing are described. These results can then be used to evaluate the possible hazard to materials stored inside. Of special interest is the evaluation of the effectiveness of earth ground systems and how they affect energy penetration to the facility interior.

1.0 INTRODUCTION

Lightning hazards to explosives storage, handling, and maintenance facilities can be described in terms of electric and magnetic fields (and their time derivatives) and the resulting direct

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and induced electrical currents which are found in and around critical locations of the facility during a lightning strike.

The space and time distributions of such fields and currents follow solutions of Maxwells Equations providing that appropriate initial and boundary conditions can be supplied in the regions of interest and that a method of solution can be applied.

This paper describes a numerical computer model which applies Maxwells Equations to describe a specified lightning attachment to a specific building or facility. The result shows how electromagnetic fields and currents are distributed in space and time in and near the facility during the lightning strike.

Examples are given; 1. For an earth covered storage igloo with iron rebar re-enforced concrete walls, and 2. For a rectangular building with cinder-block walls and a metal roof. Both structures have provisions for "lightning protection" in the form of air terminals connected to a ground counterpoise system. It will be shown that fields and currents within these structures can be significantly high during a lightning strike.

2.0 DESCRIPTION OF THE NUMERICAL MODELS

The numerical model of the structure and surrounding environment is based upon a finite difference time domain solution of Maxwell's equations. The solution technique is explicit and accurate to second order in the time and spatial increments, which in these models correspond to the three dimensional cartesian coordinate increments as obtained by Merewether and Fisher [1].

A problem space containing the facility and surrounding environment is divided into rectangular cells. Each cell has a staggered spatial grid, as shown in Figure 1, composed of the vector components of E and H. There are approximately one million cells in the lightning strike problem spaces discussed in this paper. The cell dimensions Δx, Δy and Δz are 12"x6"x6" for the igloo and 6"x12"x12" for the building. The field components in each cell are calculated numerically via the finite difference form of Maxwell's Equations [1].

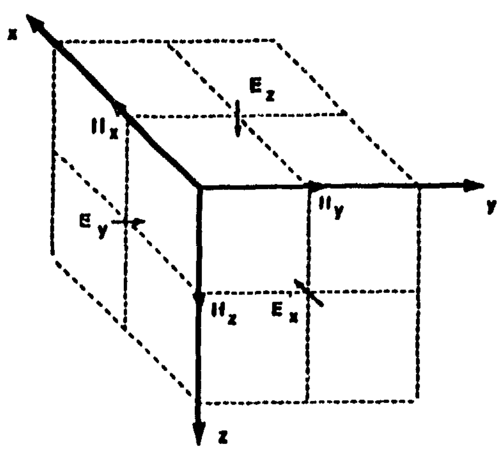

Figure 1 Staggered Spatial Grid

MAXWELL'S EQUATIONS

$$\mu\frac{\partial H}{\partial t} + \nabla \times E = M \quad (1)$$

$$\varepsilon\frac{\partial E}{\partial t} + \sigma E - \nabla \times H = -J \quad (2)$$

$$\nabla \cdot E = \frac{\rho}{\varepsilon} \quad (3)$$

$$\nabla \cdot H = 0 \quad (4)$$

The time step (increment) for this finite difference solution of Maxwell's equations is determined by the Courant criterion, which may be viewed as requiring that the speed of numerical propagation be greater than the fastest physical wave speed, in this case the speed of light in air. Specifically, the Courant condition is:

$$\Delta t \leq \frac{1}{c\sqrt{\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2}}} \tag{5}$$

where Δt is the time step, Δx, Δy, and Δz are the three cartesian spatial increments and c is the speed of light in the air. For the igloo Δt is $.25 \times 10^{-9}$ s and for the building Δt is $.33 \times 10^{-9}$ s. The smallest spatial increments control the time step, but the largest spatial increments determine the bandwidth of the solution. The rule of thumb used is that the upper frequency limit of the solution, f_{max}, is given by

$$f_{max} = \frac{c}{5 \max(\Delta x, \Delta y, \Delta z)} \ . \tag{6}$$

For the igloo and building models discussed here, this corresponds to an f_{max} of a few hundred MHz, which is more than sufficient for the worst case lightning environment scenario.

Maxwell's curl equations (1), (2) form a system of hyperbolic partial differential equations which not only require initial conditions at all spatial locations, but also the boundary values of the electromagnetic field components (or their normal derivatives) at all times to obtain a well posed solution. These values must be supplied at the boundaries of the computational volume by an appropriate termination condition. The boundary condition employed was derived by Mur [2], and is essentially a first order integration along outgoing (with respect to the interior of the computational volume) characteristics. That is, the characteristic direction is chosen to be causal in time and along the outward normal to the bounding surface, which is a two dimensional cartesian coordinate plane. Boundary conditions also must be imposed on metallic surfaces such as the door, interior wall and metal equipment. The boundary condition on metal surfaces at least as large as a cell face is that the tangential electric fields at the surfaces of the metallic objects are set equal to zero each time step. Although this is correct only for perfect electrical conductors, on the time scale of interest, it is an excellent approximation.

If the Maxwell divergence equations (3, 4) are satisfied at the initial time step then the finite difference time development of the curl equations automatically satisfy the divergence equations at each time step. Thus the static solution in the problem space satisfying (3) and (4) is tantamount to specifying the initial conditions for the problem. The simplest initial condition is to set $E = H = \rho = 0$ throughout the problem space. However, physically, a lightning discharge is normally a dynamic release of a static field buildup between the cloud and ground. The building or facility under consideration will usually cause local static field enhancements from the charge buildup between cloud and ground. The air dielectric breakdown will then usually occur at the point of highest electric field, e.g., an air terminal or protrusion of the structure.

Thus it is sometimes necessary to obtain the initial static solution for the facility under high field conditions in order to faithfully track the fields and currents of the resulting lightning strike.

At other times it may be sufficient to realize that under linear conditions and a given lightning current injection waveform, the final solution is the superposition of the initial static solution and a dynamic solution with the initial fields and charge density set to zero. This paper will be primarily concerned with the dynamic part of the solution under zero initial conditions.

In addition to the appropriate boundary and initial conditions, the material properties at each cell location must be specified. This consists of the magnetic permeability, μ, in equation (1); the conductivity, σ, in equation (2) and the dielectric constant, ε, in equations (2) and (3). If the material is homogeneous within the cell (for example, volumes of air, soil, concrete, etc.) then the appropriate values of μ, σ, and ε are included in the time advance equations for the cell in question.

If the material properties are inhomogeneous in each cell (detailed structure, etc.) then a decision must be made on how to represent the properties in each cell. In some cases average properties are sufficient and in other cases they are not. Special considerations are available for treating apertures in metal walls and also for pipes and thin wires (radii much smaller than cell dimensions) which may run throughout the problem space. These pipes and wires can be carriers of high current.

The buildings and facilities of interest usually have a great deal of "thin wire" situations in the form of signal and power lines, rebar in reinforced concrete, pipes, plumbing, metal poles, the lightning protection air terminals, down conductors, counterpoise, etc.

The thin wires and rods are implemented in a self consistent fashion by making use of the telegrapher's transmission line equations. The telegrapher's equations (7), (8) are a one dimensional solution of Maxwell's in terms of currents, I_w, and voltages, V_w, on the wires, which are required to have diameters less than cell size (spatial increment). The per unit length inductances and capacitances are defined (9), (10) with respect to the cell size and the wire diameter, 2a.

One Dimensional Transmission Line Equations:

$$\frac{\partial V_w}{\partial z} = - L_w \frac{\partial I_w(k)}{\partial t} - I_w R_w + Ez(i_w, j_w, k) \tag{7}$$

$$\frac{\partial I_w}{\partial z} = - C_w \frac{\partial V_w}{\partial t} - G_w V_w \tag{8}$$

where L_w and C_w is the in-cell inductance and capacitance of the wire per unit length.

$$L_w = \frac{\mu o}{2\pi} \ell n \left(\frac{\Delta y}{2a}\right) \tag{9}$$

$$C_w = \frac{2\pi a \varepsilon E_r(a)}{V_w} = \frac{2\pi\varepsilon}{\ell n \left(\frac{\Delta y}{2a}\right)} \tag{10}$$

G_w is the in-cell conductance from the wire to the surrounding conductive medium

$$G_W = \frac{\sigma}{\epsilon} C_W \tag{11}$$

The wire resistance per unit length, R_w, is obtained by considering the surface conduction of the metal in question using the skin depth obtained for a frequency of 1 MHz. The resistance for pipes, wire, iron rebar, etc., is normally on the order of 10^{-3} Ohms/meter. In practice, the major results at early time seem to be relatively insensitive to variations of the resistance.

In the computer code, the wires and pipes are embedded into the staggered grid and are driven by the electric field component (see equation (7)) calculated by the three dimensional solution of Maxwell's equations. In order to maintain electrical charge conservation, this wire current must also be injected back into the driving electric field component as a source current via Maxwell's Equation (2). At the interconnections, which are voltage nodes, Kirchoff's law is invoked. At locations where the wires are situated in the soil or concrete, the wires are in electrical contact with the soil or concrete with in-cell conductance given by G_w in equation (11). This is also true of the facility ground wire which is in contact with the soil.

Complex networks of thin wires (e.g., concertina or metal rebar mesh embedded in conducting concrete) are included in the model by a vectorized extension of the transmission line formalism. Vectorized average wire currents coincide with the electric field vectors in each cell and a corresponding average inductance and resistance is associated with each wire current vector. Six component tensors exist at the cell corners (nodes) describing the equivalent transmission line voltages, wire capacitance, and conductance to the embedding medium. A 36 component connectivity tensor exists at each node describing the ways that wires are connected at the nodes.

At the boundaries of the problem space, some termination condition must be applied to both the counterpoise extensions and the power and signal lines and metal pipes entering the problem space. The boundary condition is applied at current nodes and is the equivalent of the Mur boundary condition applied to the magnetic fields [2].

3.0 THE LIGHTNING STROKE CURRENT WAVEFORM AND INJECTION

The problem is initiated by imposing a pre-determined lightning wave form from the top edge of the problem space to a specific point on the structure. In a typical computational case described below, the lightning current waveform is characteristic of a 1% stroke of negative lightning. The lightning current, I(t), is given as a function of time by

$$I(t) = 1.1 \times 10^5 \sin^2\left(\frac{\pi t}{10^{-6}}\right) \text{ A}$$

$$0 \leq t \leq .5 \times 10^{-6} \text{s} \tag{12}$$

$$I(t) = 1.1 \times 10^5 \sin^2\left(\frac{t - .5 \times 10^{-6}}{5 \times 10^{-5}}\right) \text{ A}$$

$$.5 \times 10^{-6} < t$$

which has a peak current of 110 kA occurring at .5 µs. The lightning current appears without propagation delays in a line of vertical electric fields (E_z) from the top of the computational volume to the attach point. The lightning current is injected into the electric fields by dividing the current by the cell area whose normal is parallel to the vertical direction. This becomes the source current density, J, in Maxwell's equation (2). A number of different parameters are studied: lightning stroke attachment location, soil electrical conductivity, structure wall rebar composition, and power box attachment at the walls and ceiling. These parameters are varied in order to provide environments based upon the range of situations which could be encountered.

The computer model contains features of interest such as, soil, concrete, rebar, counterpoise, etc., which are included in the computer model in a modular form. These separate features may be included or excluded from the model by calling subroutines specific to the features desired. The computations are performed on a CRAY II computer. Typical run times are 1 hour of computer time for each microsecond of real time.

4.0 LIGHTNING STRIKE MODELS

The analysis of the preceding sections has been applied to two structures: (1) an earth covered storage igloo with iron rebar reinforced concrete walls as shown in Figure 2 and, (2) a rectangular constructed building with a metal roof as shown in Figure 3.

The igloo interior is completely surrounded with either metal or iron rebar which forms a "leaky" electromagnetic shield for the interior. A schematic drawing of the igloo vertical mid-cross-section is shown in Figure 4.

The building is made of concrete block outer walls with no rebar, a metal roof, and concrete with rebar floor and inner walls with rebar. Thus the building cannot be considered as having a contiguous shielding effect.

For both models the numerical computer output from a simulated lightning strike may be categorized as follows:

1. Contour Plots - These are "snapshots in time" of the electric and magnetic field structures on a plane cross-section of the building at some time after the initiation of the strike.

2. Time Dependent Plots - these are time dependent graphs of electric and magnetic fields at selected points in the problem space. Currents and voltages on thin wires and rods also have time dependent plots at selected points.

3. Current Arrays - These are spreadsheet tabulations of wire currents in specific areas of the building.

4. Field Maxima - These are computer searches at selected times to find the maximum electric and magnetic fields and the maximum time derivative of the magnetic field within a specified boundary inside the building.

Figure 5 shows a contour plot of the vertical mid-plane longitudinal cross-section of the igloo corresponding to the schematic in Figure 4. The electric field pattern outlines some of the prominent features of the igloo, i.e., the z-cage, soil berm over the igloo, headwall, backwall, etc.

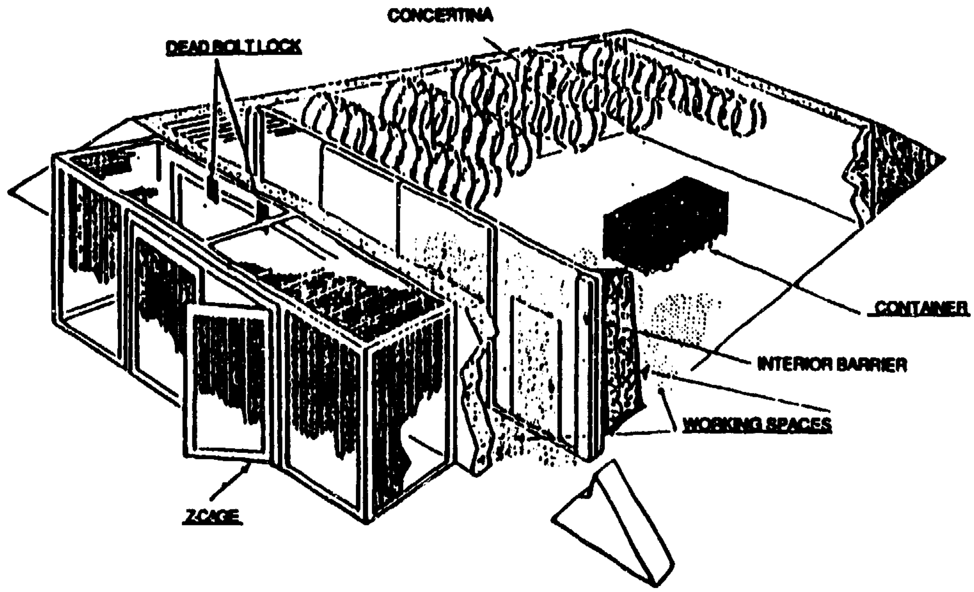

Figure 2 Earth Covered Storage Igloo -- Lightning Strike Model

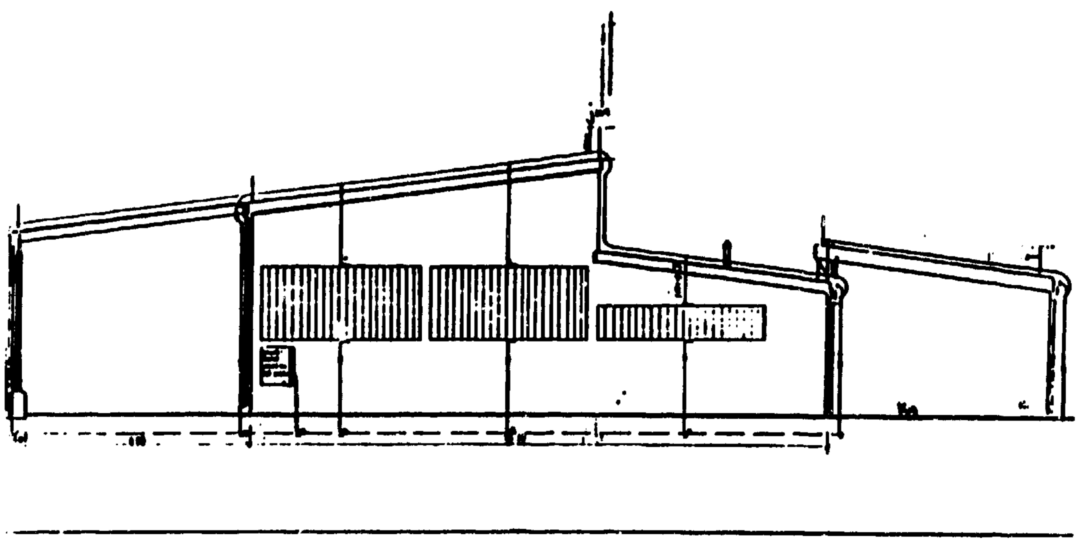

Figure 3 Building - Right Side View With Window Screens and Lightning Protection System

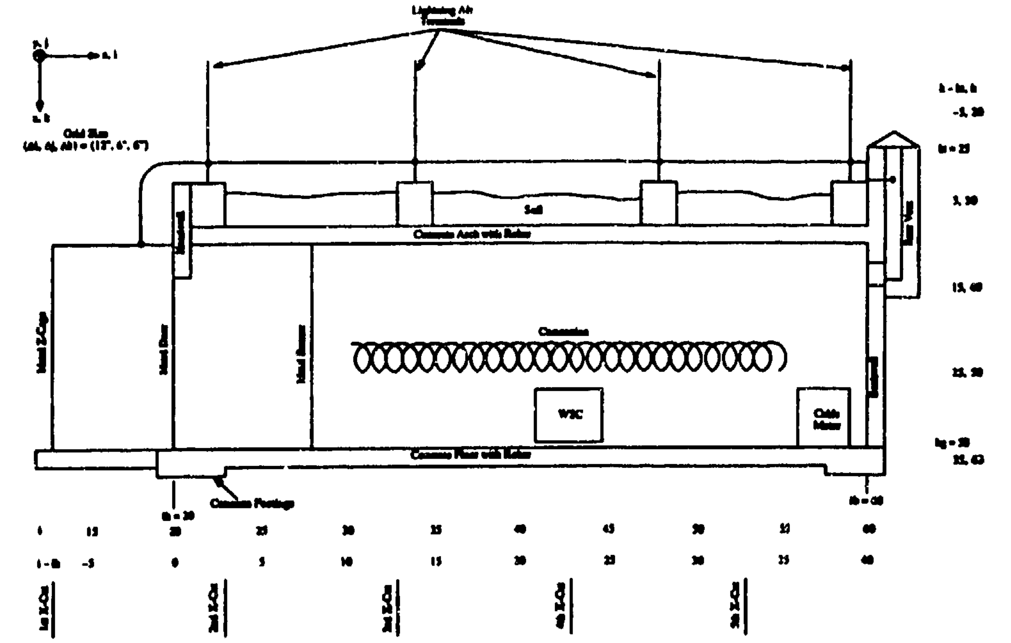

Figure 4 Igloo Vertical Cross-Section at j = jm = 75

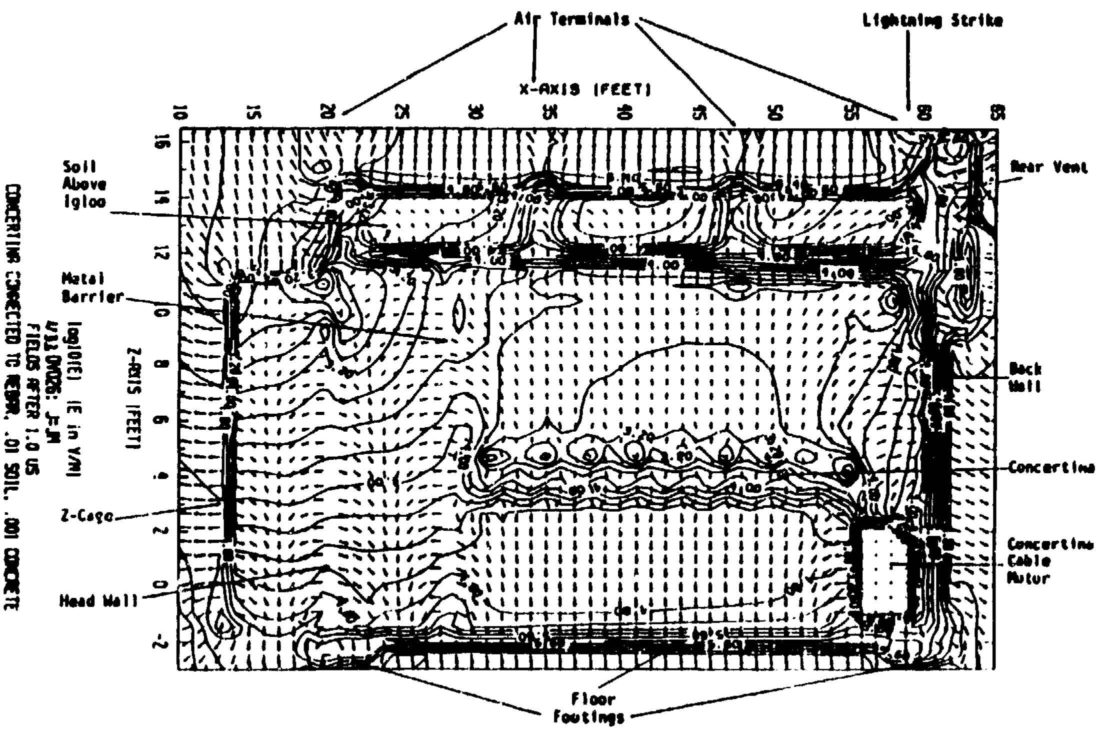

Figure 5 Electric Field Vector and Magnitude Contour Plot for Vertical Mid-Cross-Section of Igloo

The vectors show the projection of the electric field vector at each cell onto the mid-plane at a time 1 μsec after the initiation of the strike. The length of the vector is proportional to the logarithm of the electric field. The contour lines show lines of equal electric field magnitude labeled as powers of 10 of the field magnitude in volts per meter. For example, the line labeled 4.0 represents field magnitudes of 10,000 volts/meter.

Figure 6 shows a contour plot on a vertical x-z plane of the building cutting through wire mesh on the window nearest the strike. The view is as if looking from the back of the building. The field patterns show essential geometrical features of the model, i.e., roof, supporting I-beams, outer wall, etc.

The window mesh, a wire grid covering the building windows, is being charged (note E-field vectors pointing away from the mesh) and appears to focus the electric field into the interior of the building. The field levels are very high within the building approaching 1 Megavolt/meter (contours are labeled as powers of 10 of the electric field magnitude).

In this case, Figure 6, the lightning protection system is not connected to the metal roof. At .462 μ seconds the top of the roof is positively charged and the bottom of the roof is negatively charged.

Figure 7 shows the effect of adding an I-beam (perpendicular to the contour plane) with a hanging metal cable hoist. The field at the bottom of the hoist is on the order of a few megavolts/meter and represents a potential for arcing between the hoist and the floor rebar (or any other piece of grounded equipment). In this case the lightning protection system is in contact with the metal roof which is also in contact with the I-beam.

Figure 8 shows time dependent plots, corresponding to Figure 7, of the lightning injection current (given by equations (12)), the electric field and wire voltage in the middle of the window screen, and the voltage between the hoist hook and the floor rebar. This is a case showing that connecting the lightning protection system to the building structure can enhance the hazard inside the building.

5.0 INDUCTIVE AND CAPACITIVE COUPLING TO THE INTERIOR OF THE IGLOO

The construction of the igloo provides that the interior of the igloo is completely surrounded by a "leaky" electromagnetic shield consisting of rebar in conductive concrete and metal doors, walls, etc. If is of interest to examine the character of electromagnetic energy leaking into the igloo interior from the point of view of the model.

Figure 9 shows time dependent plots the lightning injection current waveform at the air terminal and electric field components at a point on the igloo center line near the back wall and ceiling of the igloo. In this case the igloo contains only the internal metal wall. The strong Ex component of the field peaks at .5 μsec and its waveform appears to follow the time derivative of the lightning current injection waveform. This is interpreted to mean that there is an inductive coupling between currents flowing on longitudinal elements of rebar and the interior electromagnetic field.

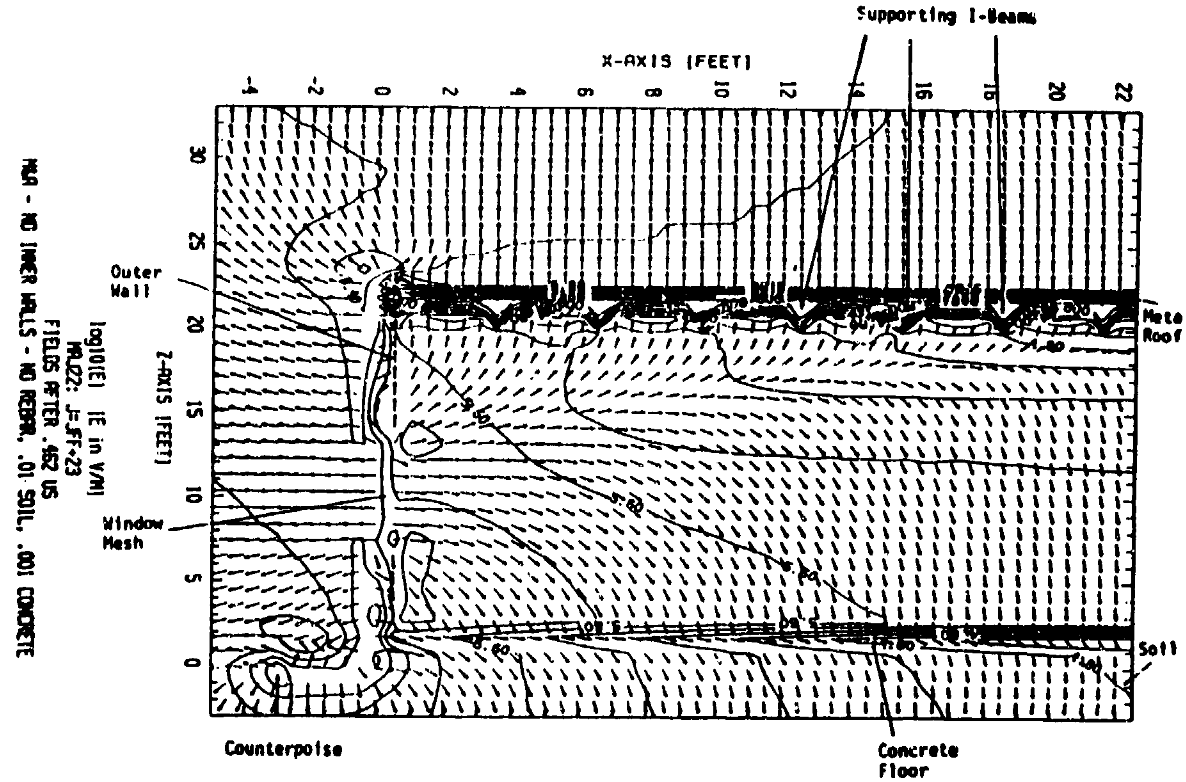

Figure 6 Electric Field Vector and Magnitude Contour Plot for a Vertical Plane Passing Through the Window Mesh of the Building

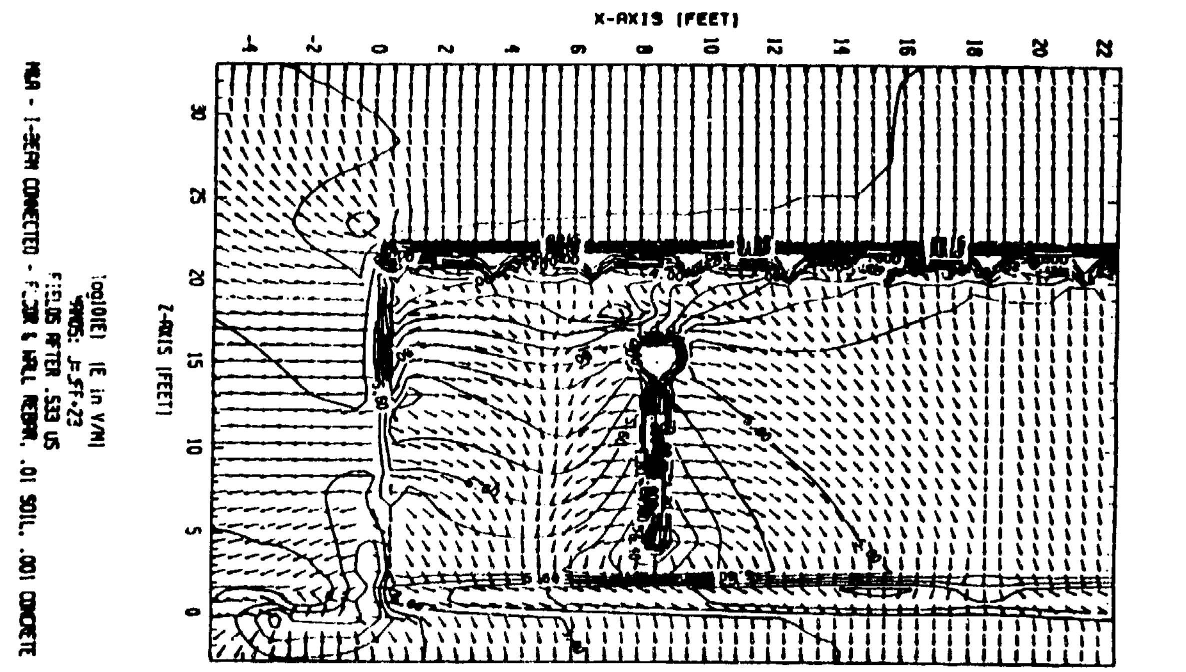

Figure 7 Electric Field Vector and Magnitude Plot for Building Showing the Effect of an Internal I-Beam and Metal Cable Hoist

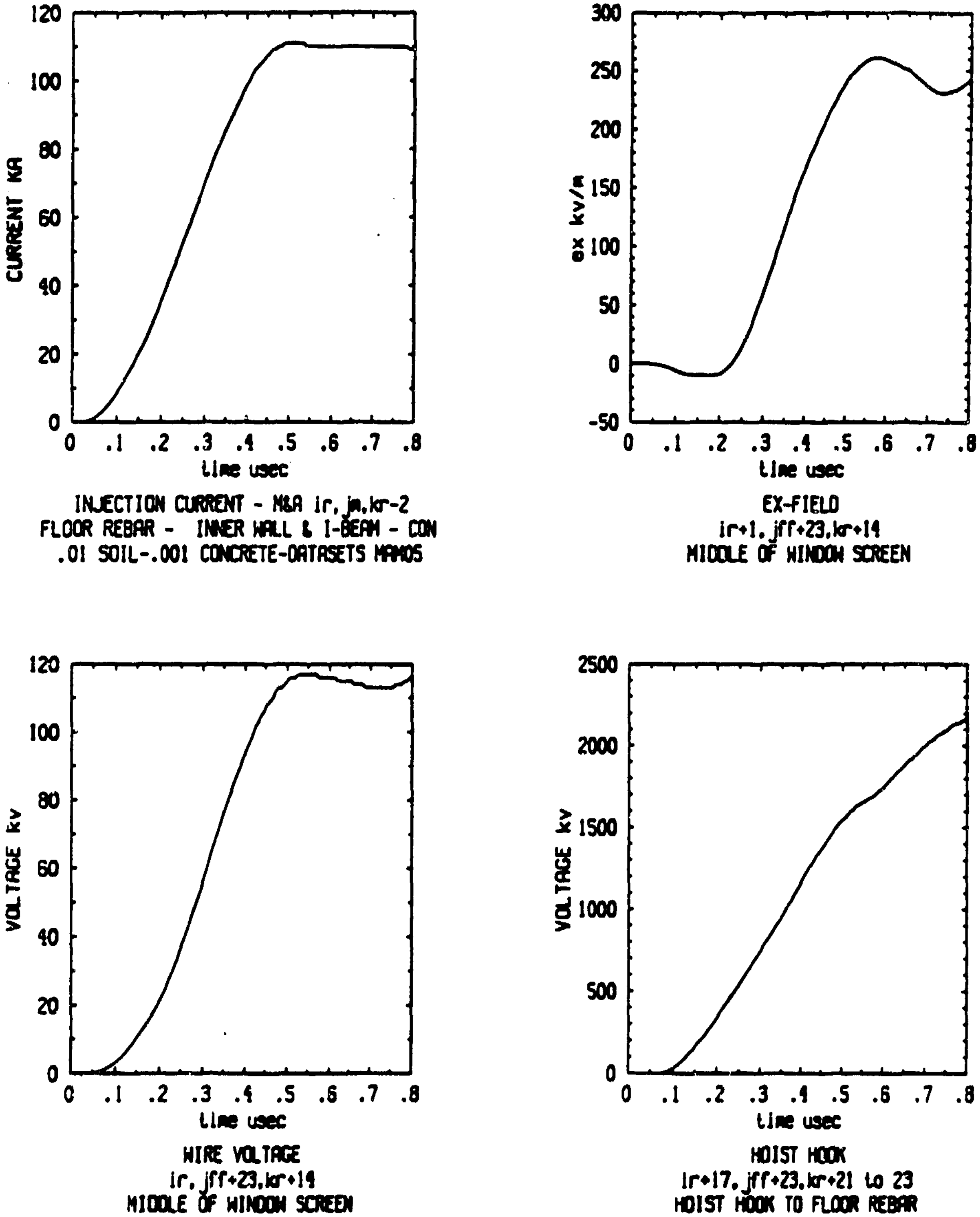

Figure 8 Time Dependent Plots of Building Fields and Lightning Injection Current

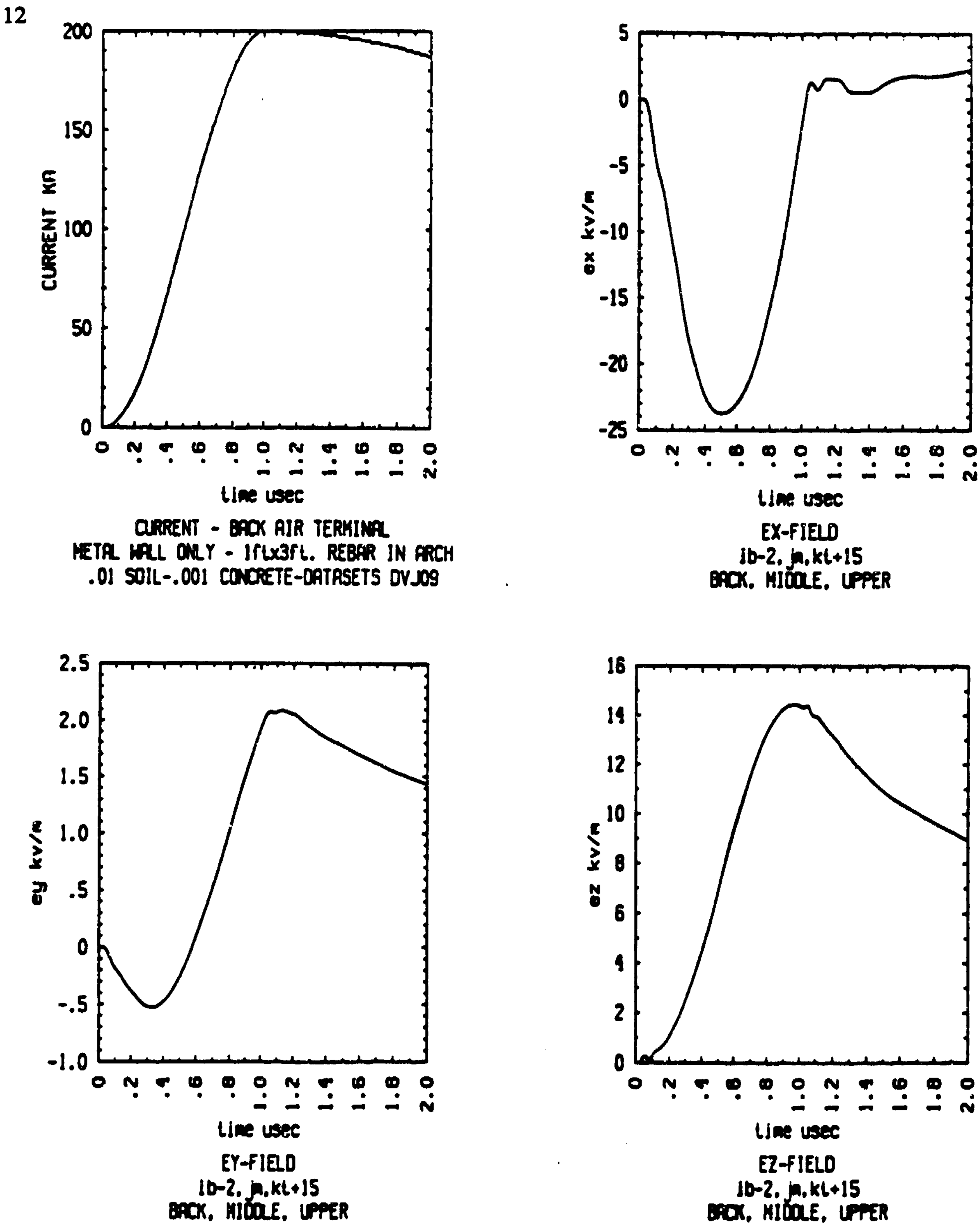

Figure 9 **Time Dependent Plots of Electric Field Components for a Point in the Igloo and the Lightning Injection Current on the Back Air Terminal**

In contrast, the vertical Ez field peaks at 1 μsec and its waveform is similar to the lightning current injection waveform except that it decays more rapidly. This is presumably capacitive coupling due to charge collecting on the rebar which is in contact with the lighting protection system at several different grounding locations. The decay in field strength at late time appears to be due to charge leaking off the rebar onto the counterpoise system and by conduction through the concrete and soil.

The inductive and capacitive coupling is illustrated globally by comparing interior field contour plots at .5 μsec (Figure 10) and 1 μsec (Figure 11). In Figure 10 the Ex component is large throughout much of the interior and at later time (Figure 11) the vertical Ez field dominates.

The charge collecting on the rebar may be noted in Figures 10 and 11 by observing electric field vectors pointing away from the ceiling and back wall in both directions.

It is noted that the largest fields are near the floor in both figures and are on the order of 100 Kvolts/meter at 1 μsec. This is due primarily to capacitive coupling of charge on the rebar which, again, is enhanced by electrical contact between the lightning protection system and the igloo metal structure.

6.0 CONCLUSIONS

A numerical computer model of Maxwell's Equations has been applied to buildings typical of munitions storage and handling structures to calculate potential hazards due to lightning strikes. It is seen that detailed electromagnetic field profiles and currents may be calculated which estimate in a realistic manner the hazardous areas in and around the facility. The possibility of both inductive and capacitive electromagnetic coupling to the interior of the structures has been demonstrated. This coupling can be enhanced by electrical contact between the lightning protection system and the metal structural components of the facility. Hazardous non-linear effects such as electrical arcing and explosive decomposition of building structure (e.g., shrapnel from pieces of exposed wood or concrete) are possible for the calculated examples. These results and techniques may be applied to evaluate potentially hazardous explosive storage and handling situations.

7.0 REFERENCES

1. Merewether, D.E., and R. Fisher, "Finite Difference Solution of Maxwell's Equations for EMP Applications," Electro Magnetic Applications, Inc. Report, EMA-79-R-4, Final Revision, 1/15/82.

2. Mur, G., "Absorbing Boundary Conditions for the Finite Difference Approximation of the Time-Domain Electromagnetic-Field Equations," IEEE Trans. EMC, EMC-23, 4, pp. 377-382, November 1981.

3. Saroja, E., "Betonin Ominaivastus," Voima Valo 32, pp. 84-86, 1963.

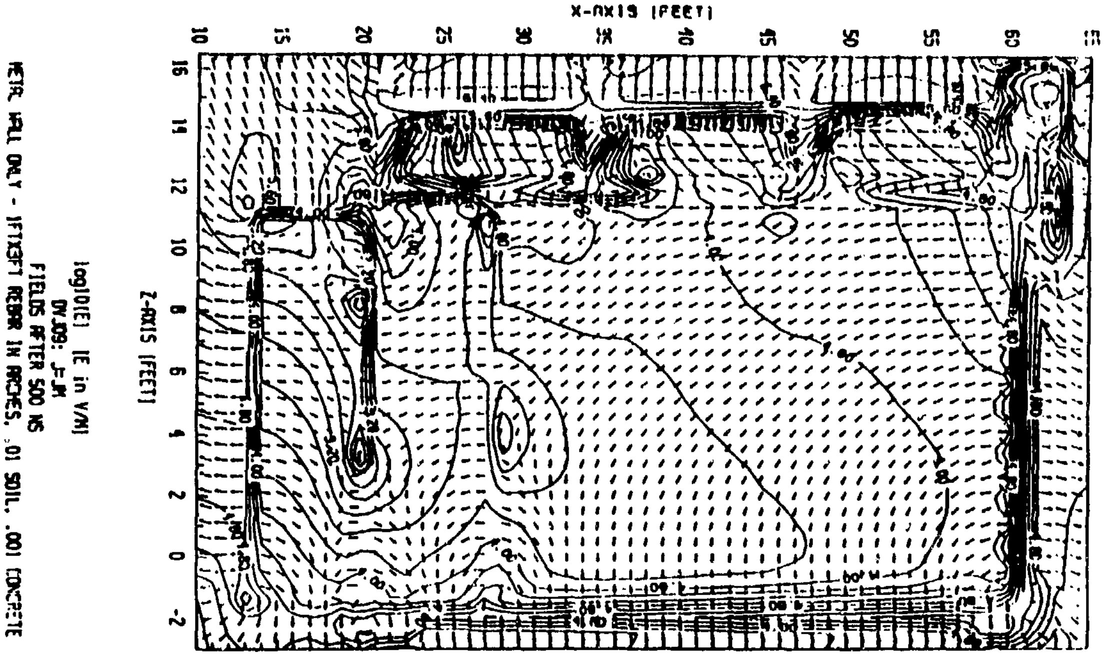

Figure 10 Electric Field Contour in Igloo After .5 μsec

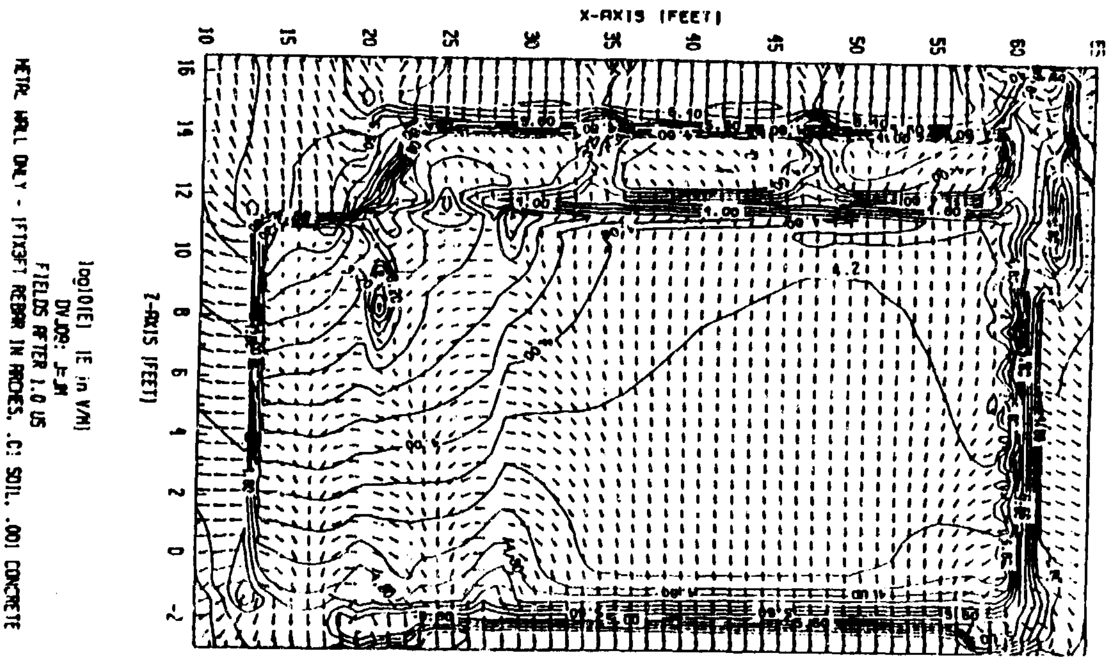

Figure 11 Electric Field Contour in Igloo After 1 μsec

Risk Assessment of an Existing School to the Effects from an LPG Vapor Cloud Explosion

Ray W. Anderson
Agbabian Associates
Pasadena, California

Carl F. Bagge
The Ralph M. Parsons Co.
Pasadena, California

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ABSTRACT

This work had two objectives, the first of which was to assess the risk of injury to humans at an existing school facility from the effects of the accidental explosion of a distant, unconfined LPG vapor cloud. The second objective was to recommend ways of reducing the risk of human injury to acceptable levels. Potential injury from the explosion effects was investigated for the case when the overpressure acts directly to cause injury and for the case where facility failure is the direct cause of injury. The effects of an enhancing atmosphere, such as inversion layer that could trap blast energy near the ground, were considered.

The risks to humans when the explosion effects act directly on persons included ear damage, lung damage, skull fracture and whole-body impacts, skin burns, and eye-retinal burns. The resistance of structural components of the school facility to the blast overpressure were investigated including structural systems, window glass, doors, and upset/failure of building contents. Risk mitigation measures were recommended for strengthening specific structural and nonstructural building component.

1. INTRODUCTION

The primary objective of this study was to assess the risk of injury to humans on the Smith Site School Grounds from the effects of the explosion of a distant, unconfined Liquid Petroleum Gas (LPG) vapor cloud. Potential injury from the explosion effects was investigated for the case when the blast overpressure acts directly to cause injury and for the case where facility structural or nonstructural failure/upset is the direct cause of injury. A second objective was to recommend ways of reducing the risk of human injury.

2. GIVEN EXPLOSION EVENT

Figure 1 is a topographic map that shows the relationship of the Smith Site property with school facilities to the Chevron U.S.A. - managed Gaviota Oil and Gas Plant. The map contours indicate the general features of the terrain. Note the east-west orientation of the coastline and location of the school in close proximity to adjacent California State Highway 101, Southern Pacific railroad tracts and shore line. Figures 2 thru 5 show the intervening terrain and the rise of the nearby coastal mountain range. This area is approximately 30 miles west of the City of Santa Barbara, California.

The source of the given explosion event was taken as the easterly wind translated, unconfined vapor cloud that would be formed by 100% vaporization of the contents of the eastern most 105,000-gal capacity butane vessel. The distance between the center line of this tank and the west edge of the school building is 7700 ft. The unconfined vapor cloud was assumed to be ignited at its eastern most flammable edge, and to detonate, to produce the given explosion event. The explosion source is characterized below based primarily on information published by Arthur D. Little, Inc. (References 1 and 2). Note that two conditions were investigated - one for a vessel 86% full and the other for a vessel 40% full.

Parameter	86%-Full Vessel	40%-Full Vessel
Weight of Butane Vapor, lb (@ SG = 0.6)	450,000	210,000
Downwind Range of Effective Center of Explosion from Butane Vessel, ft	3,000	2,100
Vapor Cloud Dimensions at Time of Explosion, ft	3,000 x 300	2,100 x 300
TNT Explosion Equivalence of Butane Vapor Cloud Explosion, lb of TNT		
Half-Space Release	170,000	79,000
Half-Space Less 15 Deg Release	200,000	92,000

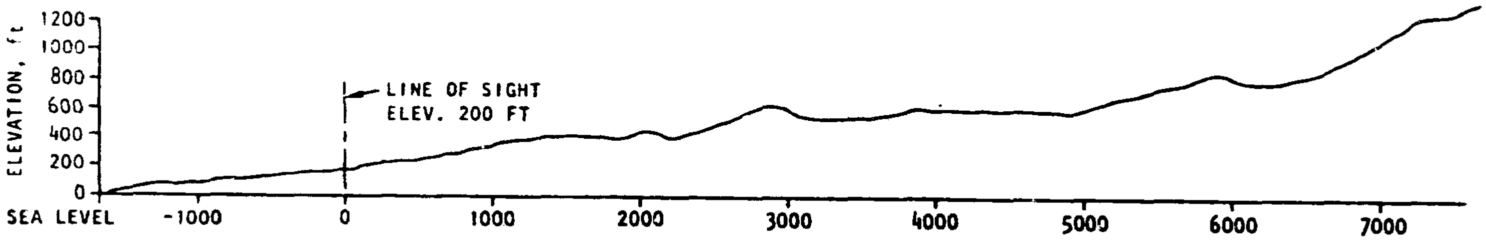


FIGURE 1-3. SECTION B-B 3000 FEET EAST OF LPG VESSEL

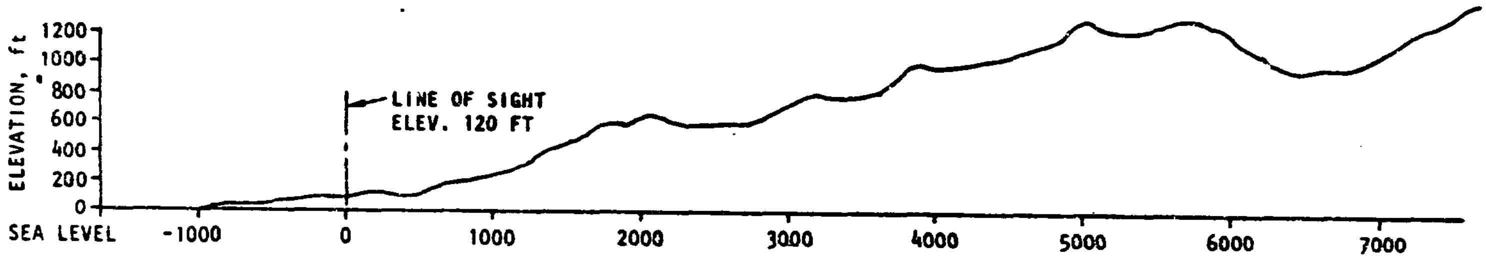


FIGURE 1-4. SECTION C-C 5500 FEET EAST OF LPG VESSEL

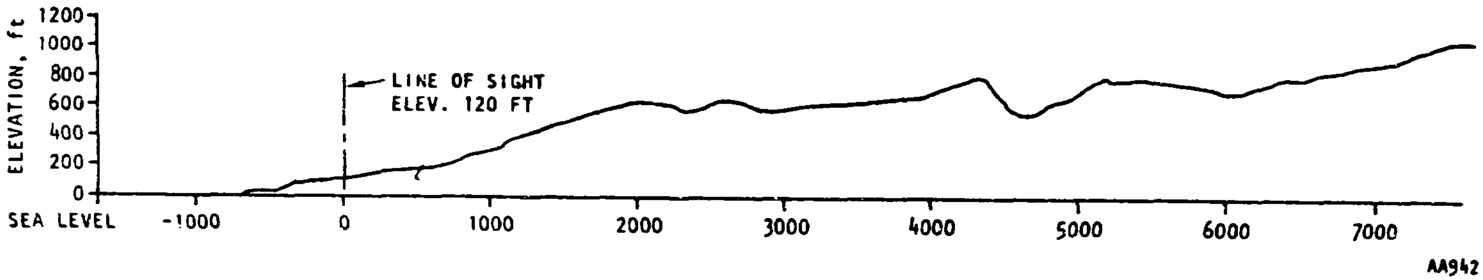


FIGURE 1-5. SECTION D-D AT WEST FACE OF SCHOOL BUILDING ON SMITH SITE

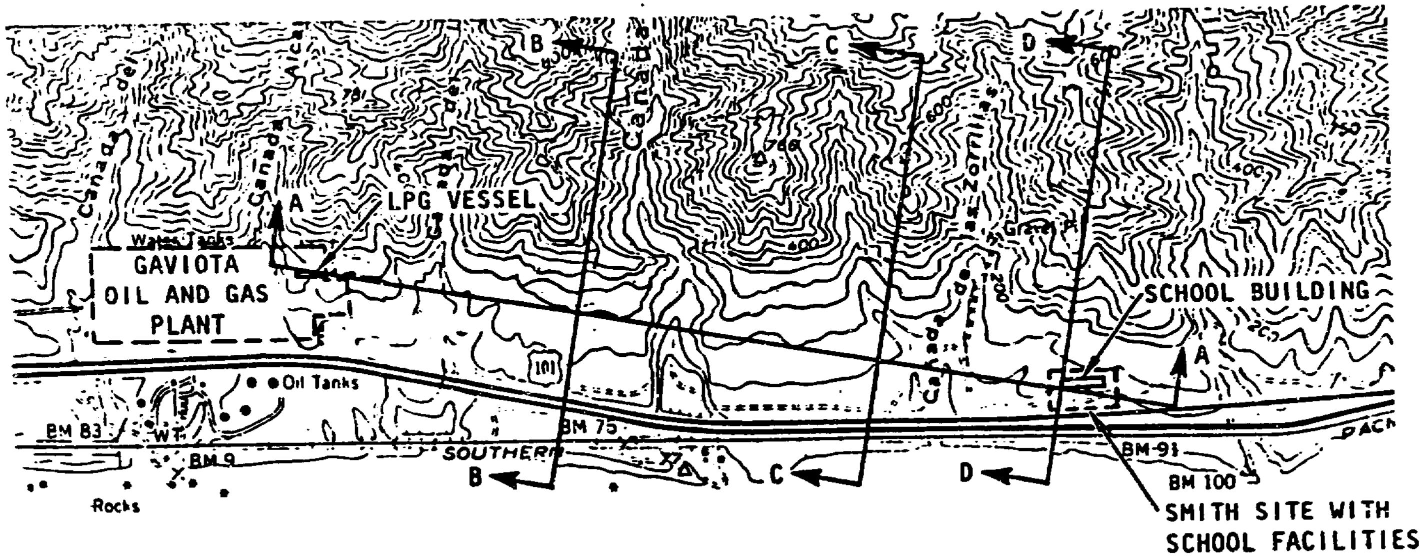


FIGURE 1. TOPOGRAPHIC MAP

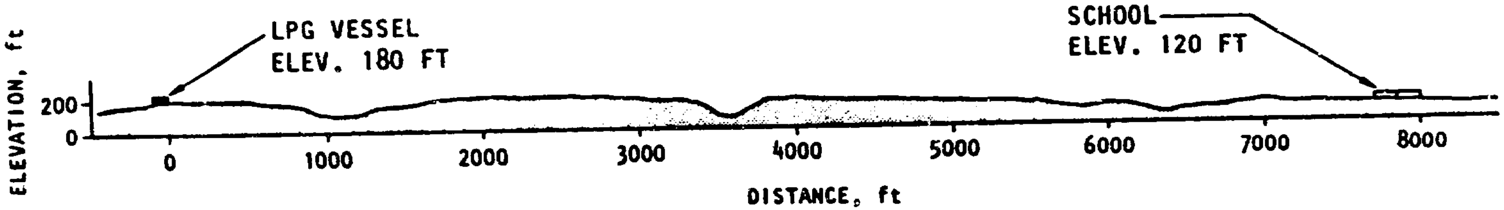


FIGURE 2. SECTION A-A, LINE-OF-SIGHT CROSS SECTION

Two TNT equivalent explosions are given-one for a half-space release of energy, i.e., for flat topography, and the other for a half-space minus 15 deg release of energy. This latter case, which simulates the effects of the approximately 15-deg slope of the nearby costal mountain range has been used as the basis for this study. The effect of the terrain that lies between the explosion source and the Smith Site (See Fig. 2) is expected to have little influence on the attenuation of overpressure. This terrain effect was therefore neglected.

3. SMITH SCHOOL SITE OVERPRESSURE CONTOURS

Figure 6 shows contours of free-field overpressure on the Smith Site for the two vessel ullages defined in the previous paragraph and for two atmospheric conditions. The quoted distances are from the effective center of the explosion (point of ignition). The first overpressure quoted in each set has been calculated for a uniform, or standard, atmosphere. A uniform atmospheric condition is generally assumed when estimating the attenuation of airblast effects with distance. The second overpressure quoted in each set has been calculated for an enhancing atmosphere, which traps blast energy back to the ground, or bends blast energy back to the ground, or both. An invasion layer is the most common example of an enhancing atmosphere - such as the early morning coastal cloud and fog covers common for the school site. Estimates for overpressure for the enhancing atmosphere were made using the upper-bound enhancement factors that are typically used by the DoD to help manage the far-field effects of large explosions in remote areas. The estimates of overpressure for the standard atmosphere were taken from a DoE handbook (See Reference 3).

As shown in Figure 6, the overpressure is more-or-less constant over the site and equal to about 0.4/0.65 psi and 0.25/0.5 psi for the 86% and 40% - full vessel accidents, respectively. Also note that the overpressure difference between the two ullage conditions narrows for the enhancing atmosphere.

The free-field airblast parameters of importance at the range of the west end of the school building are shown below:

Blast Parameter	86% Full	40% Full
Overpressure		
Peak Pressure	0.43/0.67 psi 163/167 db	0.25/0.53 158/165
Impulse	0.065/0.11 psi-sec	0.032/0.068

Duration (positive)	0.31/0.31 sec	0.27/0.27
Dynamic Pressure		
Peak Pressure	0.64/1.6 psf	0.22/0.98
"Wind" Velocity	15/24 mph 23/35 fps	9/19 13/28

These particular values are representative of the entire site, as noted earlier. If nothing else, the peak overpressure presents a tremendously loud noise, as indicated by its 158 to 167 decibel (db) level. The overpressure impulse is the area under the overpressure-time curve out to the time when the overpressure goes negative, which in this case is about three-tenth of a second. The impulse, or equivalently the duration, can be critical to the response of humans and facilities to airblast effects. The dynamic pressure, or the force of the blast winds, is benign for this study. The school structure was designed for a 15-psf pressure, which corresponds to about a 75-mph wind. The air blast arrives at the school site about 3 sec after detonation of the vapor cloud.

4. RISK OF INJURY WHEN EXPLOSION EFFECTS ACT DIRECTLY

Hazard Scenarios

The following hazard scenarios are postulated for the case where the explosion effects act directly on a person to cause injury.

Air Blast

Ear Damage
- Eardrum Rupture
- Temporary Hearing Loss

Lung Damage

Whole-Body Displacement
- Skull Fracture
- Whole-Body Impact

Fireball Thermal Radiation

Burn
- Skin
- Eye

Figure 6.

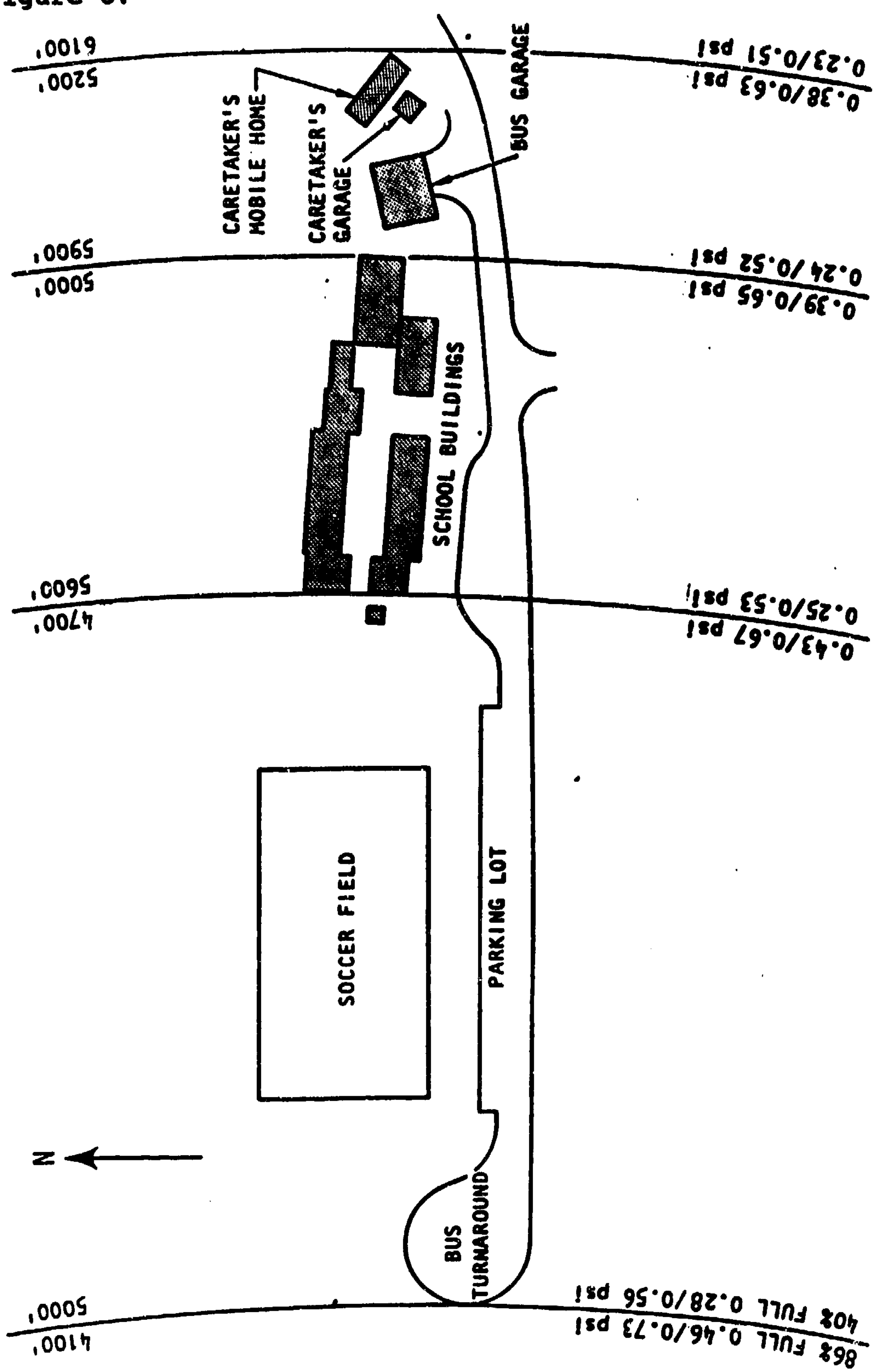


FIGURE 6. SMITH SITE OVERPRESSURE CONTOURS

The hazard of impact of debris and crater ejecta thrown from the explosion source region was not considered. The energy density of the vapor cloud is insufficient to scour the ground under the cloud or to throw the debris of any facilities that may be developed by the cloud to the Smith Site school grounds.

Summary

The risk of injury when the explosion effects act directly on persons located at the Smith Site school grounds are summarized as follows:

(1) There will be no damage to the ear other than a temporary partial hearing loss, which will be restored in a day or two.

(2) There will be no lung damage, no injury from knockdown, no skin burns, and no chorioretinal burns.

This conclusion is applicable for the 86%-full vessel accident and an enhancing atmosphere, and for all lesser threats.

The figures and tolerance data used in this evaluation are taken from Reference 4, a readily available reference on explosion hazards. Each hazard scenario is discussed below.

Ear Damage

Figure 7 shows the dependence of ear damage on the peak pressure and impulse of a fast-rising overpressure. The curve labeled TTS, is the threshold of a temporary loss of hearing. This loss, which is partial, would be reversed within a day or so. The full range of Smith Site overpressures are indicated on the figure as the cross-hatched area. It is seen that the Site overpressures are far too weak to rupture eardrums, but are strong enough to cause a temporary loss of hearing.

The TTS, asymptotic overpressure corresponds to a sound level intensity of about 155 db (By comparison, artillery fire is about 145 db). Since typical building construction attenuates sound levels by at least 20 db, those persons inside the school building and caretaker's trailer will not experience a temporary loss of hearing, provided the doors and windows are closed.

9

Figure 7.

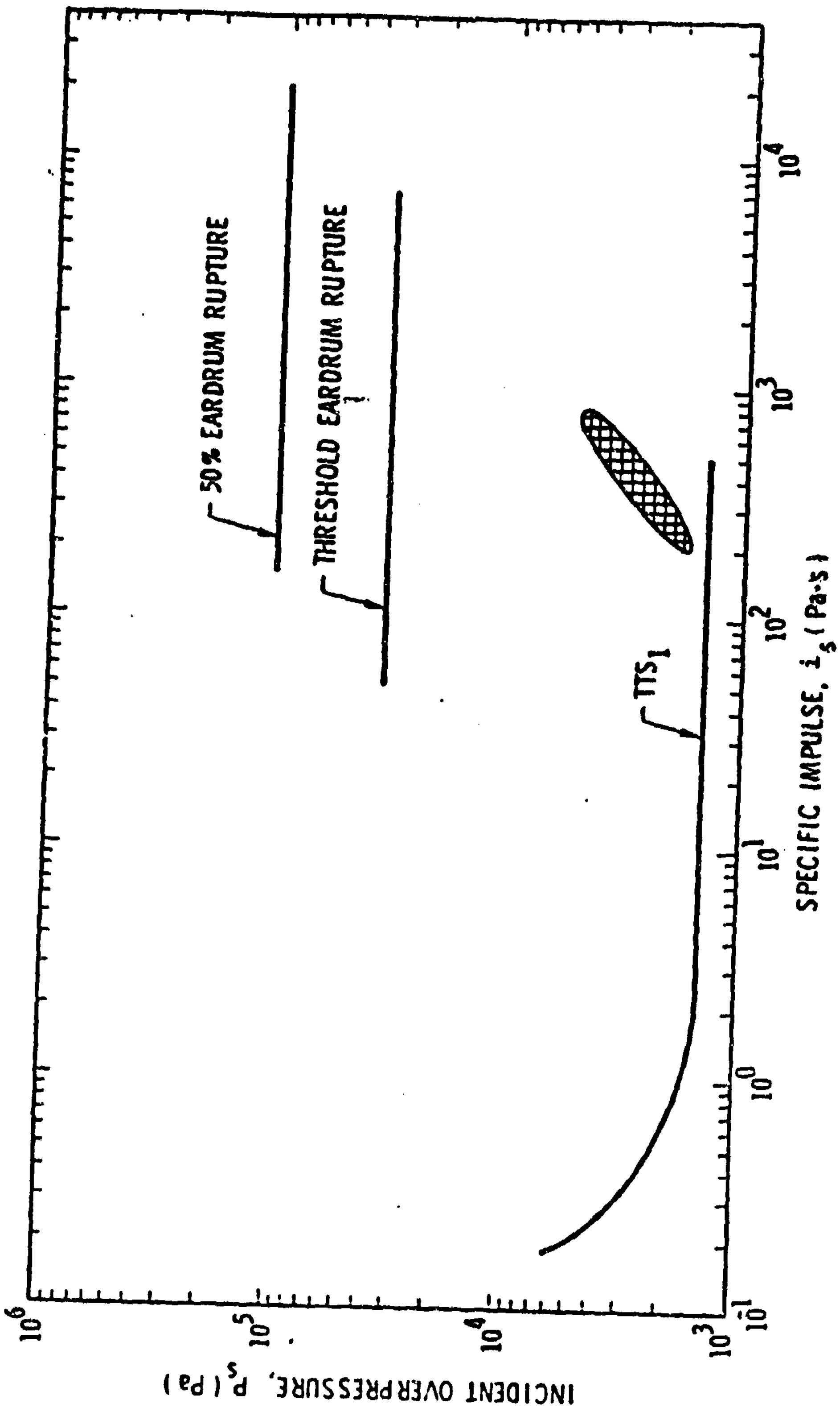


FIGURE 7. HUMAN EAR DAMAGE CURVES FOR BLAST WAVES ARRIVING AT NORMAL ANGLE ON INCIDENCE

Lung Damage

Figure 8 shows lung damage as a function of the peak pressure divided by ambient atmospheric pressure and the impulse of a fast-rising overpressure. The impulse is seen to be divided by the square root of the ambient atmospheric pressure (p_o) and the cube root of the mass of the person (m). The arrow indicates where the interaction of the Smith Site worst-case overpressure and an infant (m = 3 kg) falls (off the plot). Clearly, there will be no lung damage on the Smith Site school grounds.

Skull Fracture and Whole-Body Impacts

A sufficiently strong airblast can knock a person down and even carry them downrange. The attained maximum velocity has been related to impact injury. Shown below are the skull fracture and whole-body impact tolerances that have been derived from primate and cadaver experiments.

Skull Fracture	Related Impact Velocity, m/s	(ft/sec)
Mostly "safe"	3.05	(10)
Threshold	3.96	(13)
50%	5.49	(18)
Near 100%	7.01	(23)

Whole-Body Impact	Related Impact Velocity m/s	(ft/sec)
Mostly "safe"	3.05	(10)
Lethality threshold	6.40	(21)
Lethality 50%	16.46	(54)
Lethality near 100%	42.06	(138)

For purpose of reference, it is noted that an impact velocity of about 5.3 m/s (17fps) results from falling out of an upper bunk, and a whole-body impact velocity of about 27 m/s (88 fps) results from exiting a car traveling 60 mph.

The above data have been used to construct Figure 9. The figure indicates tolerance levels for skull fracture plotted against the peak pressure and impulse of the overpressure. The impulse is divided by the cube root of the mass of the person (m). The lighter the body, the higher the attained velocity and the more likely skull fracture. The full range of the Smith Site overpressure acting on a toddler (m=10kg) is indicated by the cross-hatched oval. It is seen that the Smith Site airblast is far too weak to cause skull fracture. This same conclusion also applies for whole-body impact. The maximum blast-induced velocity

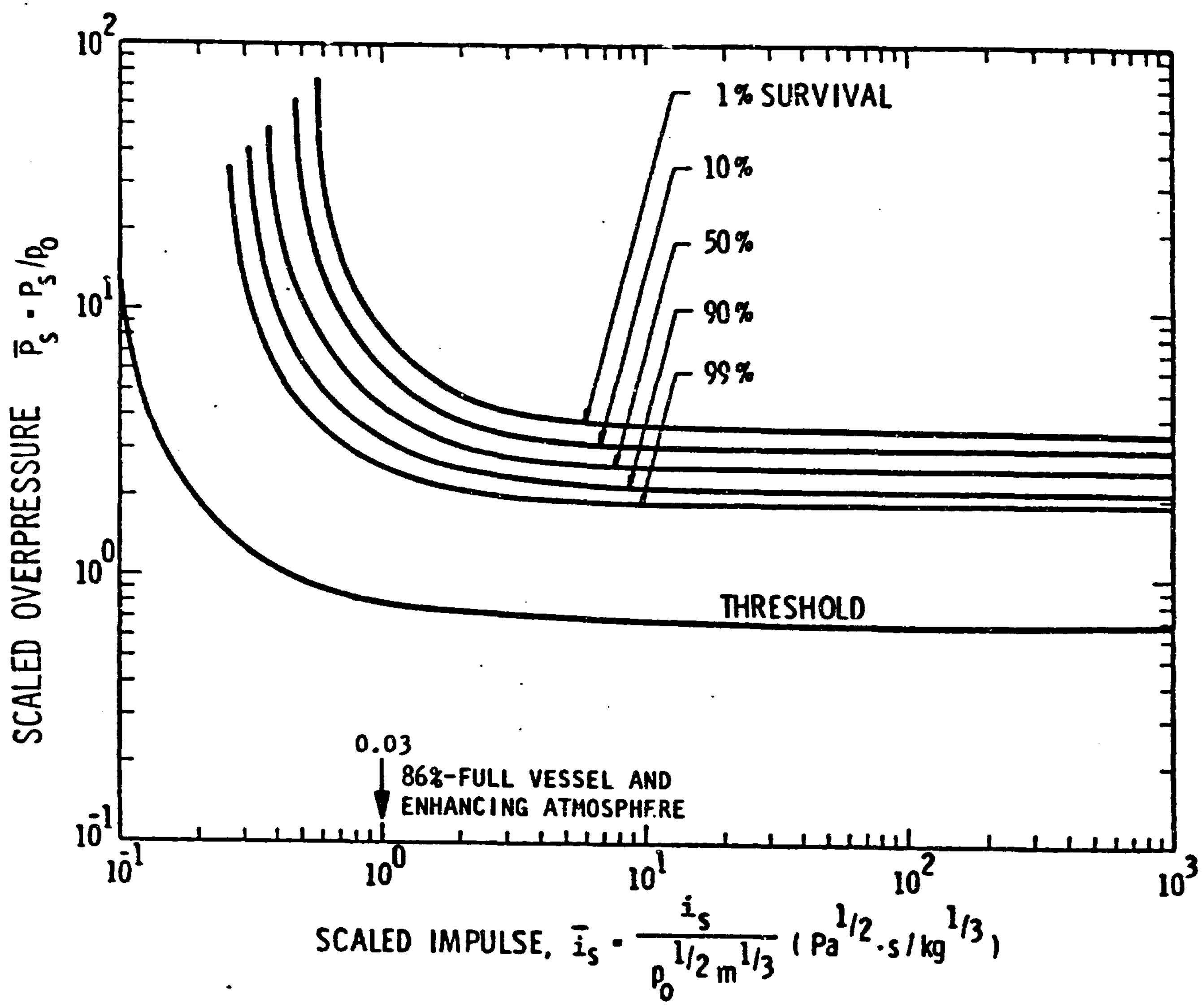


FIGURE 8. SURVIVAL CURVES FOR LUNG DAMAGE TO MAN

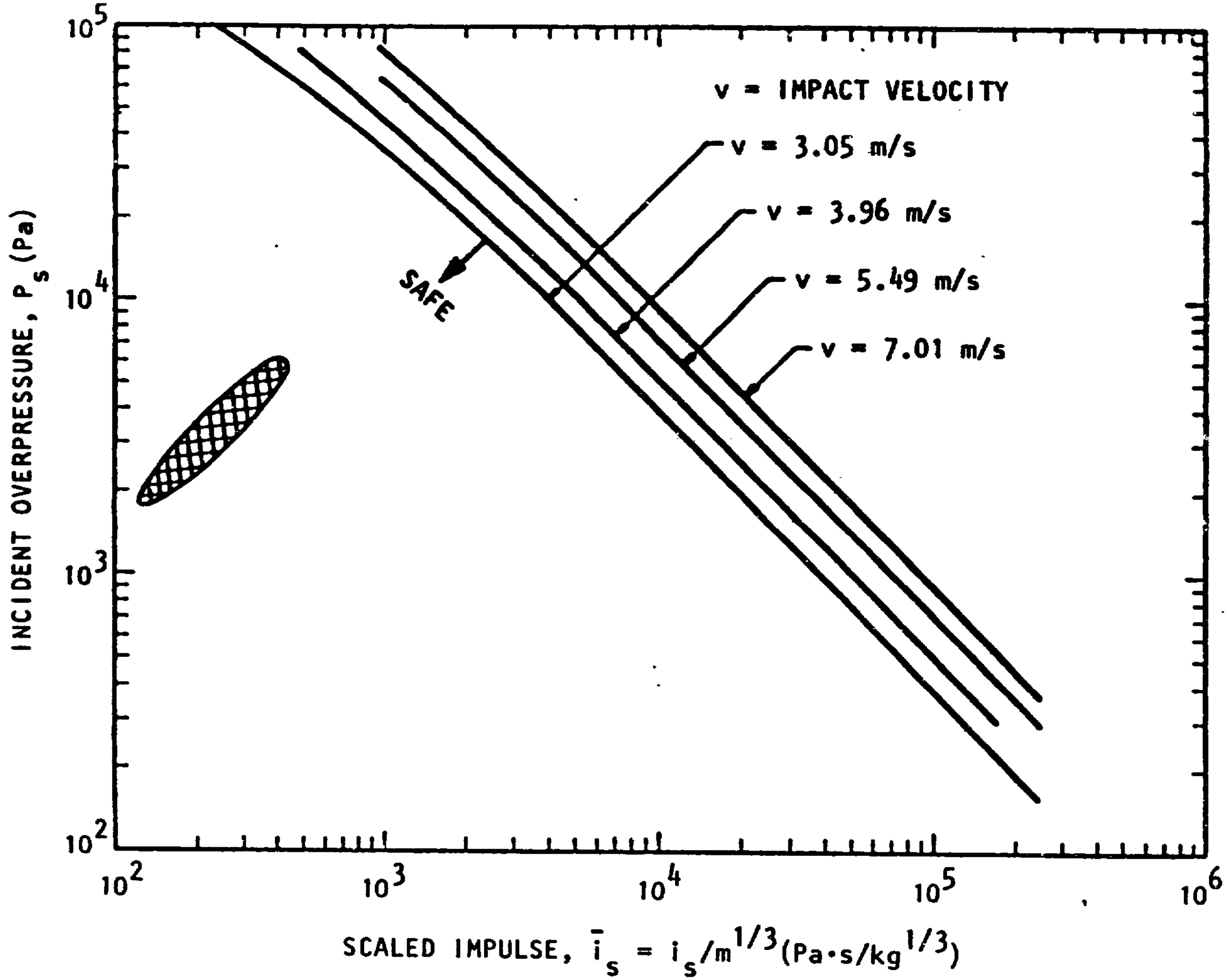


FIGURE 9. SKULL FRACTURE

that a person attains on the Smith Site school grounds is less than about 2 fps.

Skin Burns

Figure 10 shows how much and how fast thermal radiation must be delivered to human skin to cause unbearable pain, i.e., to burn. It is seen from the figure that the thermal radiation falling on the Smith Site school grounds for the 86%-full vessel accident and enhancing atmosphere is so low that it falls off the plot.

Chorioretinal Burn

As shown in Figure 11, the thermal radiation delivered to the Smith Site school ground is too low to cause chorioretinal damage, even to the indicated wide-eyed observer of the entire fireball burn. For an explanation of the derivations of geometrical image diameter and Foveal threshold for chorioretinal burns, Reference 4 should be consulted.

5. RISK OF INJURY WHEN EXPLOSION EFFECTS ACT INDIRECTLY

Hazard Scenarios

The following hazard scenarios are postulated for the case where the explosion effects act indirectly to cause injury through structural failure of the facilities or by failure/upset of equipment or nonstructural components.

Air Blast

Facility Structural Failure
- Impact
- Fire

Facility and Vehicle Window Glass Breakage
- Impact / Penetration

Facility Door Failure
- Impact

Facility Contents and Nonstructural Systems Failure/Upset
- Impact
- Fire
- Chemical Spill

Appurtenance Failure
- Impact

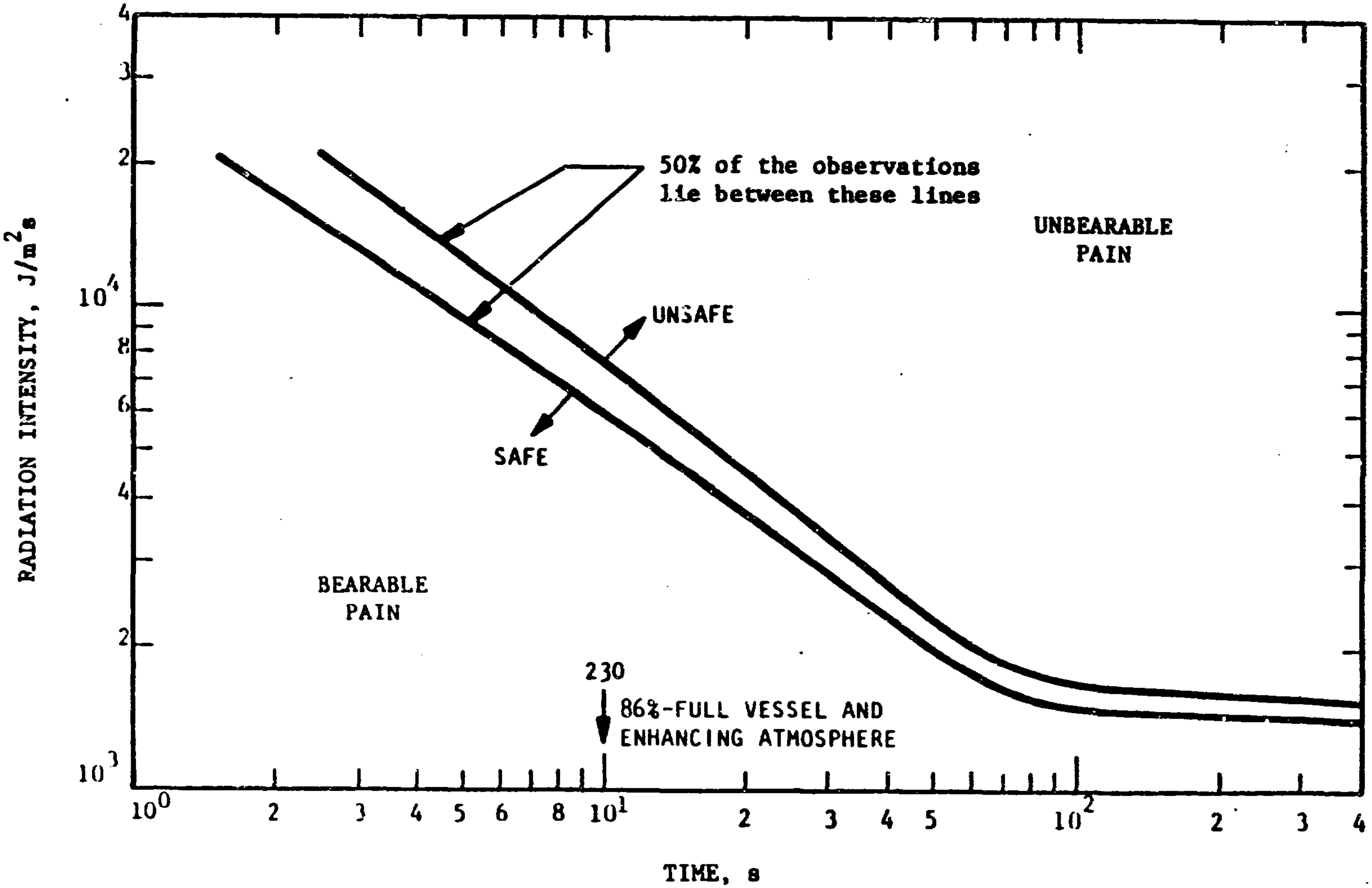


FIGURE 10. THRESHOLD OF PAIN FROM THERMAL RADIATION ON BARE SKIN

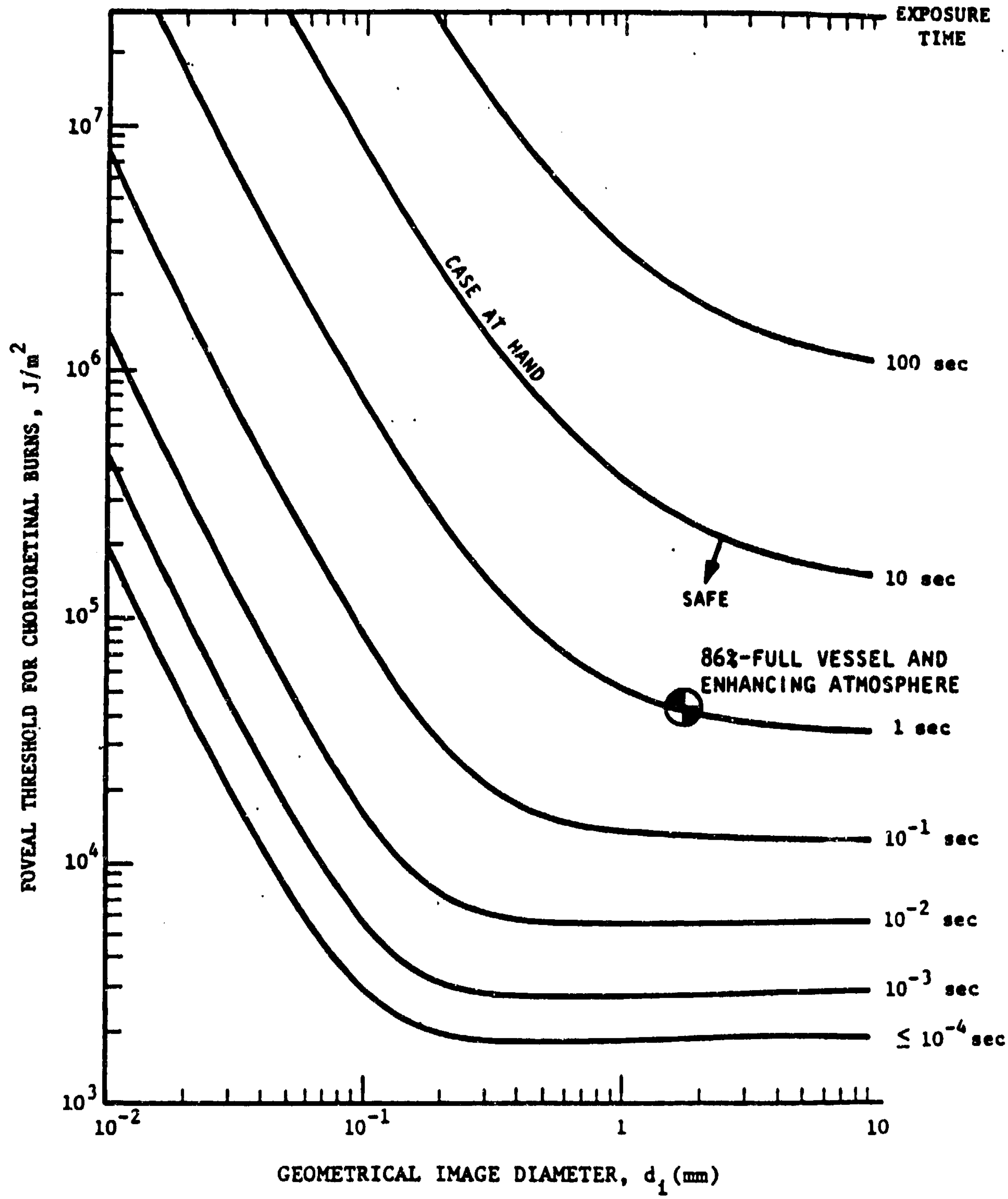


FIGURE 11. CHORIORETINAL BURN THRESHOLDS FOR PRIMATES

Airblast Loadings on Buildings

The airblast loads that act on the exterior surfaces of the various buildings are shown in Figure 12, where the typical values of P_S indicated by the overpressure contours indicated in Figure 6 are applicable. Note that the duration of the load has been standardized at 0.3 sec. The school building is optimally oriented, in that only one door and a few windows see a reflected pressure. Only the west-facing walls of the school building see a reflected overpressure.

At the overpressure levels being considered, the peak reflected overpressure, P_R, is double the peak free-field incident, or side-on, overpressure, P_S. The duration of the reflected overpressure has been standardized at 0.03 sec.

In the following sections, the facilities' capacity, or resistances, will be quoted for each considered failure mode in terms of a side-on pressure, P_S. Such specifications will account for reflected airblast, as applicable.

Basis for Analysis and Evaluation of Structures

In the evaluation of the school facilities, life-safety was the controlling consideration, i.e., insure that persons within or outside the buildings will not be injured by structural failures induced by the blast overpressures. Damage to the buildings as determined by permanent deformation of structural elements was permitted, but conservative limits on the amount of inelastic behavior (permanent displacement) were selected to insure safety of occupants and provide a margin of safety against collapse.

Dynamic, inelastic analyses were performed of the building roof and side wall structural framing systems to determine the amount of plastic deformation each will sustain under the appropriate airblast side-on overpressure indicated for the buildings in Fig. 6. The plastic deformations were compared with empirical data that relate deformation to damage levels and margin of safety against failure/collapse. Limits on inelastic behavior were based on the ratio of maximum allowable deflection of a structural element to the yield deflection depending on the ductile characteristics of the construction materials, time history of the loading, and yield strength of the material. Ultimate strength design procedures were utilized in the analyses to take advantage of the reserve strength in a member or structure that has been stressed beyond the elastic yield point.

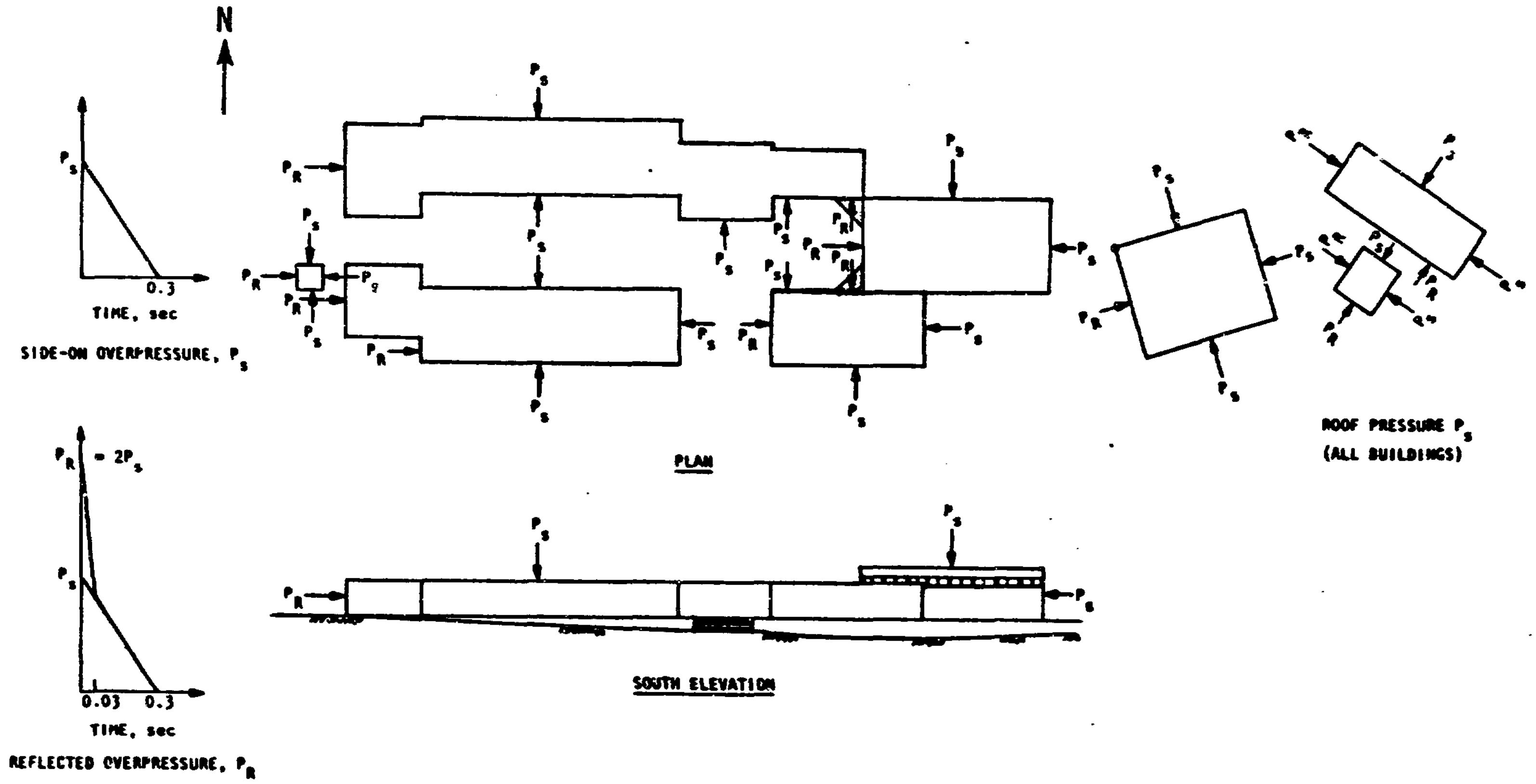


FIGURE 12. AIRBLAST LOADINGS ON SCHOOL AND ANCILLARY BUILDINGS

6. EVALUATION OF STRUCTURES

Structures evaluated at the Smith Site School consisted of the school building, caretaker's mobile home, the bus garage, a two-car garage, and a ball storage room. Results of the evaluations are summarized below, including a brief description of their construction.

6.1 School Structure Evaluation

Results of the evaluation of school building roof and sidewall structural systems are summarized below.

(a) Description of Construction

The school building is constructed using steel-framed, factory-assembled skeleton modules, nominally 10ft by 40ft, or 12ft by 40ft, in plan by 10ft or 17ft high. Modules are assembled in groups of 2, 3, 4, and 8 to form classrooms or other administrative support areas.

The grouping of modules for the school is shown below by module size.

10 x 32 Modules

30 x 32	Classroom Buildings (3-10x32)
40 x 32	Library (4-10x32)
40 x 32	Administration Building (4-10x32)
20 x 32	Toilet Building (2-10x32)
40 x 20	Faculty Building (4-10x20)

10 x 40 and 12 x 40 Modules

32 x 40 Kindergarten (10, 10, 12, x 40)

10 x 40 Modules

80 x 40 Multipurpose Building (8-10x40)

Roof: The roof structure comprises steel roof trusses spanning 32ft or 40ft supported on steel tubular columns with 6-in. by 14-gauge cold-formed steel C channel purlins at 4ft o.c., covered by 3/4-in. plywood sheathing.

Walls: Wall framing is nominally 2 x 4 wood studs at 16 in. on center or 2 x 6 wood studs at 16 in. on center depending on module height. Window and door openings are framed in the exterior walls as required following typical wood-frame construction details.

(b) Summary of Findings

Table 1 summarizes the maximum resistance, expressed in terms of a side-on overpressure, of school building elements to blast overpressure.

Roof System: The resistance of the roof construction is at least 0.60 psi.

Wall Framing for 10 Ft High Modules: The resistance of the 10 ft high side walls is limited to 0.31 psi because of the single stud used to frame a single window opening, as indicated in Figures 13a, 13b, and 13c. Double studs are used between two window openings when they occur in a single module, as indicated in Figure 13d, and they are reinforced with a flat 2 x 8 as shown in Figure 13e. Walls framed in this manner have a resistance of 0.74 psi. The resistance of the single-stud condition can be increased by nailing a flat 2 x 6 to the main and trimmer studs, in a manner similar to that shown in Figure 13e.

Wall Framing for the 17-ft High Multipurpose Room: The typical 2 x 6 stud framing (no openings) resistance is at least 0.67 psi. However, the resistance of this continuous framing is limited to 0.46 psi by the bolted wall to steel member connection at the top and bottom, when considering reflected overpressure.

The framing for the north wall is not subjected to reflected overpressures and has a resistance of at least 0.61 psi. However, the south wall framing, because of differences in how the wall is framed for the window openings, is limited by the connection detail used to attach the window sills to the steel module corner columns. This occurs at 9 locations. See Figure 14 for difference in framing for north and south walls. The 1985 Uniform Building Code (UBC), Section 2506(d) and (e), requires that the strength of bolted joints in a wood connection be evaluated not only for the bolt or load but also as a notched beam, considering the notch to extend from unloaded edge of the member to the center of the nearest bolt. This requirement limits the resistance of the wall framing to 0.14 psi. The joint should be reviewed for its adequacy to resist the static design wind load of 15 psf (0.1 psi). In any event, the connection can be strengthened by connecting adjacent window sills with a long steel strap attached to the beams by lag screws. This is required at 9 locations.

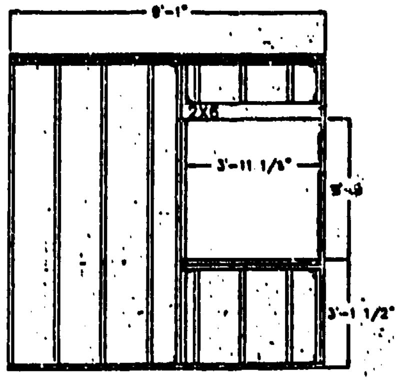
TABLE 1. MAXIMUM RESISTANCE OF SCHOOL BUILDING ELEMENTS TO BLAST OVERPRESSURE

ROOF		
Element	Failure Mode	Resistance, psi
3/4-in. Plywood Sheathing	Deflection	1.10
6-in. Steel Purlin	Bending	0.99
32-ft Steel Truss	Welding	0.70
40-ft Steel Truss	Welding	0.60

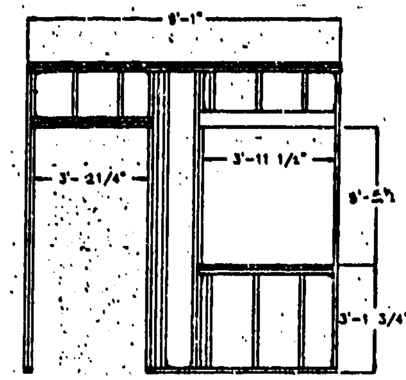
SIDE WALLS		
10-ft High Typical Construction		
Typical 2 x 4 studs @ 16" O.C.	Bending	0.58
Same as above subjected to reflected overpressure	Bending	0.42
Double 2 x 4 studs between 4' x 3-1/2' windows	Bending	0.74
Single 2 x 4 stud at side of single 4' x 3-1/2' window	Bending	0.31
3 x 3 x 1/4 L (bottom chord of roof truss) braced to roof purlin by knee-brace at 8 ft spacing	Bending	0.60

TABLE 1. (CONCLUDED)

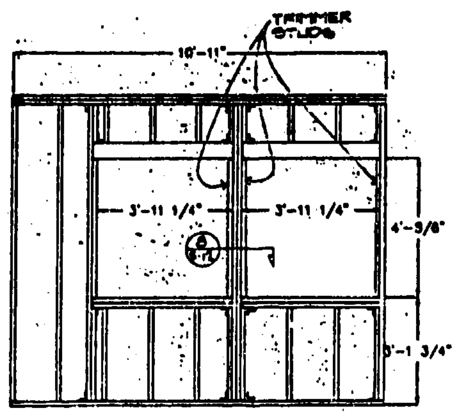
Element	Failure Mode	Resistance, psi
17-ft High Multipurpose Room Typical 2 x 6 studs @ 16" O.C.	Bending	0.86
Same as above subjected to reflected overpressure	Bending	0.67
Typical wall bolted connections of top and bottom plates to steel members	Shear	0.59
Same as above subjected to reflected overpressure	Shear	0.46
North Wall, 3 – 2 x 6 studs between 4' x 2' windows	Bending	0.71
North Wall connections	Shear	0.61
South Wall – 4 x 6 window sill	Bending	0.86
South Wall – bolted connection of 4 x 6 window sill to steel tube roof column	Notch Shear	0.14
South Wall – bolted stud connection at floor at 6 ft wide door jamb	Notch Shear	0.13
3 x 3 x 1/4 L (bottom chord of roof truss) braced to roof purlin by knee-brace at 8' spacing	Bending	0.37
2 – 2 x 6 studs at 6' wide door jamb	Bending	0.60



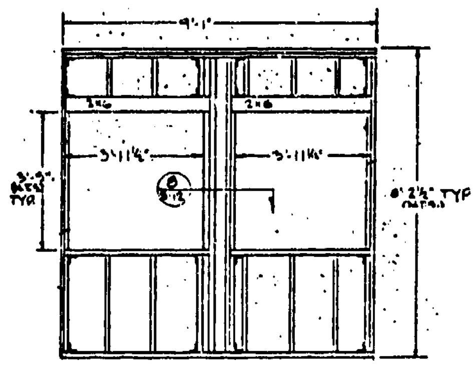
(a) 10-ft end wall, 4 places



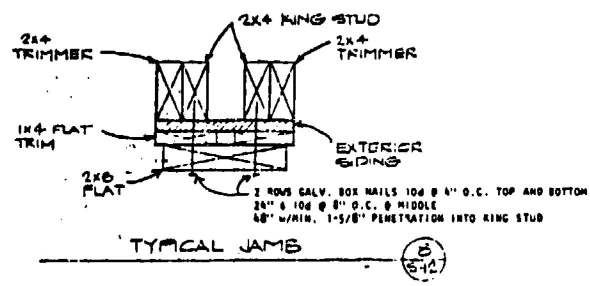
(b) 10-ft end wall, 12 places



(c) 12-ft end wall, kindergarten room, 1 place

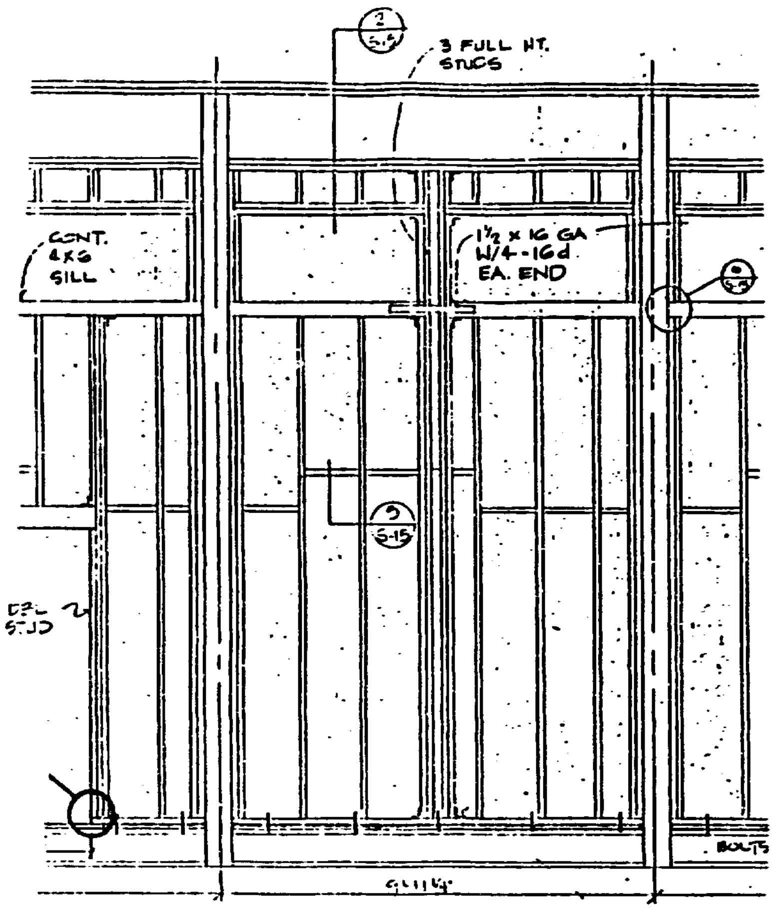


(d) 10-ft end wall, 19 places

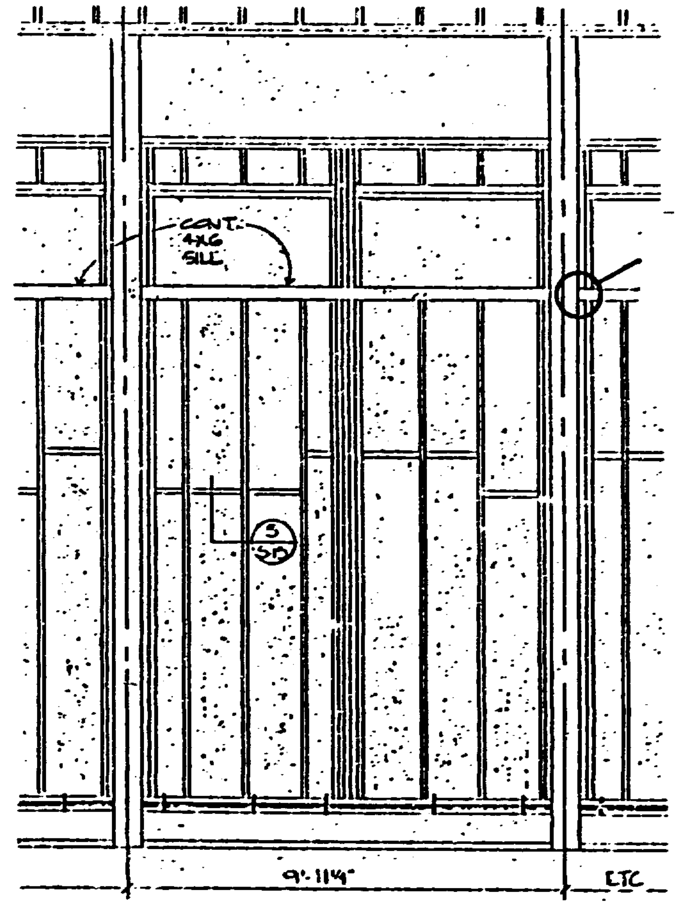


(e) Detail at double window

FIGURE 13. TYPICAL WALL FRAMING AT WINDOWS AND DOOR OPENINGS



(a) Multipurpose room, north wall framing



(b) Multipurpose room, south wall framing

FIGURE 14. MULTIPURPOSE ROOM WALL FRAMING

The notched-beam limitation on horizontal shear stress in bolted connections also limits the resistance of the wall framing because of the tie-down connection that anchors door jamb studs to the steel floor channels at double doors. This connection limits the resistance of the door jamb studs to 0.13 psi at 8 locations. The connection can be strengthened by using a variation of the detail described above for the window sill, but the steel strap has to extend below the floor and weld to the steel module frame.

The multipurpose room wall framing spans from the floor to the 3 x 3 x 1/4 steel angle that is the bottom chord of the module roof truss. This member must carry the wall reaction in horizontal bending between knee-braces that are spaced 8 ft apart. The spacing of the braces limits the overpressure that the walls can transmit to the bottom chord angle to 0.37 psi.

The resistance of the multipurpose room is currently limited to 0.13 psi by the bolted connections in wood members framing the south wall that must be treated as notched beams. If these connections are brought up to code, the resistance of the multipurpose room will be at least 0.4 psi. To further increase the resistance of the multipurpose room, the wall bolted connections at top and bottom (resistance of 0.46 psi) and the bottom chord of the roof truss (resistance of 0.37 psi), require strengthening.

(c) Special Reflected Pressure Condition at West Multipurpose Room Wall and Adjacent Classroom Buildings

There will be a reflected pressure build-up on the walls of the adjacent modules due to overpressure reflection on the west wall of the Multipurpose Room. The clearing of the reflected pressure from the Multipurpose Room is impeded by the walls of the adjacent buildings and the build-up of pressure on these walls will approximate the reflected pressures. This increase in side-on overpressure will extend back from the Multipurpose Room wall a distance about equal to the height of the wall.

The school room walls experiencing the increased loading includes three doors and two sliding windows. Two of the doors open inward and their resistance is limited by the strength of the door latch. Refer to Paragraph 8 for further discussion of the doors.

The resistance of the sliding classroom windows is controlled by the center aluminum mullion. The mullion resistance to reflected overpressure is 0.27 psi. The glazing resistance to reflected overpressure is 0.7 psi.

The single-stud framing condition at window openings in the area subjected to the reflected pressure should be reinforced using a flat 2 x 6 as discussed previously for similar situations.

6.2 Bus Garage Evaluation

Results of the evaluation of the bus garage roof and wall structural systems are summarized below.

(a) Description of Construction

The building is a clear span rigid frame steel structure 60 ft by 50 ft in plan and 14 ft high with a 12 ft by 24 ft roll-up door. The roof is framed with purlins covered by ribbed sheet metal panels and cross-braced by steel cables. The walls are framed by girts and wind columns and covered by ribbed sheet metal panels. The end walls are cross-braced by cable.

(b) Summary of Findings

Roof System: The roof panels and purlins and the tapered girder each have a resistance of at least 0.67 psi.

End Wall System (North and South Walls): The wall girt resistance is 0.41 psi, and the wall panel resistance in 0.48 psi.

Side Wall System (East and West Walls): The resistance of the wall girts and panels is at least 0.4 psi. The rigid frame column has a resistance of at least 0.7 psi.

6.3 Two-Car Garage Evaluation

Results of the evaluation of the two-car garage roof and wall structural systems are summarized below.

(a) Description of Construction

The building is a steel-framed structure 25 ft by 20 ft in plan by 10 ft high with a 7 ft by 16 ft door. The front and back walls are rigid frames. The side walls and roof are cross-braced by cables. Construction is similar to the bus garage. The building is covered by ribbed sheet metal panels.

(b) Summary of Findings

Roof System: The resistance of the roof purlins is 0.50 psi. The resistance of the roof panels and tapered steel rigid frames is at least 0.7 psi.

Wall Framing Systems: The resistance of the wall girts is at least 0.7 psi. The resistance of the wall panels is limited to 0.46 psi.

6.4 Caretaker's Mobile Home Evaluation

This structure is a conventional wood-framed double-wide unit mobile home approximately 26 ft by 66 ft supported on steel leveling piers. It was not possible to obtain fabrication drawings from the supplier, but it can be assured that the unit complies with Manufactured Home Construction and Safety Standards, Section 3280.404, issued by the Department of Housing and Urban Development. From a visual inspection of the mobile home, it appeared that the unit is sturdy and well constructed.

The adequacy of the wood-framed building was evaluated using the maximum resistances of the school building elements summarized in Table 1. The vulnerability of the window glazing is discussed in Paragraph 7. The building is supported off the ground on steel leveling piers approximately 18 to 24 in. high that are not braced or anchored to the ground. The building does not have a lateral force bracing system below the floor level and is vulnerable to being displaced and falling to the ground when subjected to earthquake ground motion or reflected blast overpressures.

6.5 Ball Storage Room Evaluation

This structure is a wood-framed building 10 ft by 12 ft in plan and 8 ft high. The walls are constructed with 2 x 4 studs covered by plywood sheathing. The roof is flat, framed with 2 x 8 rafters and covered by plywood and built-up roofing.

The adequacy of the structure was evaluated using the maximum resistances of school building structural elements summarized in Table 1. The top plates of the 10 ft long end walls have a resistance of 0.24 psi under wall loading and require bracing at the center to reduce their span.

7. WINDOW GLASS RESISTANCE TO OVERPRESSURE

All exterior glazing used in the school building is either tempered safety glass or laminated safety glass. Tempered safety glass is a single piece of specially heat-treated glass, which has a locked-in stress pattern that ensures that the piece will fracture into numerous granular, nonjagged fragments. This type of glass has a significantly higher impact strength than ordinary glass. The laminated safety glass consists of two pieces of glass held together by an intervening layer of plastic materials. It will not fall apart when cracked by impact, since splinters and sharp fragments will adhere to the plastic interlayer.

The resistances of the windows on the school site to overpressure are summarized in Table 2.

7.1 School Building Windows

The blast resistance of the sliding classroom windows is limited by the strength of the vertical aluminum mullion at the center of the window. Although the glazing itself will withstand overpressures of 1.3 psi, the mullion will fail under the tributary window loading imposed by an overpressure of 0.3 psi. The mullions can be strengthened by attaching an aluminum bar to the exterior flange of the mullion with self-tapping sheet metal screws.

The strength of the laminated safety glass in the multipurpose room windows is limited to 0.4 psi. Substitution of tempered safety glass would increase this resistance to at least 0.7 psi.

The exterior windows in the administration area are judged safe for all threats being considered since they will resist an overpressure of 0.9 psi. The windows in the administration restrooms are also adequate for the largest overpressure being considered.

7.2 Vehicle Windows

In the United States, vehicle window glazing is exclusively tempered safety glass. In a 175-ton high-explosive test conducted by the U.S. Department of Defense Explosive Safety Board at the Naval Weapons Center, China Lake, CA, automobiles were located at various distances from the center of the explosion and exposed to face-on (reflected) overpressures (Reference 5). The results of this test can be summarized as follows:

TABLE 2. MAXIMUM RESISTANCE OF WINDOWS

Window		Resistance, psi
Location	Description	
Classroom	4'-0" x 3'-6" Sliding – Dual Glaze with 3/16-in. Tempered Safety Glass	1.3
	Aluminum Mullion	0.3
Multipurpose Room	4'-0" x 2'-0" Projection – Single Glaze with 1/4-in. Safety Glass	0.4
Administration	2'-0" x 6'-0" Single Hung witn 3/16-in. Tempered Safety Glass	0.9
Automobiles and Buses	Vehicle Glazing – Tempered Safety Glass	0.5 to 1.2
Caretaker's Home	Normal Residential Glazing – Annealed Glass	< 0.20

Overpressure	Range of Damage
0.5 psi	- No damage
0.9 psi	- No damage - Multiple fractures
1.2 psi	- No damage - Multiple fractures - Completely broken out

Therefore, it is judged that the windows in vehicles on the school property should sustain at most fracture of windows under the entertained overpressure threats.

7.3 Windows in Caretaker's Home

The windows in the caretaker's home are plain, annealed glass and will be easily fractured at the overpressures of interest, especially windows normal to the direction of the blast wave, which are subject to reflective overpressure. Typical breakage of annealed glass produces long, sharp-edged splinters. It is prudent to replace all windows in the caretaker's home with tempered safety glass.

8. DOOR RESISTANCE TO OVERPRESSURE

The school building door leaves are all 3 x 7 ft, of solid core wood construction, and hung by three hinges. Both inward and outward swinging leaves are used. Hollow metal door frames are used. The door leaves and hinges resist the applied overpressures with large margins of safety. The catches on leaves that swing inward, however, will probably fail, thus allowing the door leaf to sing open. The side-on overpressure that is required to accelerate the leaf to the 10-fps mostly safe impact velocity (see Paragraph 4) is about 0.6 psi, which is about equal to the largest overpressure being entertained.

For leaves that open outward and that are open when struck by the airblast, a peak side-on overpressure of 0.3 psi produces the 10-fps threshold velocity. This overpressure is lower than the above value because the leaf sees a reflected overpressure.

The inward swinging door leaves, with the two exceptions noted below, are judged safe for all threats being entertained. The outward swinging door leaves, however, have potential for inflicting injury. The Faculty Workroom and Music Room inward swinging doors are subjected to the same reflected pressure that the adjacent high wall is subjected. As a result, these two doors could be accelerated beyond the mostly safe 10-fps velocity.

All outward swinging doors and the two inward swinging doors identified above can be fitted with double-acting door closures to eliminate all risk of injury under the full range of threat conditions under consideration.

9. UPSET/FAILURE OF BUILDING CONTENTS

The airblast-induced shock created by the interaction of a blast wave with a structure and the resulting deformation of the building may upset contents, or upset or fail nonstructural systems, or both. These responses are similar to those induced by earthquake.

Free-standing equipment such as bookshelves, filing cabinets, lockers, vending machines, and storage racks can overturn due to floor motions and injure persons, damage contents, and impede egress from the facility. It was noted during visits to the school that bookshelves and lockers appear to be well anchored against overturning.

Chemical spills in the science laboratory and storage lockers can create hazardous conditions from mixing of chemicals. Containers on shelves or in cabinets should be constrained to prevent their falling on the floor. It was noted that chemicals in the Science Laboratory Room were stored in cabinets, but that the cabinet doors were not well secured. It is prudent to install positive latches or other means to prevent these cabinet doors from opening accidentally when not in use.

Suspended ceilings and light fixtures should be well secured to prevent them from falling and injuring persons or damaging equipment. Recessed light fixtures should be secured to the roof structure by hanger wires at corners of the fixture. T-bars supporting the suspended ceilings should be well anchored to the roof hangers. An examination of the construction drawings for the school indicate details for securing the suspended ceilings and light fixtures are sufficient for the largest overpressure being considered.

Anchorage of mechanical and electrical equipment is to prevent loss of the usage of the equipment and for life safety. Water heaters/boilers are well anchored to prevent translation and/or overturning. Transformers, switchgear, and electrical panels are anchored. Broken gas lines can create hazardous problems where sparks could result in fires or explosions. The installation of earthquake-activated shutoff valves can reduce this hazard. It was noted during the inspection that the LPG tank providing gas for the Science Laboratory was not tied down. It is prudent to secure this tank against movement.

There is an interior window and a trophy case within the administration area that is glazed with plain glass. It is prudent to replace these glazings with safety glass since they are vulnerable to accidental breakage and are a hazard to students and faculty. There is an outside bulletin board mounted to an exterior wall in the open court between classrooms. The bulletin board is covered by plain glass. The glass can be easily broken by students playing ball, roughhousing, etc., as well as by blast overpressure, and presents a hazardous condition. It is also prudent to replace this glazing with tempered safety glass.

10. RECOMMENDATIONS

The following recommendations were made for mitigating the risk of hazards to humans on the school site from the effects of the accidental explosion of an LPG vapor cloud or from a major earthquake in the vicinity of the school.

10.1 Prudent Risk Mitigation Measures

Implement the following seven prudent risk mitigation measures regardless of whether the tanks are filled to 40 or 86% capacity:

1. Replace all windows in the caretaker's home with tempered safety glass to mitigate explosion effects.

2. Install positive latches on cabinet doors in the Science Laboratory to mitigate explosion/earthquake effects.

3. Secure the LPG tank that services the Science Laboratory to mitigate earthquake effects.

4. Replace the interior window and trophy-case glazings with tempered safety glass to mitigate explosion/mishap effects.

5. Replace the Bulletin Board glazing with tempered safety glass to mitigate explosion/mishap effects.

6. Correct all shear-notch deficiencies in the school building framing to mitigate wind/explosion effects.

7. Brace the caretaker's mobile home against lateral displacement to mitigate explosion/earthquake effects.

10.2 Optional Risk Mitigation Measures

Implement, on an optional basis, the following ten measures for either tank ullage condition based on descending order of importance:

1. Sliding Classroom Window Mullions. Strengthen the aluminum mullion used in all sliding classroom windows by attaching an aluminum bar to the exterior flange of the mullion with self-tapping sheet metal screws (40 bars).

2. Doors. Install double-acting door closures on all exterior outward swinging doors excepting the north and west double doors to the Multipurpose Room and the kitchen door (16 closures) and the exterior inward swinging doors to Rooms 24 and 27 (2 closures). Limit the door swing velocity to 10 fps.

3. Ball Storage Room. Install continuous blocking between the 2 x 8 roof rafters at the center of the building from end wall to end wall.

4. Multipurpose Room Windows. Substitute tempered safety glass for all the laminated safety glass in the Multipurpose Room windows (28 places).

5. West School Wall and West Ball Room Wall. Construct new walls of 2 x 6 studs at 16 in. on center directly over the existing wall and cover with plywood sheathing to match the existing architecture. The studs should extend the full height of the wall and attach to the upper chord of the roof truss at the roof diaphragm.

6. Window Jambs. Reinforce window jambs that are framed by a single stud by nailing a flat 2 x 6 to the main stud and trimmer studs, the full height of the wall, on the building exterior. This technique is similar to the typical detail that was used to reinforced existing double studs between two window openings. The addition of the flat 2 x 6 would be required at 36 locations.

7. <u>Multipurpose Room Walls</u>. Strengthen the bolted connections used to attach the top and bottom plates of the Multipurpose Room walls to the steel support members by using additional nailing. Pneumatic equipment is available that can attach wood members to steel by penetrating the steel framing with special pins. This can be used to provide additional shear resistance between the bottom plate and the steel channel. At the top of the wall, the bottom truss angle supporting the wall at the top should be accessible through the suspended ceiling for attaching to the top plates through the angle leg. Holes can be drilled in the angle leg for nailing or lag bolting; or pneumatic nailers can be used.

8. <u>Multipurpose Room Wall Framing Support Angle</u>. Add additional knee-braces to the 3 x 3 x 1/4 angle of the bottom chord of the roof truss to which the Multipurpose Room walls are framed. Weld or bolt diagonal angle struts between the bottom chord angle and the roof purlins so that the chord angle is braced every 4 ft.

9. <u>Bus Garage</u>. Except for the rigid frame, the building utilizes light-gage, cold-formed structural members for purlins, girts, and other framing members, and for exterior covering. Field tests of this type of construction subjected to blast overpressures in tests at the Nevada Test Site indicate that the building can accommodate large permanent deformations without failure, provided connections do not fail. Reference 6 concludes that presently designed structures of this type may be regarded as being repairable provided they are not exposed to blast pressures exceeding 1.0 psi. Based on this information, it is concluded that the framing for the Bus Garage is adequate for the maximum pressures entertained, even though the calculated resistances indicate that wall system members are only adequate for about 0.3 to 0.4 psi. However, connections should be inspected and those that appear to be marginal should be reinforced.

10. <u>Two-Car Garage</u>. The resistance of the building to overpressure loading is higher than the Bus Garage. Although the resistance of the purlins, girts, and wall panels is approximately 0.5 psi, it is concluded that the building is adequate for the maximum overpressure entertained, as discussed

in Measure 9. Connections should be inspected and reinforced as may be appropriate.

10.3 Implementation of Risk Mitigation Measures

All seven prudent risk mitigation measures and ten optional risk mitigation measures, recommended above have been implemented.

11. REFERENCES

1. Little. (1985a) Letter dated 11 July 185 to Ms McCarty/Chevron from Peter Athens/Arthur D. Little, Inc.

2. ----. (1985b) *Safety-Related Impacts at the Chevron Molino Canyon Site and at the Tajiguas Site from Existing and Proposed Oil and Gas Processing Facilities,* C54689. Santa Barbara, CA: Arthur D. Little, Inc. Nov.

3. Department of Energy (DOE). (1980) *A Manual for the Prediction of Blast and Fragment Loadings on Structures,* DOE/TIC-11268.

4. Baker et al. (1983) *Explosion Hazards and Evaluation.* New York, NY: Elsever Scientific Publishing Co.

5. Weals, F.H. (1976) *Eskimo III Magazine Separation Test,* NWC TP 5771, Naval Weapons Center. Washington, DC: Department of Defense Explosives Safety Board, Feb.

6. Glasstone, S. and Dolan, P.J. (eds) (1977) *The Effects of Nuclear Weapons,* Third Edition. Washington, DC: USGPO.

EXPLOSIVE SAFETY COMPLIANCE OF A WEAPON ASSEMBLY OPERATION

By:

Mohsen Sanai and Gary Greenfield

SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

DoD Explosives Safety Seminar
St. Louis, Missouri
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ILLUSTRATIONS

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INTRODUCTION

SRI International evaluated the explosive operations of a weapons assembly operation to determine compliance with the U.S. Department of Defense (DoD) quantity/distance (Q/D) requirements for blast overpressure and fragment projection distance. Figure 1 shows a schematic of the weapon assembly and inhabited buildings. The closest distance between the two buildings (for later use with Q/D charts) is 550 ft.

Our objective was to obtain a credible estimate of the hazardous overpressure range and fragment projection range should an accidental explosion (or "maximum credible event") occur in the weapon assembly building. The estimated hazardous ranges can then be compared with the 550-ft separation between the two buildings. The range estimates given here are based on computer simulation of mass detonation of an equivalent high explosive (HE) charge. The hydrocode calculations model the HE detonation, the formation and propagation of the resulting airblast, and the initial velocity imparted to fragments of known material and mass. A special algorithm (called UFO) was developed to trace the fragment trajectories and calculate the maximum projection distance possible for a given fragment mass and initial speed.

The maximum amount of explosive and propellant in use in the weapon assembly operation at any given time was calculated from a combination of rocket motors, warheads, and complete weapons stored in several locations. The total equivalent HE for the entire weapon assembly operation is about 2450 lb. Thus, for the 6650 ft^2 weapon assembly building, the average explosive loading density is 0.37 lb/ft^2. This loading density is used in the blast overpressure and fragment projection distance calculations discussed in the following sections.

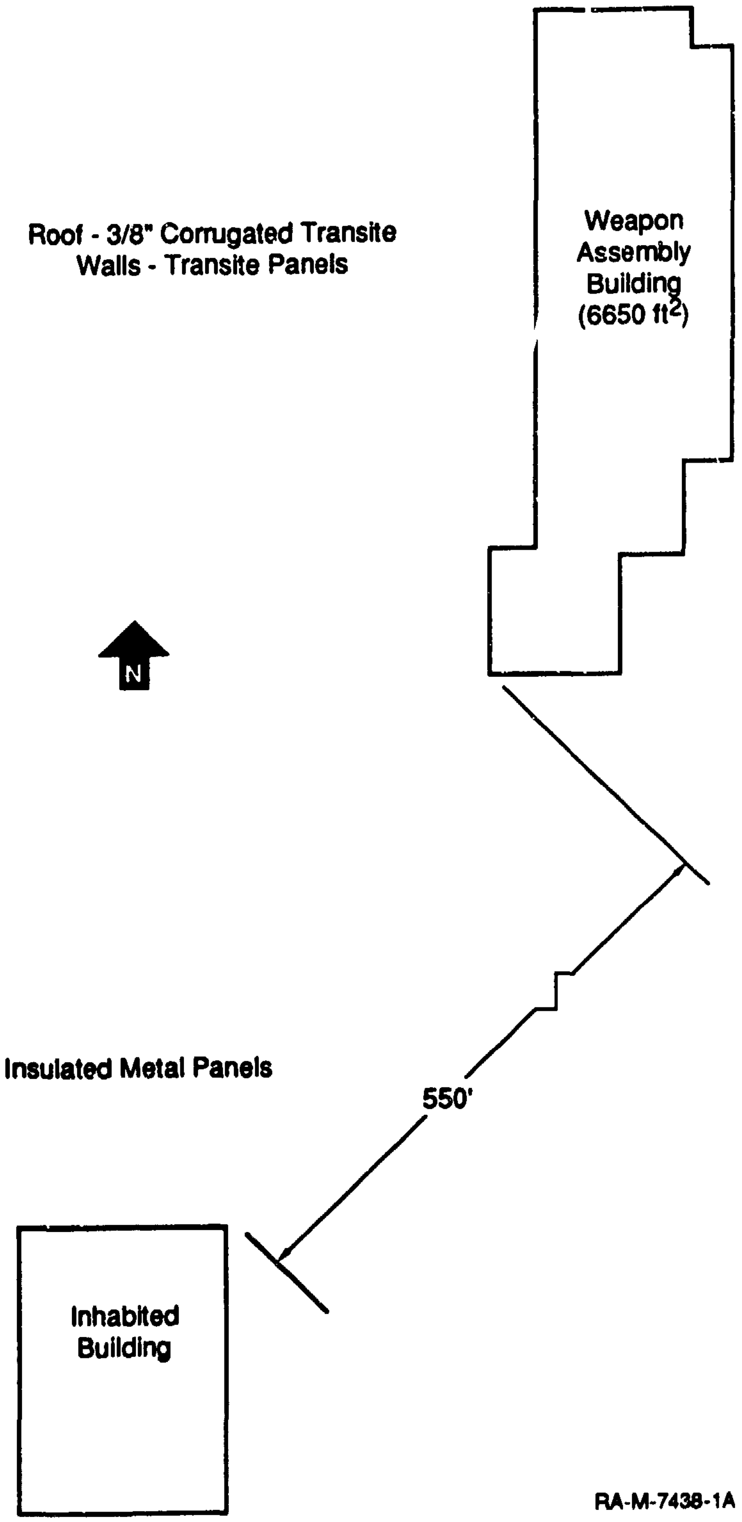


Figure 1. Relative locations of assembly and inhabited buildings.

BLAST OVERPRESSURE

To calculate the maximum blast overpressure that could occur at the inhabited building, we modeled the mass detonation of the equivalent HE charge in the weapon assembly building using the SRI two-dimensional L2D Lagrangian hydrocode. Figure 2 shows the overall computer zone layout used in this calculation, and Figure 3 shows an enlarged view of the central section.The outer concrete walls are modeled as rigid; the much weaker blowout roof is not included in the calculation so that the calculation of pressures is conservative (upper bound). The assembly building is modeled as a 46-ft-radius cylindrical chamber with a cross sectional area of 6650 ft^2 equal to the floor area of the actual assembly building shown in Figure 1. TNT explosive is assumed to be distributed uniformly on the floor, and its detonation is modeled by a standard JWL equation of state.

Figure 4 shows the constant-pressure (isobar) contours 5 ms after the HE is detonated. The pressure contours show that at this early time the flow near the center is moving upward and the flow near the edge is spilling over the outside wall. The numbers on each pressure contour signify the pressure level. Number 1 indicates a pressure of 1 bar and number 8 a pressure of 8 bar. The pressure contours are closer to each other near the outer region of the flow, indicating the presence of an expanding shock wave in air with a peak overpressure of about 100 psi at this time.

Figure 5 shows the calculated peak overpressures as the blast reaches the vicinity of the inhabited building. The overpressures are plotted versus the standoff distance measured from the edge of the weapon assembly building so that it can be compared directly with the 550-ft standoff distance between the two buildings. This plot shows that the expected peak blast overpressure at the inhabited building is about 0.3 psi, which is significantly lower than the maximum allowable overpressure level of 1.2 psi specified in the DoD safety manual. The results of the calculations clearly show that the DoD blast overpressure standard for inhabited buildings is amply satisfied for the 2456-lb HE capacity of the weapon assembly building.

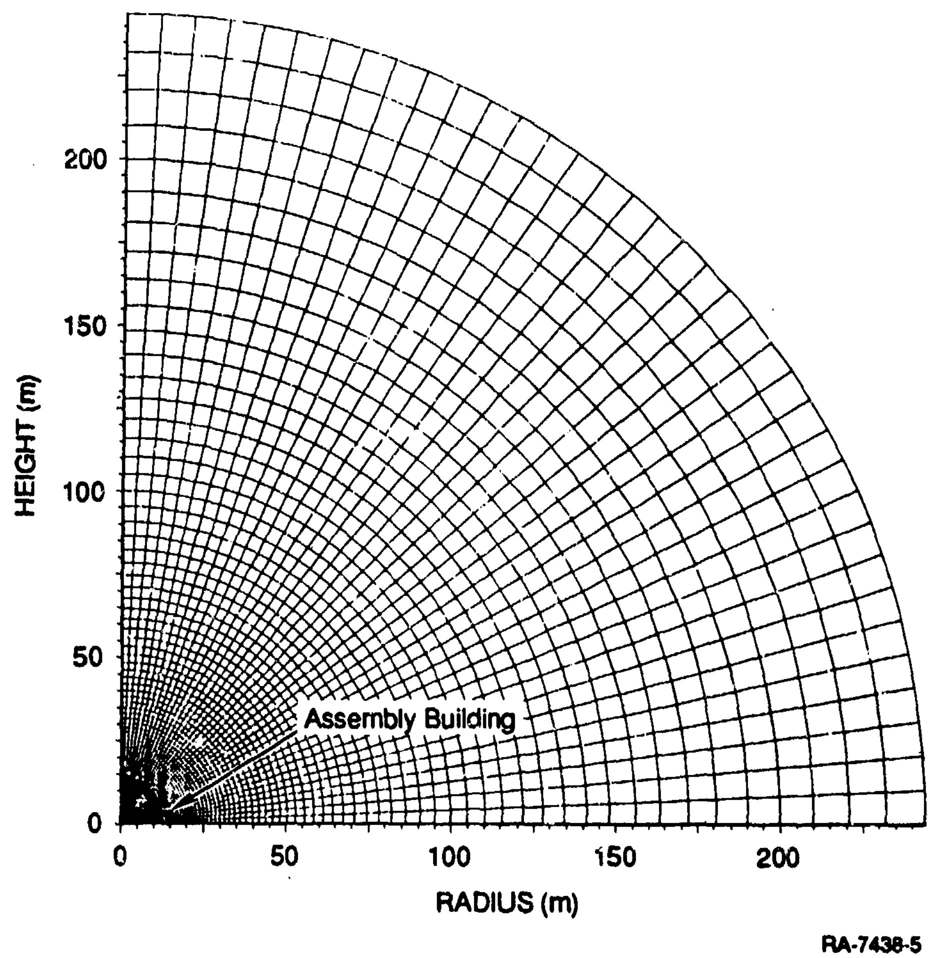


Figure 2. Computer zone layout for airblast calculations.

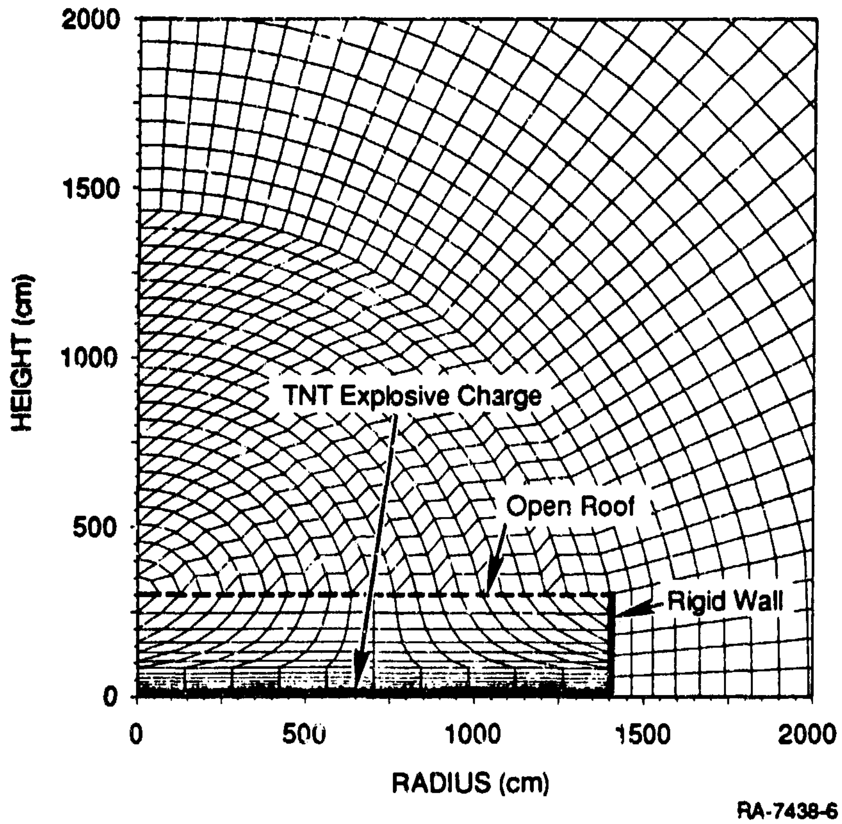


Figure 3. Exploded view of computer zone layout for airblast calculations.

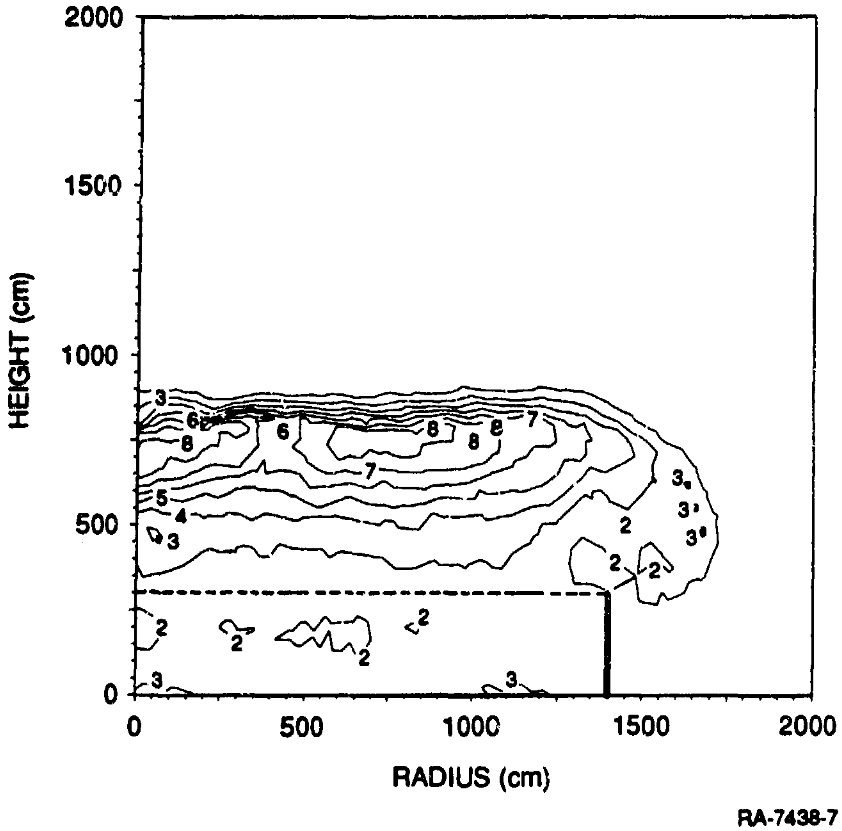


Figure 4. Pressure contours 5 ms after explosive charge initiation.

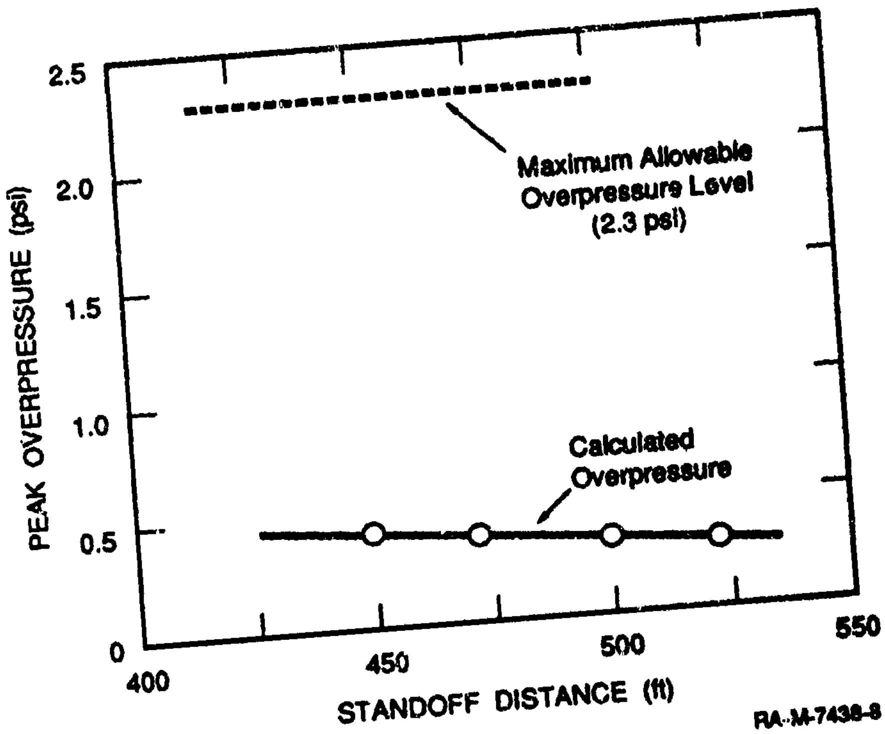


Figure 5. Variation of airblast overpressure with standoff distance from the weapon assembly building.

FRAGMENT VELOCITIES AND DIMENSIONS

To calculate the hazardous fragment ranges, we need to estimate not only the initial velocity but also the expected dimensions (or mass) of each fragment. As will be seen in the next section, this velocity and mass information is used in the UFO algorithm to calculate the maximum projection distance for any projection angle.

FRAGMENT VELOCITIES

We identified two major sources of fragments and debris in the event of an accidental explosion in the weapon assembly building. They are (1) fragments produced by the rupture of the steel casing of the weapon round and (2) fragments produced by the roof material due to explosive detonation. In each case, the fragment velocity is determined based on a series of hydrocode calculations similar to those used to calculate the blast overpressure in the previous section.

Figure 6 shows the idealized axisymmetric model used for the weapon casing in the hydrocode calculations. The model is based on the height, diameter, and total weight of the actual weapon. The equivalent TNT weight obtained above is modeled as an HE cylinder with a radius of 2.1 cm. A steel shell surrounds the HE. As the HE is detonated, the steel shell is expanded and fragmented into long narrow strips. Because the present one-dimensional calculation neglects the strength of the shell and the expansion of explosive products from the two ends of the weapon casing, it provides a conservative (higher) estimate of the projection velocity for the fragments (steel shell).

The calculated time history of the steel shell is shown by the solid curve in Figure 7. The shell is accelerated rapidly and reaches its limiting velocity of 1750 m/s about 80 μs after charge initiation at zero time. The dashed curve lying below the solid curve in Figure 7 is the shell velocity calculated from a two-dimensional hydrocode calculation in which the shell was assumed to be fragmented into 0.2-cm-wide strips. As the shell expands, the explosive products escape through the widening gaps between neighboring fragments, thus imparting less momentum (and velocity) to the fragments. Again, to be conservative, we used the maximum velocity of 1750 m/s calculated from the one-dimensional calculations (solid curve in Figure 7) as the projection velocity for the fragments produced by the weapon casing.

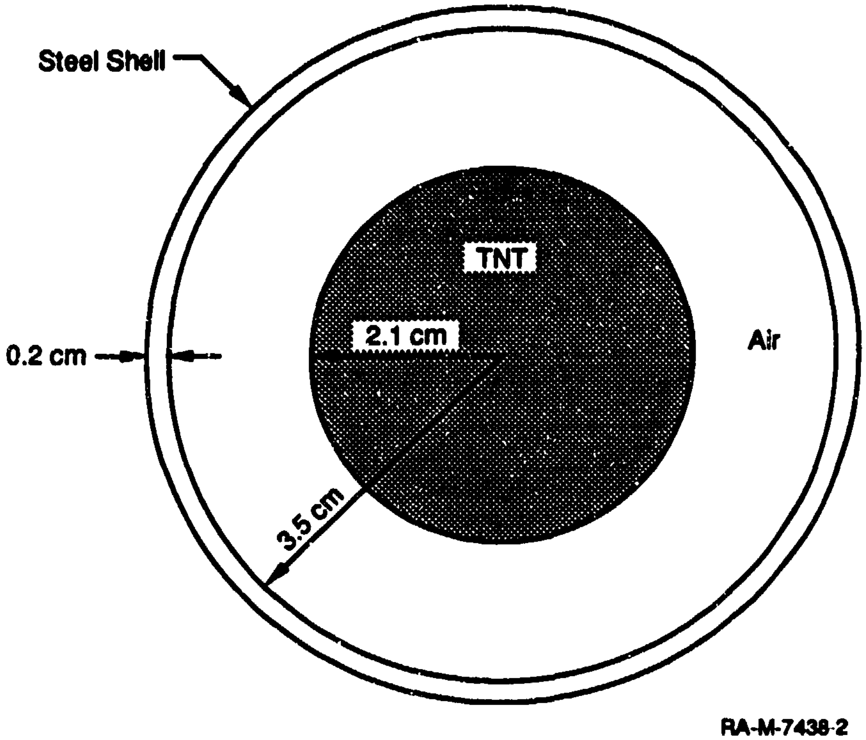


Figure 6. Model of weapon round used in hydrocode calculations performed to estimate maximum projection velocity of steel shell fragments.

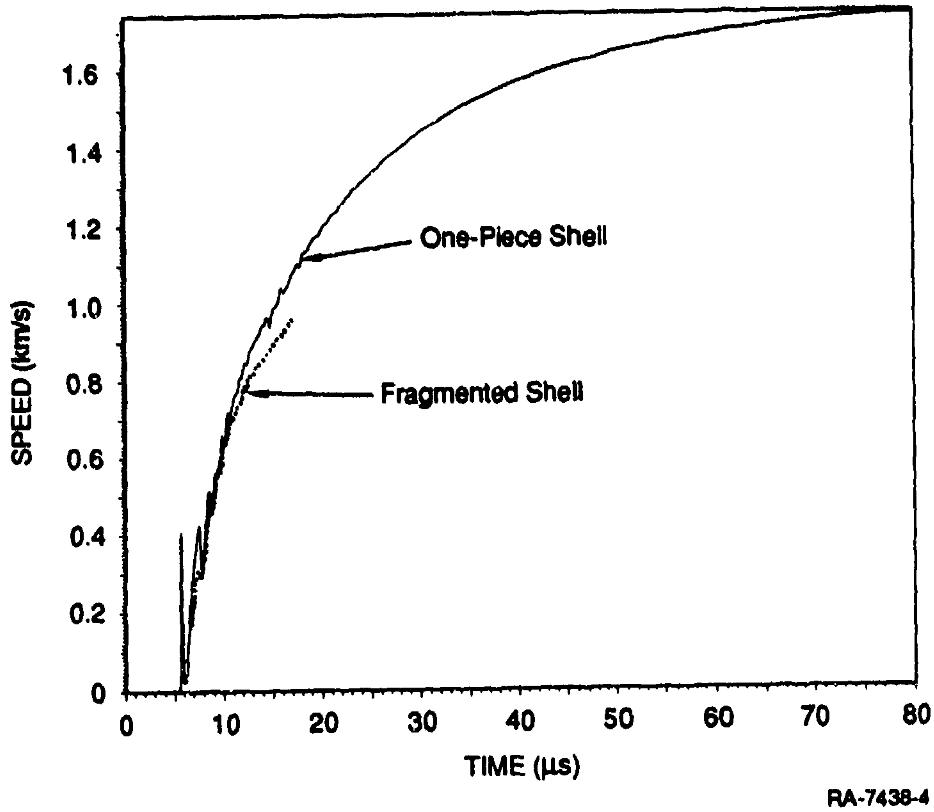


Figure 7. Calculated projection velocity of steel shell fragments.

To calculate the roof fragment velocity, we used the idealized one-dimensional model shown in Figure 8. As before, the calculations provide a conservative (higher) estimate of the projection velocity because the effect of gas escape through fragmented roof panels is neglected. Note that the total explosive areal density calculated above is used here without any downward adjustment of the HE weight due to the explosive energy converted into the kinetic energy of the weapon casing. (Based on the calculated casing velocity of 1750 m/s, the kinetic energy of the casing is over 30% of the total explosive energy.) The kinetic energy imparted to the weapon casing clearly reduces the intensity of the shock wave responsible for projecting the roof material, so the present calculations should result in a conservative (higher) estimate of fragment velocities.

The idealized model shown in Figure 8 is based on the manufacturer's specifications for corrugated "400" sheets. The average thickness of the panels is 3/8 in., but we used a .5-in.-thick (1.27-cm) panel in the calculations to account for the extra weight per unit area due to the corrugation. The maximum velocity of the roof panels obtained from this calculation was 383 m/s.

FRAGMENT DIMENSIONS

The weapon casing and roof panels are expected to fragment into long narrow strips and be projected in arbitrary directions following an accidental explosion. These strips can be as long as the undamaged unit: 4 ft for the weapon casing and 6 ft for the roof panels. The nominal widths of these strips can be obtained from the standard Mott theory discussed in References 1 and 2. According to this theory, the nominal fragment size is determined by the competition between the momentum diffusion velocity and the loading rate.

Straightforward application of Mott's theory resulted in nominal widths of 0.2 cm and 1.78 cm for the weapon casing and roof panels, respectively. (As expected, these values are comparable to the original thicknesses of the weapon casing and roof panels.) To account for the statistical variation of fragment widths, we made the assumption that the maximum fragment width can be as much as three times greater than the nominal value calculated based on Mott's theory. In accordance with the available literature on fragmentation of bomb casings, we believe this assumption leads to a reasonably conservative (high) estimate of fragment widths.

The nominal fragment weights calculated using Mott's theory are 38.1 g and 669 g for the weapon casing and roof panels, respectively. The maximum values used in the UFO calculations (discussed in the next section) are 114 g and 1970 g, three times larger than the nominal values.

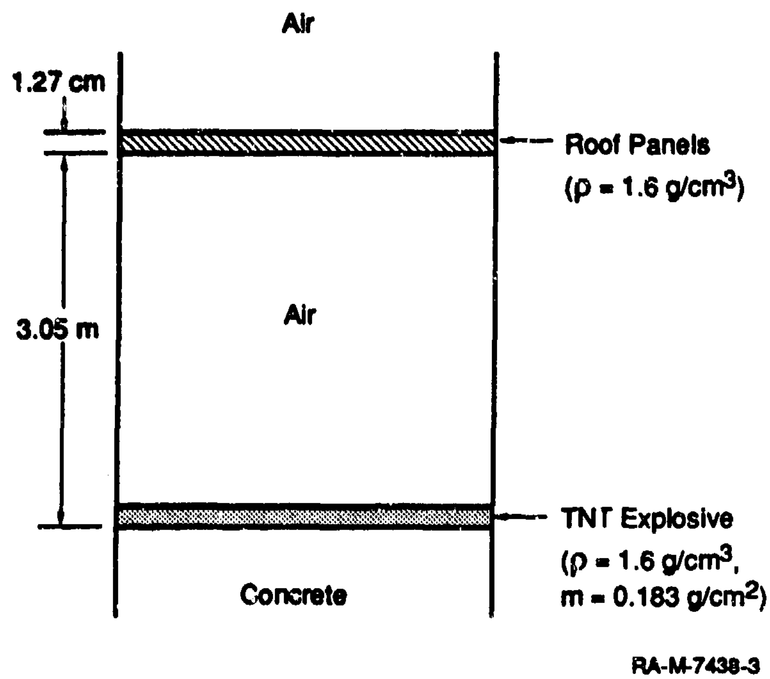


Figure 8. Model of weapon assembly building used in hydrocode calculations to estimate maximum projection velocity of roof panel fragments.

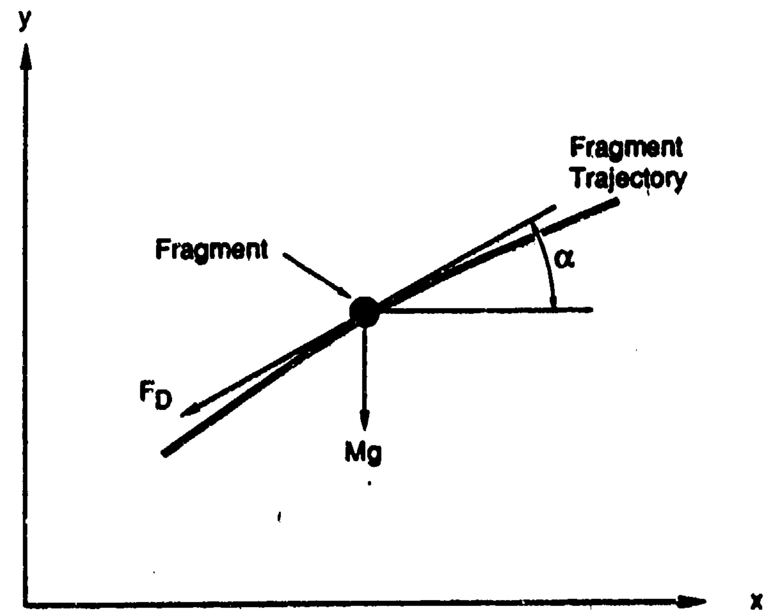
FRAGMENT PROJECTION DISTANCES

To calculate the fragment projection distances, we wrote a computer algorithm (called UFO) that calculates possible trajectories for a fragment with known weight and initial speed. As shown in Figure 9, the trajectory of a fragment in free flight depends only on its weight, Mg, and air drag, F_D. Based on Newton's Law, fragment acceleration in the horizontal and vertical directions is given by the formuli in Figure 9, where C_D is the drag coefficient and A_D is the projected area of the fragment on a surface perpendicular to the flight trajectory. Once the values of C_D and A_D are determined, the UFO calculates possible trajectories by changing the initial projection angle from 0 to 90 at one-degree intervals. The UFO algorithm is validated in the Appendix, where its results are shown to be consistent with known analytic trajectories as well as with the results of a similar algorithm discussed in References 3 and 4.

Realistic estimates of C_D and A_D are needed to calculate the maximum projection distances. Both C_D and A_D change continuously as the fragment tumbles in flight. The fragments of interest are in the form of long strips. Figure 10 shows three extreme flight orientations for a strip fragment and the corresponding drag coefficients and projection areas. (Projected areas are shaded in Figure 10.) We simply averaged the drag coefficients and projected areas of the three extreme flight orientations shown in Figure 10. This should give representative values for C_D and A_D for the UFO calculations.

Results of UFO calculations for the weapon casing and roof panels are shown in Figures 11 through 14. Each figure shows the flight trajectory obtained for 17 projection angles ranging from 5 to 85 degrees at 5-degree intervals. Figures 11 and 13 show the trajectories obtained with nominal fragment weights obtained from Mott's theory. The maximum projection distances obtained for the weapon casing and roof panels are 351 ft and 400 ft, respectively. These results show that the hazardous range for nominal-size fragments is less than 400 ft, irrespective of the orientation at which they are projected. Similar calculations shown in Figures 12 and 14 for the largest fragments (three times the nominal widths) indicate that the hazardous ranges are increased to 528 ft and 525 ft for the weapon casing and roof panels, respectively.

The estimates of fragment weights and speeds are generally conservative (i.e., resulting in maximal values). With the several conservative assumptions included, we calculate that the hazardous range for fragments is smaller than the 550-ft separation between the weapons assembly and inhabited buildings.



$$F_D = 1/2\, \rho\, C_D A_D (\dot{x}^2 + \dot{y}^2)$$

$$\ddot{x} = -\frac{F_D \cos \alpha}{M}$$

$$\ddot{y} = -\frac{F_D \sin \alpha}{M} - g$$

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Figure 9. Formulas used in SRI UFO algorithm to calculate fragment trajectory and projection distance.

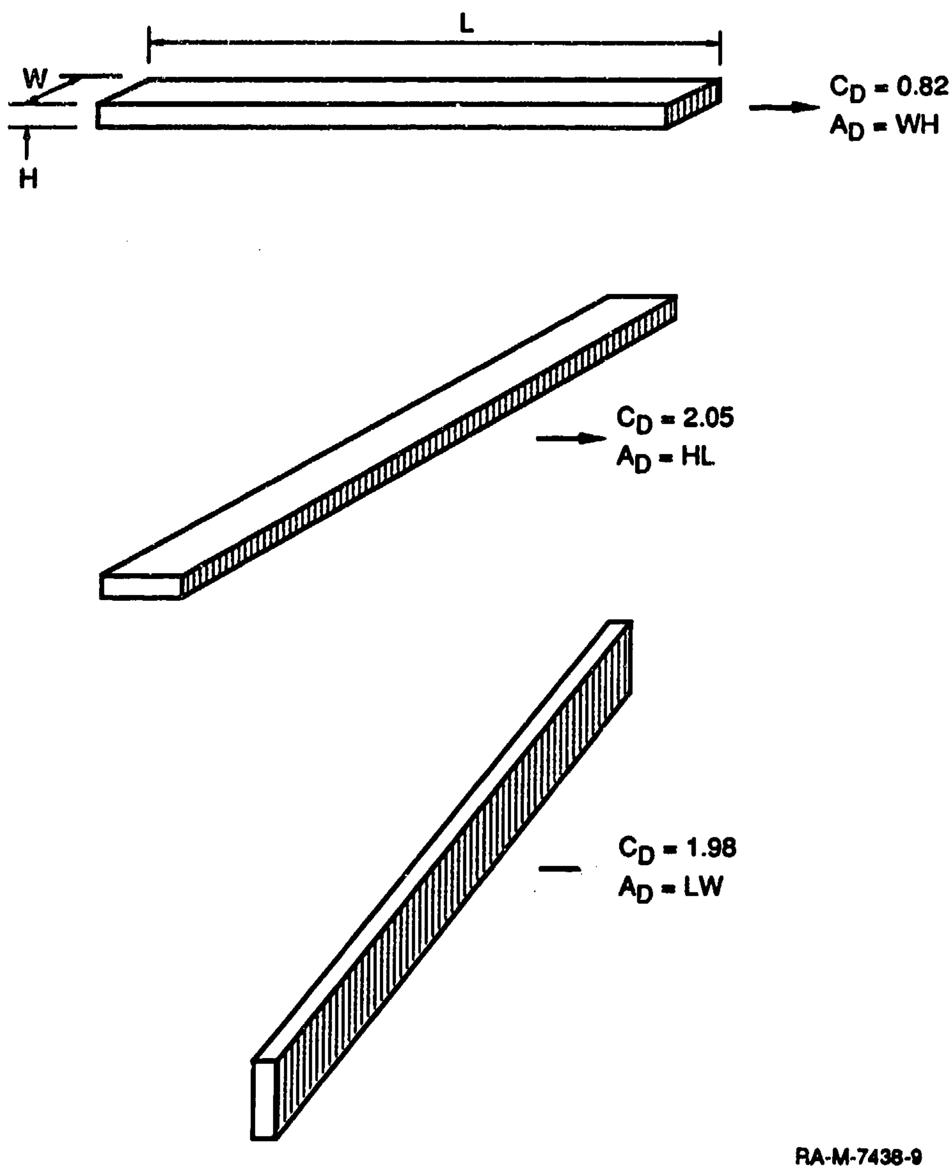


Figure 10. Drag coefficients for strips (Refs. 3 and 4).

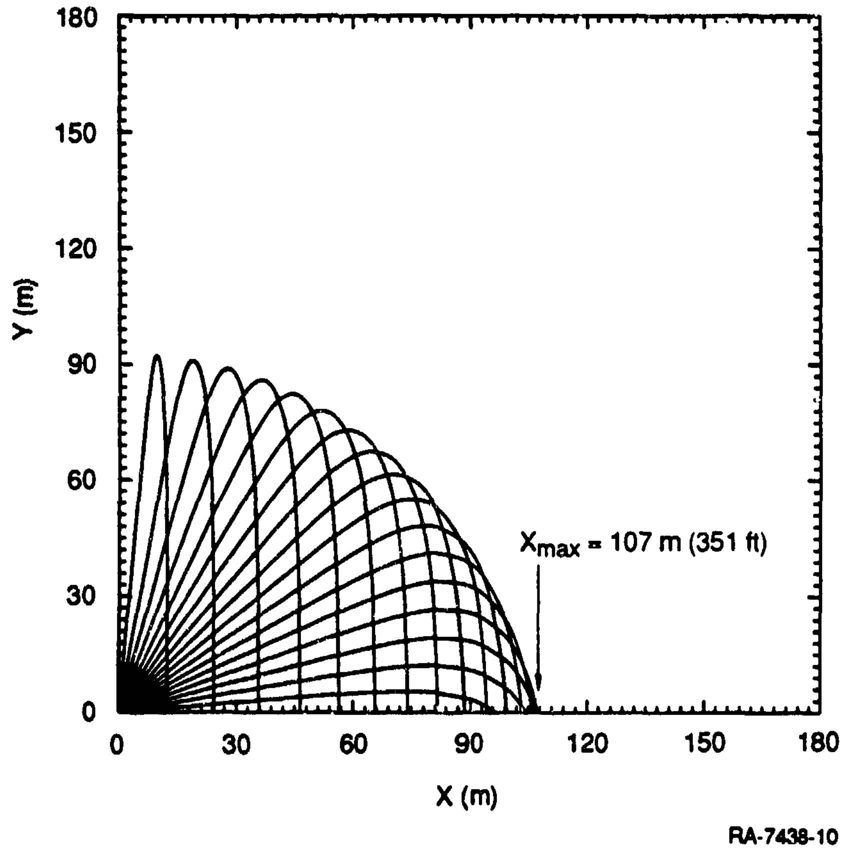


Figure 11. Projection distances calculated for a 0.2-cm-wide, 1.2-m-long steel shell fragment.

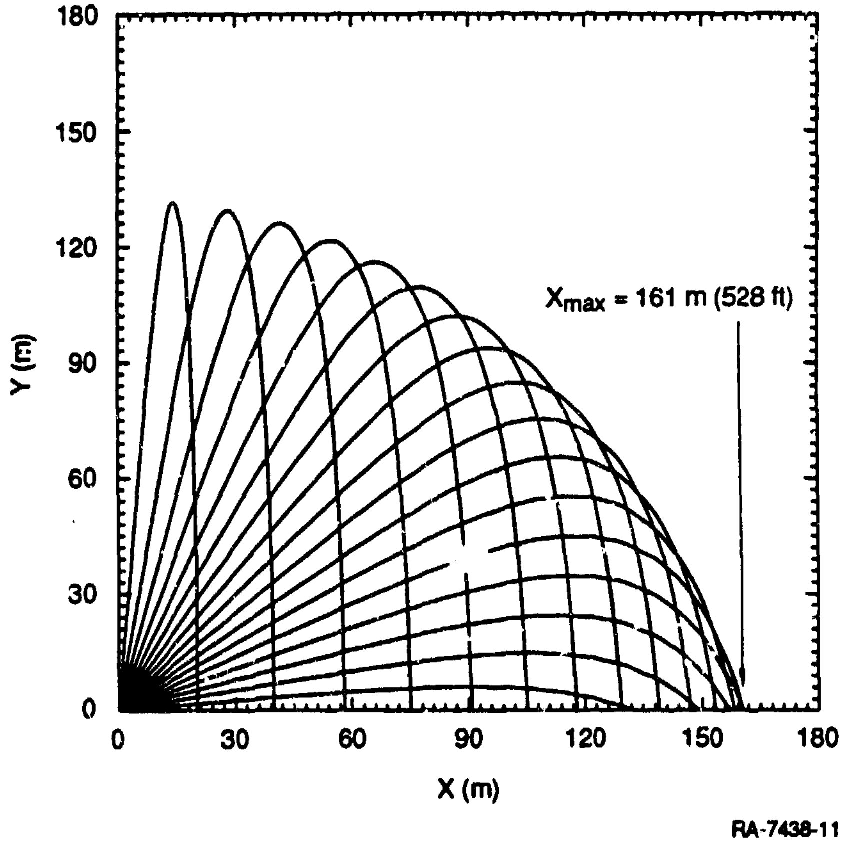


Figure 12. Projection distances calculated for a 0.6-cm-wide, 1.2-m-long steel shell fragment.

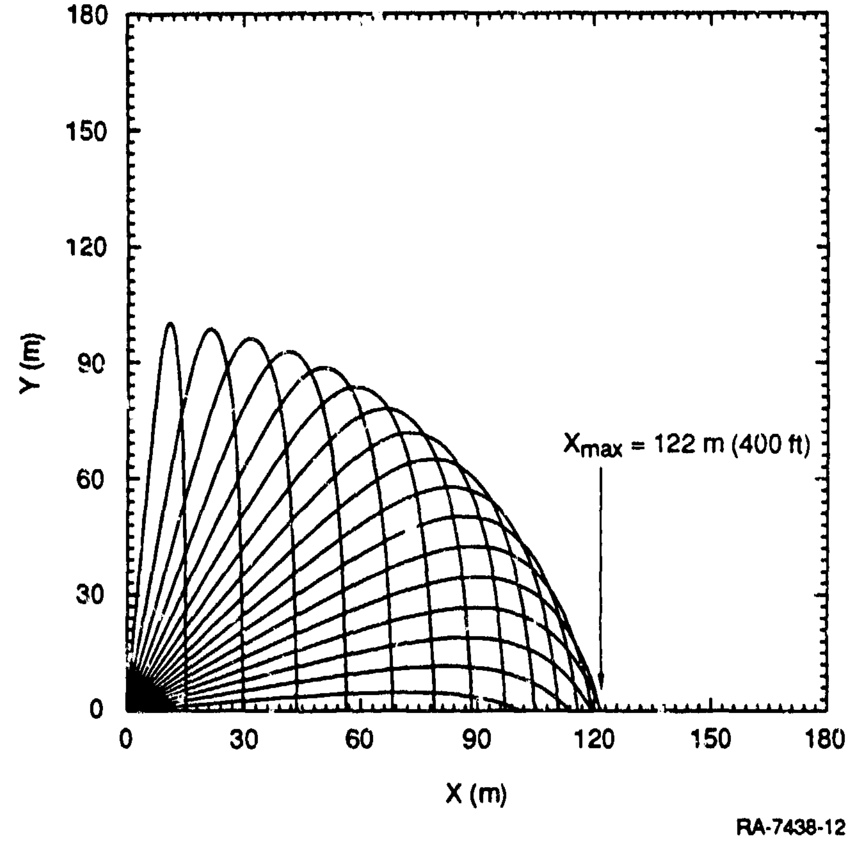


Figure 13. Projection distances calculated for a 1.8-cm-wide, 1.8-m-long roof panel fragment.

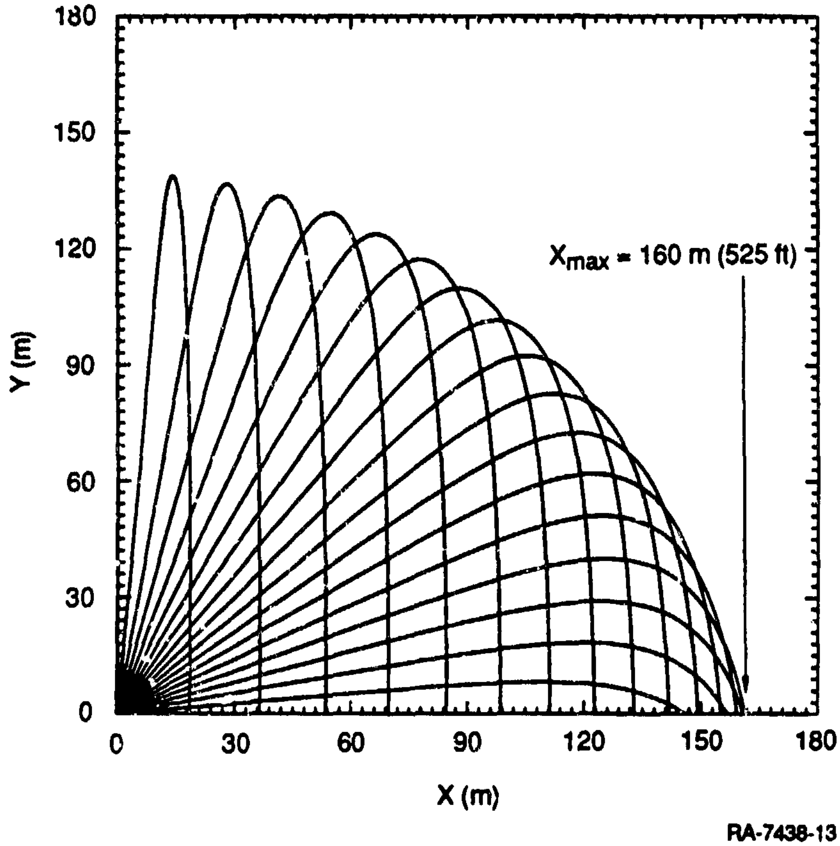


Figure 14. Projection distances calculated for a 5.3-cm-wide, 1.8-m-long roof panel fragment.

CONCLUSIONS

The results of the computer simulation and fragment trajectory calculations discussed in this report show that the 550-ft distance between the inhabited building and the weapon assembly operation is consistent with the safety guidelines provided in the DoD manual for peak blast overpressure and hazardous fragment range. In particular, these calculations have shown that an accidental mass detonation of an equivalent HE charge (2456 lb of TNT) will result in a peak blast overpressure at the inhabited building of about 0.5 psi, which is much less than the 1.2 psi allowed under the current regulations. In addition, calculations performed for fragments produced from the weapon casing and roof panels indicate that the nominal fragment hazardous range is 400 ft and the maximum range is 528 ft, both less than the 550-ft separation between the two buildings.

REFERENCES

(1) N. F. Mott, Proc. R. Soc. Lond. A 189, 300-308 (1947).

(2) D. E. Grady and M. E. Klipp, J. Mech. Phys. Solids 35(1), 95-118 (1987).

(3) W. E. Baker et al., "Workbook for Estimating Effects of Accidental Explosions in Propellant Ground Handling and Transport Systems," NASA Contractor Report 3023, Contract NAS3-20497 (August 1978).

(4) W. E. Baker et al., "Explosion Hazards and Evaluation," Fundamental Studies in Engineering 5 (1983).

APPENDIX

UFO ALGORITHM FOR CALCULATING FRAGMENT PROJECTION DISTANCES

To calculate the fragment projection distances, we wrote a computer algorithm (called UFO) that calculates all the possible trajectories for a fragment with known weight and initial speed. As shown in Figure 9 above, the trajectory of a fragment in free flight depends only on its weight, Mg, and air drag, F_D. Based on Newton's Law, fragment acceleration in the horizontal and vertical directions is given by the formuli in Figure 9, where C_D is the drag coefficient and A_D is the projected area of the fragment on a surface perpendicular to the flight trajectory. Once the values of C_D and A_D are determined, the UFO calculates possible trajectories by changing the initial projection angle from 0 to 90 at one-degree intervals.

We validated the UFO algorithm by comparing it with the classic case of a free flying projectile in vacuum (no air drag). As shown in Figure A-1, the flight trajectory is a parabola for this case. For the projection angle of 45 degrees used in the present calculation, the maximum range should be four times larger than the maximum height, which is seen to be the case in Figure A-1.

Figure A-2 shows how the orientation of the flight trajectory changes with projection distance. The orientation angle changes from +45 degrees to -45 degrees at the initial and final intersections of the flight trajectory with the horizontal ground plane. The orientation angle of zero corresponds to when the projectile has reached its maximum height. As shown in Figure A-3, the kinetic energy of the projectile at this point reaches its minimum value and the potential energy of the projectile (projectile weight times its height above the ground plane) reaches its maximum value.

The UFO algorithm was further validated by comparing it with a similar code discussed in References 3 and 4. Over 5000 UFO calculations were performed to generate the universal curve shown in Figure A-4(a). Every main parameter that influence the maximum projection distance was changed in small steps over a range extending at least one order of magnitude. The parameters included were the drag coefficient, fragment weight, initial speed, and projected area. For each combination of these parameters, the maximum fragment projection distance was calculated by changing the projection angles from 5 to 85 degrees at small intervals. The maximum nondimensional projection distance R [ordinate in Figure A-4(a)] was then plotted against

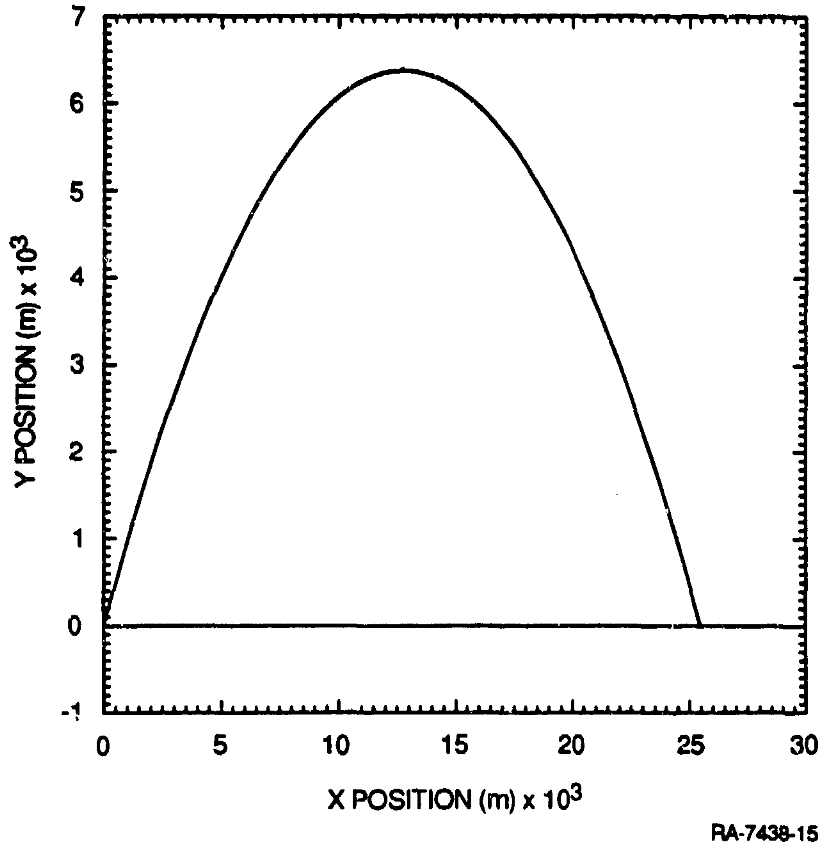


Figure A-1. Trajectory calculation to check SRI UFO algorithm ($C_D = 0$, $\alpha = 45°$).

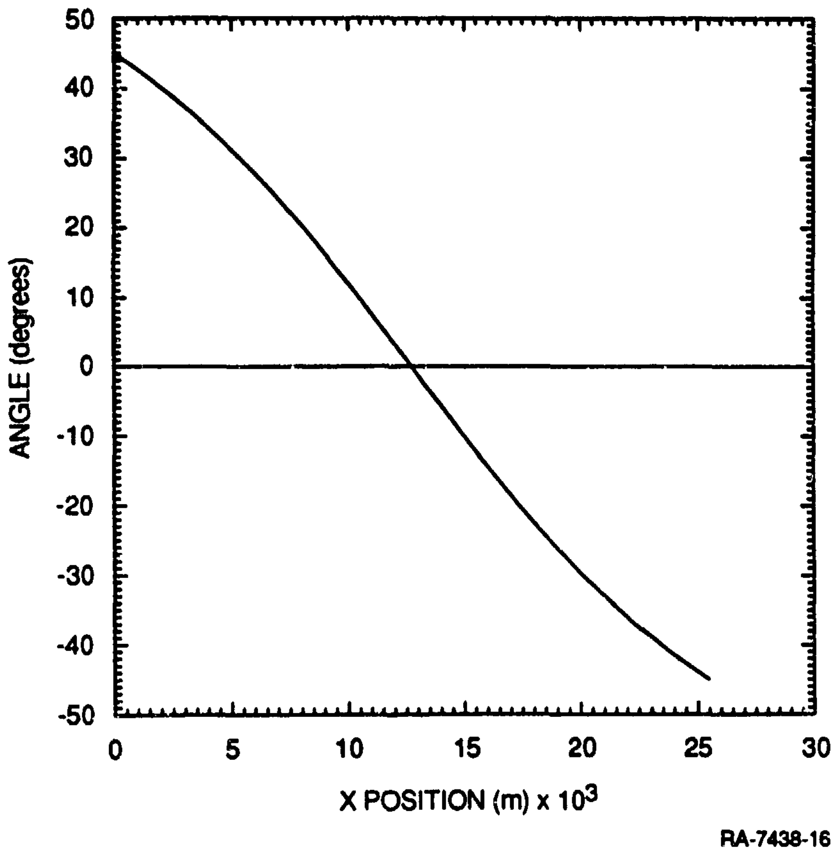


Figure A-2. Variation of trajectory angle with distance ($C_D = 0$, $\alpha = 45°$).

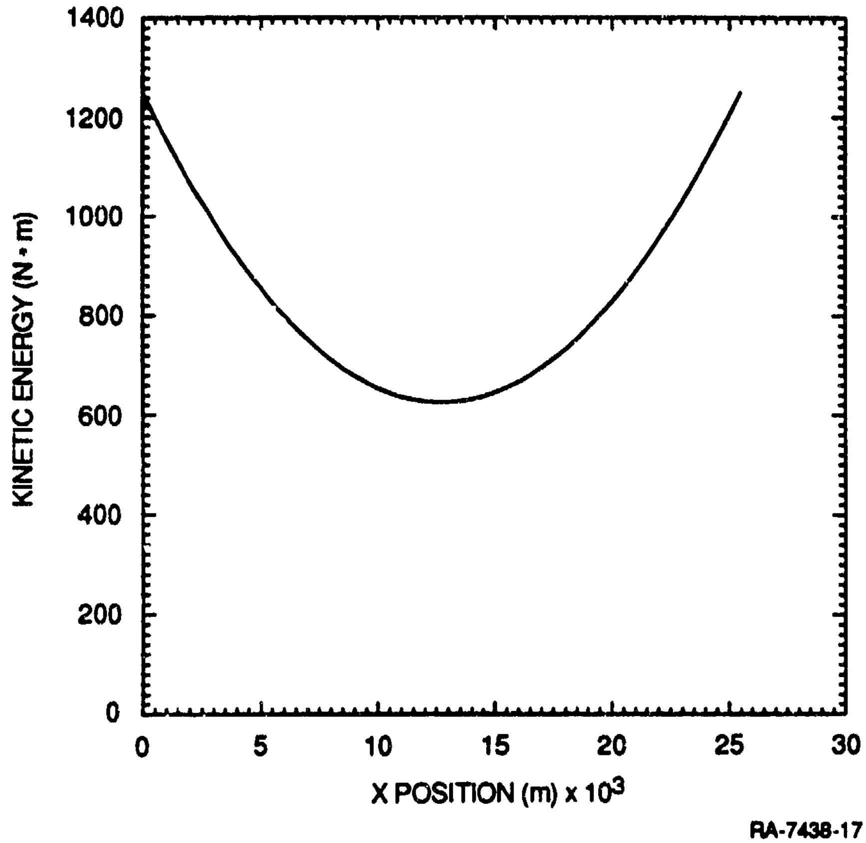
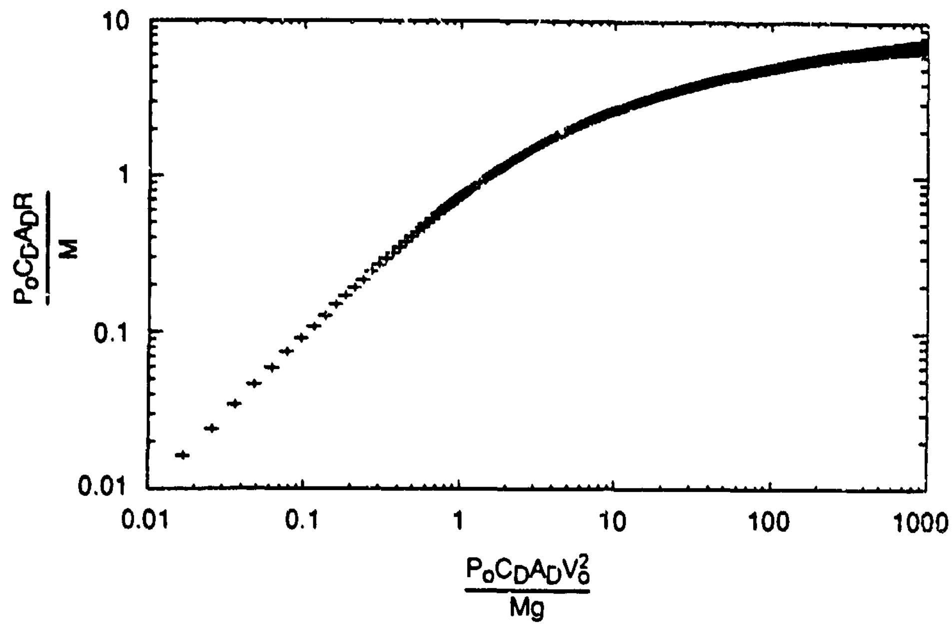
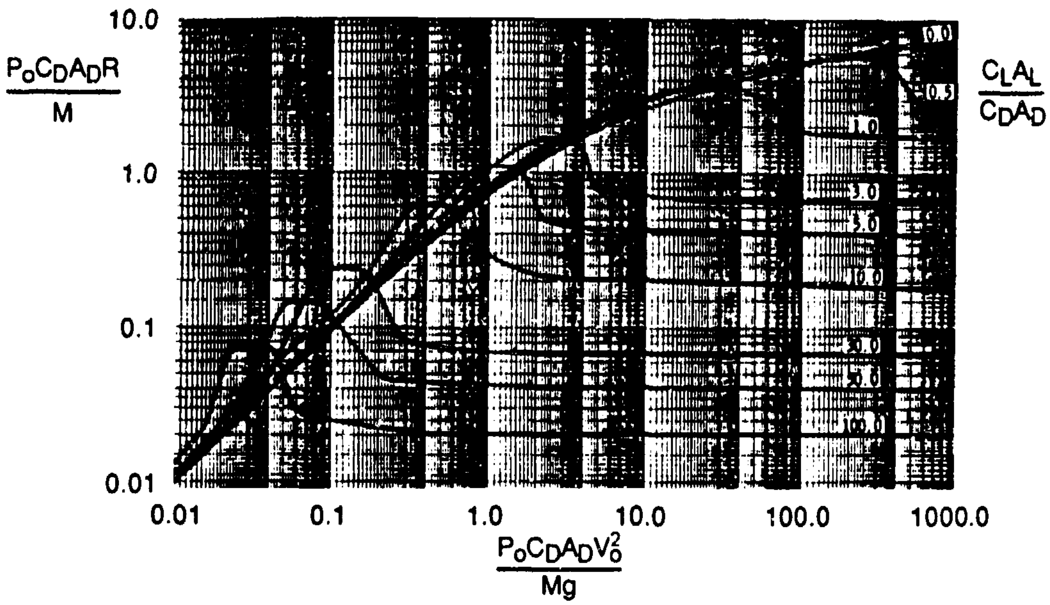


Figure A-3. Variation of fragment kinetic energy with distance (C_D = 0, α = 45°).



(a) SRI UFO calculation



(b) NASA FRISBEE calculations (Ref. 3)

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Figure A-4. Fragment maximum projection distances predicted by NASA FRISBEE and SRI UFO algorithms.

another nondimensional parameter that includes the square of the initial projectile speed. The UFO algorithm predicts that the nondimensionalized range increases monotonically with the initial speed and approaches a plateau of 10.

Results of similar calculations reported in Reference 3 are shown in Figure A-4(b). If superimposed, the central curve that is marked 0.0 exactly overlays the UFO curve. This 0.0 number signifies the ratio of the lift to drag coefficients, which is assumed to be zero for the UFO calculations. Incidentally, note that the calculations with finite drag coefficients result in a smaller projection distance, indicating that the assumption of zero lift coefficients made in the UFO results in conservative (greater) fragment projection distances.

RESPONSE SPECTRUM OF STRONG EXPLOSION SEISM AND SEISMIC FORCE CALCULATION UNDER LINEAR CHARGE

Li Zheng
(Engineering Disign and Research Institute, Beijin, China)

Yang Shengtian
(Institute of Engineering Mechanics, State Seismological Bureau, Harbin, China)

Abstract

In This paper, acceleration response spectrum of neer-field strong explosion seism under linear charge ($l/d \leq 20$, l, d — length and diameter of linear charge)and calculation method for seismic force are given according to the explosion seismic acceleration date measured at near-field in the media of granite, conglomerate and yellow soil, and date of building response measured from single-storey and multi-storey buildings.

Keywords: acceleration response spectrum of explosion seism, seismic force of explosion.

1. FORWORDS

In the field of damage analysis and safety evaluation of seismic effect caused by explosion on the building, the best relativity is exisiting between maximum perpendicular speed of earth surface and damage of buildings, and the stresses are provided by wave propagating within medium. The perpendicular speed of vibration of earth surface is adopted as standard evaluation by China and most of other countries. Actual data indicate that single layer reinfoce concrete workshop under $v_{\perp} < 25$ cm/s or single layer brick buildings under $v_{\perp} < 15$ cm/s appear no such damages which are able to influence the safety of buildings and that civil buildings(including multi-storey and high-rise buildings)under $v_{\perp} \leq 5$cm/s cause only cracking and falling of root mortar. This kind of evaluation of seismic effect of explosion is satisfactory in engineering practice in far-field. As the method posseses only one control index, it is impossible to consider the influences of properties of explosion source (quantity of explosion, shape of charge, characteristics of explosion), geological conditions of explosion field and buildings, and dynamic feartures of builgings (size, material, structure), so, the evaluation results are rather macroscopic and rough, and can't be used for satisfactory design of proof seism of explosion. In order to work out the calculating method of seismic force of explosion, some numerical technique such as finite element method may be used and also response spectrum of natural earthquake may be used for calculating the response spectrum of explosion seism and then makes a dynamic analysis to buildings.

up to now as to the knowledge of the authors, no research report or paper has been found both in China and abroad, which dealt with accelerate response spectrum of near-field explosion seism for linear charge (l/d <14—20, l, d—length and diameter of linear charge), and propertional distance $\bar{R}=R/W^{1/3}<2m/Kg^{1/3}$. In this paper, research are carried out on acceleration response spectrum of strong explosion of linear charge in near field ($\bar{R}<2m/Kg^{1/3}$), in which buildings are set up according to the actual arrangements of industry, and the seismic effects of explosion on building are measured. Threfore the calculating problems of seismic force of explosion are solved.

2 ARRANGEMENT OF FIELD AND MEASURING POINTS

Experiments are made on geological conditions — granite medium, conglomerate medium and yellow soil medium. The physical mechanical targets of media are shown in table 1.

Tunnels of charge are digged in hills of granit, conglomerate and yellow soil, and alleys are digged for arranging the measuring points in the perpendicular and paraller directions of the tunnels. The ground surface of alleys and tunnels are at the same horizontal level. the mesuring points of acceleration of explosion seismic wave are on the earth surface of alley and in the range of propertional distance $\bar{R}=$ 0.2134—2.0759$m/Kg^{1/3}$ (equal to the quantity of charge $\bar{Q}$=4.6860—0.4817 $kg^{1/3}/m$), Tere are 156 points in all.

The energy of explosion is equivalent to 1.69 — 3.50 times of that of natural earthquake.

3 CALCULATION OF ACCELERATION RESPONSE SPECTRUM OF STRONG EXPLOSION SEISM FOR LINEAR CHARGE

While the menmade explosion takes place generally in shallow layer of earth sueface, energy is smaller, time of vibration maintains shorter, decay is faster, vibrating frequency is higher, energy of explosion seism concentrates on high frequency zone (>10 Hz), wave figure of explosion seism hase features of impact vibration, the natural earthquake normally takes place in deep layer of earth surface, energy is larger, time of vibration maintains longer, decay is slower, vibrating frequency is lower, energy of earthquake concentrates on low frequency(< 10 Hz), wave figure has the features of random vibration. Never the less, both of them have the same vibrating equation and similar mechanism of damage to building. Thus, it is possible to extend the method of calculation of earthquake force from acceleration response spectrum to seismic force of explosion. In this paper, single particle system is researched.

The kinetic equation of single particle system is

$$\ddot{x} + 2\xi\omega^{1}\dot{x} + \omega x = -a(t) \qquad (1)$$

where ξ, damping ratio

ω, circular frequency of self-vibration of single partical system

assume that acceleration a(t) changes in the form of straght line between t_i and t_{i+1}, equation (1) can be rewritten in the incremental form

$$\ddot{x} + 2\xi\omega\dot{x} + \omega^{1}x = -a_i - \frac{\Delta a_i}{\Delta t_i}(t-t_i) \qquad (2)$$

where

$$\Delta t_i = t_{i+1} - t_i$$
$$\Delta a_i = a_{i+1} - a_i \qquad (3)$$

then, the solution of equation (2) is

$$x = e^{-\xi\omega(t-t_i)}[c_1\sin\omega\sqrt{1-\xi^{1}}(t-t_i) + c_2\cos\omega\sqrt{1-\xi^{1}}(t-t_i)]$$
$$-\frac{a_i}{\omega^2} + \frac{2\xi}{\omega^3}\frac{\Delta a_i}{\Delta t_i} - \frac{1}{\omega^2}\frac{\Delta a_i}{\Delta t_i}(t-t_i) \qquad (4)$$

where $t=t_i$; $x=x_i$; $\dot{x}=\dot{x}_i$, the integral constants are

$$c_1 = \frac{1}{\omega\sqrt{1-\xi^{1}}}[\xi\omega x_i + \dot{x}_i - \frac{2\xi^2-1}{\omega^2}\frac{\Delta a_i}{\Delta t_i} + \frac{\xi}{\omega}a_i] \qquad (5a)$$

$$c_2 = x_i - \frac{2\xi}{\omega^3}\frac{\Delta a_i}{\Delta t_i} + \frac{a_i}{\omega^2} \qquad (5b)$$

Insert constants c_1 and c_2 in equation (4) and at $t=t_{i+1}$, the distance x and speed $\dot{x}$ are

$$\bar{x}_{i+1}=A(\xi,\ \omega,\ \Delta t_i)\bar{x}_i + B(\xi,\ \omega,\ \Delta t_i)\bar{a}_i \qquad (6a)$$

where

$$\bar{x}_i=[x_i \quad \dot{x}_i] \qquad \bar{a}_i=[a_i \quad a_{i+1}]^T \qquad (6b)$$

$$A=\begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} \qquad B=\begin{vmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{vmatrix} \qquad (6c)$$

coefficients $a_{11}, a_{12}, a_{21}, a_{22}, b_{11}, b_{12}, b_{21}, b_{22}$ are fuctions of ξ, ω, Δa_i, and their mathematical expressions are

$$a_{11}=e^{-\xi\omega\Delta t_i}\left(\frac{\xi}{\sqrt{1-\xi^2}}\sin\omega\sqrt{1-\xi^2}\Delta t_i+\cos\omega\sqrt{1-\xi^2}\Delta t_i\right) \qquad (7a)$$

$$a_{12}=\frac{e^{-\xi\omega\Delta t_i}}{\omega\sqrt{1-\xi^2}}\sin\omega\sqrt{1-\xi^2}\Delta t_i \qquad (7b)$$

$$a_{22}=e^{-\xi\omega\Delta t_i}\left(\cos\omega\sqrt{1-\xi^2}\Delta t_i-\frac{\xi}{\sqrt{1-\xi^2}}\sin\omega\sqrt{1-\xi^2}\Delta t_i\right) \qquad (7c)$$

$$b_{11}=e^{-\xi\omega\Delta t_i}\left[\left(\frac{2\xi^2-1}{\omega^2\Delta t_i}+\frac{\xi}{\omega}\right)\frac{\sin\omega\sqrt{1-\xi^2}\Delta t_i}{\omega\sqrt{1-\xi^2}} + \left(\frac{2\xi}{\omega^3\Delta t_i}+\frac{1}{\omega^2}\right)\cos\omega\sqrt{1-\xi^2}\Delta t_i\right]-\frac{2\xi}{\omega^3\Delta t_i} \qquad (7d)$$

$$b_{12}=-e^{-\xi\omega\Delta t_i}\left[\left(\frac{2\xi^2-1}{\omega^2\Delta t_i}+\frac{\xi}{\omega}\right)\frac{\sin\omega\sqrt{1-\xi^2}\Delta t_i}{\omega\sqrt{1-\xi^2}} + \frac{2\xi}{\omega^3\Delta t_i}\cos\omega\sqrt{1-\xi^2}\Delta t_i\right]-\frac{1}{\omega^2}+\frac{2\xi}{\omega^3\Delta t_i} \qquad (7e)$$

$$b_{21}=e^{-\xi\omega\Delta t_i}\left[\left(\frac{2\xi^2-1}{\omega^2\Delta t_i}+\frac{\xi}{\omega}\right)\left(\cos\omega\sqrt{1-\xi^2}\Delta t_i-\frac{\xi}{\sqrt{1-\xi^2}}\cdot\sin\omega\sqrt{1-\xi^2}\Delta t_i\right)-\left(\frac{2\xi}{\omega^3\Delta t_i}+\frac{1}{\omega^2}\right)\left(\omega\sqrt{1-\xi^2}\sin\omega\cdot\sqrt{1-\xi^2}\Delta t_i+\xi\omega\cos\omega\sqrt{1-\xi^2}\Delta t_i\right)\right]+\frac{1}{\omega^2\Delta t_i} \qquad (7f)$$

$$b_{22}=-e^{-\xi\omega\Delta t_i}\left[\frac{2\xi^2-1}{\omega^2\Delta t_i}\left(\cos\omega\sqrt{1-\xi^2}\Delta t_i-\frac{\xi}{\sqrt{1-\xi^2}}\sin\omega\sqrt{1-\xi^2}\Delta t_i\right)-\left(\frac{2\xi}{\omega^2\Delta t_i}+\frac{1}{\omega^2}\right)\left(\omega\sqrt{1-\xi^2}\sin\omega\sqrt{1-\xi^2}\Delta t_i+\xi\omega\cos\omega\sqrt{1-\xi^2}\Delta t_i\right)\right]-\frac{1}{\omega^2\Delta t_i} \qquad (7g)$$

At arbitrary time t_i, the absolute acceleration $\ddot{z}_i$ is the sum of earth surface acceleration and acceleration of single particle system, that is

$$\ddot{z}_i=\ddot{x}_i+a_i=-(2\xi\omega\dot{x}_i+\omega^2x_i) \qquad (8)$$

If distance x_i and speed $\dot{x}_i$ at time $t=t_i$ are known, the distance x_{i+1} and speed $\dot{x}_{i+1}$ at time $t=t_{i+1}$ can be calculated from equation (6a), then, the acceleration $\ddot{x}_{i+1}$ can be calculated from equation (8)

At the beginging of explosion seism, the single particle system is in static state, that is, the initial conditions are $x_0=0, \dot{x}_0=0$. repeat using equation (6a) and (8), the seismic response of single partical system can be worked out step by step. In order to guarantee the accuracy of results calculation, the length of time step should be chosen in such that $\Delta t\leq T/10$ (T--natural period of vibration of single partical system), and in this paper, the length of calculating step is chosen $\Delta t=2\times10^{-4}$ second.

In order to diminishing calculating error, the measured time equations of acceleration (a-t figure) are changed into numerical time equations (a-t fiqure). Inputting them into computer, acceleration response spectrum of strong explosion seism for linear charge can then be accuratly calculated. The main results of calculation are introduced below.

1. The individual measured curve of time equation of acceleration is inputted to computer and acceleration response spectrum of explosion seism for linear charge can be calculated under different damping factor such as shown in figure 1.

2. In the medium of granite, the acceleration response spectrums of of near-field strong explosion seism for linear charge are shown in figure 2.

3 The acceleration response spectrum in perpendicular, horizontal radial and horizontal tangential directions are shown in Fig.3, which indicate the near-field strong explosion seism for linear-charge in medium of granite.

4 Under different damping factor, the acceleration response spectrum

of near-field strong explosion seism for linear charge are shown in Fig.4.

5.On different geological conditions (yellow soil, granite, conglomerate), the acceleration response spectrums of near-field strong explosion seism are shown in Fig.5.

6 The acceleration response spectrums under different blasting are shown in figure 6.

Following features of acceleration response spectrum of near-field strong explosion seism for linear charge can be found from the results of calculation shown above,

1. The features of response spectrum

The shape of acceleration response spectrum curve of near-field strong explosion seism is similar to the shape of acceleration response spectrum of natural earthguake, both have a mainpeak, and as envelop line is taken, the peak is changed into a platform and decayed in the form of hyperbola with the increasing of period. The trend of outline of response spectrum is related to acoustic impedance of rock and soil. The smaller the acoustic impedance, the longer moving of peak position in direction of big values of period, that is the width of platform becomes wider. The width of platform is smaller than 0.1 second, in the acceleration response spectrum of near-field strong explosion seism for linear-charge. The position of mainpeak of response spectrum is about the dominate period of rock and soil of earth surface.

2. Influence of horizontal and perpendicular vibration to response spectrum

As shown in Fig.3. the shape, trend and numrical value of both radial and tangential acceleration response spectrum are similar to that of perpendicular acceleration response spectrum, and the curve of perpendicular acceleration reponse spectrum of seism is a little bit bigger than that of both radial and tangential acceleration response spectrum. When the response spectrum is made for design, response spectrums of radial, tangential and perpendicular are sumed up and eventop line is taken, so, influence of radial, tangential and perpendicular vibration have been considered.

3. The influence of damping

As shown in Fig.4, the value of response spectrum peak decreases dastically as the damping factor increasing. For instance, the peak value under damping factor $\xi=0.5$ is about half of the peak value under damping factor $\xi=0$.This indicates that damping has a remarkable effect on decreasing explosion seism. Actulally, damping is related to structure as well as material, and the damping factor increases with the increasing of deformation of foundation, that is the damping factor is related to interaction between rock or soil and structure, so, normally, the value of damping factor is obtained by experiment.

4. The influence of geological conditions to the response spectrum

As shown in Fig.5, the value of response spectrum is the biggest in yellow soil, then in granite and the least in conglomerate. This means the bigger the acoustic impedance of rock and soil, the smaller the peak value of response, and the smaller the seismic force of explosion to building.

5. The influence of blasting forms to response spectrum

As shown in Fig.6, the value of acceleration response spectrum is the biggest under directional blasting, intermediate under tunnel blasting for linear charge and the least under loosing blasting, so, when the seismic force of explosion is colculated the acceleration response spectrums should be used according to forms of blasting and then the accuracy of calculation can be raised. Under the same form of blasting and geological condition, the value of acceleration response spectrum of near-field is bigger than that of far-field. Nowdays, in China, the data of research about acceleration response spectrum is more in far-field and less in near-field. If the acceleration response spectrum of far-field is used to near-field, the calculated seismic force is smaller, and it may cause results unsafe.

4 THE CALCULATION OF SEISMIC FORCE OF EXPLOSION

As mentioned above, the seismic effect of explosion can be studied with the helps of methods that are used in studying the effects of natural earthquake, when the response spectrum of explosion seism has been worked out, the seismic force of explosion can be calculated directly.

For the single degree of freedom system, the shearing force which acts on the foundation of system is the same as the maximum intertial force which acts on system. In practical application of engineering, the seismic force acted on single particle system can be written in the following form,

$$F = m\ddot{z} = m\,|\ddot{x} + \ddot{\delta}_g|_{max} = \frac{|\ddot{\delta}_g|_{max}}{g} \cdot \frac{|\ddot{x} + \ddot{\delta}_g|_{max}}{|\ddot{\delta}_g|_{max}} \cdot W = k\alpha W \qquad (9)$$

K, seismic coefficient, $k = |\ddot{\delta}_g|_{max} / g$, ratio of maxmum horizontal acceleration of explosion over acceleration of gravity

α, dynamic coefficient, $\alpha = |\ddot{x} + \ddot{\delta}_g|_{max} / |\ddot{\delta}|_{max}$ ratio of maximum acceleration of single particle system over maximum acceleration of earth surface under the seicmic effect of explosion

δ_g, moving distance of earth surface

W, total weight of buildings which produce explosion seismic load.

equation (9)becomes

$$F = \beta W \tag{10}$$

where β, influence coefficient, $\beta = k\alpha$, the β-curve of near-field strong explosion for linear charge is shown in Fig.7.

In fact, during the process of explosion, plastic deformation is allowed in the structrue, and at the same time, the unload effect takes place in the structure, this them reduces the seismic force acted on structures.so it is necessary that the equation (10) is multiplied by a struture influence coefficient c which is smaller than 1. The value of coefficient is related to the premitting deformation and ductility of structure. In normal case, $c = 1/\mu \sim 1/\sqrt{2\mu - 1}$ (μ- ductility factor). when $\mu = 3-5$, $c = 0.45 \sim 0.35$ so the equation (10) becomes

$$F = c\beta w \tag{11}$$

where c, structure influence coefficient

reinforced column c=0.35

brick column c=0.40

reinforced concrete arch c=0.35

multi-storey house c=0.40

According to the arrangement of industrial production, single-storey and multi-storey buildings are set up in near field-propertional distance $\bar{R} \leq 2.0$ m/kg$^{1/3}$, and when the linear charge is explosion, the seismic force of explosion acted on building are measured.Becaus some favorable factors, such as inhibition of foundation and buildings to moving of foundation, interaction between foundation and bualdings and reducing effect of structure measures of anti-shock bualdings to effect of seismic damage can not be expressed in mathematics form, so us the ratio of explosion seismic force calculated by equation (11) over measured explosion seismic force is 1/2 to 1/4, it suites the reason why comprehensive influence coefficiente need to be considered.

Rewrite the equation (11) in normal engineering form,

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$$Q_o = c \beta \eta W \quad (12)$$

where Q_o, shearing force on the foudation of structure 10N

c, structure influence coefficient, seeing equation (10)

β, explosion seismic influence coefficient seeing Fig.7.

η, comprehensive influence coefficient

brick column $\eta = 1/2$

reinforced concrete arch $\eta = 1/4$

multi-storey house $\eta = 1/2.5$

W, total weight of buildings which produce explosive seismic load T

$$W = \sum_{i=1}^{n} W_i \quad (13)$$

The horizontal seismic load of particle i is

$$P_i = \frac{W_i H_i}{\sum_{i=1}^{n} W_i H_i} Q_o \quad (14)$$

W_i, weight which concentrated on particle i T

H_i height of particle i

The explosion seimic force of multiple degree of freedom system can be calculated with the principle of supeposition.

The horizontal seismic load of particle i in viberating mode j of structure is

$$P_{ji} = c \beta_j \gamma_j x_{ji} \eta W_i \quad (15)$$

(number of particle i=1, 2…n; number of mode of viberation j=1, 2, …m)

where P_{ji}, horizontal seismic load of particle i in viberating mode j of structure

β_j, seismic influence coefficient which correspouds with natural period T_j of vibrating mode j of structure, seeing Fig.7

X_{ji}, relative horizontal moving distance of particle i in vibrating mode j of structure

γ_j, joining coefficient of vibrating mode j of structure

$$\gamma_j = \frac{\sum_{i=1}^{n} x_{ji} W_i}{\sum_{i=1}^{n} x_{ji}^2 W_i} \quad (16)$$

c, η, seeing equation (11)

W_i seeing equation (14)

In the point i of structure, as the maximum inner forces produced by each vibrating mode j don't take place at the same time and according to the research of response of earthquake inprobability, the squar root of sum of squares of maximum inner forces of each mode of vibration in point i can be taken as the maximum response of earthquake on point i. So, under the seismic load of horizontal explosion, the structure inner forca S_i produced in point i can be written in the general form

$$S_i = \sqrt{\sum_j S_{ji}^2} \quad \text{(number of mode of vibration } j=1, 2, 3 \cdots m;$$

in normal case j=1, 2, 3) (17)

shearing force at point i

$$Q_i = \sqrt{\sum_j (\sum_{i=1}^{i} P_{ji})^2} = \sqrt{\sum_j [\sum_{i=1}^{i} \beta_j \gamma_j x_{ji} \eta W_i]^2}$$

$$= \sqrt{\sum_j Q_{ji}^2} \quad (i=1, 1, \cdots n) \quad (18)$$

shearing force in foundation

$$Q_0 = \sqrt{\sum_j (\sum_{i=1}^{n} P_{ji})^2} = \sqrt{\sum_j [\sum_{i=1}^{n} c \beta_j \gamma_j x_{ji} \eta W_i]^2}$$

$$= \sqrt{\sum_j Q_{j0}^2} \quad (i=1, 1, \cdots n) \quad (19)$$

bending moment at point i

$$M_i = \sqrt{\sum_j M_{ji}^2} \quad (i=1, 2 \cdots n) \quad (20)$$

bending moment in foundation

/ /

$$M_{i}=\sqrt{\sum_{j} M_{ij}^{2}} \qquad (j=1, 2, \cdots n) \qquad (21)$$

Equation (17) is called equation of canbination of modes of vibration of square root of sum of squares, when bigger intervals are among the former values of frequency of mode of vibration, satisfactory results can be obtained, otherwise error is bigger. The guaranteed efficiency of the canbination method of modes of vibration is more than 96%.

The conbination methods of modes of vibration are different in different countries. In different countries. In Japan thr maximum inner force is taken the sum of obsolute value of maximum response of each mode vibration, and it is absolutly safe. American professor N.M. Newmark points out if the numbers of freedom in system are less than four, the inner force under the effect of natural earthquake is very close to (only a little bit smaler) the sum of obsolute maximum value; If the numbers of freedom degree in system are more than twelve, the inner force under the effect natural earthquake is very close to square root of sum of square of maximum value and if the numbers are between four and twele, the real ineer force is among the values calculated by this two method.

If the method of square root of sum of squares is directly used to calculate the maximum seismic load of explosion equation (15) becomes

$$P_{i}=c\,\eta\,W_{i}\sqrt{\sum_{j}\left[\beta_{j}\gamma_{j}X_{ij}\right]^{2}} \qquad (22)$$

and using the load calculated by equation (22) to calculate the inner force of system, this seismic effect is bigger than the seismic effect calculated by equation (11). There are two reasons for this difference, one is that the modes of vibration except the first mode are alternately changed between positive and nagtive along the height, but equation (22) doesn't express this change feature; The other is that the relation isn't linear relation between structure stress and load, so, it is much more accurate and strict that using the method of square root of sum of squares calculates the inner firce than that using the method of squares root of sum of square calculates load and then calculates inner force.

5. MAIN CONCLUSION

1. According to practical requires of industrial production, experiments of explosion for linear charge have been made. Plenty of accele-

ration figure of near-field strong explosion seism are abtained in media of granit, conglomerate and yellow soil, when the figures are inputted to computer, the accelerate response spectrum of near-feild strong explcsion seism for linear charge can be calculated. This is most meaning for both in theory and in practice for calculating the seismic force of explosion on buildings in near-field($\bar{R} \leq 2m/Kg^{1/3}$ and designing proof seism of explosion, so the buildings in near-field explosion are ensured.

2. According to measurement and theoretical analyses of seismic force on single -storey and multi-storey buildings in near-field of explosion seism for linear charge, the comprehensive influence coefficients which are used in calculating equation of seiamic force of explosion are determined for singl-storey and multi-storey buildings. It is very important for quantitative calculation of seismic force of explosion. The error of calculating seismic force of explosion in this paper compared with measuring seismic force of explosion is about 20—30%.

REFERENCE

(1). Yang Shengtian, Zhai Tong, Qu Chuanjun, Wang Jichun, Response spectrum of near-field linear charge for design of shock proof structure. research report of Institute of Enginnering Mechanics, State Seismological Bureau, China, 1989.

(2). Li Guohao, Shock proof mechanics of engineering structure (chinese) pp 94-96, Shanghai science and technology publicatopn, 1981.

Table 1 The physical mechanical targets of media*

physical mechanical name targets	specific gravity g/cm³	dry volume gravity g/cm³	porosity %	compressive strength kg/cm²	tensile strenge kg/cm²	elastic modle kg/cm²	Poisson ratio	adhesive force kg·cm²	friction angle degree
granic	2.65	2.95	2.30	960	22.90	1.4×10^{5}	0.20	162	41.6
conglomerate		2.58		572	11.00	4.75×10^{5}	0.22		
soil Q_4		1.55	0.84			2.667×10^{3}	0.309	0.23	27.5
Soil Q_3						2.083×10^{3}	0.312	0.39	27.8

* The numbers in table are direct results of testing

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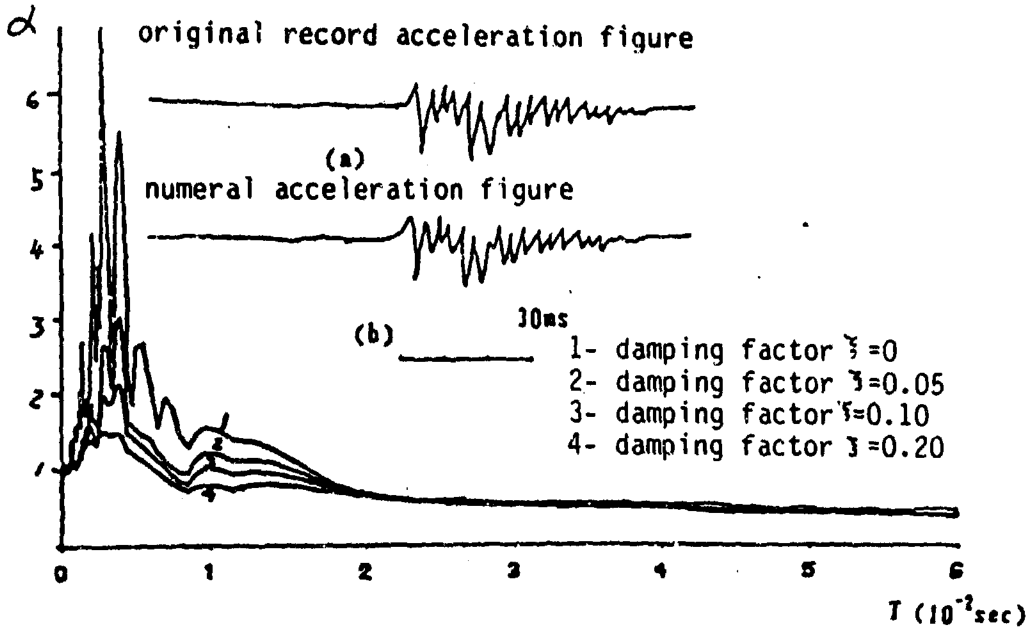

Fig. 1 The acceleration response spectrum of explosion earthquake in granite medium

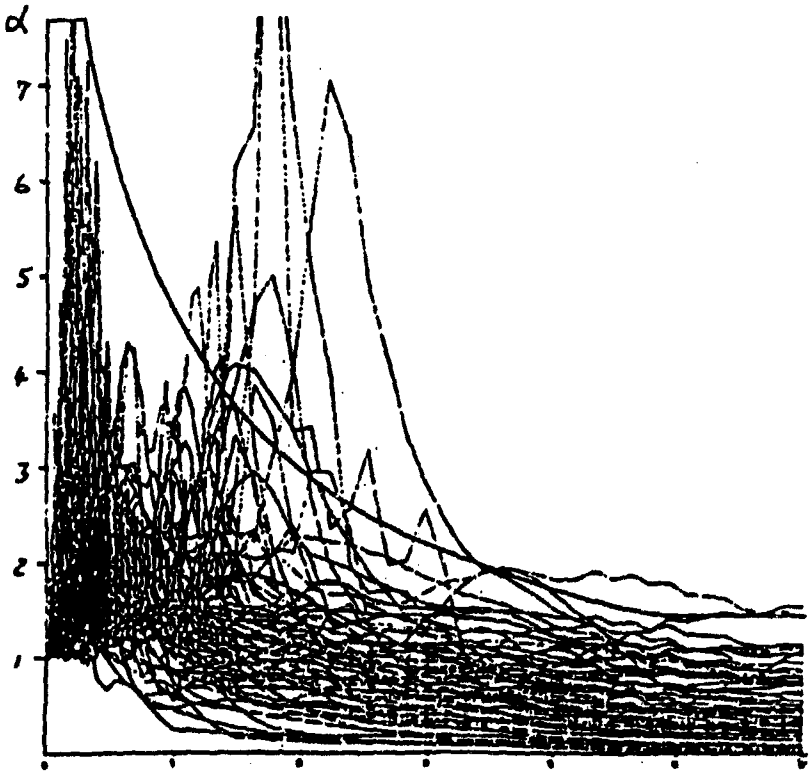

Fig. 2 The acceleration response spectrum of near-field explosion earthquake for linear charge in granite medium

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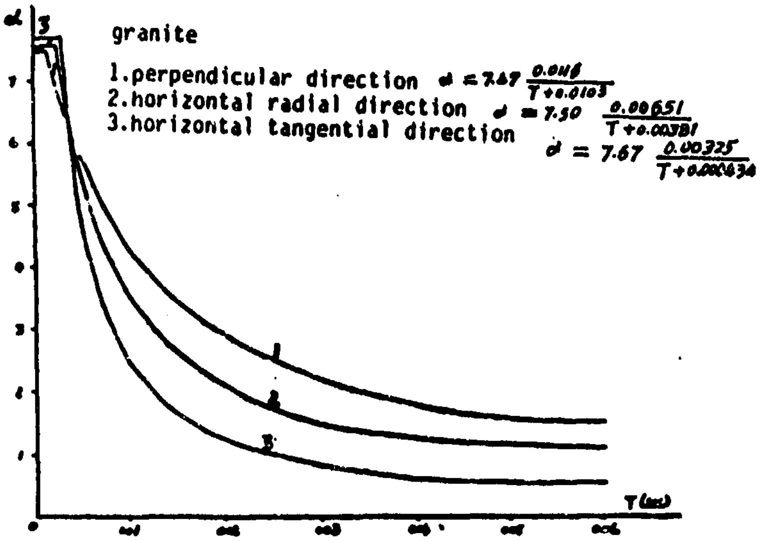

Fig.3 The acceleration response spectrum in the direction of horizontal radial, tangential and perpendicular line (damping factor ξ =0)

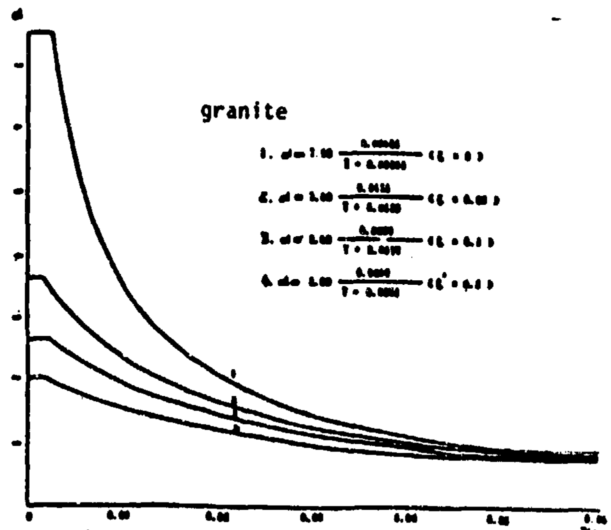

Fig.4 The acceleration response spectrum in different damping factor

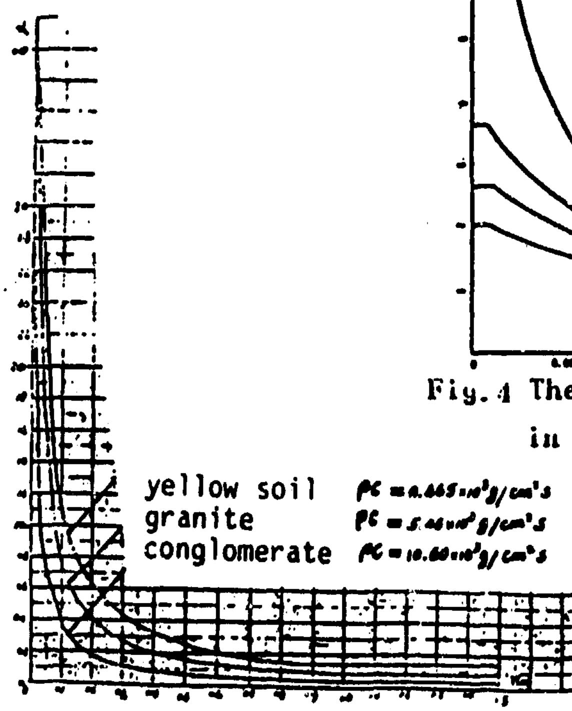

Fig.5 The acceleration response spectrum about granite conglomerate and yellow soil (damping factor ξ =0)

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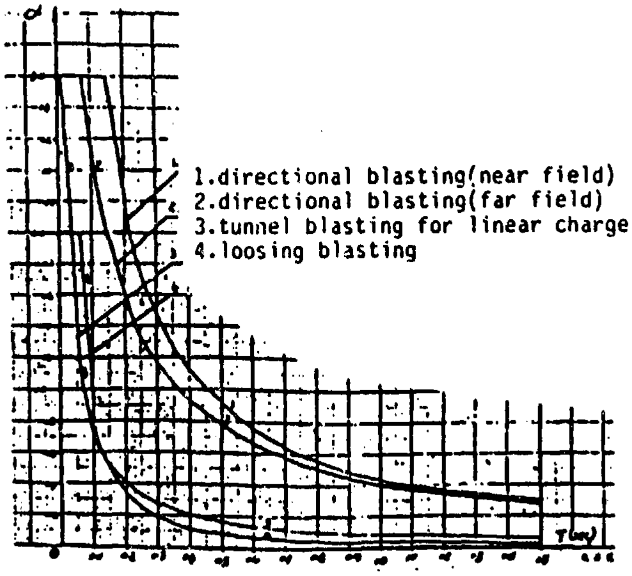

Fig.6 The acceleration response spectrum for different blasting

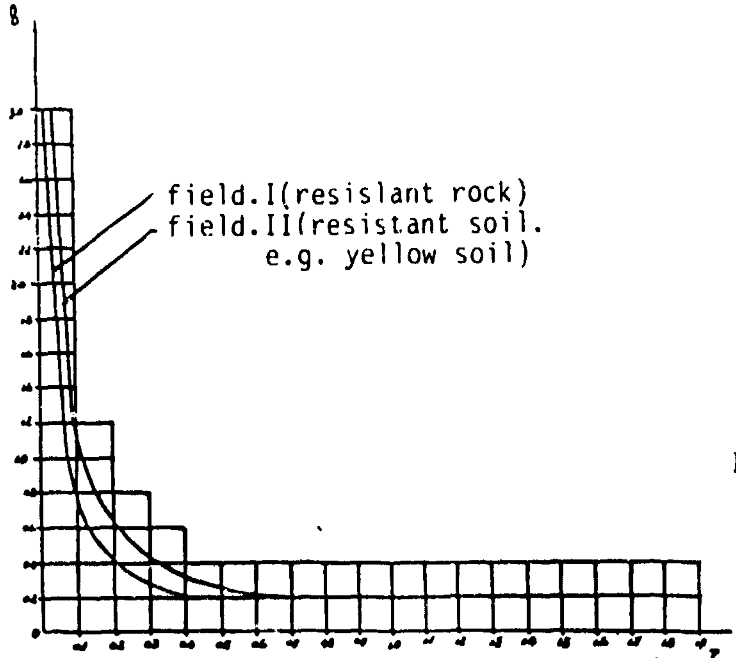

Fig.7 Influence coefficient of explosion seism

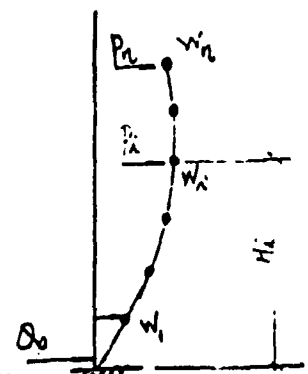

Fig.8 Diagrammatic sketch for calculating

P. 1

SAFETY DISTANCE FOR A PERSON UNDER ACTION OF AIR SHOCK WAVE

Li Zheng
Engineering Disign and Research Institute
P.O.Box 55, Beijing100053, P.R.China

Abstract

To study safety distance between a person and explosive spots, some explosive experiments relating to TNT, in which the weight of TNT varied from 1kg to 10^5kg, were imposed to animals, such as sheep, dogs and rabbits, in China. At the same time, some investigations of personal injuries in the cases of accidental explosion were carried out. Based on the results from the experiments and the data from the accidental explosions, some further work involving in safety distance for person near to a spot of explosion was done.

Introduction

In the process of the production and the storage of industrial explosive charges and in explosive operation in departments of mine, railway, water conservancy and hydroelectric power, it is necessary to know the problem of safety distance for a operator or person near to a explosive spot to prevent his being injuried by shock wave in case an accidental explosion happen. In this view of point, some experiments were imposed on animals, such as sheep, dogs and rabbits. The weight

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of TNT used in those experiments varied from 1kg to 10^5kg. The dogs and the sheeps were tied on some steel racks and at the height of 0.8 meter. The abdomens of animals were forced to face the center of explosion. For every testing point, two animals of the same kind were put. Rabbits were put in cages of iron wire. After explosive experiments, all animals were dissected and made pathological sections besides physical examination.

In this paper, only the case of injuries caused by air shock wave will be discussed and those caused by broken glass, bullet pieces, stone and the collapsing of houses will not be included in.

1. Injuries by air shock wave

Injuries caused by overpressure or its minus pressure were called shock injury. Injuries to person and animals usually take place in periods of plus pressure or that of minus pressure appearing often after the plus pressure vanishes. It is emphasised that the main cause of minus pressure injuries is that the time that minus pressure exists is much longer than the time that plus pressure exists. In fact, pathological changes because of shock injuries were found in animals which suffered from experiments of minus pressure.

The mechanism of injuries to ear is: when air shoke wave enters an outerear, the tympanic membrane is pressed direct and a difference of pressure forms between the passage of outerear and the tympanum of mid ear. When the tympanic membrane fails to undertake such pressure difference, it will break and deaf will be caused.

2.3

The mechanism of injuries to lung is: when air shock wave acts direct on the surface of thoracic cavity, the volume of air in thoracic cavity decreases drastically and the air pressure increases by tens times, even hundreds times. As soon as overpressure vanishes, minus pressure will appear. In this case, the compressed alveoli expand drastically, and as a result, capillaries and microveins in tissues surrounding them are torn to bleed. Therefore, the blood enters bronchi and mix with the exudate to form red foamy blood, that is pulmonary edema. It is the large volume of bleeding and severe air embolism that cause people and animals injure or die.

As an internal organ containing a great many air bubbles, compared with other neighbouring tissues, the density of lung is lower. As a result, it is easiest to be injured among all other internal organs. The limit of overpressure for lung is the lowest in comparison with other internal organs.

The breaking of lung takes place only under relatively high overpressure. In fact, it is usually caused by dash of body of person under dynamic pressure. The criterion of dash injury is the dash speed. When the speed is smaller than 3.0 m/s, the safe capacity is enough.

The mechanism of shock injury to the heart is: on the one hand, overpressure of air shock wave direct injures the heart (for instance, bleeding of endocardium, bleeding of heart wall, expansion of right ventricle, even rupture of the myocardium), On the other hand, under air shock wave, lung will be injured first and the pulmonary circulation will be obstructed because of the lung bleeding and pulmonory edema, which make the right ventricle expand further and accelerate injury to the heart. Even in this case, the overpressure that heart could sustain is

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higher than that in lung.

The mechanisms of injuries to liver and spleen are: both liver and spleen are located at abdomen which takes a larger body surface. Therefore, liver and spleen would be struck easily by air shock wave. Strong overpressure from air shock wave leads direct to liver and spleen bleeding, hemotonia and breaking. In the condition of explosion, percentage of spleen breaking was higher than that of liver breaking. The overpressure borne by liver and spleen were higher than those borne by heart and lung.

2. The relations between injury of animals and overpressure

Before experiments, animals were taken physical examination and the animals suffering from diseases were put away, and to make them similar in physical conditions, all animals were finely reared for two weeks. After experiments, every animal was dissected. The internal organs were made pathological sections. Wounds of some animals were sewed up after dissection, and these animals were then fed up to observe the degree of injury and recovery.

From the results of experiments, injuries to sheep and dogs were the same. The injury to rabbits was lighter. This may be referred to the fact that rabbits were put in cages and their abdomens were not forced to face the centre of explosion.

According to the various injured organ, such as heart, lung, liver, kidney, stomach and spleen, the injuries were divided into several kinds. According to the degree of injuries, the injuries were divided into five grades, grade one refers to no injury, grade two light injury, grade three mid injury, grade four heavy injury, grade five death.

Experimental results indicate: under the same overpressure, the longer the time of plus pressure acting, the more severe the corresponding injury is. The times of action as one of parameter was given, too, in the table of the relations between the degree of injury and the threshold of overpressure. The relations between degree of injury and threshold of overpressure were shown in Table 1. In Table 1, for no injury, $\Delta p < 9.81$ kPa, for light injury, $\Delta p = 9.81 \sim 19.61$ kPa, for mid injury, $\Delta p = 19.61 \sim 39.23$ kPa, for heavy injury, $\Delta p = 39.23 \sim 58.84$ kPa, and for death, $\Delta p > 58.84$ kPa.

3. The relation between degree of injury and time of action

From experimental results involving in animals, the degree of injury is not only related to threshold of overpressure but also to time of action. Under the same grade of injury, the relations between threshold of overpressure and time of plus pressure action are as follows:

$$\left.\begin{array}{lll} 1.\ \text{no injury} & \Delta p = 0.17\,\tau^{-0.35} & (\text{outer envelop time}) \\ 2.\ \text{light injury} & \Delta p = 0.30\,\tau^{-0.27} & (\gamma = -0.7520) \\ 3.\ \text{mid injury} & \Delta p = 0.94\,\tau^{-0.34} & (\gamma = -0.8785) \\ 4.\ \text{heavy injury} & \Delta p = 1.22\,\tau^{-0.26} & (\gamma = -0.9096) \\ 5.\ \text{death} & \Delta p = 2.0\,\tau^{-0.28} & (\gamma = -0.8308) \end{array}\right\} \quad (1)$$

where Δp: threshold of injuring from incident overpressure of air shock wave (kPa)

τ: time of plus pressure action of air shock wave (ms)

γ: relative coefficient

The curve of relations between threshold of overpressure P, from which the percentage of injury were 80~100%, and time of plus pressure action are shown in Fig.1:

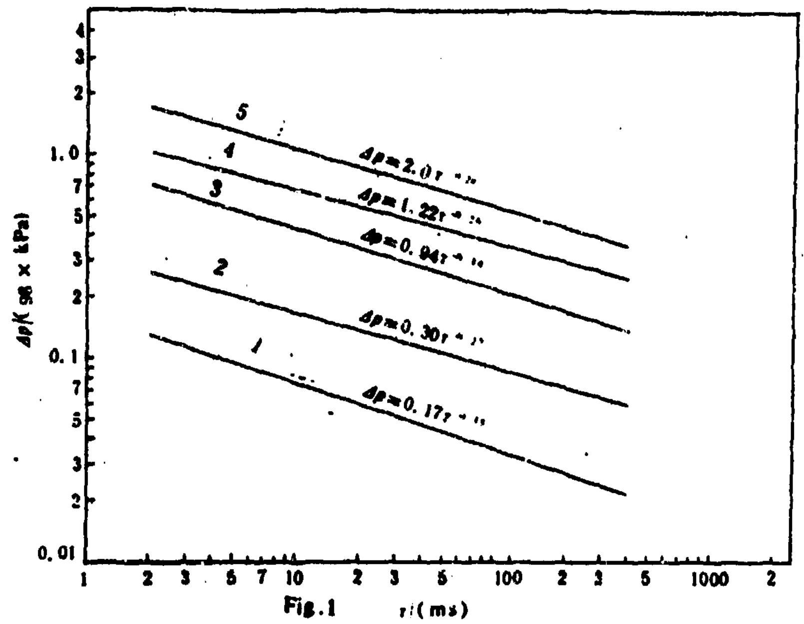

Fig.1 The relations between threshold of overpressure and time of plus pressure action

As shown in Fig.1, to the same grade of injury, threshold of overpressure decrease with the time of plus pressure action.

4. Influence of circumstance and posture to degree of injury

The data about animal injury in Table 1 came from the experiments in which animals abdomen faced to centre of explosion --the worst case. From the experiments, it was found that the degree of injury of animals tied on steel rach in buildings (the stomach faced to centre of explosion), that in 0.8x0.8x1.5 m^3 hole, that in cage (standing posture and stomach faced to centre of explosion), are about 25% lower than that of the animals which were tied on steel rach and of which abdomen facing to centre of explosion, in the case of the same distance and the same amount of explosive charge

5. Threshold of overpresure which will lead to personal injury under air shock wave

In United States, experiments were made on animals by virtue of shock tube. To the case that the time of plus pressure action is three milliseconds, the corresponding injuries of incident overpressure of air shock wave are shown in Table 2.[1]

Table 2 The relation between incident overpressure and personal injuries in shock tube experiments in U.S.

	lung		ear membrane		percentage of death	
organ	critical value of injury	heavy injury	critical value of breaking	50% breaking	50% death	100% death
ΔP/(kPa)	206.92 ~275.58	551.15	34.32	102.97	896.36 ~1240.59	1378.86 ~1724.07

According to the data from some papers i Russian, the injury effects of incident overpressure of air shock wave on per-

P.8

son are shown in Table 3.

Table 3 The relation between incident overpressure and personal injury

Degree of injury	breaking of ear membrance	light injury	heavy injury	percentage of death 1%	50%	99%
ΔP/(kPa)	34.32 ~102.97	19.61 ~39.23	39.23 ~98.07	235.37 ~304.02	304.02 ~372.67	372.67 ~441.32

The light injuries in Table 3 are some slight implicit injuries (such as sick and headache) and trauma. The heavy injuries refer to severe implicit injuries and injuries of internal organs. The overpressure threshold of personal ear membrane breaking used in the Soviet Union was the same as that used in the U.S. It was supposed that injuries to personal ear membrane are related to position of head and direction of wave front of air shock wave (personal ear is paraller or perpendicular to the wave front of incident shock wave). Moreover, in Russian, it was emphasised that dynamic pressure could injure person. For instance, when incident overpressure is $\Delta p = 29.42 \sim 39.23$ kPa, the speed of air stream behind wave front will be 60~80 m/s. Except that the acting time is very short, person could not bear such a big flowing velocity and shock injuries such as falling injuries and bumping injuries will be produced. It was believed in the Soviet Union that the maximum overpressure which person could stand does not exceed 19.61 kPa. In MITI, Japan, explosion experiments were done, from 1963 to 1968, in which the weights of charge varied from 100kg to 1000kg. Rabbits used in the experiments were put in cages and fixed in a posture of standing. The results of experiments are rabbits's ear membrance does not break if $\Delta p \leq 98.07$ kPa , and limit over-pressure that will lead to death is $\Delta p = 294.21 \sim 490.35$ kPa

From the results of experiments in China, the degrees of injuries to animals are related to time of action as well as threshold of overpressure.

The results of experiments on animals could be transmitted to person according to investigations of personal injuries in accidents of explosion. Results from analysis are shown in Table 4.

Table 4 The threshold of overpressure of different degree of personal injuries

		Threshold of overpressure (△p/kPa)				
No.	Accidental explosion	ear membrane perforation	light injury	moderate injury	severe injury	death
1	2300 ton ammonium nitrate explosion in the U.S.(1947)	13.73 ~19.61 (1200 ~900*)	19.61 ~37.27 (900 ~600)	37.27 ~49.04 (600 ~500)	49.04 ~127.49 (500 ~340)	>127.49 (<340)
2	1800kg TNT explosion in China (1976)	/	10.79 ~27.46 (130 ~70)	35.31 ~49.04 (60 ~50)	49.04 ~156.91 (50 ~30)	>156.91
3	artillery firing in Chnia	17.65	/	/	/	/

*The numbers in brackets refer to distances corresponding to threshold of overpressure (m)

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In Table 4, the TNT equivelent weight of ammomium nitrate used is 0.89 and explosive overpresure of earth surface should be calculated according to H.L.Brode's method. When the overpressure is lower than 13.73 kPa during artillery firing, there is no perforation in ear membrane of artillerymen, and when overpressaure is 17.65 kPa , perforation happens in ear membrance of artillerymen.

6. Safety distance for person under air shock wave

To sum up, the thresholds of overpressures in the incident explosion and animal experiments in the U.S. and the U.S.S.R. as well as the experiments in the paper are as shown in Table 5.

Table 5 The criteron of threshold of overpresure for person suffering from different injury degrees

Δp/(kPa)

No.	source of data	breaking of ear membrane	light injury	mid injury	heavy injury	death
1	U.S.	34.32	15.69*	23.54*	53.94*	>136.33*
2	U.S.S.R.	34.32	19.61 ~39.23	/	39.23 ~98.07	>235.37
3	accidental explosion	13.73	10.79 ~27.46	27.46 ~49.04	49.04 ~127.49	>127.49
4	animal experiments	19.61	9.81 ~19.61	19.61 ~39.23	39.23 ~58.84	>58.84
5	this paper	13.73	13.73	29.43	49.05	>127.49

*cited from "safety standardization of ammunition and explosive charge" by Defence Department of United States DOD5154.45

According to the requires of application, "no injury" is taken as the basis in explosion works in departments of mine, railway, water conservancy and hydroelectric power, light and mid injuries as the basis in accidents of explosion in production of explosive charge, and mid and heavy injuries as basis in accidents of explosion in explosive charge storage.

The criterion for No Injury to person is that ear tympanic membrane does not break and does not perforate, but about fifty percent of ear tympanic membrane bleeds. The corresponding overpressure threshold Δp is 6.86 kPa at this time.

The criterion for light injury to person is that the breaking of ear tympanic membrance is less than five percent, internal organs are injured slightly and slight pulmonary emphyseme exists.

At this time, the threshold of overpresssure ΔP is 13.73 kPa.

The criterion for mid injuries is that the percentage of breakage of ear tympanic membrane is less than 10%. Sheet bleeding appears in some internal organ and pulmonory emphysema exists in lung. The threshold of overpressure Δp is 29.43 kPa.

The criterion for severe injuries is that mid ear is injured seriously, sheet bleeding or big area bleeding ($>1 cm^2$) happens in a couple of internal organs, rare local rupture of mycardium, big area of pulmonary emphysema and pulmonary contusion exist in lung. The threshold of overpressure ΔP is 49.05 kPa.

According to dimensional analyses, the overpressure ΔP at wave front of air shock wave under standard states should be a function of distance ($\bar{R} = R/Q^{1/3}$). In calculation of safety distance, the function is normally:

$$\Delta p = K_1 \left(\frac{R}{Q^{1/3}}\right)^{-n_1} \qquad (2)$$

then $R = KpQ^{1/3}$ (3)

where ΔP -- incident overpressure of air shock wave (kPa)

R -- distance from centre of charge to testing point. It refers to the distance from the entrance of tunnel to the observed point in the case of tunnel blasting.(m)

Q -- energy of explosion, that is the weight of charge (TNT, $l=1.5g/cm^3$) (kg)

K_1, n_1 : experimental constants

Kp : coefficient $Kp=\left(\frac{K_1}{\Delta p}\right)^{1/n_1}$ are shown in Table 6.[3]

From the threshold of overpressure of personal injuries, the values of Kp can be obtained.

7. Conclusions

1. By experiments of explosion (weight of TNT varied from 1kg to 10^5kg) involving in animals, the thresholds of overpressure of various degrees of animal's injuries were obtained and given in Table 1, that is: to no injury, $\Delta p<9.81kPa$; to light injuries, $\Delta p=9.81\sim19.61kPa$; to mid injuries, $\Delta p=19.61\sim39.23kPa$; to heavy injuries, $\Delta p=39.23\sim58.84kPa$; to death, $\Delta p>58.84kPa$. The results of experiments accord with the thresholds of overpressure of corresponding degree of personal injuries in incident explosion. Therefore, the bases to determine the safety distance for person under air shock wave were founded

2. By the experiments of animals, it was found that to the same injury grade, the threshold of overpressure (ΔP) decreases as the time of plus pressure acting increases.The mathematical

relation was induced from the results of experiments (seeing equation (1))

3. According to the laws of transmission of air shock wave in various conditions of explosion and various blasting forms, the values of coefficient (Kp) of safety distance for person in the cases of no injury, light injuries, mid injuries, heavy injuried and death can be calculated easily and used in real engineering.

References

[1]. L.P.Anders, W.d.James, "A Review of Factors Affecting Damage in Blasting", PB-242221,1975.

[2]. C.K.Savenko, A.A.Gurin, "Air Shock Waves Under Gallery", Moscow, 1973.

[3]. Li Zheng, "Safe Distance Under Air Blast Loading", Explosion and Shock, Vol.4, No.2, 1984, pg.39-52.

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Table 1 The relation between injury grade and overpressure for animals

Injury grade	Degree of injury	Cases of shock injury: ear and internal organs	pulmonary edema	pulmonary bleeding	(kg/cm^2)	(ms)
1	nothing	nothing	nothing	nothing	<0.10	>280
2	light	spot bleeding in local organs (2~3), light pulmonary contusion, without mid ear contusion.	only sheet wetting, a little edema liquid, no foamy blood in branchi, area of sporadic emphysema take one fourth of whole lung.	a few bleeding under pulmonary membrane, diametre is about 1cm.	0.10 ~0.20	280 ~110
3	mid	bleeding of sab-membrane surrounding liver and spleen, sheet bleeding ($0.5cm^2$) in organs (1~3) or sheet bleeding (>$1cm^2$) in one organ, bleeding of heart wall, moderate pulmonary contusion, moderate contusion of ear.	foamy bloody liquid is full of small branchus, area of emphysema takes one third of whole lung.	sporadic spot bleeding (diametre is about 1~2cm).	0.20 ~0.40	110 ~90
4	heavy	fracture / dislocation, sheet bleeding (about $0.5cm^2$) in three organs or sheet bleeding (>1 cm^2) in two organs, local rupture of mycardium, severe contusion in lung and ear.	main branchi are full of foamy bloody liquid, area of emphysema takes a half of lungs.	sporadic spot bleeding (diametre is about 2~3cm).	0.40 ~0.60	90 ~70
5	death	breaking of body cavity, diffuse of the mycardium, breaking of lung and severe contusion of both lungs, death or unrescued injuries.	all lobes of lung are of extensive edema, trachea is full of foamy bloody liquid.	all lobes of lung are of extensive spot bleeding.	>0.60	70 ~50

Note: 1. The organs include the heart, liver, spleen, lung, kidney and stomach.
2. All data in Table 1 are based on experiments of ground blasting involving in dogs and sheep, in which the weight of TNT varied from 1 to 10^5 kg.

? /5

Table 6 Coefficient Kp of safety distance for person

No.	explosion conditions or blasting forms	Kp: no injury	light injury	mid injury	heavy injury	death
1	ground explosion (without fortified mud).	12 ~10	10.00 ~7.00	7.0 ~5.40	5.40 ~3.30	<3.30
2	ground explosion (with fortified mud).	7.4 ~6.5	6.50 ~5.00	5.00 ~4.00	4.00 ~2.70	<2.70
3	explosion of ammunition in earth covered igloo of steel arch (gathered stocking).	13.40 ~10	10.00 ~6.70	6.70 ~4.80	4.80 ~2.50	<2.50
	explosion of ammunition in earth covered igloo of steel arch (scatter stocking).	13.40 ~10.50	10.50 ~6.00	6.00 ~4.30	4.30 ~2.20	<2.20
4	explosion of explosive charge in earth covered igloo of steel arch.	12.00 ~9.00	11.00 ~7.50	7.50 ~5.70	5.70 ~3.50	<3.50
5	explosion of explosive charge in earth covered igloo of reinforced concrete.	11.00 ~9.50	9.50 ~5.70	5.70 ~4.40	4.40 ~2.00	<2.00
6	blasting in tunnel.	6.30 ~5.0	5.00 ~3.50	3.50 ~2.40	2.40 ~1.40	<1.40
7	open bulk blasting deep-hole blasting.*	7.00 ~5.50	5.50 ~4.00	4.00 ~3.00	3.00 ~1.50	<1.50
	open bulk blasting adobe blasting.*	13 ~11	11.00 ~7.20	7.20 ~5.40	5.40 ~3.20	<3.20

*including instantaneous blasting and millisecond blasting.

DESIGN OF THE HIGH EXPLOSIVE SUBASSEMBLY FACILITY AND THE WEAPONS SPECIAL PURPOSE BAY REPLACEMENT COMPLEX

DOE PANTEX PLANT
AMARILLO, TEXAS

Presented by:
David A. Parkes
Black & Veatch

AT THE
24TH DEPARTMENT OF DEFENSE
EXPLOSIVES SAFETY SEMINAR

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ST. LOUIS, MISSOURI

The High Explosive Subassembly Facility (HESF) is a 100,000 sq ft facility containing 15 assembly bays and one vacuum chamber bay. Design of this facility was completed in 1987 and construction was completed in May, 1989. The Weapons Special Purpose Bay Replacement Complex (WSPBRC) is a 78,000 sq ft addition to the HESF. It contains two staging bays, two Linac bays, one X-ray bay, one vacuum chamber bay, one weapons aging bay, and paint/abrasive blast bay. Design of this facility was completed in 1989 and it is currently under construction.

Both facilities were designed to provide protection for personnel from the effects of an accidental explosion. Personnel in any bay or break area are protected from an explosion in a donor bay. The design basis accident (DBA) was defined as the accidental detonation of 300 lbs, 390 lbs TNT equivalent, of high explosive within any bay. The surface of the charge was capable of being located at any point within the bay at least two feet from any wall and three feet above the floor. The DBA also included a steel fragment weighing 13.6 lbs having a velocity of 3050 feet per second.

This paper deals with the design concepts used for these facilities and how problems associated with these types of facilities were handled. These include gas pressure venting, blast resistant doors, fragment control, and constructibility.

I. LAYOUT OF THE FACILITY

These facilities were designed using the separated bay concept. Each bay is separated from adjacent bays by 13.5 feet of sand fill. In addition, the roof of each bay is covered by a minimum of two feet of earth fill. The sand fill between the bays helps attenuate the blast loads on the walls of adjacent bays and provides additional mass to limit the dynamic response of the walls. The earth fill on the roofs also provides additional mass to limit the dynamic response of the roof. The layout of the HESF is shown in Figure 1 and the WSPBRC in Figure 2.

Why was the separated bay concept used instead of a common wall type structure? Our client had determined that although a separated bay facility requires more land area than a common wall type facility, the separated bay facility is cheaper to construct than a common wall type structure. The additional cost of the sand and earth fill is more than offset by the reduced concrete and reinforcing usage resulting from the thinner walls. In addition, the reinforcing is not as congested resulting in improved constructibility.

One problem in the design of a separated bay facility is the determination of the blast loads on the walls of a bay adjacent to the donor bay. The procedures contained in TM 5-1300 do not apply. The loads used in the design of these facilities were determined from data contained in Technical Report SL-83-6, "An Evaluation of the Separated Bay Concept for a Munitions Assembly Complex; An Experimental Investigation of the Department of Energy Building 12-64 Complex" by Volz and Kiger.

II. FRAGMENT CONTROL

A primary concern at the Pantex plant is large fragments resulting from the breakup of structures and equipment during an event. The concern is the effect that these fragments would have on personnel and adjacent facilities. Two fragments were of primary concern in the design of these facilities.

The first is the steel fragment defined in the DBA. This fragment, determined by the client, results from a contact explosion of high explosive with a piece of equipment. It was determined that this fragment would penetrate the 18" thick concrete walls and roofs but would be trapped in the sand fill between the bays or in the earth fill on the roofs. In those areas where there was no sand fill, it was determined that the walls would have to be a minimum of 24" thick to stop the fragment.

The second large fragment that had to be considered was the blast resistant doors that provide access to each bay. It was not practical to design the doors to remain attached to the structure. Therefore, a system was needed to prevent the doors from becoming a projectile beyond the facility. This was accomplished through the use of closely spaced steel beams in the wall and roof of the corridor outside each bay as shown in Figure 3. These beams were connected at the floor and roof by single steel pins to ensure that the joints would be free to rotate. Our analysis indicated that fixed joints would severely limit the energy absorption capacity of the members due to the high localized strains associated with fixed joints.

III. GAS PRESSURE VENTING

One of the problems faced in designing this type of facility is how to vent the gas pressure associated with a confined explosion. The problem is compounded in these facilities by the requirement to contain the primary fragment associated with the DBA. This requirement prevented the use of any large lightweight areas for venting. Three different venting systems were used depending on the configuration of the bay.

The assembly bays were designed to vent through the roof and doors. The roof and doors were designed to be dislodged in a controlled manner by the effects of the DBA. The roof slab of the bay was divided into two equal panels. In the event the DBA occurs in the bay, the roof slab panels will rotate about the line of attachment and impact the earth cover surrounding the bay. The roof slab panels were designed not to disengage or break up upon impact. The response time of the slab is such that the primary fragment will impact the roof slab and be stopped before the roof opens. The doors will be dislodged but will be trapped by the fragment shield located in the corridor. Although the combination of the doors and the roof do not provide full venting, the resulting blowdown time is significantly reduced from that which would be attained by using only the doors.

Several other bays were designed in a similar manner except only a portion of the roof area was utilized for venting. Due to the size and configuration of these bays a split concrete roof panel was not feasible. The roof area used for venting was comprised of concrete filled steel panels made of structural steel plates and shapes. These panels do not have earth cover and were designed to prevent the primary fragment from perforating the panel. In the event the DBA occurs in the bay the panels will rotate about the line of attachment to the structure without disengaging. The remainder of the roof was framed with concrete slabs and beams that will remain intact during the DBA.

The Linac bays were designed to vent entirely through the doors. This was required because the large amount of earth fill on the roofs, required for radiation shielding, precluded any feasible venting methods through the roof. This resulted in a relatively long blowdown time but the effects on the structure were substantially reduced because of the large amount of fill.

IV. BLAST RESISTANT DOORS

Access to the bays is through interlocked blast resistant doors. Each bay has separate personnel and equipment airlocks. The personnel airlocks contain 3'x7' single doors and the equipment airlocks contain 4'x8' double bi-parting doors.

The doors were designed to resist the blast pressures associated with the DBA occurring in an adjacent bay. The doors are built-up sections fabricated from steel face sheets separated by structural shapes and cold formed stiffeners. The 3'x7' doors weigh 900 lbs and the 4'x8' doors weigh 1,200 lbs.

One of the primary problems associated with swinging doors is how to install the door so that it does not drag the floor. Also, the door must be well balanced so that excessive force is not required to operate the door. Both of these problems were solved on this facility by the use of custom designed three-way adjustable hinges. These hinges, shown in Figure 4, allowed the contractor to adjust the doors after being installed. This resulted in a door installation that required less than five pounds of force to operate.

Because of our client's past experience with swinging doors, it was their standard practice to require hydraulic operators on the doors. The use of the three-way adjustable hinges was so successful on the HESF that they decided not to require door operators on the WSPBRC.

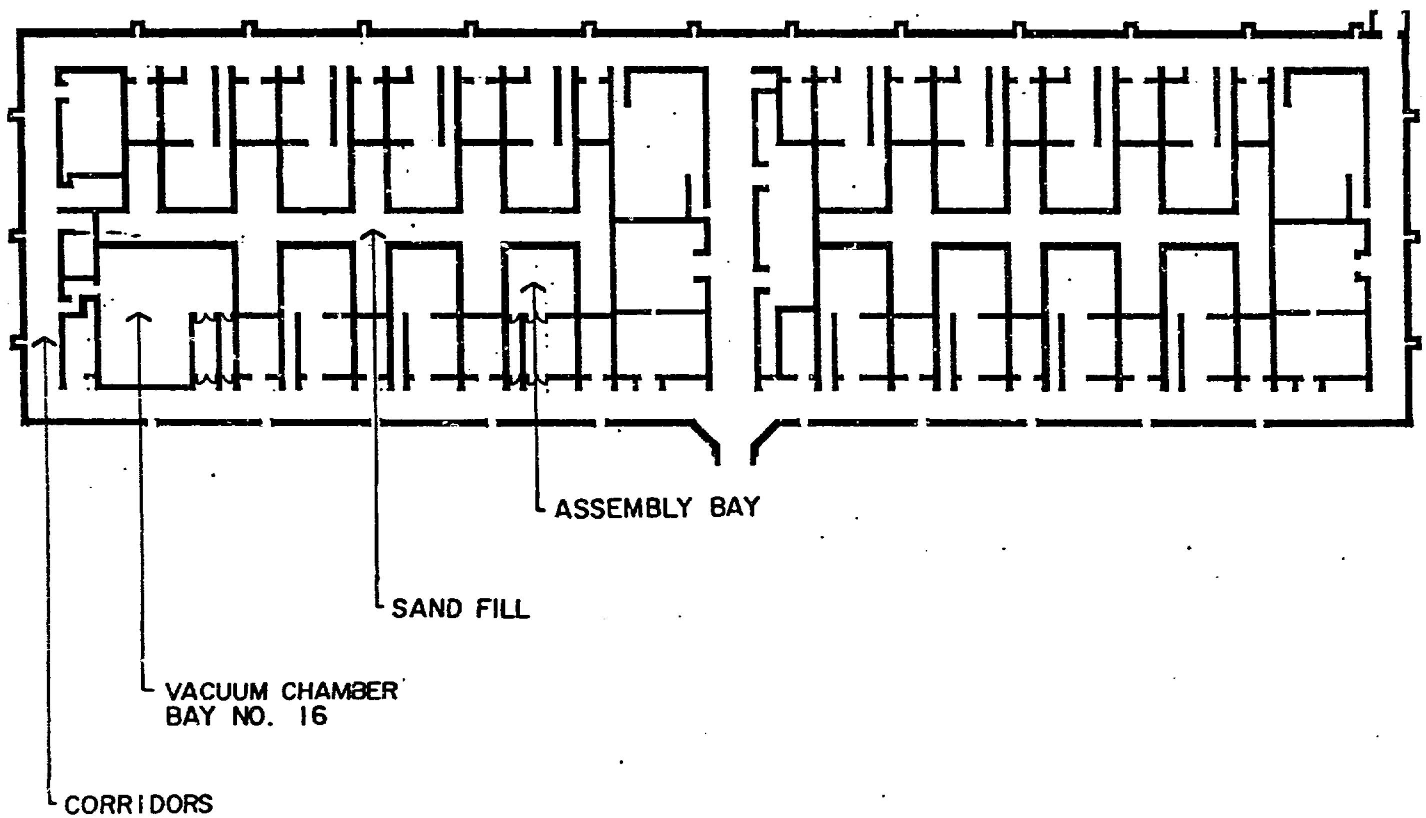
Each set of doors are interlocked so that a direct path from the bay to the corridor is never open. This is to ensure personnel safety in case of an event. The interlock system is an electrical system controlled by programmable logical controllers (PLC). The PLC's receive input from switches in the doors and control electro-magnetic locks on the doors. The system is fail-safe unlock upon power loss.

V. CONSTRUCTIBILITY

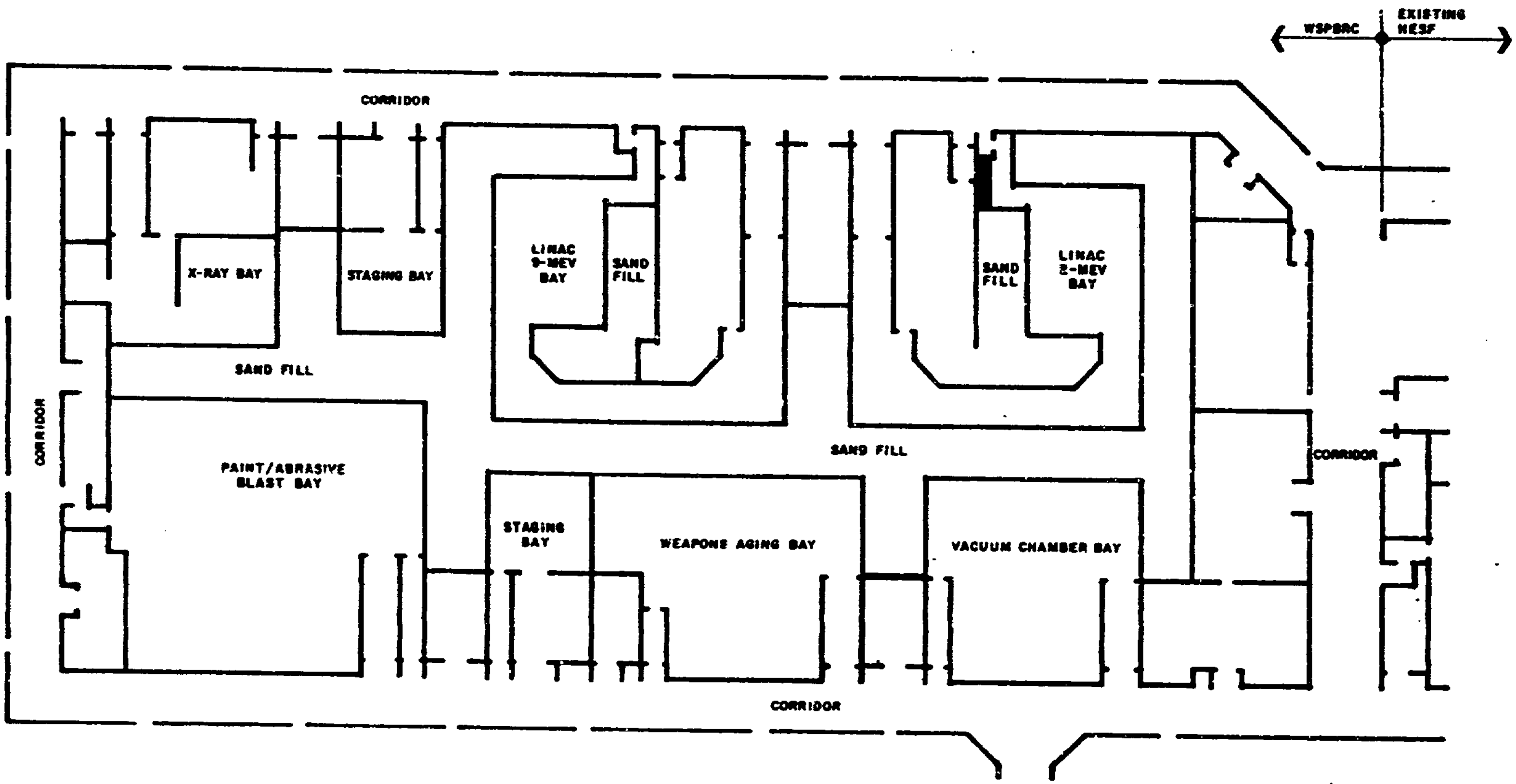
There are a number of areas of constructibility that could be discussed on this type of facility. Reinforcing placement and concrete specifications are two subjects that have received a great deal of attention. However, one subject that has received very little attention in the past, but has caused a number of construction problems, is everything that is embedded in the concrete. This can include conduit and piping penetrations, ductwork penetrations, and unistrut embedments. When there are two 18" thick concrete walls separated by 13.5 feet of fill and the contractor forgets to put in a penetration, the fix can be rather difficult.

This problem was solved on both of these facilities by preparing drawings dedicated to locating all items that needed to be placed in the concrete walls and roofs. The system consists of two parts. The first, see Figure 5, is a drawing of each wall and roof locating all penetrations and unistruts that are to be placed in that wall. Each penetration is assigned a unique number. The second part of the system is a series of schedules, see Figure 6, that indicate for each penetration number the size of the penetration, how to make the penetration, and what the penetration is for.

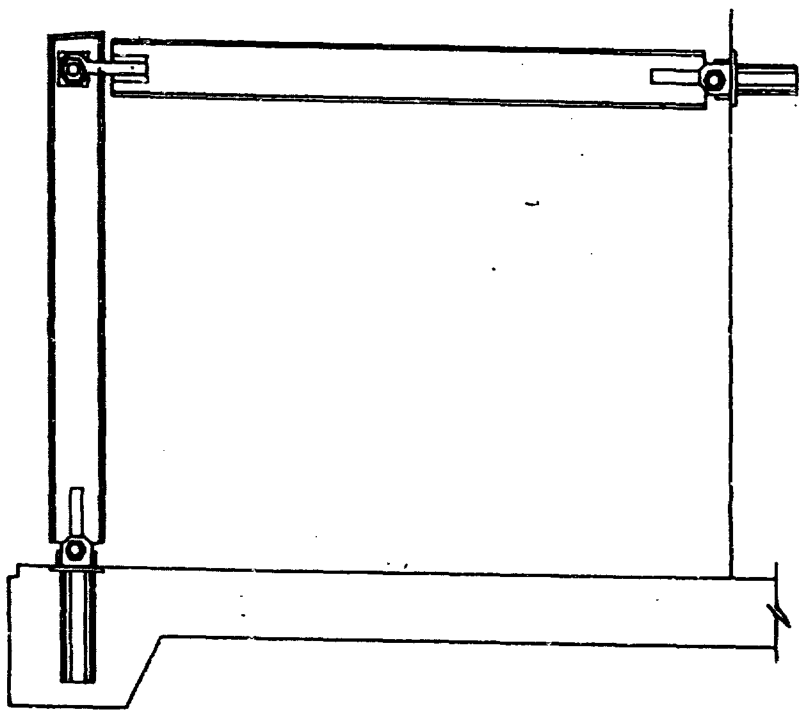
This system was used successfully on the HESF. Out of 330 wall or roof surfaces there were a total of 1,084 penetrations. A total of three 1-1/2" diameter penetrations were missed. The system provides the method to coordinate all trades and help ensure good construction.



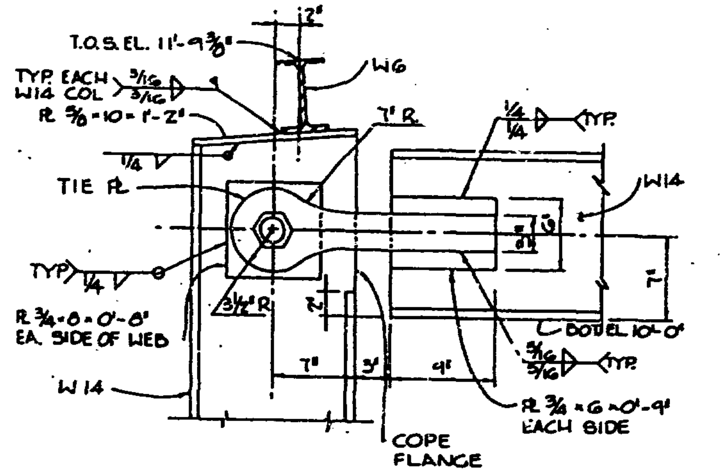
HIGH EXPLOSIVE SUBASSEMBLY FACILITY
FIGURE 1



WEAPONS SPECIAL PURPOSE BAY
REPLACEMENT COMPLEX
FIGURE 2



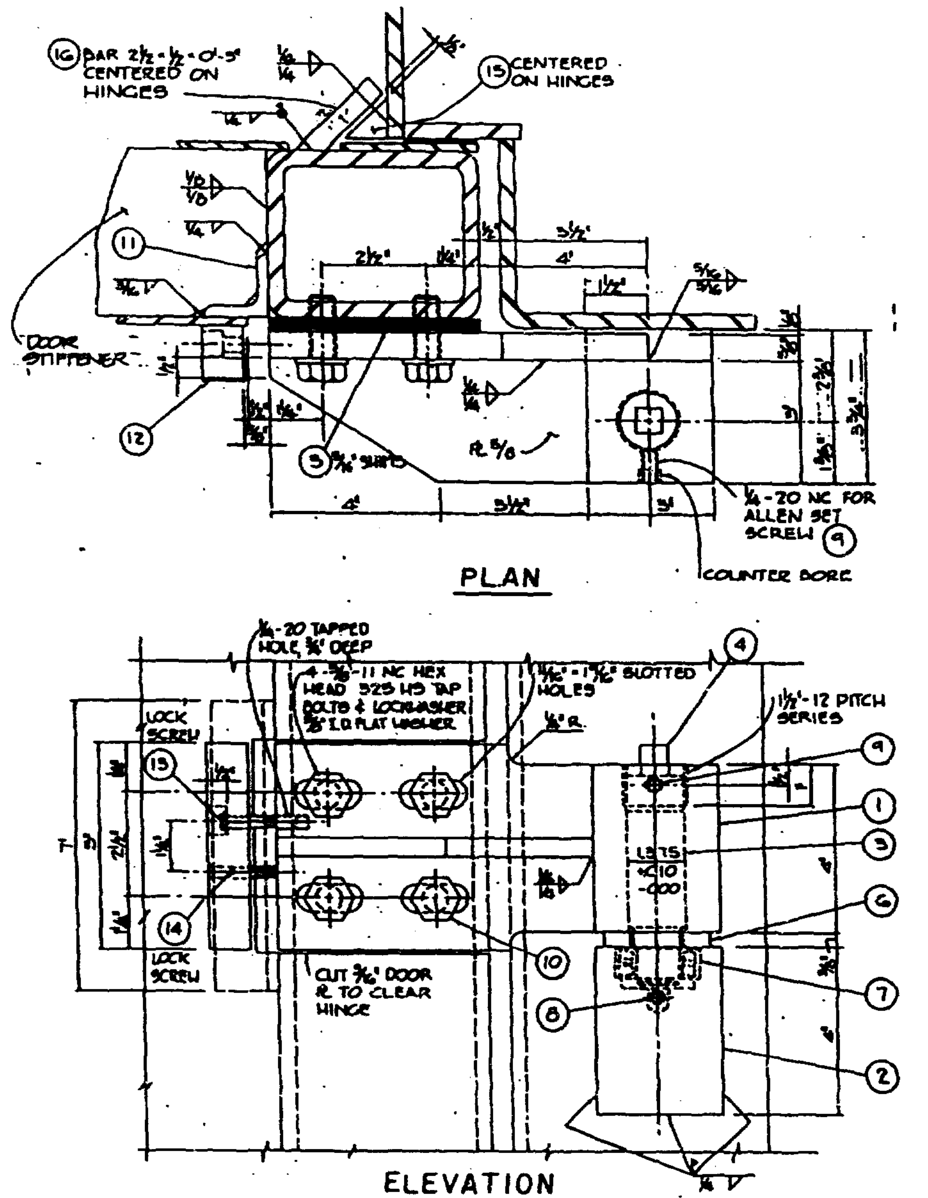
CORRIDOR SECTION



ELEVATION

BEAM/COLUMN CONNECTION

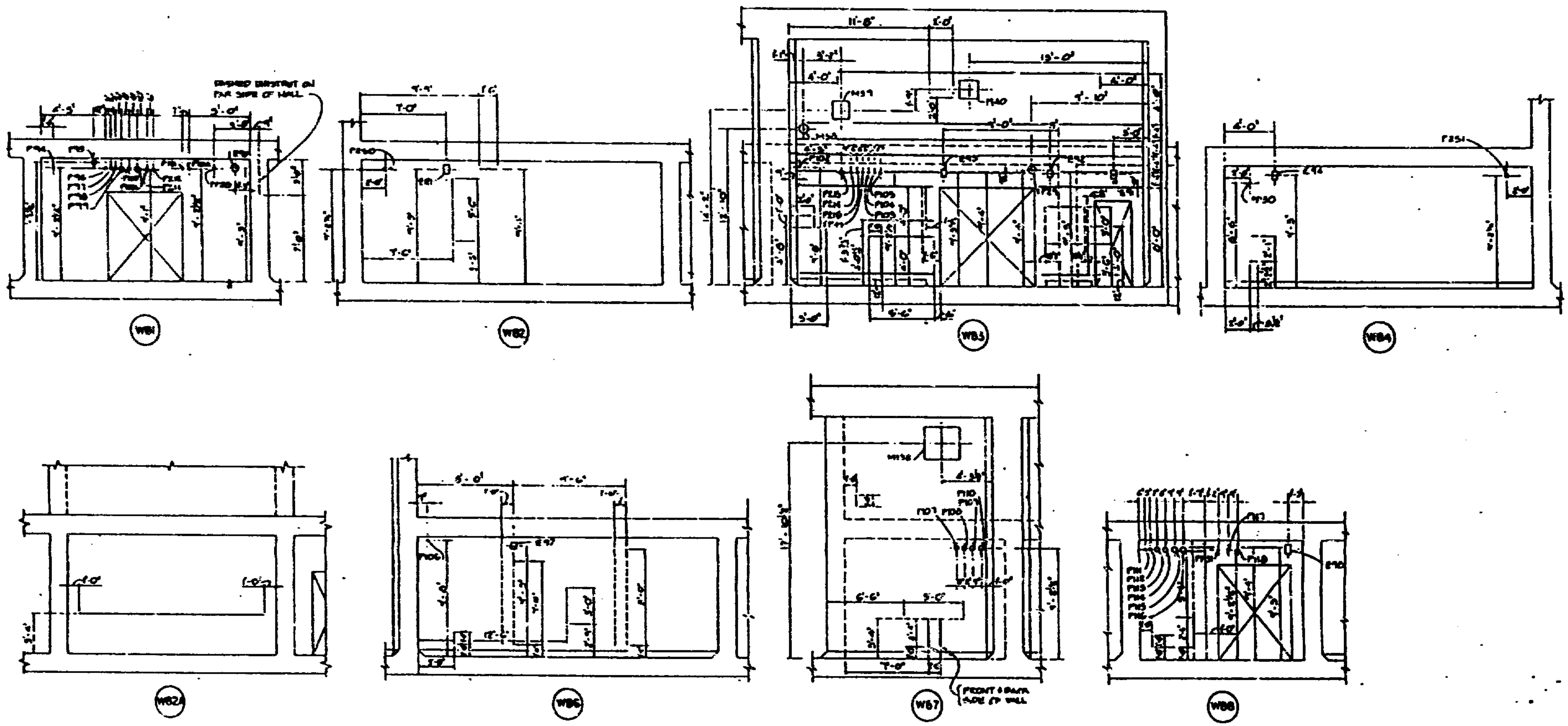
FRAGMENT SHIELD
FIGURE 3



THREE WAY ADJUSTABLE DOOR HINGE

FIGURE 4

MATERIAL FOR ONE HINGE		
PART NO.	DESCRIPTION	QTY.
1	HINGE HALF ON DOOR, MATL. A 36	1
2	HINGE BLOCK ON JAMB, MATL. A 36	1
3	HINGE PIN, MATL. 1045 C.D.	1
4	HINGE ADJUSTING SCREW, MATL. A 36	1
5	HINGE SHIMS, MATL. A 36	1 SET
6	DUST RING, SOFT FELT	1
7	BEARING NO. FAG 22205 ESTUB	1
8	STRAIGHT ⅛" ALEMITE GREASE FITTING	1
9	¼-20 NC ALLEN SET SCREW, CUP PT.	1
10	⅝-11 NC HEX HD. TAP BOLTS & L.W. & F.W.	4
11	L 1½ × 1½ × ¼ × 0'-7"	1
12	BAR 1⅜ × 1 × 0'-5"	1
13	¼-20 × 1½" LG. ALLEN CAP SCREW W/ WASHER	1
14	¼-20 × 1½" LG. ALLEN SET SCREW	1
15	BAR 1 × 1 × 0'-3" (CUT)	1
16	BAR 2½ × ½ × 0'-3"	1



TYPICAL PENETRATION DRAWING
FIGURE 5

PENETRATION MARK	LOCATION SURFACE NO.	SURFACE LOCATION DWG. WHERE TAKEN	SURFACE LOCATION DWG. WHERE SHOWN	AREA	ELECTRICAL MCT TYPE	ELECTRICAL MCT LOCATION	ELECTRICAL SLEEVE SIZE	ELECTRICAL PENETRATION NUMBER	MECHANICAL SYSTEMS FUNCTION	MECHANICAL SLEEVE SIZE	OPENING SIZE L	OPENING SIZE H	DETAIL	REMARKS
E1	W1	S109	S114	F. STOR.	B	F	-	N-155A/M-4-2	-	-	5 1/2"	9 3/8"	1	
E2	W1	S109	S114	F. STOR.	A	F	-	N-155A/M-1-1	-	-	5 1/2"	7 1/8"	1	
P1	W1	S109	S114	F. STOR.	-	-	-	-	HWS	3"	-	-	2	
P2	W1	S109	S114	F. STOR.	-	-	-	-	HWR	3"	-	-	2	
FP33	W1	S109	S114	F. STOR.	-	-	-	-	FP	2"	-	-	2	INSPECTOR'S TEST
E3	W2	S109	S114	B. AREA	B	F	-	N-154E/M-4-1	-	-	5 1/2"	9 3/8"	1	
E4	W2	S109	S114	B. AREA	A	F	-	N-154B/M-1-1	-	-	5 1/2"	7 1/8"	1	
FP1	W2	S109	S114	B. AREA	-	-	-	-	FP	3"	-	-	2	
FP2	W3	S109	S114	B. AREA	-	-	-	-	FP	1"	-	-	2	
E5	W4	S109	S114	B. AREA	A	F	-	N-154A/E-1-1	-	-	5 1/2"	7 1/8"	1	
FP3	W5	S113	S114	PER. A.L.	-	-	-	-	FP	1"	-	-	2	
E6	W6	S109	S114	PER. A.L.	B	F	-	N-154B/M-6-1	-	-	5 1/2"	9 3/8"	1	
E7	W7	S109	S114	PER. A.L.	B	N	-	N-154B/S-6-1	-	-	5 1/2"	9 3/8"	1	
E8	W8	S109	S114	PER. A.L.	B	N	-	N-154C/M-6-1	-	-	5 1/2"	9 3/8"	1	
E9	W9	S109	S115	PER. A.L.	B	F	-	N-154C/S-6-1	-	-	5 1/2"	9 3/8"	1	
E10	W10	S109	S115	ME. RM.	B	F	-	N-164A/M-6-1	-	-	5 1/2"	9 3/8"	1	
E11	W10	S109	S115	ME. RM.	B	F	-	N-164A/M-6-2	-	-	5 1/2"	9 3/8"	1	
P3	W10	S109	S115	ME. RM.3	-	-	-	-	CW	4"	-	-	2	
P4	W10	S109	S115	ME. RM.3	-	-	-	-	HW	4"	-	-	3	
P5	W10	S109	S115	ME. RM.2	-	-	-	-	TA	1 1/2"	-	-	2	
FP4	W10	S109	S115	ME. RM.3	-	-	-	-	FP	8"	-	-	2	
M1	W10	S109	S115	ME. RM.3	-	-	-	-	RA	-	12"	10"	1	
M2	W10	S109	S115	ME. RM.3	-	-	-	-	[illegible]	-	13"	8"	1	
M3	W10	S109	S115	ME. RM.3	-	-	-	-	SA	-	14"	12"	1	
E12	W14	S109	S115	ME. RM.3	C	F	-	N-164A/E-10-1	-	-	5 1/2"	11 3/4"	1	
P6	W11	S109	S115	ME. RM.3	-	-	-	-	CW	4"	-	-	2	
P7	W11	S109	S115	ME. RM.3	-	-	-	-	V	3"	-	-	2	
P8	W11	S109	S115	ME. RM.3	-	-	-	-	A	4"	-	-	2	

PENETRATION MARK	LOCATION SURFACE NO.	SURFACE LOCATION DWG. WHERE TAKEN	SURFACE LOCATION DWG. WHERE SHOWN	AREA	ELECTRICAL MCT TYPE	ELECTRICAL MCT LOCATION	ELECTRICAL SLEEVE SIZE	ELECTRICAL PENETRATION NUMBER	MECHANICAL SYSTEMS FUNCTION	MECHANICAL SLEEVE SIZE	OPENING SIZE L	OPENING SIZE H	DETAIL	REMARKS
P9	W11	S109	S115	ME. RM.3	-	-	-	-	CV	4"	-	-	2	
P9a	W11	S109	S115	ME. RM.3	-	-	-	-	COND	6"	-	-	2	
P9b	W11	S109	S115	ME. RM.3	-	-	-	-	COND	5"	-	-	2	
P9c	W11	S109	S115	ME. RM.3	-	-	-	-	HWS	8"	-	-	2	
P9d	W11	S109	S115	ME. RM.3	-	-	-	-	HWR	8"	-	-	2	
P9e	W11	S109	S115	ME. RM.3	-	-	-	-	CHS	8"	-	-	2	
P9f	W11	S109	S115	ME. RM.3	-	-	-	-	CHR	8"	-	-	2	
P10	W11	S109	S115	ME. RM.3	-	-	-	-	COND	6"	-	-	2	
P11	W11	S109	S115	ME. RM.3	-	-	-	-	RD	5"	-	-	2	
P12	W11	S109	S115	ME. RM.3	-	-	-	-	RD	5"	-	-	2	
P13	W11	S109	S115	ME. RM.3	-	-	-	-	RL	4"	-	-	2	
P14	W11	S109	S115	ME. RM.2	-	-	-	-	RL	4"	-	-	2	
P179	W11	S109	S115	ME. RM.3	-	-	-	-	SPARE	3"	-	-	2	
P180	W11	S109	S115	ME. RM.3	-	-	-	-	SPARE	3"	-	-	2	
								-	SPARE	3"	-	-	2	
FP30	W11	S109	S115	ME. RM.3	-	-	-	-	FP	6"	-	-	2	

PENETRATION MARK

- E ELECTRICAL SLEEVE OR OPENING (CONDUIT)
- P MECHANICAL PIPE SLEEVE
- M MECHANICAL OPENING (DUCT)
- FP FIRE PROTECTION SLEEVE

SURFACE IDENTIFICATION

- W WALL ELEVATION
- R REFLECTED ROOF PLAN
- C COLUMN ELEVATION

AREA ABBREVIATIONS

- S. BAY STAGING BAY
- BREAK A. BREAK AREA
- F. STOR. FILTER STORAGE ROOM
- CORR. CORRIDOR
- EL. RM. ELECTRICAL ROOM
- EQ. A.L. EQUIPMENT AIRLOCK
- FAN RM. FAN ROOM
- ME. RM. MECHANICAL ROOM
- LIN. BAY. LINAC BAY
- PER. A.L. PERSONNEL AIRLOCK
- STOR. STORAGE
- X. BAY X-RAY BAY
- P./R.B. BAY PRIME/REPULSIVE BLAST BAY
- V.C. BAY VACUUM CHAMBER BAY
- W.A. BAY WEAPONS ARMING BAY

ELECTRICAL

MCT MULTI-CABLE TRANSIT TYPE - SEE DRAWING 012-1044-E23

LOCATION "N" DENOTES MCT MOUNTED ON NEAR SIDE OF WALL
"F" DENOTES MCT MOUNTED ON FAR SIDE OF WALL

PENETRATION NO. - SEE DRAWING 012-1044-E23

ABBREVIATIONS FOR SYSTEMS FUNCTION

CHR	CHILLED WATER RETURN	RD	REFRIGERANT DISCHARGE
CHS	CHILLED WATER SUPPLY	RH	REFRIGERANT HOT BYPASS
A	COMPRESSED AIR	RL	REFRIGERANT LIQUID
COND	CONDENSATE	RS	REFRIGERANT SUCTION
CV	CONTAMINATED VACUUM	RA	RETURN AIR (HVAC)
CW	DOMESTIC COLD WATER	SA	SUPPLY AIR (HVAC)
FP	FIRE PROTECTION	V	VACUUM (PROCESS)
HW	DOMESTIC HOT WATER	VENT	VENT THROUGH ROOF (P.I.R.)
HWR	HOT WATER RETURN	HV	HIGH VACUUM
HWS	HOT WATER SUPPLY	EA	EXHAUST AIR
S	HIGH PRESSURE STEAM	O.A.	OUTSIDE AIR
TA	INSTRUMENTATION/CONTROL AIR	LOU.	LOUVER
NP	NON POTABLE WATER		

OPENING SIZE

WALL PENETRATIONS

- L HORIZONTAL DIMENSION
- H VERTICAL DIMENSION

ROOF PENETRATIONS

- L AND H ARE DEFINED ON "DWG. WHERE TAKEN"

REFERENCE DRAWINGS

STRUCTURAL

PENETRATIONS AND UNISTRUTS

REFERENCE PLANS	DRAWINGS 012-1044-S109 THRU S113
WALL ELEVATIONS	DRAWINGS 012-1044-S114 THRU S120
ROOF PLANS	DRAWINGS 012-1044-S121 THRU S144
DETAILS	DRAWING 012-1044-S145
SCHEDULE	DRAWINGS 012-1044-S146 THRU 156

UNISTRUTS

SCHEDULE	DRAWINGS 012-1050-S156 THRU S157
ELECTRICAL	DRAWING 012-1044-E23
HVAC	DRAWINGS 012-1044-M1 THRU M36
PLUMBING AND PROCESS	DRAWINGS 012-1044-P1 THRU P20
FIRE PROTECTION	DRAWINGS 012-1044-F1 THRU F8

GENERAL NOTE

SEE MECHANICAL AND ELECTRICAL DRAWINGS FOR PENETRATIONS THROUGH FLOOR SLABS.

TYPICAL PENETRATION SCHEDULE

FIGURE 6

R I S K   V A L U A T I O N

OF

THE LIMITS OF EXPLOSIVES

IN

P R O C E S S   B U I L D I N G S

BY

* P. M. DESHPANDE, IOFS (RETD)

AND

** N. R. APHALE

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* Ex-Dy General Manager,
Ordnance Factory Board, INDIA.

** Ex-Safety Section In-Charge,
Ammunition Factory, PUNE, INDIA.

RISK VALUATION OF THE LIMITS OF EXPLOSIVES IN PROCESS BUILDINGS

General:

1.0 An Explosive is a substance or mixture of substances - Solid or liquid - which, when properly stimulated, evolve enormously greater volumes of gaseous products. When this evolution takes place in an enclosed space, with so tremendous rapidity, this causes the disruptive effect of the Container leading to an Explosion.

1.1 The Hazardous characteristics of Explosive substances and the inherent risk involved in their manufacture/processing in process Buildings are well-known.

1.2 The Valuation of such Risk is an important subject which needs very careful considerations especially at the design stage in arriving at the Limits of Explosive Holdings in process Buildings.

1.3 The Dictionary meaning of "Valuation" is "Estimation of Value" - in this particular case "Risk" -- Risk of handling the quantum of Explosive substances in process Buildings.

1.4 Risk, in the simplest form, is defined as the Probability and Consequence of an Accident. Risk is equated to the Expected damage it is likely to cause.

1.4.1 Risk can also be defined as the Product of Frequency of an event and the Consequences, given that the event occurs.

1.5 Process Buildings where the Explosives/Explosive Substances are processed in Bare/Nascent form are the most vulnerable areas of the Risk of Explosion.

2.0 Risk Assessment:

2.1 It is just not possible to remove every risk factor during the Processing of Explosives/Explosive Substances in the Process Building.

2.1.1 It is, therefore, essential to initially identify the Risk-factors involved in the Process which are likely to cause accidents or

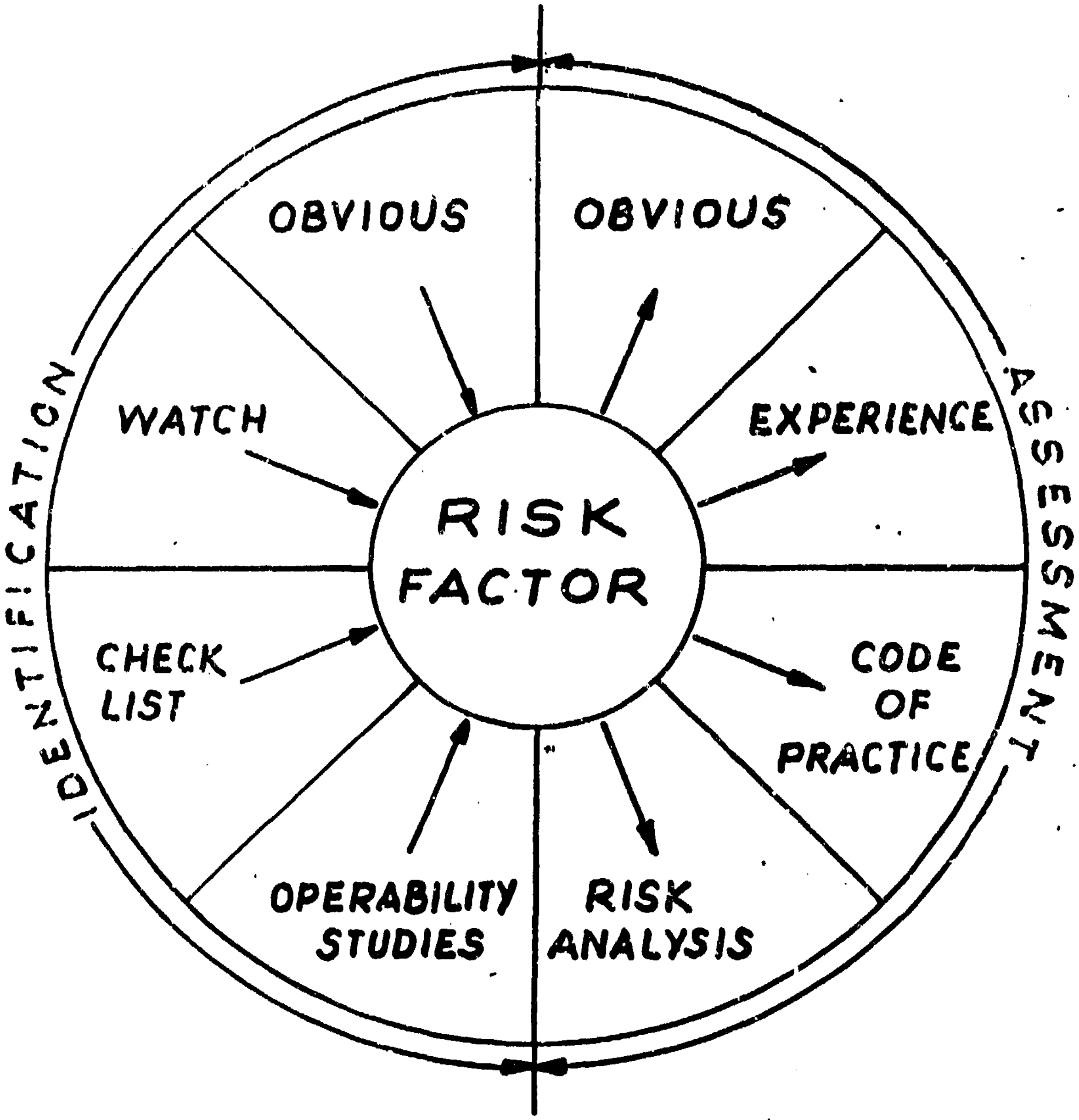


FIG. METHOD OF IDENTIFYING AND ASSESSING RISK FACTORS reach "Near-miss" situations likely to lead to accidents; and then minimise their probabilities by Limiting the Explosive Holdings in the Process Building.

2.2 The risk can be identified by -

Possible causes,

Process deviation, AND

Possible Consequences.

2.3 Once the risks are identified, the next step is to assess the Risk, to assess Safety Aspects for keeping the Risks to the minimum; and accordingly, decide upon the Limits of Explosive Holdings in the Process Building.

2.4 The two major elements of the Risk assessment are -

(i) Risk analysis,

(ii) Risk Appraisal.

2.4.1 The object of Risk analysis is to determine the probability of Accidents and the Expected Damage. This is mainly done by Simulation; Field Trials; Experience of the Experts on similar earlier simulations substantiated by Statistical data, if any. It is important that the data on "Near-miss" situations is taken cognizance of and not lost sight of.

2.4.2 The main purpose of Risk Appraisal is to arrive at the Risk Criteria in an Explicit and Quantitative manner and determine the Limits in the Process Building as "Safe and Acceptable". It is this Appraisal that is very vital while sanctioning the Limits of Explosive Holdings in the Process Building.

3.0 Safety Assessment:

It is inescapable to assess the safety aspects of the system of operations in the Processing, in order to arrive at the Limits. The main consideration are -

(i) The Safety of an Individual Operator exposed to the Hazard.

(ii) Collective safety of the personnel in the Process Building.

(iii) The safety of the adjacent operative Building and also the Expense Store within the Process area.

(iv) The perceived risk of accidents likely to cause panic in Public in general.

(3)

3.1 It is important that the quantum of Explosives/Explosive Substances opposite any operator is properly quantified and sanctioned so as to minimise risk to him.

3.1.1 Similarly, it is equally important that the total quantum of Explosives in the process Buildings is quantified, well distributed depending upon the operations involved and sanctioned as much as to minimise the risk aspects at (ii), (iii) & (iv) above.

3.2 In order that the severity of Risk involved in the process Building is well understood, it is pertinent that -

(i) The Design Considerations are carefully studied.

(ii) Proper facilities for the handling of Explosives/Explosive substances are worked out; and

(iii) The Limits of Explosive Holdings in these Buildings are properly assessed, sanctioned and strictly adhered to.

4.0 Design Considerations:

4.1 The Risk Factors and the Safety Assessment are the major points for -

(i) Design Aspects of the Process Buildings inclusive of the requisite safety protections such as Blast Walls, Earth Traverses, etc.

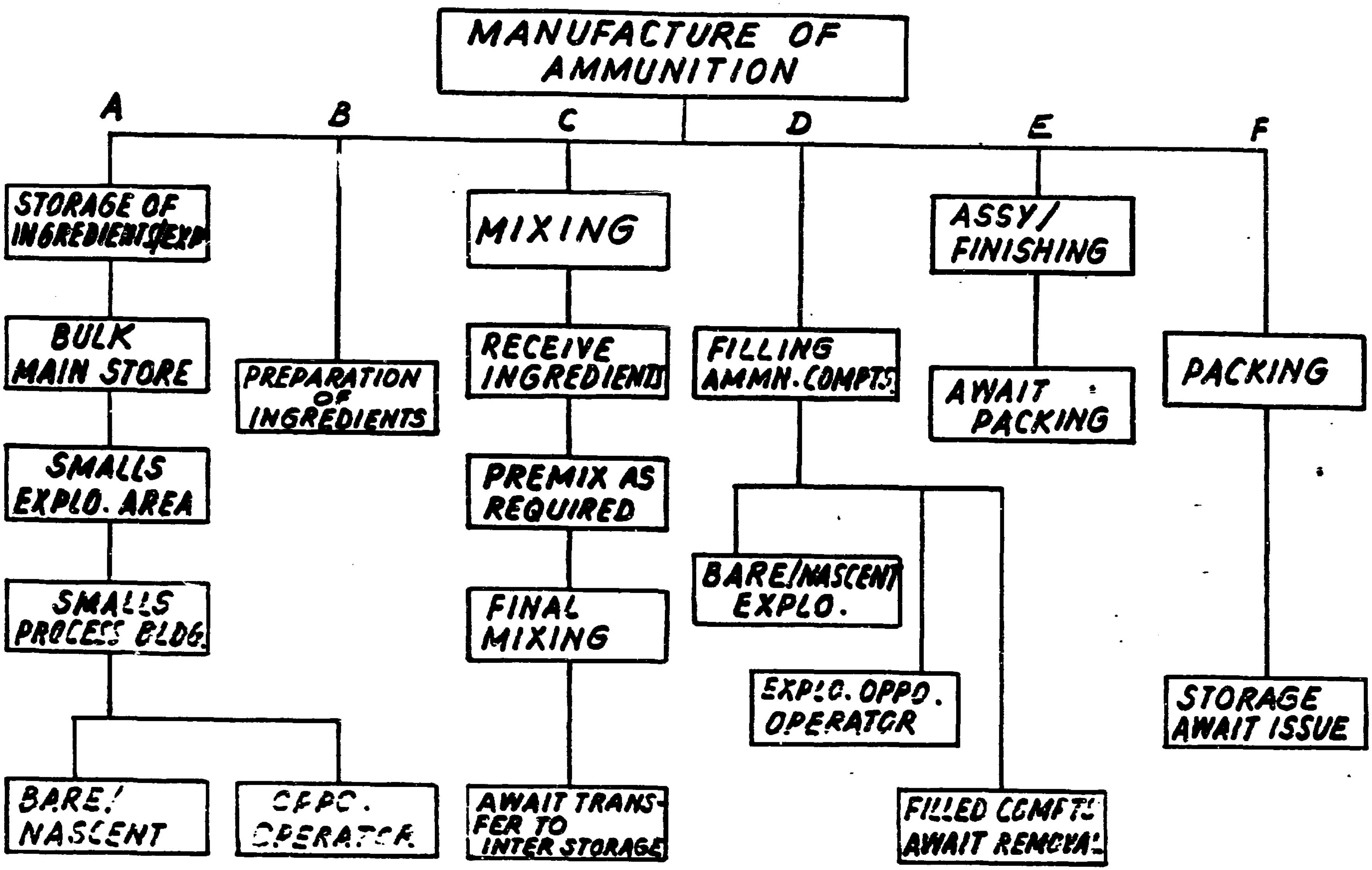
(ii) The determination of the Explosive Holdings to be sanctioned in any Process Building.

4.2 The various stages generally involved in the manufacture of Ammunition Stores are shown in the chart.

4.3 This paper deals mainly with the Design aspects for the Process Buildings and the Expense Storage Buildings in the Process Area.

4.4 The Process Area is initially decided upon by the Management for the Optimum Production of the Ammunition Store. Once this is earmarked, the next step is to break-up the stages of manufacture of the store; decide on the number of Buildings and other ancillary Buildings to cover all the Stages; and then locate the Process Building as per the requirement.

4.5 Any Building in the Process Area is basically designed and located as per the Categorization of the Ingredients and the Explosives to be processed. This involves the following main Aspects -


MANUFACTURE OF AMMUNITION
A
B
C
D
E
F
STORAGE OF INGREDIENTS/EXP
BULK MAIN STORE
SMALLS EXPLO. AREA
SMALLS PROCESS BLDG.
BARE/ NASCENT
PREPARATION OF INGREDIENTS
MIXING
RECEIVE INGREDIENTS
PREMIX AS REQUIRED
FINAL MIXING
AWAIT TRANSFER TO INTER STORAGE
FILLING AMMN. COMPTS.
BARE/NASCENT EXPLO.
EXPLO. OPPD. OPERATOR
FILLED COMPTS. AWAIT REMOVAL
ASSY/ FINISHING
AWAIT PACKING
PACKING
STORAGE AWAIT ISSUE

(5)

(i) The Dimension of the Process Building and its construction details.

(ii) The distance between two working Process Buildings.

(iii) The distance between any working Process Building and the Expense Store.

(iv) The distances of these Buildings from the Administrative Block in the Process Area and the utilities to be provided therein.

(v) The provision of requisite safety Protection for the Buildings such as Blast Walls, Earth Traverses, etc.

4.6 The main tools at the disposal of the Design Team to achieve these aspects are -

(i) U.N.Categorization of the sensitive materials/Explosives.

(ii) The S.T.E.C. Regulations.

4.7 The distances as required in Para 4.5 are arrived at by following the RB Values.

4.7.1 RB Value is defined as the Radius upto which Barrack Damage will take place causing Total Demolition of any construction within that Radius or Causing Irrepairable Damage to such Constructions by the Explosion in the Process Building/Storage Building.

4.7.2 The RB Values differ for different situations and have been arrived at, after extensive Simulations, Field-experiments, and the Experience gained as a result of the Investigations of Accidents in various Countries.

4.7.3 Based on the above, the Radii are maintained as under -

(i) The distance between two explosive storage Buildings is maintained at 1 RB depending upon the Explosive Holdings.

(ii) The distance between two Process Buildings in the Process Area is maintained at 1.5 RB.

(iii) The distance between a Process Building and Explosive Expense Store in the Process Area is also maintained at 1.5 RB; and

(iv) The distance between Process Buildings/Area and the General Public Utilities is kept at 4 RB.

5.0 Explosive Limits in Process Building:

5.1 Taking into consideration all the above parameters, it is still difficult to exactly quantify the Explosive Limit for a Process Building.

5.2 The two important conditions to quantify these Limits are-

(i) Where the quantum of Explosives is the main consideration, and the Buildings suitably constructed.

(ii) Where the Dimensions of the Buildings are already fixed and the Explosive Holdings are to be arrived at due to other Constraints -

5.3 The Explosive Holdings in any Process Building depend upon -

(i) The category of the Explosive being processed, as per the U.N. Classification.

(ii) The operation schedule.

(iii) The Input of Nascent Explosives/Explosive Substances.

(iv) The Inter-stage storage of filled Components in the semi-stage awaiting further operations in other Process Building or storage in Expense Store.

(v) The safety distance of the Process Building from (a) adjacent operating Building and (b) Expense Store within the Process Area.

(vi) The construction of the Process Building for the specific operations to be carried out therein; AND

(vii) Finally, the optimum quantum of Explosives/Explosive Substances in various stages required to be stored commensurate with -

(a) Limitations of the Building Dimensions, AND

(b) The limitation of Optimum Production to be achieved.

5.4 The constraints of working out the maximum permissible quantum of Explosives in a Process Building have been brought out in Para 5.2. This quantum, however, is further scaled down while sanctioning the Explosive Limit especially from the safety aspects in order that even if the shop-floor personnel inadvertently exceeds this limit marginally, the maximum permissible limit is not reached. The sanctioned limits is worked out from another angle also, viz. "In the event of any accident, the damages to the personnel, Plant & Machinery, the Building and its surroundings will be minimum and will not cause Panic in Public in General."

5.5 As an example, the maximum permissible limit for the Process Building working with Explosives of U.N. Classification 1.3 will be such that the fatal dose of 4 Calories/Sq.cm. of the Heat

Dosages is not reached. The sanctioned limit is, ofcourse, less than the maximum permissible limit.

6.0 Distribution of the Explosive Holding within the Process Building:

The total Explosive content of the Process Building is not concentrated at any one point, but is suitably distributed depending upon the type of operations and the constructional details of the Building such as Cubicles, Bays, etc. The risk, therefore, gets further reduced.

7.0 Inspite of the fact that all the above mentioned considerations are carefully taken into account, and the Explosive limits sanctioned, instances are not wanting when the Shop-floor Personnel, at times, exceed such Limits due to factors well-known to themselves. Initially nothing untoward appears to take place, and the tendency to exceed a little more creeps in. When this tendency increases, the catastrophic events take place. Once the major accident takes place, everyone tries to convince the Enquiry Committee that all the regulations were properly followed by them; and that there was no likelihood of Excess Explosive Holdings in the Building. However, it is not impossible to assess the quantum of Explosives at the time of Explosion from the damages caused. In the succeeding paragraph are brought out a few such case studies.

8.0 Case Studies:

Case No.1 - There was a loud Explosion in one of the Process Buildings in which there was not only serious structural damage to the Building but loss of life also.

The splinters flew out in more than 50 metre radius. The loud explosion and the loss of life caused panic in general population. Luckily there was no damage to any neighbouring working/ process Buildings.

The operations which were being carried out in the two bays of this Building were (i) Mixing of a Sensitive Explosive Composition, and (ii) Filling of this Composition into Ammunition Components. These two bays were separated by a Partition Wall.

(8)

There was no survival to explain the Cause of the Accident. The likely Causes which could be surmised from the circumstantial evidence were (a) Excessive Dust Cloud formation, (b) Electrical Short-circuit, (c) Development of Static Electrical Charge and/or (d) Accidental fall of a Container of this Sensitive Composition/ Filled Components.

It transpired from the circumstantial evidence that although the shop-floor Leading Hand was an experienced one, fully aware of the hazard of this Sensitive Explosive Composition, he might have taken Calculated Risk and Exceeded the sanctioned Explosive Limit, not repeat not being fully aware of the consequences of such excess quantum of the Explosives in case of any accidental situation.

In addition to the above, there might have been some slippage while constructing the partition wall due to which the wall totally collapsed and the number of loss of life increased a little more.

The Explosion reached the catastrophic stage, therefore, due to (a) Excess Holdings in one or both the bays and (b) the possible defect in the construction of the Partition Wall.

Had the sanctioned Explosive Limits been strictly adhered to, and partition wall built strictly as per laid down regulations, the loss of life and the catastrophic nature of the accident could have been minimum.

<u>Case No.2</u> - In one of the Explosive Process Buildings, an explosion occurred when bulk of filled components exploded due to sympathetic detonation. The building completely collapsed. The operators within the building lost their lives. The Supervisor who was just entering the building got severe burn injuries which proved Fatal.

As per the Operation Schedule in the Process Building, the Explosive Components were suitably distributed into different bays and the total explosive limit for the building sanctioned was within Limits, as per regulations.

From the Circumstantial evidence it was surmised that (i) the bulk of filled components which were to be stored in the last bay and removed to the Expense Store would not have been removed, (ii) the operator started the operation in his bay on the fresh Input of the Components, prior to the above and/or (iii) that one of such filled components would have accidentally exploded, thereby causing sympathetic detonation of all the filled Components in the building causing such serious structural damage and loss of life.

If the bulk of the filled components had been removed to Expense Store prior to commencement of the operations on the fresh Input, the devastating damage and the loss of life could have been avoided even if one of such filled component had exploded.

Case No.3 - There was a sudden loud bang, followed by another loud bang in an Explosive Process Building due to explosion.

The building and one of the Blast Walls completely collapsed. The other Blast Walls were bent but did not collapse. The lobbed parts of the roof blew over to adjacent building but did not cause any serious damage. There was a severe Ground Shock but no major damage was noticed.

All the personnel inside the building lost their lives and there was no survival to explain the cause of the event.

The operations carried out in the building were - (i)Pre-mixing of sensitive Explosive Composition and (ii)Final mixing in the Mechanical Mixer.

The two operations were adequately separated by the Partition Wall. The rear wall of the building was constructed as a 'Weak Wall'.

All the facilities such as provision of Blast Wall on all sides, weak rear wall, safety distances for the building were satisfactorily provided.

The explosive limit sanctioned for this building was also as per the Regulations. The same was suitably distributed.

The Circumstantial evidence brought out that there could have been the initial bang at the Blender Mixer end, presumably due to (i) Electrical Short-circuit at the time of starting the machine, (ii) the likelihood of the improper pre-mixing (even hardened) and/or (iii) excess dust cloud formation. This would have caused further sympathetic explosion/detonation in the neighbouring pre-mixing bay leading to such a devastating damage and loss of life. The operative personnel were aware of the potential hazards and the likely damages.

The extent of damage of such a devastating nature could not have taken place but for the exceeding of the sanctioned Explosive Limit for the building, although not intentionally, and presumably to achieve the increased production.

9.0 <u>Remedial Measures</u>:

9.1 Having discussed the Case Studies, it is pertinent to suggest the following remedial measures. The paramount importance of the Safety of Personnel in the Process Buildings as also those in the neighbourhood Building needs no special emphasis.

9.2 <u>Responsibility of the Employer</u>:

In order that the Shop-floor Personnel do not exceed intentionally or otherwise, the Explosive Holdings in the Process Area, the Employer should -

(i) Organise the Safety Department independent of other Departments, to be headed by a Senior Manager directly reporting to the Top Executive.

(ii) The staff of this Department causes surprise checks in the Process Buildings at the time of his visit and record the same.

(iii) In case the sanctioned limit is observed to be in excess, he immediately reports to his Manager. He also keeps close watch on 'near-miss' situations.

(iv) The staff looks into the preventive maintenance schedule for the Plant and Machinery and Electrical Equipments and check the records for the same. Any deficiencies should be reported for immediate rectification.

(v) The Top Executive should take serious note of such reports from the Safety Department with the same importance which he normally gives to the Production activities.

9.3 Responsibility of the Employee:

The Employer, on his part, lays down the sanctioned Limits for the Process Buildings, the Operations Schedule, clearly mentioning the Special Precautions to be taken and the Special Dangers to be avoided, and also the preventive maintenance schedule. It will be the primary responsibility of employee that -

(i) He is fully aware of the hazardous characteristics of the Explosives/Explosive Substances being processed.

(ii) He carries out the operations strictly as per the Operation Schedule.

(iii) He does not exceed the total Sanctioned Limits for the building and its distribution at any stage and time; specially ensuring that he does not exceed the quantum of the sanctioned amount of explosive in front of him, which cumulatively would add to the Excess Explosive Holdings.

(iv) He must remember that "A Chance-Taker is the Accident-Maker"

10 Conclusion:

Both the Employer and the Employee must remember the following Golden Rules :

(i) Do not underestimate the Hidden Hazards involved in the Holdings of Explosive/Explosive Substances.

(ii) Desist from any increase in the Explosive Limit beyond the sanctioned one even though demanded by increased production.

(iii) Remember that the increased Production can also be achieved by ensuring that the Explosives/Explosive Substances and the semi-stage components are not allowed to accumulate at any stage beyond the Sanctioned Limit.

(iv) Do not allow the likely tendency of every operator to keep slightly higher quantum of the Explosive Holdings in front of him since this would add to the increased Explosive Limit which would result in "near-miss"/Catastrophic accidental situation, and finally

(v) Remember that "Good House-keeping" is the key for safe practice and avoidance of accidental situation.

:::

Design and safety organization for explosives environmental test facility

Maurice CHIZALLET
MATRA DEFENSE
37 avenue Louis Bréguet
78146 - VELIZY VILLACOUBLAY - FRANCE

- **Abstract** -

When designing an explosives facility, French manufacturers must refer to the basic principle of French safety regulation, which states:
"Buildings must be designed and built in a manner such that any accidental explosion shall not generate a major risk for persons other than those who, due to their work, must remain exposed to the possible effects of a potential accident".

This paper shows the concrete application of this principle when designing a missile warhead environmental test facility, setting the safety organisation, stipulating the operating rules and justifying the options and decisions to the Official French Agencies.

Presented at the 24th Explosive Safety Seminar August 90
Saint Louis - MISSOURI

I. Introduction

The major principles for explosive safety are well-known to the international technical community. In each country, they are subject to the rules and regulations in force which mainly differ in form but are similar as regards their technical content.

In France, however, the situation may be considered as rather particular. Indeed, a national regulation which is applicable to the entire French explosive products and items industry defines the principles, the resulting technical arrangements and the conditions according to which manufacturers must demonstrate the validity of the steps taken to the administration ensuring the safety of the personnel and the environment.

At the 23rd, E.S.S., I spoke on this regulation, and its application by MATRA DEFENSE in the context of a MISTRAL missile production facility. In particular I indicated the means installed to control the safety of the establishment and the environment.
As MATRA DEFENSE develops and manufactures missile systems, we have designed and constructed a new workshop intended for environmental testing of missile components and munitions. This installation is a good example of the method chosen by MATRA DEFENSE to provide the best safety level for the operators as well as for neighboring installations, in accordance with criteria fixed by the French regulation.

II. Explosive safety rules

Before starting studies on a new munitions test facility, it is appropriate to outline the basic principles the designer must adhere to in preparing his study.

In the United States the principle of facility safety is illustrated by a paragraph of the DOD document : Ammunition and explosives safety standards 6055-9 :
"Construction features and location are important safety considerations in planning facilities that are to be P.E.S., or exposed to the damaging effects of potential explosion (that is E.S.). The effects of potential explosions may be altered significantly by construction features that limit the amount of explosives involved, attenuate resultant blast overpressure or thermal radiation, and reduce the quantity and range of hazardous fragments and debris. Proper location of exposed sites in relation to P.E.S. ensures against unacceptable damage and injuries in event of an accident".

In France, the applicable regulation (Decree N° 79-846) stipulates :
"Buildings must be designed and built in a manner such that any accidental explosion shall not generate a major risk for persons other than those who, due to their work, must remain exposed to the possible effects of a potential accident".

These general requirements are completed by the Zi/Pj/ak formula which establishes maximum risk exposure conditions. Using this approach, operator safety is evaluated according to the following criteria :

- Hazard zones (Zi), representing the consequences of an accident exposing personnel to overpressures, fragment projections, and thermal effects :

Zi	PERSONAL INJURY	PROPERTY DAMAGE
Z1	LETHAL INJURIES IN MORE THAN 50 % OF CASES	VERY SEVERE DAMAGE
Z2	SERIOUS INJURIES WHICH MAY BE LETHAL	SEVERE DAMAGE
Z3	INJURIES	MEDIUM AND SLIGHT DAMAGE
Z4	POSSIBILITY OF INJURIES	SLIGHT DAMAGE
Z5	VERY LOW POSSIBILITY OF SLIGHT INJURIES	VERY SLIGHT DAMAGE

- **Probability of an explosive accident (Pj).** This point is determined by an analysis of operations carried out, that is, stimuli liable to affect the munitions, the sensitivity of the munitions to these stimuli and the preventive measures to be implemented.

Pj	LEVEL	EXAMPLES
P1	EXTREMELY RARE	STORAGE AND HANDLING
P2	VERY RARE	FABRICATION OPERATIONS-PACKING
P3	RARE	MACHINING OF SENSITIVE, ENERGETIC MATERIAL, COMPLETE ROUND TEST OPERATIONS
P4	RATHER FREQUENT	OPERATIONS ON VERY SENSITIVE MATERIALS, PRODUCTION OF PRIMARY EXPLOSIVES
P5	FREQUENT	MIXING, COMPRESSION OF PRIMARY EXPLOSIVES

- **Risk exposure** : for the facility under study-considered as risk donor or potential explosion site (P.E.S), called "ao", the different types of installations and personnel risk receivers - or exposed sites (E.S.) - are succinctly classified in three categories :

1. **Facilities inside the plant**

   - a_1 Explosive facilities having to be located near "ao"
   - a_2 Other explosive facilities and inner roads
   - a_3 Inert buildings

2. **Roads outside the plant**

   - b_1 Traffic < 200 vehicles/day
   - b_2 Traffic between 200 and 2000 vehicles/day
   - b_3 Important traffic > 2000 vehicles/day

3. **Buildings or other places outside the plant**

   - c_1 Uninhabited, short presence
   - c_2 Inhabited by, or with, plant personnel present
   - c_3 Other facilities, houses...
   - c_4 Public places : markets, schools, hospitals, dense built-up areas.

According to the product of Zi × Pj, limits are established for risk exposure to both operators and installations. These possibilities are indicated in the following table :

probability / hazard zone	P1	P2	P3	P4	P5
Z1	a_0	a_0	$a_0^{(x)}$	$a_0^{(xx)}$	$a_0^{(xx)}$
Z2	a_1 a_2	a_1 $a_2^{(x)}$	a_1	$a_1^{(x)}$	$a_1^{(xx)}$
Z3	a_1 b_1 c_1 a_2 a_3	a_1 b_1 c_1 a_2	a_1 a_2	a_1	$a_1^{(x)}$
Z4	a_1 b_1 c_1 a_2 b_2 c_2 a_3	a_1 b_1 c_1 a_2 b_2 c_2 a_3	a_1 b_1 c_1 a_2	a_1 a_2	a_1
Z5	a_1 b_1 c_1 a_2 b_2 c_2 a_3 b_3 c_3	a_1 b_1 c_1 a_2 b_2 c_2 a_3 b_3 c_3	a_1 b_1 c_1 a_2 b_2 c_2 a_3 b_3 c_3	a_1 b_1 c_1 a_2 b_2 c_2 a_2 b_3 c_3	a_1 b_1 c_1 a_2 b_2 c_2 a_3 b_3

<u>NOTE</u>: (*) Indicates that the personnel required to operate the facility concerned shall not be subjected for more than 10 % of their working time to risks equalling to those to which they are exposed in this installation.

(**) Indicates, that no person shall be present in the zone and installation concerned, in application of the requirements of Article 27 of Decree No.79-846 of September 28, 1979.

A minimum number of persons shall be allowed to gather simultaneously in zones Z1 and Z2.

The number of persons simultaneously present throughout installation "ao" exhibiting a probability of explosive accident greater than P1 shall not normally exceed 5.

Thus, it clearly appears that when environmental tests, such as climatic, vibration, impact and so on, are conducted in a facility, the probability of an explosive accident will be at least P3 and that special measures should be taken to protect operators.

One of the essential aspects of the French regulation is that the analysis briefly described must be conducted in the form of a safety study on which the opinion of the personnel or its representatives is given. The study is then submitted for approval to the competent governmental authorities.

III. Design of the "Environmental test" facility

To begin the study for the facility, a preliminary 3-step examination should be undertaken :

1 - Precisely defining needs, in other words, the type of munitions concerned, net explosive quantity (N.E.Q.) of the maximum credible event, and the various operations that will be carried out. For example : munitions with explosive charges rated at 15 kg N.E.Q. and climatic or mechanical testing (impact, vibration, acceleration tests).

2 - Defining facility characteristics which will ensure personnel safety environment and worktool protection. For this, the workshop must :
   - Withstand the effects of an accidental explosion during testing ;
   - Contain hazardous fragments, and
   - Reduce the effects of such an explosion to an acceptable level for the environment.

3 - Defining the number of rooms required - this kind of installation necessitates test cells, a storage cell, a corridor, and a facility control center.

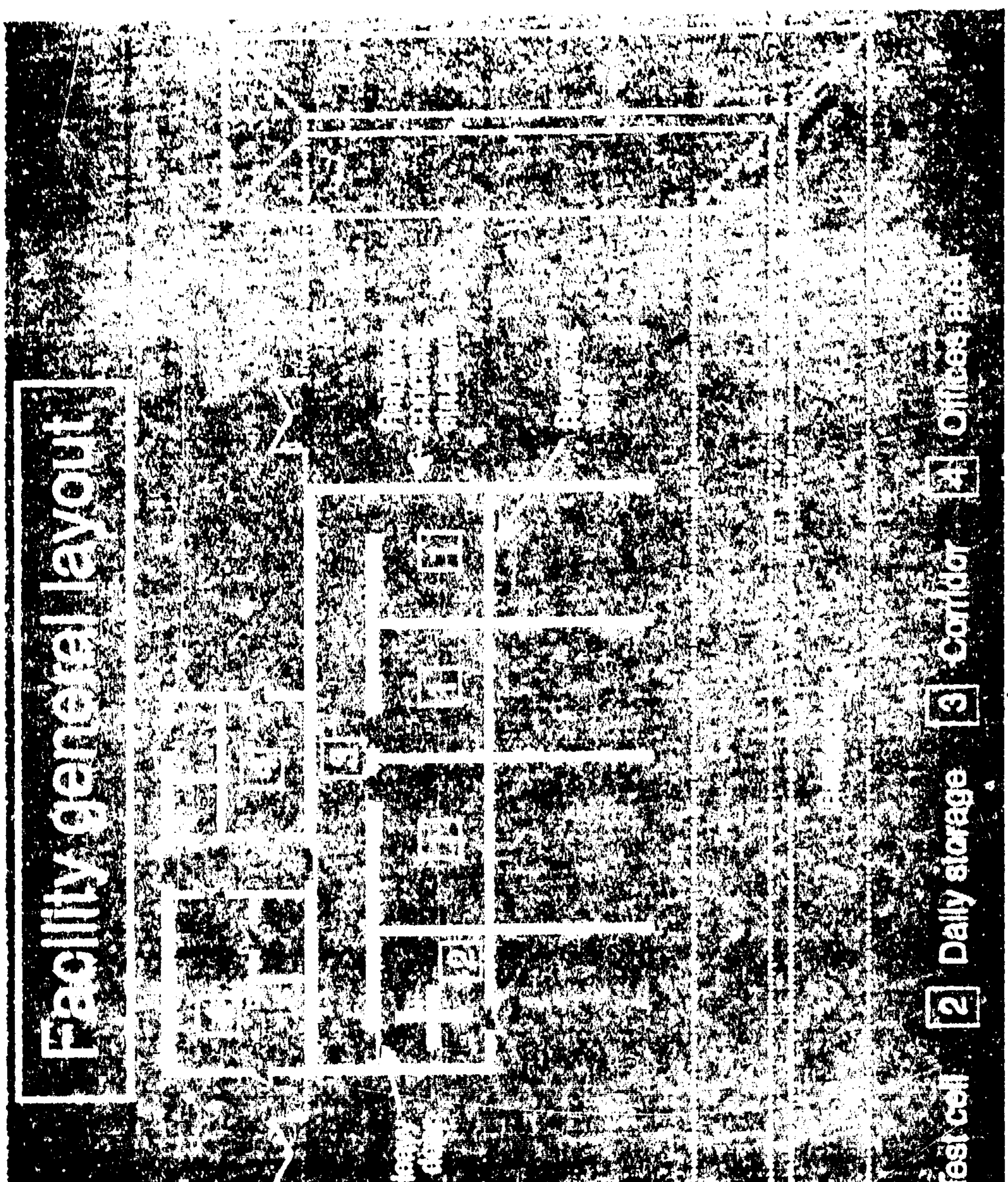
The principle of limiting personnel risk exposure, combined with the previous three steps, means the building layout should be based on the following criteria :
- Maximum risk separation,
- Containing the effects of an explosion, and
- Designing each room to the risk level of the operations carried out in it.

3.1. Facility general layout

The facility requires 4 kinds of workspaces which can be split into two parts :

a) **Explosive Area**
- Contiguous cells for test (1) and one cell for storage (2).
- A corridor (3) for transportation of explosive charges and for personnel movement.

b) **Facility control and processing section**
Several rooms needed for facility control, instrumentation and management (4).
This arrangement makes it feasible to easily examine the impact of each risk donor (P.E.S.) on the others, considered as risk receivers (E.S.).


Facility general layout
1 Test cell
2 Daily storage
3 Corridor
4 Offices area

3.2. Design of Explosive Area (P.E.S.)

The cells in the explosive area are composed of five blast resistant walls and one blow-out wall. The lateral walls extend in the direction of a barricade. At their upper parts shield plates are bolted for arresting fragments or channeling them towards the barricade and damping the shock wave. A heavy, sliding, electronically-controlled door enables entry to each cell.

The corridor is composed of the strong walls of the cells and a strong vertical wall separating the explosive area from the inert zone. It acts as an airlock between the inert zone and the test cells. As the risk level in the corridor is low the roof is light but capable of resisting the back-pressure wave coming from a blow-out wall of one of the cells. It is equipped with meshing to protect the personnel from falling roof fragments.

3.3 Design of the control and processing section (E.S.)

This part of the building adjoins the corridor. Its construction is designed to withstand the effects of an accident produced in one of the P.E.S.s and consequently to guarantee the safety of personnel in this area. A sliding heavy door provides access to the corridor which, in turn, provides access to other parts of the building.

IV Internal safety organization

4.1 Safety equipment

Risk management requires the implementation of checking, surveillance, and intervention devices, such as :

- A communication network linking all facility cells to the control center.
- A video camera network for the surveillance of all cells and the corridor.
- A lighted panel signalling system indicating the status of each cell (explosive or inert activity).
- An emergency cut-off switch near each test machine.
- Fire protection including a high speed deluge system and conventionel fire fighting systems.
- Lightning protection.
- grounding of all conductive elements.
- building access control by means of the facility manager's control board.

The facility manager's control center provides the following capabilities :

- control of the closed circuit surveillance system.
- control of auditory signals indicating the transfer of explosive items.
- Control of lighted panels situated above the heavy doors.
- manual control of the deluge system, and
- building access control.

4.2 Operating rules

Operating rules, based on the facility characteristics adopted in the design phase, make it possible to ensure safety by determining the conditions in which the various functions will be carried out.

In an environmental test facility each risk donor (P.E.S.) should contain any possible hazard ; no propagation of any incident can be allowed.The heavy doors between the cells and the corridor should therefore be used according to strict procedures.

- When not in use, all heavy doors remain closed.
- Any particular door can be opened only if all the others are closed.
- Opening a cell door immediately cuts-off all machinery in that cell.
- Opening a cell door is accomplished through electric command units placed in the corridor and inside the cell. If necessary, doors can be opened manually from the corridor and from inside the cell.
- The door opening unit is regulated by a timer. Automatic closing of the door is prevented in case an obstacle (either a person or an object) lies in its path.
- Access to the storage cell is controlled by the facility manager, and is only possible when the test cells are not in use.

The test cells can be used in two modes :

Inert mode : Personnel may be inside the cell for adjustment, control, and testing operations involving inert materials.

<u>Active mode</u> : Operators may be present during the installation and instrumentation phases involving test equipment ; the risk level at these times is rated at P2. During the operation of test machinery, the cell is strictly off-limits to all personnel, as the risk level here reaches P3.
The cell mode is selected on the control panel located in the control center through the use of a key. The mode selected is automatically indicated on the control panel as well as on the lighted panel above the cell door.

4.2.1 - <u>Activation of a test cell</u>

In order to keep the test procedure under control, a single key kept in the test engineer's possession at all times enables :

- The cell mode (active or inert) to be selected,
- The activation of the test machine.

In "active mode" the machine can only be switched on from the control panel located in the control center using the unique key kept at all times in the test engineer's possession. The machine is stopped in the same way, or the event where the cell door is opened.

In "inert mode" activating the test equipment requires authorization for the necessary electrical power from the test engineer. He must insert his key into a lock on the machine, then convey the order to start-up the machine by intercom to an operator in the control center, who then activates the equipment by pressing a button. The test equipment can be stopped either from the control center or by use of the emergency cut-off switch located near the machine ; opening the cell door automatically shuts down the test equipment.

When the machine is shut down, its electrical power supply is desactivated. This means that the entire sequence must be rerun for the next startup.

4.2.2 - A normal operating sequence

a) Transporting material for the test

The person in charge of the test collects the material in the storage cell and contacts the control room by intercom. All cells are alerted by intercom and by an audible signal, of the imminent material transport. All cell doors are closed during this operation.

b) Preparing the test

The material is removed from its packing and put in place on the test machine with the specific instrumentation.

c) The test

The person in charge of the test returns to the control center, places his key in the switch and begins the test sequence. At the end of the test sequence, when the test equipment has been switched off, the test engineer removes his key from the control panel, returns to the test cell, performs the necessary verifications, repacks the material and returns it to the storage cell under the same transport conditions as before.

4.3 - Analysis of personnel risk exposure

Tests of explosive charges in the facility, under the operating rules previously cited, must be analysed to determine if the level of residual risks to which personnel are exposed is acceptable. This analysis is based on the criteria defined earlier : Hazard (Zi), and the probability of an accidental explosion (Pj).

In order to conduct this analysis we should examine 4 types of situation :

- material storage phase,
- material transport phase,
- the test preparation phase,
- the test phase.

In each of these cases, the most significant hazard lies in the accidental explosion of the charge.

4.3.1 Material being held in the storage cell

A maximum of four charges of a unitary net weight inferior or equal to the TNT equivalent weight allowed by the cell's explosion resistance rating can be stored in the cell. Steps are taken to prevent more than one charge from detonating simultaneously.

The horizontal and vertical walls are capable of withstanding the effects of an accidental explosion, with the door between the cell and the corridor closed. The blow-out wall allows for an internal overpressure, and the shock wave would be directed towards the barricade.

Personnel in all other parts of the facility would be entirely protected.

Operations are limited to simple material handling, conducted by two employees. The maximum risk exposure could be described thus, in regulation terms :

- P.E.S. - a_0 - 2 persons / Hazard zone Z1 / Probability level P1. In other words, a major hazard, but with an extremely low probability.

- E.S. - a_1 - Other cells and the inert zone - 4 persons / Hazard zone Z3 / Probability level P1. Here, the hazard is slight and the probability of an accident extremely low.

No other person or installation is exposed to a significant risk ; the situation is acceptable.

4.3.2. - Material transport phase

A charge is transported from the storage cell to a test cell, and back, in its packing and under conditions that make it possible to avoid any false handling. Only one door can be open during this phase : either the door of the test cell or the door of the storage cell, and only when the charge is being moved in and out of each cell.

All personnel informed that material is being transported are either in a cell or in the inert zone. The vertical walls of the corridor would direct any eventual blast effects and projectiles upward. The roofs of the cells and the inert areas are calculated to withstand overpressures and to support any eventual projectile fallback.

The maximum risk exposure is therefore :

- P.E.S. - a_0 - 1 (or 2 person(s) / Hazard zone Z1 / Probability level P1
- E.S. - a_1 - cells and inert zone - 5 persons / Hazard zone Z3 / Probability level P1.

No other person or installation is exposed to a significant risk ; the situation is acceptable.

4.3.3. - Test preparation phase

Test preparation operations consist of placing the charge on the test machine and installing the necessary instrumentation ; the charge is subjected to no particular stimuli, but we nonetheless consider the probability of an accident higher in this phase.

In the event of an accidental explosion, the vertical walls and heavy door would contain the blast effects. The cell's blow-out wall would be destroyed. The blast wave and projected fragments would be directed along the extended lateral walls and fragment-shielding plates toward the barricade.

Follow-up of Recommendations Resulting from System Safety Analysis

by

J. M. Crable

Hercules Aerospace Company
Hercules Incorporated
Radford Army Ammunition Plant
Radford, Virginia 24141

ABSTRACT

System safety analyses often specify a corrective action to mitigate or eliminate potential hazards and comply with applicable safety requirements. Often the recommended action(s) cannot be taken immediately due to lack of funding, scheduling problems, etc. One way of tracking a large number of recommendations to ensure a satisfactory disposition is to use a computerized data base that includes all pertinent information. A tracking system program was developed to facilitate identification of recommendations by process, equipment, building, etc. Files are maintained on a daily basis. New recommendations are entered as safety analyses reports are finalized.

The status of older recommendations is updated as their disposition progresses. Validation of recommendation dispositions is done to assure that suitable corrective action(s) has been taken to reduce or eliminate the potential hazard and that the action has not introduced any new hazard into the operation.

INTRODUCTION

Recommendations resulting from system safety analyses per DARCOM-R 385-3 are tracked as required by MIL STD 882B. Tracking recommendations from system safety analyses of facilities, equipment and processes at the Radford Army Ammunition Plant is complicated by the shear size and versatility of the plant. As shown in Figure 1, there are eight major production areas that use either basic raw ingredients or intermediate materials to manufacture primary items that are used to produce propellant or explosive products (Figure 2). As shown in Figure 3 many operations are required to produce the final products. Many of these operations are conducted in individual buildings spaced to limit damage/injury if an accident would occur. The literally hundreds of recommendations resulting from system safety investigations of these diverse operations and products were tracked initially using a labor intense manual operation. This system often "forgot" some long term recommendations and these were not implemented. Some recommendations were implemented in such a way as to introduce a new hazard(s). A computerized system was devised to track and account for all hazards analysis system safety recommendations on a regular (quarterly) basis. The system also includes a follow up review of the implemented recommendations by the recommendation initiator to assure that new hazards are not introduced.

DISCUSSION

A computerized recommendation recall program was structured so that it would be manageable and allow tracking of the recommendation's status. The program contains all details relevant to the recommendation and shows which department is responsible for implementation.

Considerable effort went into developing the program because of the diverse plant operations. The program was structured using the dBase III format and as shown in Table 1, only the required information to track the recommendation is included. The information presented allows tracking of each recommendation by the Safety Department Coordinator (SDC), the responsible department and verification by the Hazards Analysis Department.

As shown in Table 1, tracking of recommendations in the diverse plant operations has been reduced to a manageable system.[1] This allows each plant area to quickly find the status of recommendations relating to them and provides the Safety Department with a way to track the recommendations. It also provides necessary information pertaining to the basic hazards assessment and provides management information on how timely implementation is proceeding by dividing the table into two sections: the first section is for the current quarter and section two is for previous quarters. An example of the information in the tracking system is shown in Table 1. A peristaltic valve in a blender located in the Finishing Area was assessed by Mr. C. A. Ferguson in Hazards Analysis Report HI-90-S-040(FW). Only one out of four recommendations was implemented when the quarterly status report was published. In the Recommendation Column, the letter and number in brackets, e.g., (B.1) is the identity of the recommendation in the reference hazards analysis report. By referring to sections 1 and 2 of the table, Management can determine the effectiveness of their departments in timely implementation of the system safety recommendations.

Hazard Track and Risk Resolution Task 105 in MIL STD 882B[2] specifies the need to track recommendations. Therefore, a recommendation tracking system must be closed loop. This is accomplished by requiring the responsible department to inform the SDC in writing when implementation of a recommendation(s) has been completed.

An example of the recommendation implementation process follows. First the recommendations (Table 2) being made are presented in writing to the department responsible for their implementation. Then the recommendations are entered in the data base file. The responsible department evaluates the recommendations and notifies the SDC of what action has been taken (Figure 5). The Hazards Analysis Department evaluates the action taken by the responsible area and notifies the SDC (Figure 6). Entry is made in the data base file that Recommendation 1 has been satisfied by inserting the word "Implemented" in the Status Column. Subsequent paperwork (Figure 7) informs the SDC of action pertaining to Recommendation 2. Hazards Analysis evaluates the responsible areas response and notifies (Figure 8) the SDC. All recommendations have now been implemented; therefore, as shown in Figure 8, the report file is closed. The data base is updated to show that Recommendation 2 has been implemented. A quarterly report is issued to Management for their review. The recommendation recall system is summarized in Figure 1.

CONCLUSIONS

Recommendations resulting from system safety analyses as required by DARCOM-R 385-3[3] can be tracked as required by MIL STD 882B by using a computerized data base. The program allows for tracking individual recommendations for all major production areas until implemented. After implementation they are automatically dropped from the Recommendation Recall Program.

REFERENCES

[1]Hazards Analysis Department Recommendation Recall Program, Hercules Aerospace Company, Hercules Incorporated, Radford AAP, Radford, VA.

[2]MIL STD 882B, "System Safety Program Requirements".

[3]DARCOM-R 385-3, "Hazards Analyses For Facilities, Equipment and Process Developments".

Status of Field Engineering Recommendations

Through June 30, 1990

Area, Operation and Equipment	Report Number	Recommendation	M or S*	Assigned To	Status of of 6-30-90
1. Field Engineering Activity (This Qtr)					
A. Finishing					
1. Blending					
a. Valve, Peristaltic	HI-90-S-040(FM)	1. (B.1) -----------------	M	Production	Open
	05-31-90	2. (A.3) -----------------	M	Production	Open
	C. A. Ferguson	3. (A.2) -----------------	M	Production	Implemented
		4. (C.1) -----------------	S	Hazards Analysis	Open

(All Recommendations This Quarter Are Listed)

Recommendation Recall Program Modified Summary
Table 1

Status of Field Engineering Recommendations (cont)

Area, Operation and Equipment	Report Number	Recommendation	M or S*	Assigned To	Status of of 6-30-90
2. Field Engineering Activity (Previous Qtrs)					
A. Finishing					
1. Material Handling					
a. Monorail System Building 1827	HI-89-S-012(FW) 02-06-1989 E. Burnett	1. (A.1)------------------	M	Production, Maintenance	Open

(All Uncompleted Recommendations Are Listed)

*M = Mandatory, S = Suggested

Recommendations to Increase NC Wringer Operation Safety

Recommendation	Safety Benefit	M or S*	Authority	Assigned To	Status
Equipment					
1. Change the control box cooling air intake/exhaust for #3 and #4 wringers at Building 4026.	Reduce/eliminate #3 wringer kickout during hot weather	M	Standard Safety Practice	Engineering	Open

SYSTEM SAFETY ANALYSES RECOMMENDATIONS

Table 2

Recommendations to Increase NC Wringer Operation Safety (cont)

Recommendation	Safety Benefit	M or S*	Authority	Assigned To	Status
Procedure					
1. Discuss processing of "thick" NC slurry during safety meetings	Reduce/eliminate wringer problems caused by an unbalanced load	M	Standard Safety Practice	Production	Open

*M=Mandatory, S=Suggested

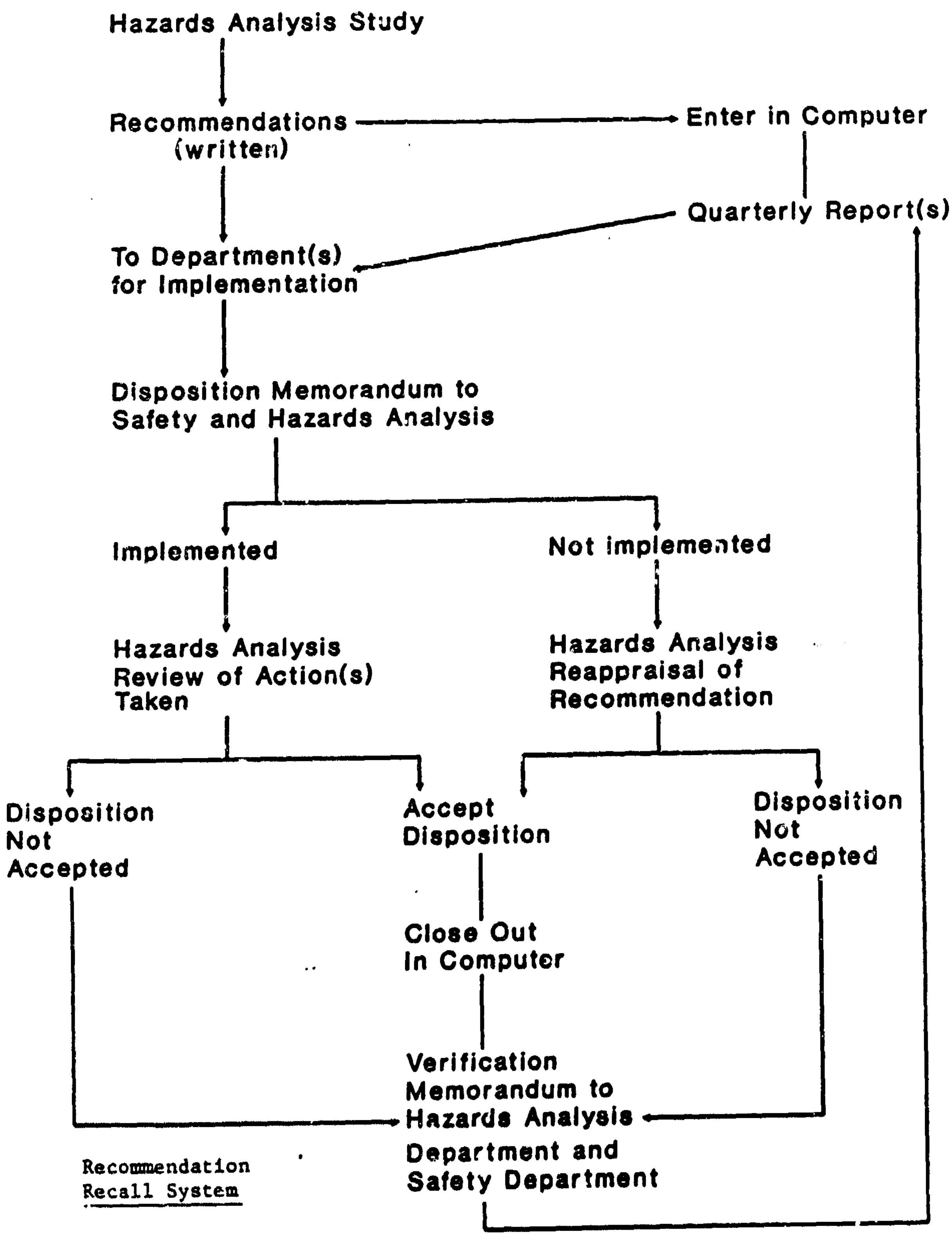
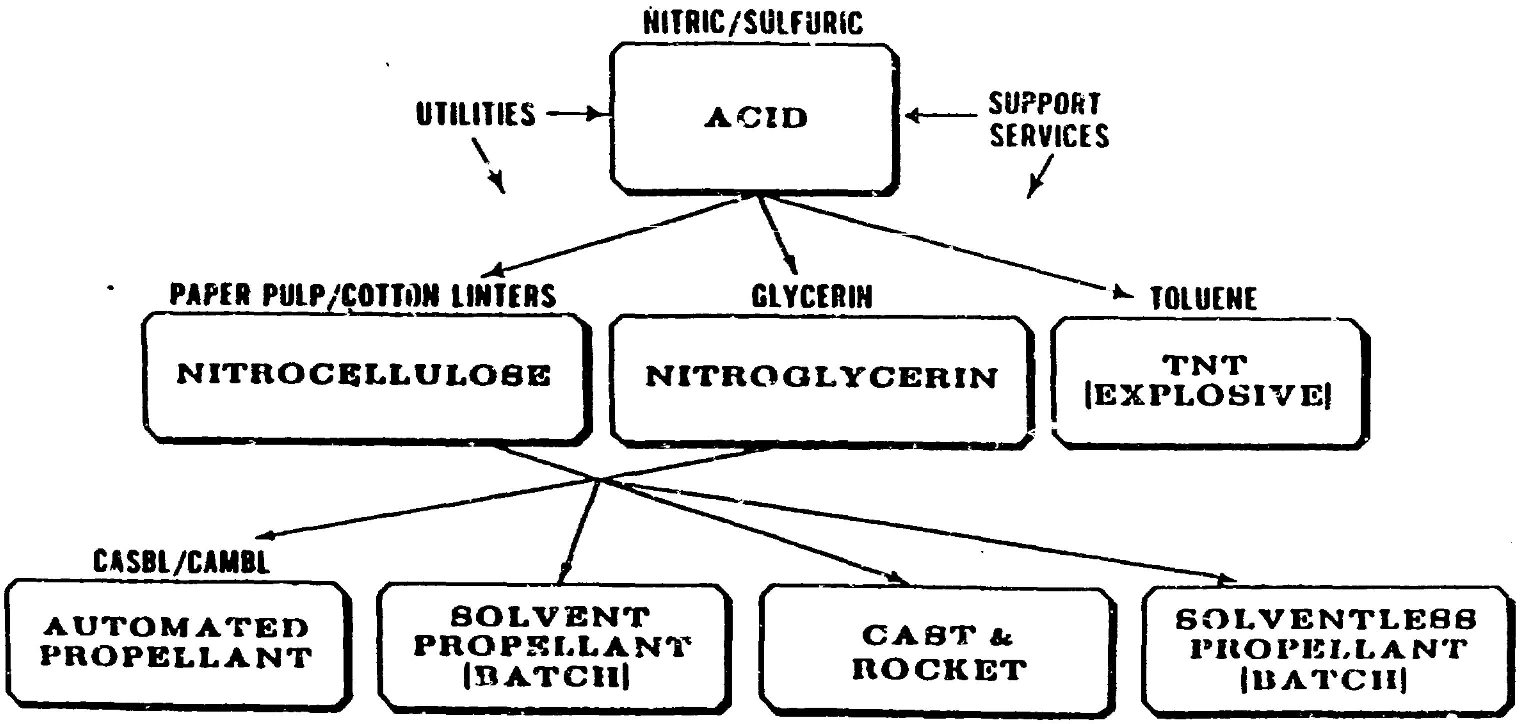
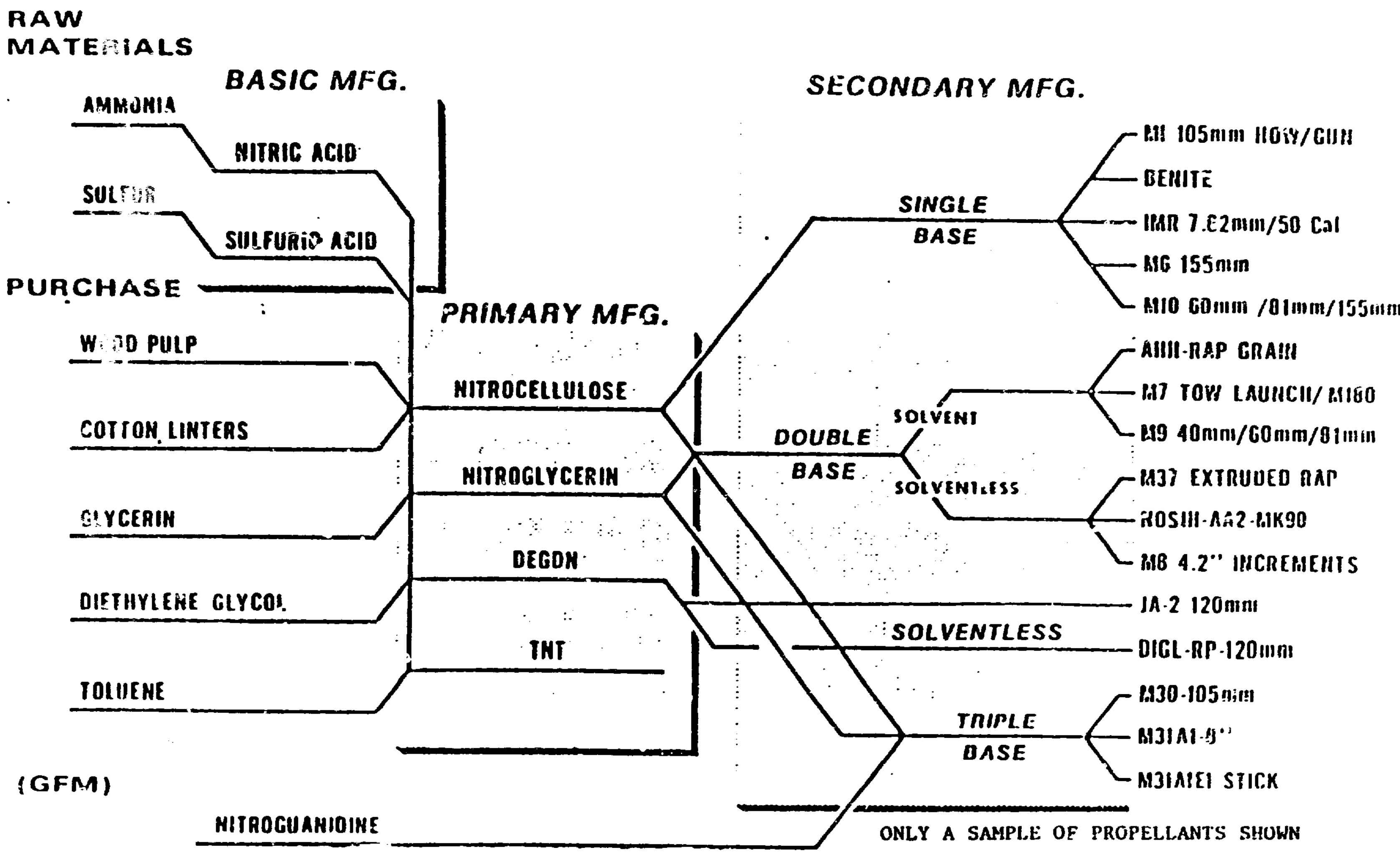

Hazards Analysis Study
Recommendations (written)
Enter in Computer
Quarterly Report(s)
To Department(s) for Implementation
Disposition Memorandum to Safety and Hazards Analysis
Implemented
Not implemented
Hazards Analysis Review of Action(s) Taken
Hazards Analysis Reappraisal of Recommendation
Disposition Not Accepted
Accept Disposition
Disposition Not Accepted
Close Out In Computer
Verification Memorandum to Hazards Analysis Department and Safety Department
Recommendation Recall System

Figure 1



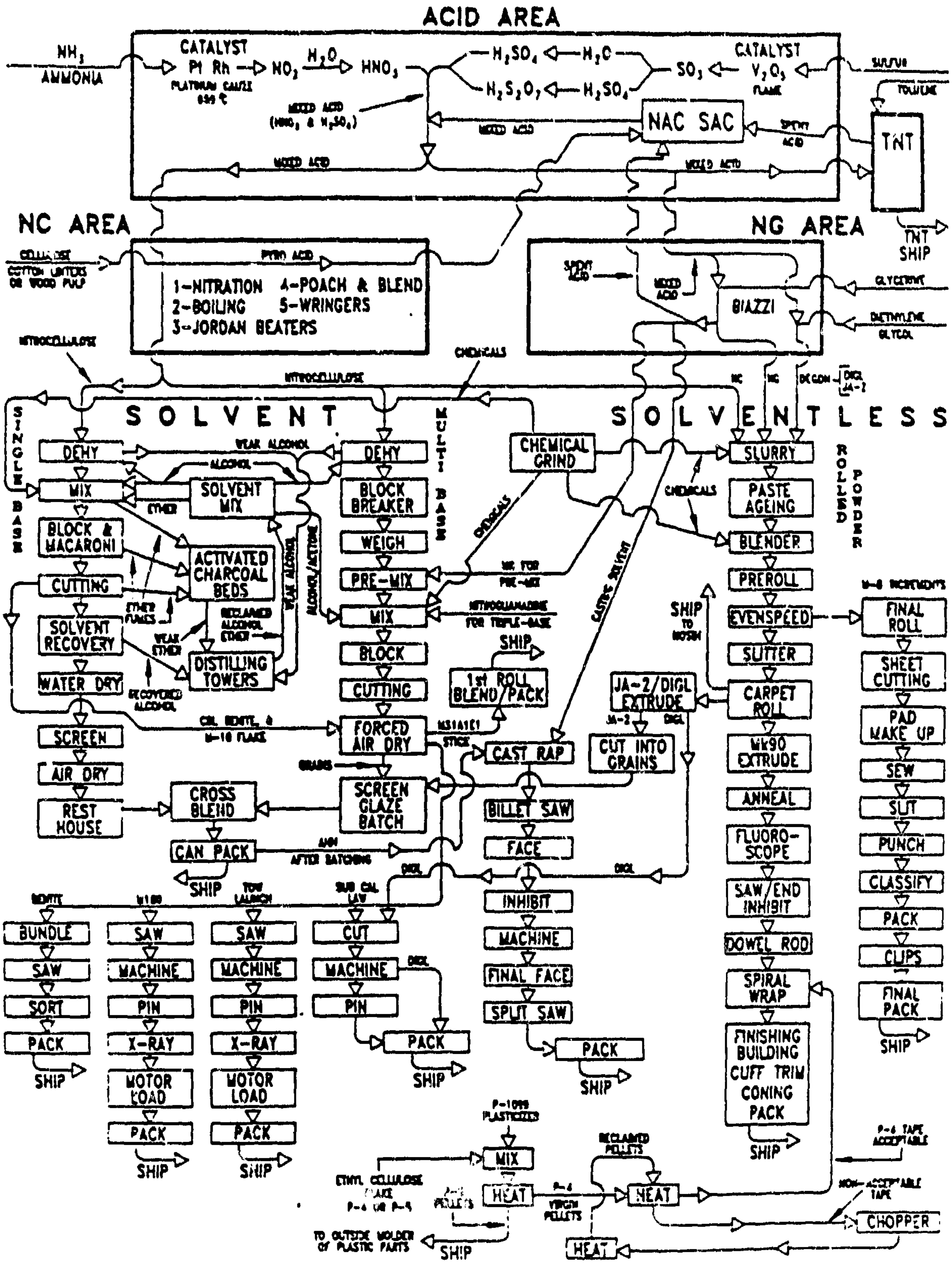
RAAP MAJOR PRODUCTION AREAS

FIGURE 2



BASE MATERIALS FLOW DIAGRAM
FOR PROPELLANTS MANUFACTURED AT RAAP

FIGURE 3



RAAP PROCESS FLOW
FIGURE 4

HERCULES
RADFORD ARMY AMMUNITION PLANT

Safety is part of your job.

April 30, 1990

Memorandum

c: Dept. Managers

TO: Safety Department Coordinator

FROM: ______________________________

NC Purification Area Supervisor

SUBJECT: Recommendation #1, Hazard Analysis Field Engineering Survey #HI-90-S-019FW

Safety meetings were conducted with all personnel on the importance of processing a thick slurry with which to load the wringers. This will assist in keeping a wringer from wobbling. Even then, loading #3 wringer in 4026 with extreme caution, it still had a tendency to wobble. Therefore, maintenance was requested to disassemble the transmission to check it. A buffer in the transmission was found to be worn. It was replaced and reassembled. This eliminated the wobbling problem on #3 wringer. This bad buffer was instrumental in the incident on March 5.

JRF/mlw

AREA RESPONSE TO RECOMMENDATIONS

FIGURE 5

RA-173 REV. 8-84

HERCULES
RADFORD ARMY AMMUNITION PLANT

Safety is part of your job.

July 9, 1990

Memorandum

c: Dept. Managers

TO: Safety Department Coordinator

FROM: ______________________________

Hazard Analysis Engineer

<u>Evaluation of Response(s) to Hazard Study Recommendations</u>

<u>Reference Report</u>: HI-90-S-019(FW), Equipment Damage.

<u>Plant Area/Operation</u>: Chemical Process/NC, Building 4026.

<u>Evaluation Method</u>: Review of response from NC Area Supervision to SDC dated April 30, 1990.

<u>Results</u>: Recommendation #1 has been satisfied. Processing of thick NC slurry was discussed with all wringer house personnel at safety meetings. In addition, disassembly of the transmission on wringer #3 revealed a worn buffer which contributed to the wobble problem. The worn buffer was replaced.

Recommendation #2 remains open. NC Area is requested to advise the SDC when recommendation #2 is completed.

____

Hazard Analysis Supervisor

Evaluation of Response(s) to Hazard Study Recommendations

Figure 6

RA-173 REV. 8-84

HERCULES
RADFORD ARMY AMMUNITION PLANT

Safety is part of your job.

Memorandum

July 12, 1990

c: Dept. Managers

TO: Safety Department Coordinator

FROM: ______________________

NC Department Supervision

SUBJECT: Hazards Analysis Field Engineering Survey HI-90-S-019(FW)

The subject survey had two recommendations. As per my memo of April 30, 1990, Recommendation #1 has been satisfied.

Since June 11, 1990 the #4 wringer control box exhaust has been relocated to prevent it from entering the #3 wringer control box air intake. This satisfies recommendation #2.

JRF/mlw

Area Response to Recommendations
Figure 7

RA-173 REV. 8-84

HERCULES
RADFORD ARMY AMMUNITION PLANT

Safety is part of your job.

Memorandum

July 17, 1990

c: Dept. Managers

TO: Safety Department Coordinator

FROM: ____________________________

Hazard Analysis Engineer

Evaluation of Response(s) to Hazard Study Recommendations

Reference Report: HI-90-S-019(FW), Equipment Damage.

Plant Area/Operation: Chemical Process/Nitrocellulose, Building 4026.

Evaluation Method: Review of memo from NC Area Supervision to SDC dated July 12, 1990.

Results: All recommendations have been implemented. This report is closed.

____
Hazard Analysis Supervisor

Evaluation or Response(s) to Hazard Study Recommendations
Figure 8

RA-173 REV. 8-84

Hazard Class/Division 1.6: Articles Containing Extremely Insensitive Detonating Substances*

prepared by

Michael M. Swisdak, Jr.
Naval Surface Warfare Center
10901 New Hampshire Avenue
Silver Spring, MD 20903-5000

ABSTRACT

A brief history of Class/Division 1.5/1.6 is presented. The protocol which has been developed and approved by the United Nations for testing these materials is presented. The results of testing to determine if certain substances are Extremely Insensitive Detonating Substances (EIDS) is presented.

BACKGROUND

This paper is excerpted from a longer study[1] performed by the author for the Department of Defense Explosives Safety Board (DDESB). This paper also contains comments and insights taken from a paper prepared by Dr. J. Ward[2], of the DDESB.

The interest in less sensitive military explosives and ammunition within the Department of Defense (DOD) and the Department of Energy (DOE) dates back to the late 1970's. Since that time, these materials have been called by a variety of names. These include UN Class/Division (C/D) 1.5, DOD Insensitive High Explosives (IHE), and UN C/D 1.6. Also in the same time period, the test protocol and the corresponding pass/fail criteria for inclusion into this special group has changed as the transition has been made from the US DOD to the international (UN) arena.

In its 1977 revision of its document on the Transport of Dangerous Goods [3] the United Nations Group of Experts on Explosives defined "very insensitive explosives" and limited them to Type B and E blasting agents (as defined in Reference 1). In June 1979, the Air Force requested the DDESB concurrence/approval for a Department of Transportation (DOT) hazard classification of 1.5L for TATB (Triaminotrinitrobenzene) and various TATB formulations. This represented the first instance of the UN Class 1.5 designation being sought for a DOD/DOE explosive.

Shortly thereafter, the DDESB raised several technical questions regarding the application of the 1.5 classification to military materials. In order to resolve these questions, they proposed the following solution:

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...It is suggested that the objective development of criteria for hazard division 1.5 could best be accomplished by a tri-Service working group with recognized expertise in evaluating explosive properties, such as the Joint Technical Coordinating Group for Munitions Development Working Party for Explosives, in cooperation with Service safety office representatives.

The DDESB further requested that the Joint Technical Coordinating Group for Munitions Development: Working Party for Explosives (JTCG/MD/WPE) [4]:

(a) Review the UN Classification scheme for 1.5 materials and determine its applicability to DOD/DOE materials
(b) Define the levels of sensitivity, response to stimuli, and effects on surroundings for division 1.5 storage/operational applications
(c) Recommend the minimum probabilities and confidence levels to be accepted in a Division 1.5 testing scheme
(d) Express opinions as to whether sensitivity, reaction effects, or both should be the criteria used for reducing/eliminating quantity-distance requirements.

In February 1980, the JTCG/MD/WPE established an Ad Hoc Study Group to advise the DDESB and to determine a tri-Service position on the Hazard Classification 1.5 for explosive materials (high explosives, propellants, pyrotechnics, etc) and munitions containing these materials. The terms of reference for this group included:

(a) Define the criteria to be used to establish the 1.5 Classification Criteria for military explosives and munitions
(b) Study other issues arising from the introduction of the UN classification scheme, as required

The official title of the Group was the Ad Hoc Study Group on Criteria for Insensitive Explosives, Hazard Classification Division 1.5. The members of the Ad Hoc Group represented the three services and the Department of Energy. After much discussion and deliberation, the Group reached a consensus on a test protocol for Division 1.5 substances and recommended them back to the DDESB on 24 April 1980.

The Secretariat at the DDESB indicated that they supported the test procedures for classifying insensitive high explosives substances as hazard division 1.5. They further recommended that for hazard classification testing of articles (note: emphasis is theirs) containing hazard division 1.5 substances, the requirements of STANAG 4123 (Methods to Determine and Classify the Hazards of Ammunition)[5] and TB 700-2 (Department of Defense Explosives Hazard Classification Procedures)[6] should be followed. At the 279th Meeting of the Department of Defense Explosives Safety Board, the report of the Ad Hoc Study Group was accepted with minor changes. These changes included the following redefinition of Hazard Division 1.5:

> This division comprises class/division 1.1 explosives substances which, although mass detonating, are so insensitive that there is negligible probability of initiation or transition from burning to detonation in transport or storage.

The DDESB, however, still desired a well-defined test protocol which could be used for articles--not just substances. On January 21, 1981 a DDESB memorandum for the three Service Board Members summarized the status of Hazard Classification for Insensitive Explosives. The following is quoted from that memorandum:

> ...The 279th and 281st meetings of the Board ...addressed hazard classification criteria for insensitive explosives. At the 279th meeting, the Board accepted the JTCG Ad Hoc Study Group report ... with certain changes and, in addition, established an interim hazard division 1.5 quantity-distance standard. At the 281st meeting, the Board addressed validation tests information furnished by the Ad Hoc Study Group and the Department of Energy on certain TATB formulations and comparative explosives. Included were results of tests which were not addressed ... (e.g. multiple bullet impact test). It was stated that the multiple bullet impact test can give different, sometimes more violent, results than the single bullet impact test. The question was raised, but not resolved, as to its applicability in the test scheme for evaluating Division 1.5 explosives.

On March 16, 1981, the Ad Hoc Study Group was disestablished. The WPE then convened a special meeting for the purpose of reviewing and modifying as necessary the WPE recommendations to the DDESB and to prepare a final WPE position on this matter. As a consequence of this meeting, the WPE forwarded to the DDESB a set of comments on modifications to its proposed test scheme. One of the comments is of particular importance and is quoted below:

> ...UN hazard classification division 1.5 was devised for commercial blasting agents which are insensitive because of large critical diameters. A separate classification 1.X (or 1. some other designation) is recommended for military explosives which have relatively small critical diameters but still are insensitive. These two types of insensitive explosives respond differently to hazard stimuli and should not be covered in one category. ... The division 1.X classification would apply and be restricted to materials passing an appropriate test scheme and criteria, and having the same physical and chemical state properties as when tested.[7]

During this same time period, the Air Force recommended the following tests for the Ground Launched Cruise Missile (GLCM) which it hoped to be classified as a Class/Division 1.5 article :

Impact Test (Sled Track or Pull Down)
Bonfire
Bullet Impact

In addition to these tests, they had run the following tests:

Forty Foot Drop
Propagation Test
Shaped Charge
Thermal Stability Test

At the 283rd and 284th meetings of the DOD Explosives Safety Board (both held in January 1982), Class/Division 1.5 testing was discussed. The discussions at the 283rd meeting concerned the bullet impact test for articles, while the discussions at the 284th meeting concerned the terminology associated with Class/Division 1.5.. Quoting from the minutes of the 284th meeting;

> ... 1.5 has its origin in transportation circles (the UN requirements for transportation), that it applies only to substances (namely, blasting agents) and that it really adds to confusion when you start talking about articles (ammunition) in the same manner. We feel that the term insensitive high explosive, as we proposed, avoids this and achieves the objective that we were trying to achieve. This does require changing the interim criteria but only in an incidental way i.e., removing references to 1.5...[8]

The report of the 284th meeting provides the definitions and test protocol for IHE (Insensitive High Explosives) and IHE ammunition as they currently appear in DOD 6055.9-STD (DOD Ammunition and Explosives Safety Standards)[9]. The protocol, as shown in this document, consists of the following:

SCREENING TESTS

Impact Test
Friction Test
Differential Thermal Analysis (DTA)
Small Scale Burn
Spark Tests

QUALIFICATION TESTS FOR IHE

Critical Diameter
Cap Test
Card Gap Test
Slow Cook-off
External Fire
SusanTest
Bullet Impact

QUALIFICATION TESTS FOR IHE AMMUNITION

Sled Test
Bonfire
Propagation
Slow Cook-off
Multiple Bullet

DOD 6055.9-STD is a United States document with applicability limited to Department of Defense agencies and their contractors. In order to achieve a wider distribution and applicability, the DDESB, as technical consultant to the Department of Transportation (DOT), continued to urge its adoption by the United Nations with the protocol incorporated into the document "Recommendations on the TRANSPORT OF DANGEROUS GOODS Tests and Criteria"[10]. In 1983, the DDESB petitioned the Department of Transportation for the establishment of a regulation for the transport of insensitive high explosive (IHE) substances and IHE ammunition articles by or for a component of the DOD. The DDESB further proposed that the test protocol incorporated in DOD 6055.9-STD be included in Title 49, Part 149 of the Code of Federal Regulations (CFR).

In 1985, the United States agreed to make a formal proposal to the United Nations Group of Experts on Explosives; this proposal concerned the inclusion of articles in Division 1.5. In April 1986, a draft of this proposal was transmitted to the United States representative at the Department of Transportation. It was formally proposed at the twenty-sixth session of the Group of Experts on Explosives, held in August 1986. The French made detailed comments and recommended several additions and changes. The test series as modified by the French was found to be generally acceptable by the United States representative.

The revised test protocol was presented and discussed at the twenty-seventh session of the Group of Experts on Explosives, held 17-21 August 1987. As a result of the discussions at this meeting, the DDESB, in late 1987, requested that the Naval Surface Warfare Center (NSWC) review the existing protocol for Hazard Class/Division 1.5 and IHE materials. This review was to include, but was not limited to :

(a) the coordination and the obtaining of recommendations of changes to the procedures with/from the appropriate Service hazard classification test experts
(b) conversion of US test weight and measure specifications into the international system of units (SI)
(c) conversion of US test materials/standard specifications to international terminology.

At that time, the proposed protocol included the following tests:

(a) Critical diameter test
(b) Cap Test
(c) Gap Test
(d) Susan Test
(e) Friability Test
(f) Bullet Impact Test
(g) External Fire Test
(h) Slow Cook-off test
(i) Stack Test

Items (a)-(h) were to be performed on the substance; items (f)-(i) were to be performed on the article containing that substance tested in (a)-(h). At this time, there were two Gap test series in the protocol. The first was proposed by the United States and the second by the French. The US tests consisted of the standard Large Scale Gap Test (LSGT) and the Expanded Large Scale Gap Test (ELSGT)[11] depending upon the critical diameter of the substance. The French Gap test also consisted of two tests--the test described in Section 2a (iv) of Reference 1 and the US ELSGT. The choice of which test was again dependent upon the critical diameter of the substance. The friability test was a French test which could be substituted for the US bullet impact and Susan Tests.

Within the US, the representative to the United Nations Committee Of Experts on the Transportation of Hazardous Materials is the Department of Transportation. Any test procedures which are to be submitted to the UN must be approved and submitted by representatives of this organization. In early 1988, discussions were held between representatives of the DOT, the DDESB, and NSWC concerning the 1.5 test procedures. As a result of these and other discussions, certain tests were simplified and one, the critical diameter test, was eliminated.

Further discussions with the French simplified the Gap Test procedures. With the elimination of the critical diameter test, it was decided that only one Gap Test Procedure would be required--the Expanded Large Scale Gap Test. Further discussions set the pass/fail criterion for this test at 276 US cards (2.76 inches) or 70 mm of polymethyl methacrylate (PMMA). A calibration curve for the ELSGT has been completed by Tasker, et. al[12].; it is reproduced in Table 1.

In December 1988, the UN Committee of Experts on the Transport of Dangerous Goods approved the inclusion of a new test protocol (Test Series 7) into the UN Tests and Criteria Book. The UN Committee also approved the new C/D 1.6 classification for extremely insensitive articles which do not have a mass explosion hazard. Class/Division 1.6 is comprised of EEI (Explosives, Extremely Insensitive) articles which contain only EIDS (Extremely Insensitive Detonating Substances), which demonstrate a negligible probability of accidental initiation or propagation (under normal conditions of transport), and which have passed Test Series 7. Note that the risk from articles of C/D 1.6 is limited to the explosion of a single article. Articles in C/D 1.6 are all in a new compatibility group N, which signifies articles containing only EIDS.

The US representative to the North Atlantic Treaty Organization (NATO) Armament Committee AC/258 (Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives) proposed to reference the Test Series 7 protocol in NATO STANAG 4123. Work on revision 3 of this document with these changes is in progress. Based on the new terminology and test protocol adopted by the UN Committee and in NATO, the DDESB plans to change the name of "insensitive high explosive (IHE) articles" to "articles, EEI, and to replace the IHE screening tests with the UN Test Series 3 protocol and to adopt the Test Series 7 protocol in the place of the IHE test requirements. These changes will require a revision to the DOD Ammunition and Explosives Safety Standards (DOD 6055.9-STD), and the DOD Explosives Hazard Classification Procedures.

CLASS/DIVISION 1.6 TEST SERIES

Materials which are candidate EIDS must pass the UN Test Series 3 protocol before they can be considered for UN Test Series 7 testing. Test Series 3, which is similar to the DOD Screening Tests for IHE, addresses the question: "Is the substance too hazardous for transport (in the form which it is tested)?" by determining the sensitivity of the substance to mechanical stimuli (both impact and friction) and to heat and flame.

After passing the Test Series 3 protocol, the EIDS candidate and the EEI article containing the EIDS candidate must pass the UN Test Series 7 protocol. This protocol consists of seven (7) substance tests and four (4) article tests. Test Series 7 addresses the question: "Is the item an extremely insensitive article?" Table 2 summarizes Test Series 7, including the pass/fail criteria. Details of the specific tests are given below.

SUBSTANCE TESTS

Test 7(a) EIDS CAP TEST. **Objective**: Determine the shock sensitivity of an EIDS candidate to the shock from a standard detonator or blasting cap. **Approach**: The approach is the same as for UN Test 5(a). The EIDS candidate is placed in a cardboard tube (minimal confinement) with minimum dimensions of 80 mm (inside diameter), 160 mm length, and maximum wall thickness of 1.5 mm. Initiation is by a standard UN detonator (U.S. No. 8 Blasting Cap (or equivalent)) inserted coaxially into the top of the explosive to a depth equal to its length. The tube is placed on one of two witnesses which are positioned on a square steel plate of 25 mm thickness and 152 mm sides. The witnesses consist of either a lead cylinder with dimensions of 50.8 mm diameter and 101.6 mm length or a 1 mm thick 160 mm x 160 mm steel plate placed on a steel ring with dimensions 100 mm inner diameter, 50 mm length, and 3.5 mm wall thickness. Temperature control and/or cycling is required for those types of explosives known to have a temperature dependent cap sensitivity result. **Pass/Fail Criteria**: A detonation of the substance is indicated if either the lead cylinder is compressed from its initial length by an amount of 3.18 mm or greater or if the witness plate shows total penetration. A substance which detonates in any of three trials is termed "cap sensitive", is not an EIDS, and the result is a failure.

Test 7(b) EIDS GAP TEST. **Objective**: Defines the sensitivity of an EIDS candidate to a specified shock level (i.e., specified donor charge and gap spacing). **Approach**: The EIDS candidate is placed in a steel tube with dimensions 95 mm outside diameter (OD), 280 mm length, and 11 mm wall thickness. The steel tube is placed (with a 1.6 mm air gap)over a 200 x 200 x 20 mm steel witness plate. A donor charge and an intervening gap material are aligned above the EIDS candidate. To aid in alignment, the entire assembly is placed in a cardboard tube having dimensions of 97 mm ID and 443 mm length.The donor charge may either be 50/50 pentolite or 95/5 RDX/Wax at a density of 1600 kg/m^3. The donor charge has dimensions 95 mm diameter and 95 mm length. The gap material is polymethylmethacrylate (PMMA) with dimensions of 95 mm diameter and 70 mm length. Initiation is by a standard UN detonator (U.S. No. 8 blasting cap (or equivalent)), positioned inside a 95 mm diameter by 25 mm long hole in a wooden block. The wood block is placed inside the cardboard tube on top of the donor charge. The explosives are to be at 25 ± 5 °C at the time of the test. **Pass/Fail Criteria**: A clean hole punched through the witness plate indicates a detonation. A substance which detonates in any of three (3) trials is not an EIDS and the result is a failure.

Test 7(c)(i) SUSAN IMPACT TEST. **Objective**: The test is designed to assess the degree of explosive reaction under conditions of high velocity impact. **Approach**: A 0.45 kg billet (dimensions 51 mm diameter by 102 mm length) of the EIDS candidate is placed in the Susan Projectile. The explosively-loaded Susan Projectile (5.4 kg total mass, 81.3 mm diameter by 220 mm long) is fired from an 31.3 mm smoothbore gun. The target is a 640 mm thick armor steel plate located 4.65 m from the muzzle. The projectile velocity should be adjusted to 333 m/s. A minimum of three overpressure measurements are taken at a range of 3.05 m from the target impact point along separate radial lines making angles of 20°, 38°, and 51° with the firing line. The test is repeated until at least 10 accurate pressure-time records are obtained from a minimum of five firings (at which the projectile velocity was 333 m/s). The maximum overpressure is determined from each airblast record. The average of the maximum pressures (minimum of 10 records) is recorded. **Pass/Fail Criteria**: If the average pressure is greater than or equal to 27 kPa, then the substance is not an EIDS and the result is a failure.

Test 7(c)(ii) and 7(d)(ii) FRIABILITY TEST. This test is an alternative to the Susan Impact Test and the Bullet Impact Test. **Objective**: This test is used to establish the tendency of a compact EIDS candidate to deteriorate dangerously under the effect of an impact. **Approach**: A bare cylindrical sample (18 mm diameter, length adjusted to give a mass of 9 grams) of the EIDS candidate is projected at a velocity of 150 m/s at a 20 mm thick steel target plate. Tthe fragments of the EIDS candidate material are then recovered (the mass of these collected fragments should be at least 8.8 grams). The fragments are then burned in a 108 cm^3 manometric bomb. Ignition of the fragments in the bomb is obtained by a firing capsule consisting of a hot wire and 0.5 grams of black powder of average diameter 0.75 mm. The pressure-time curve produced by the burning is recorded, the derivative curve (dp/dt) is constructed, and the maximum value of dp/dt is recorded. **Pass/Fail Criteria**: If the average maximum dp/dt value obtained at an impact velocity of 150 m/s is greater than 15 MPa/ms, then the substance tested is not an EIDS and the result is a failure.

<u>Test 7(d)(i) BULLET IMPACT TEST</u>. **Objective:** The bullet impact test is used to evaluate a possible EIDS candidate to the kinetic energy transfer associated with the impact and penetration of a given energy source (a 12.7 mm projectile travelling at a velocity of 820 m/s). **Approach:** The EIDS sample is placed in a seamless steel pipe with dimensions 45 mm ID, 200 mm length, and 4 mm wall thickness (these are minimum dimensions). The pipe is closed with steel or cast iron end caps torqued to 204 N-m. A standard 12.7 mm armor-piercing bulled with a projectile mass of 0.046 kg is fired at the sample from a 12.7 mm gun at a velocity of 820 m/s. The sample is secured on a pedestal by a holding device capable of restraining the target from dislodgement by the bullet impact. Three tests each are conducted with the test article aligned with the long axis perpendicular and parallel to the projectile line of flight. These orientations result in impacts through the sides and ends of the pipes, respectively. Remains of the test container are collected. **Pass/Fail Criteria:** Complete fragmentation of the container indicates an explosion or detonation. A substance which explodes or detonates in any of six trials is not an EIDS and the result is a failure.

<u>Test 7(e) EIDS EXTERNAL FIRE TEST</u>. **Objective:** The external fire test is used to determine the reaction of an EIDS candidate to external fire when it is confined. **Approach:** The EIDS sample is placed in a seamless steel pipe with dimensions 45 mm ID, 200 mm length, and 4 mm wall thickness (these are minimum dimensions). The pipe is closed with steel or cast iron end caps torqued to 204 N-m. Five of these confined samples are stacked horizontally and banded together on a metal support stand (grid) at a height between 0.5 and 1.0 meters above the fuel on the ground surface. Either firewood or liquid fuel can be used to produce a fire for a minimum of 30 minutes. Three tests with the five samples are conducted, or one test with all 15 test samples may be conducted. High speed and real time photographic coverage, blast overpressure measurements, post-shot photography of the samples, crater dimensions, and size/location documentation of the confining pipe fragments are required to determine the reaction severity. **Pass/Fail Criteria:** A substance which detonates or reacts violently with fragment (mass one gram or greater) throw of more than 15 m is not an EIDS and the result is a failure.

<u>Test 7(f) EIDS SLOW COOK-OFF TEST</u>. **Objective:** The purpose of this test is to determine the reaction of an EIDS candidate to a gradually increasing thermal environment and the temperature at which such reaction occurs. **Approach:** The EIDS sample is placed in a seamless steel pipe with dimensions 45 mm ID, 200 mm length, and 4 mm wall thickness (these are minimum dimensions). The pipe is closed with steel or cast iron end caps torqued to 204 N-m. The sample is placed in an oven which provides a controlled thermal environment over a temperature range of 40°C to 365°C and can increase the temperature of the surrounding oven atmosphere at a rate of 3.3°C per hour throughout the temperature range and ensure a uniform thermal environment for the test item. A means of relief should be provided for increased air pressure that is generated in the oven due to heating. The temperature of the air within the oven and the exterior surface of the confining pipe is to be recorded continuously or at a minimum of every 10

minutes. The test item is subjected to the gradually increasing air temperature at the prescribed rate until a reaction occurs. The temperature and the elapsed time are recorded. The test may begin with the test item preconditioned to 55°C below the anticipated reaction temperature. Three samples are subjected to this test. After each test, the pipe or any pipe fragments are recovered and examined for evidence of reaction. Such evidence may include the number and size of the recovered fragments as well as the distances the fragments are thrown. **Pass/Fail Criteria**: A substance which detonates or reacts violently (fragmentation of one or both end caps and fragmentation of the tube into more than three (3) pieces)is not an EIDS and the result is a failure.

ARTICLE TESTS

Test 7(g) CLASS/DIVISION 1.6 ARTICLE EXTERNAL FIRE TEST. **Objective**: This test is used to determine the reaction of a possible 1.6 article to external fire as presented for transport. **Approach**: The approach is the same as for UN Test 6(c). Three or more candidate EEI articles in the condition and form in which they are offered for transport are stacked and banded together on a metal support stand (grid) at a height of between 0.5 and 1.0 meters above the fuel on the ground surface. Either firewood or liquid fuel can be used to produce a fire for a minimum of 30 minutes. A vertical aluminum witness sheet (2000 x 2000 x 2 mm) or equivalent is attached to posts in the ground in each of three quadrants at a distance of 4 m from the edge of the stack. The downwind quadrant is not used for witness screens. High speed and real time photographic coverage, blast overpressure measurements, radiometric measurements, post-shot photography of the samples, crater dimensions,and size/location documentation of test article fragments are required. The degree of reaction is determined by the blast/radiometric records, cratering, and size/location of article fragments. **Pass/Fail Criteria**: The article is not an EEI article and the result is a failure if any of the following events occur during the test: instantaneous/non-instantaneous explosion of total contents, perforation of any of the three witness screens, more than 10 metallic projections (each with a mass exceeding 25 grams) thrown more than 50 m from the edge of the stack, any metallic projections with mass exceeding 150 grams thrown more than 15 m from the edge of the stack, a fireball which extends more than 3 m from the flames of the fire, the irradiance of the burning product (scaled to 100 kg) exceeds 4 KW/m^2 , or fiery projections emanating from the articles are thrown more than 15 m from the edge of the stack. If any of the above reactions occur. the candidate EEI article is classified as Class/Division 1.1, 1.2, or 1.3, according to the above events.

Table 7(h) CLASS/DIVISION 1.6 SLOW COOK-OFF TEST. **Objective**: This test is used to determine an article's reaction to a gradually increasing thermal environment and the temperature at which a reaction occurs. **Approach**: A candidate EEI article in the condition and form in which it is offered for transport is placed in an oven which provides a controlled thermal environment over a 40°C to 365°C temperature range and can increase the temperature of the surrounding oven atmosphere at a rate of 3.3°C per hour throughout the temperature range and ensure a uniform thermal environment for the test item. A means of relief should be provided for increased air pressure that is generated in the oven due to heating. The temperature of the air within the oven and the exterior surface of the confining pipe is to be recorded continuously or at a minimum of every 10 minutes. The article is subjected to the gradually increasing air temperature at the prescribed rate until a reaction occurs. The temperature and the elapsed time are recorded. The test may begin with the article preconditioned to 55°C below the anticipated reaction temperature. Two separate items are subjected to this test. After each test, the test article or its fragments are recovered and examined for evidence of reaction. Such evidence may include cratering and the number and size of recovered fragments, as well as the distance the fragments are thrown. **Pass/Fail Criteria**: The article is not an EEI article and the result is a failure if the reaction is more severe than burning. The energetic material may ignite and burn and the case may melt or weaken sufficiently to allow the mild release of combustion gases. Burning should be such that the case debris and package elements stay in the area of the test except for case closures which may be dislodged by the internal pressure and thrown not more than 15 m.

Test 7(j) CLASS/DIVISION 1.6 ARTICLE BULLET IMPACT TEST. **Objective**: This test is used to assess the response of a possible EEI article to the kinetic energy transfer associated with the impact and penetration of a given energy source. **Approach**: A candidate EEI article (complete) is secured in a holding device capable of restraining the item from dislodgement by projectiles. A 12.7 mm gun (or three guns) fires a three round burst (600 rounds/minute) of 12.7 mm armor-piercing ammunition with projectile mass of 0.046 kg at a velocity of 856 m/s to impact the candidate EEI article at a range of 3-20 m. The test is repeated in three different orientations. In the appropriate orientation(s), the striking point on the test article is selected so that the impacting rounds penetrate the most sensitive material(s), that is not separated from the main explosive charge by barriers or other safety devices. The test is documented by high speed and real time photographic coverage. The degree of reaction is determined by post-test inspection of the test films and the hardware. **Pass/Fail Criteria**: The article is not an EEI article and the result is a failure if any of the three bursts results in a detonation. Reactions of the article identified as no reaction, burning, or deflagration are considered acceptable (Passing).

Test 7(k) CLASS/DIVISION 1.6 ARTICLE STACK TEST. **Objective**: This test is used to determine if a candidate EEI article will detonate a similar item adjacent to it in the condition as presented for transport. **Approach**: The approach is the same as for UN Test 6(b), except that additional confinement is omitted. Three or more candidate EEI articles in the condition and form in which they are offered for transport are placed in a stack on a witness plate, such as a 3 mm thick mild steel sheet. One of the articles (donor) near the center of the stack is caused to function in the design mode. This test is conducted three times. Fragment data (size and number of acceptor article fragments), damage to the witness plate, and crater dimensions are used to determine whether any of the acceptors detonated. Blast data may also be used to determine if any of the acceptors detonated. **Pass/Fail Criteria**: The article is not an EEI article and the result is a failure if any of the three tests results in a detonation of an acceptor article. Evidence of a detonation includes but is not limited to: a crater at the test site appreciably larger than that for a single article, damage to the witness plate appreciably greater than that for a single article, or measurement of blast overpressure which significantly exceeds that from a single article.

The DDESB position on the implementation of this test is to conduct the first without confinement (Test 7(k)) and then conduct the next two tests with confinement (UN Test 6(b)). The unconfined test permits collection of airblast and fragmentation data without the attenuating effects of confinement; the confined tests subjects the acceptors to a more severe environment. Plans are to propose this modification to the UN Group of Experts at a future date.

TEST RESULTS

Seven explosive substances either have been or are currently being examined under the Test Series 7 protocol. These materials are:

COMPOSITION B	60% RDX, 40% TNT, 1% WAX	cast material
PBX-9502	95% TATB, 5% KEL-F	pressed material
AFX-920	22%RDX, 33%HBNQ, 15% EDDN, 14% Aluminum, 15% binder, 1% other	cast material
AFX-930	32% RDX, 37% HBNQ, 15% aluminum, 9% binder, 7% plasticizer	cast material
AFX-931	32% RDX, 37% AP, 15% aluminum, 9% binder, 7% plasticizer	cast material
B3003	80% HMX, 20% energetic binder	cast material
B3103	51% HMX, 30% energetic binder, 19% aluminum	cast material
OCTORANE 86A	86% HMX, 14% inert binder	cast material

where HBNQ is high bulk density nitroguanadine and AP is ammonium perchlorate.

The DDESB funded the testing of COMPOSITION B and PBX-9502; AFX-920, AFX-930, and AFX-931 were developed and tested under Air Force contract. B3003, B3103, and OCTORANE 86A are French explosives tested by SNPE. The US conducted the Susan test on the three French materials, while the French performed the friability test on Composition B and PBX-9502. These reciprocal tests were performed to compare the results of the alternate tests: friability versus Susan and Bullet Impact. Table 3 summarizes the results of this testing.

Examining the results in Table 3, we find that COMPOSITION B fails all of the tests, while PBX-9502 passes all of them. The French explosive B3103 does not give the same result for both the Susan Test and the Friability test--it passed the friability test and failed the Susan Test. The use of these tests as alternative procedures is currently under discussion and review.

IMPLICATIONS FOR QUANTITY-DISTANCE

As part of the protocol, the following definition and note concerning Class/Division 1.6 has been agreed to:

> This division comprises articles which contain only extremely insensitive detonating substances (EIDS) and which demonstrate a negligible probability of accidental initiation or propagation. NOTE: The risk from articles of Division 1.6 is limited to the explosion of a single article.

This has been interpreted by the DDESB to imply that bulk EIDS are to be stored with the same quantity-distance requirements as Class/Division 1.3 materials. Class/Division 1.6 articles would use the same quantity-distance requirements as either Class/Division 1.2, 1.3, or 1.4, depending upon the type of storage, the type of packaging, and whether fuzed or non-fuzed.

SUMMARY

A new class/division of energetic substances has been defined and incorporated into the United Nations classification procedures. The test protocol which must be followed in order to place articles into this class/division has been defined and approved by the United Nations Group of Experts on Explosives. These same procedures have been accepted within NATO (AC/258) for both transportation and storage. Several candidate substances have been tested and have passed the substance testing portion of the protocol. At least one classified article has passed an earlier version of the protocol as well.

REFERENCES

1. Swisdak, M. M., Jr., " Hazard Class/Division 1.6: Articles Containing Extremely Insensitive Detonating Substances (EIDS)," NSWC TR 89-356, 1 December 1989 (in review).

2. Ward, J. M., "Hazard Class/Division 1.6 Test Protocol," presented at the 1990 JANNAF Propulsion Systems Hazards Subcommittee Meeting, April 1990.

3. Recommendations on the TRANSPORT OF DANGEROUS GOODS, Sixth Revised Edition, United Nations Publication, ST/SG/AC.10/1/1/REV.6, New York, 1989.

4. DDESB Ltr dated 05 Feb 1980, subj: "Explosives Hazard Classification for Triaminotrinitrobenzene (TATB) Formulations".

5. NATO Standard National Agreement STANAG 4123 (Edition 2), "Methods to Determine and Classify the Hazards of Ammunition," October 1978.

6. "Department of Defense Explosive Hazard Classification Procedures, "Army TB 700-2, Navy NAVSEAINST 8020.8A, Air Force TO 11A-1-47, Defense Logistics Agency DLAR 8220.1, December 1989.

7. Joint Technical Coordinating Group For Munitions Development: Working Party For Explosives Ltr, Serial 64E/HGA 114 dated 4 Sep 1981, subj: "Hazard Classification For Insensitive Munitions and Explosives".

8. Minutes of 284th DOD Explosives Safety Board Meeting, 24 Feb 1982.

9. Department of Defense Ammunition and Explosives Safety Standards, DOD 6055.9-STD, First Amendment (Change 2), dated 10/28/88.

10. Recommendations on the TRANSPORT OF DANGEROUS GOODS: Tests and Criteria, United Nations Publication, ST/SG/AC.10/11, New York, 1986.

11. Liddiard, T. P. and Price, D., "The Expanded Large Scale Gap Test," NSWC TR 86-32, March 1987.

12. Tasker, D. and Baker, R., "A New Unbiased Method For Analyzing Streak Data, The Calibration of the NSWC Expanded Large Scale Gap Test (ELSGT)," paper presented at the American Physical Society Meeting, 1989.

TABLE 1 EXPANDED LARGE SCALE GAP CALIBRATION

(NOTE: Pressures in GPa)

GAP THICKNESS (mm)	INCREMENT (mm) "+0"	"+0.25"	"+0.50"	"+0.75"	GAP THICKNESS (mm)	INCREMENT (mm) "+0"	"+0.25"	"+0.50"	"+0.75"
9.00	10.96	10.89	10.81	10.74					
10.00	10.67	10.59	10.52	10.43					
11.00	10.35	10.28	10.21	10.14	56.00	4.83	4.81	4.79	4.78
12.00	10.06	9.99	9.92	9.85	57.00	4.76	4.74	4.72	4.70
13.00	9.79	9.73	9.66	9.61	58.00	4.68	4.66	4.64	4.62
14.00	9.55	9.49	9.43	9.37	59.00	4.60	4.58	4.56	4.53
15.00	9.31	9.26	9.20	9.15	60.00	4.51	4.49	4.46	4.44
16.00	9.10	9.04	8.99	8.93					
17.00	8.88	8.82	8.77	8.73	61.00	4.41	4.39	4.37	4.34
18.00	8.67	8.63	8.58	8.53	62.00	4.31	4.28	4.26	4.24
19.00	8.48	8.44	8.39	8.35	63.00	4.22	4.19	4.17	4.15
20.00	8.31	8.27	8.23	8.18	64.00	4.13	4.10	4.08	4.05
					65.00	4.02	4.00	3.97	3.94
21.00	8.14	8.11	8.07	8.03	66.00	3.91	3.88	3.86	3.83
22.00	8.00	7.96	7.93	7.89	67.00	3.80	3.78	3.75	3.72
23.00	7.86	7.83	7.79	7.76	68.00	3.70	3.68	3.66	3.63
24.00	7.72	7.69	7.66	7.62	69.00	3.61	3.59	3.57	3.55
25.00	7.58	7.55	7.51	7.48	70.00	3.53	3.51	3.48	3.46
26.00	7.44	7.40	7.37	7.33					
27.00	7.30	7.26	7.23	7.19	71.00	3.43	3.41	3.39	3.37
28.00	7.16	7.13	7.09	7.06	72.00	3.34	3.31	3.29	3.26
29.00	7.03	7.00	6.97	6.94	73.00	3.23	3.20	3.18	3.15
30.00	6.91	6.88	6.85	6.82	74.00	3.13	3.11	3.09	3.07
					75.00	3.05	3.03	3.01	3.00
31.00	6.79	6.77	6.74	6.71	76.00	2.98	2.96	2.95	2.93
32.00	6.68	6.65	6.62	6.59	77.00	2.92	2.90	2.89	2.87
33.00	6.57	6.54	6.51	6.48	78.00	2.85	2.83	2.80	2.78
34.00	6.45	6.42	6.40	6.37	79.00	2.76	2.74	2.71	2.69
35.00	6.34	6.32	6.29	6.27	80.00	2.66	2.64	2.61	2.59
36.00	6.25	6.23	6.20	6.18					
37.00	6.16	6.14	6.12	6.10	81.00	2.57	2.55	2.53	2.51
38.00	6.08	6.07	6.05	6.03	82.00	2.50	2.48	2.47	2.45
39.00	6.01	5.99	5.97	5.96	83.00	2.44	2.43	2.42	2.41
40.00	5.94	5.92	5.90	5.88	84.00	2.40	2.39	2.38	2.37
					85.00	2.36	2.35	2.34	2.33
41.00	5.86	5.83	5.81	5.79	86.00	2.31	2.30	2.29	2.27
42.00	5.77	5.75	5.73	5.71	87.00	2.26	2.25	2.23	2.22
43.00	5.69	5.67	5.66	5.64	88.00	2.20	2.19	2.18	2.16
44.00	5.62	5.61	5.59	5.57	89.00	2.15	2.14	2.13	2.11
45.00	5.56	5.54	5.53	5.51	90.00	2.10	2.09	2.08	2.07
46.00	5.49	5.47	5.45	5.44					
47.00	5.42	5.39	5.38	5.35	91.00	2.06	2.05	2.04	2.03
48.00	5.33	5.31	5.29	5.27	92.00	2.02	2.02	2.01	2.00
49.00	5.25	5.23	5.22	5.20	93.00	1.99	1.99	1.98	1.97
50.00	5.18	5.17	5.15	5.14	94.00	1.96	1.96	1.95	1.94
					95.00	1.94	1.93	1.93	1.92
51.00	5.13	5.11	5.10	5.09	96.00	1.91	1.91	1.90	1.89
52.00	5.08	5.07	5.06	5.04	97.00	1.88	1.87	1.86	1.84
53.00	5.03	5.02	5.00	4.99	98.00	1.82	1.81	1.79	1.76
54.00	4.98	4.96	4.94	4.93	99.00	1.73	1.69	1.66	1.62
55.00	4.91	4.89	4.87	4.85	100.00	1.57	1.52	1.46	

TABLE 2 CLASS/DIVISION 1.6 TEST SERIES

TEST NUMBER	NAME OF TEST	COUNTRY OF ORIGIN	FAILURE CRITERIA
TESTS ON SUBSTANCES			
7(a)	EIDS CAP TEST	Germany/US	Detonation of any sample
7(b)	EIDS GAP TEST	US	Detonation at gap of 70 mm
7(c) (i)	SUSAN TEST	US	P>27kPa @ v=333 m/s
7 (c)(ii)	FRIABILITY TEST	France	dp/dt >15 MPa/ms for v=150 m/s
7(d) (i)	EIDS BULLET IMPACT TEST	US	Explosion/Detonation
7(d)(ii)	FRIABILITY TEST	France	dp/dt >15 MPa/ms for v=150 m/s
7(e)	EIDS EXTERNAL FIRE TEST	UN	Detonation, fragment throw > 15 m
7(f)	EIDS SLOW COOK-OFF TEST	US	Detonation, > 3 fragments
TESTS ON ARTICLES			
7(g)	1.6 ARTICLE EXTERNAL FIRE TEST	UN	C/D 1.1, 1.2, or 1.3 response
7(h)	1.6 ARTICLE SLOW COOK-OFF TEST	US	Reaction > burning
7(j)	1.6 ARTICLE BULLET IMPACT TEST	US	Detonation
7(k)	1.6 ARTICLE STACK TEST	UN	Propagation

TABLE 3 SUMMARY OF HAZARD CLASS/DIVISION 1.6 TEST RESULTS

SUBSTANCE	TEST						
	EIDS CAP TEST	EIDS GAP TEST	SUSAN TEST	FRIABILITY TEST	EIDS BULLET IMPACT TEST	EIDS EXTERNAL FIRE TEST	EIDS SLOW COOK-OFF TEST
COMPOSITION B	+	+	+	+	+	+	+
PBX-9502	-	-	-	-	-	-	-
OCTORANE 86A			-	-	*		-
B3103			+	-	*		
B3003			+	+	*		+
AFX-920	-	-	-	*	-	-	-
AFX-930	-	-	-	*	-	-	-
AFX-931	-	-	-	*	-	-	-

NOTE: A "-" indicates that the substance passed the test
NOTE: A "+" indicates that the substance failed the test
NOTE: A "*" indicates an alternate test (not required)
NOTE: A blank indicates data that is not available from the French

HAZARD EVALUATION OF SOME PROPELLANTS ADOPTING UN METHODS OF 1986

* YADAVA, O.P., UPPAL, K.S., BHALLA, A.K. & IYER, V.S.

INTRODUCTION

1.1 Hazard classification of propellants used in various ammunition stores have been an intriguing phenomenon as different manufacturing countries have adopted different standards and as a result a propellant with similar chemical and physical characteristics could be accepted as HD1.1C or HD1.3C. This involved manifold problems including transhipment, quantity distance considerations and other aspects related thereto.

1.2 With the publication of U.N.Recommendations on "Transportation of Dangerous Goods", Tests & Criteria; First Edition; New York 1986, a new vista has been opened for adoption of standardised methods for classification of items belonging to Class-I, Explosives, in their respective hazard divisions; viz, HD/1.1,1.2,1.3 or HD 1.4.

1.3 A number of full scale trials have been conducted by us adopting Test series 6 as described in the aforementioned publication and ten propellants belonging to different composition groups and accepted in India as HD1.1C, used in different ammunition stores ranging from Small Arms Ammunition to large calibre Mortar and Gun ammunition have been reclassified as pertaining to UNHD 1.3C.

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*Address : Principal Author : Ministry of Defence,
Ordnance Factories Staff College,
P.O.Ambajhari Defence Project,
Nagpur-21.
Co-authors : Directorate of Explosives Safety,
New Delhi and
Ordnance Factory Board,
Calcutta-1.

BACK DROP

2.1 The list on classification of Explosives published in June 1987 by ESTC, London has shown about two dozen propellants as pertaining to UN HD1.1C, however, they did not mention as to whether their hazard divisions were evaluated using UN methods of 1986. Similarly the Directorate of Explosives Safety in India has declared practically all the propellants manufactured by Defence Ordnance Factories as pertaining to HD1.1, however, they had used detonating pellets and Detonator No.27 or Electric Detonator No.33 for giving the initiating impulse.

2.2 The UN Recommendations on "Transport of Dangerous Goods", Test & Criteria; First Edition; New York 1986, stipulated standardised procedures, as recommended by the U.N.Committee of Experts on Explosives, under Test Type 6 (a, b & c), however, these tests needed full scale field trials.

2.3 A few experiences of past as gained in some of the Ordnance Factories had shown certain propellants behaving as UN HD1.3C items and therefore it was decided to conduct trials adopting UN methods of 1986 to ascertain their Hazard Divisions as per these standardised procedures.

RESULTS & DISCUSSION

3.1 Ten propellants belonging to composition groups like, NGB (Yugoslav composition); Small Arms NC.1140/1058/688 etc. (Swedish & French composition) and some Indian developed compositions were subjected to trials adopting procedures described under Test Type 6(a,b&c). These propellants earlier classified as UNHD1.1C have turned out to pertain to UNHD1.3C. Relevant details of these propellants are placed at Annexure I.

3.2 This reclassification, whereas, would affect the Quantity distance aspects in the existing manufacturing units, would also accord a pragmatic and standardised classification throughout the world.

3.3 Propellants are basically meant to defflagrate and as such assigning them UN HD1.1 is a debatable concept in itself and in case a detonating impulse is given to them under confinement (in contrast to UN methods which stipulate use of 30.0 g of Black Powder), they are very likely to detonate, contrary to the function they are expected of.

METHODOLOGY

4.1 United Nations Recommendation on "Transport of Dangerous Goods"; Tests & Criteria; First Edition; New York 1986, have described Test Series 6 from page No.144 onwards. Tests under this series are sub-divides as Test Type 6(a) or Single Package Test; Test Type 6(b) or Stack Test and Test Type 6(c) or External Fire Test and the behaviour of a substance accepted as Class-I, Explosive under these tests indicates its UN HD; whether same pertains to HD1.1,1.2,1.3 or 1.4. Whereas trials under Test Types 6(a) & 6(b) are required to be conducted on three occassion, trial under Test Type 6(c) is to be done only on one occassion.

4.2 Test Type 6(a); Single Package Test: In the trials conducted by us a card-board carton of volume $0.15m^3$ was used being placed over a 3 mm thick mild-steel witness plate.30.0 g of G-12 (Gun Powder) was used to initiate the propellant material placed in confinement of 0.5 to 1 meter thick layer of sand filled gunny bags. G-12 was ignited using Safety-Fuze No.11, MK-II passing through unignitable tube kept in the propellant medium: Quantities of propellant varied from 135.0 kg to 180.0 kg in case of different propellants. Relevant data and observations are placed at Annexure II & IIA.

4.3 <u>Test Type 6(b); Stack Test:</u> Five to six number of original service packages containing propellant material were placed over the M.S. witness plate in a way to give the worst configuration: Propellant in the centre-most package was initiated using 30.0 g of G-12 as mentioned in para 4.2 above.

4.4 <u>Test Type 6(c); External Fire Test :</u> Five to ten numbers of packages filled with propellants were placed over a specially fabricated iron-grill, on three sides of which 2 mm thick Aluminum screen as stipulated in the U.N.Recommendations were erected. The height of grill was at a minimum of 750 mm above the ground level and the three Al-Screens were placed at distances varying from 4 to 5.2 meters. Adequate quantities of fire-wood were placed all around the propellant filled packages and fuel-liquid was sprayed profusely and then the fire-wood ignited.

OBSERVATIONS

5.1 Whereas Test Types 6(a) & (b) were conducted on three occassions, test type 6(c) was conducted only once. In some trials major events were video-taped and in some trials still photographs were taken of the important events. Details of observations and findings are abridged at Annexure-II & IIA. Some still photographs are placed at Annexure-III.

5.2 It is noteworthy to observe that there had been absolutely NO DAMAGE to 3 mm thick M.S.Witness plate and also there was NO SIGN of any crater formation at the test site in all the trials

5.3 There had been no instantaneous explosion/detonation and the propellant burnt-off leading to defflagration. Brilliant flames leaped upto 25 meters height in some cases.

5.4 In Test Type 6(b), in some trials the propellant material only in the initiated package burnt-off and the other packages remained unaffected.

5.5 In Test Type 6(c) external fire continued for some minutes before the propellant caught fire.

EVALUATION

6.1 The findings and observations have been evaluated in light of stipulations contained in the UN Recommendations of 1986 against each Test Type i.e. Test Type 6(a), 6(b) and 6(c).

6.2 The observations clearly suggest all the ten propellants tried adopting UN methods as pertaining to UN HD 1.3C and accordingly the analysis of observed and recorded events led to infer that all these ten propellants stood reclassified to UN HD1.3C.

SUMMARY

7.1 In quest of standardisation of Hazard divisions of different propellants used in a variety of ammunition stores, a number of trials have been conducted jointly by the Indian Ordnance Factories Organisation and the Directorate of Explosives Safety, Ministry of Defence, Government of India adopting Test Series 6 and thereunder Test Types 6(a), 6(b) & 6(c) as stipulated in UN Recommendations on "Transport of Dangerous Goods", Tests & Criteria; First-Edition; New York 1986.

7.2 Ten propellants earlier assigned UN HD1.1C have been reclassified as HD1.3C as the result of full scale trials conducted adopting UN methods of 1986.

ACKNOWLEDGEMENT

Authors express their gratitude to several Indian Ordnance Factories who provided all the facilities and stores for conducting the trials discussed in the present paper.

BIBLIOGRAPHY

1. U.N.Recommendation on "Transport of Dangerous Goods", Tests & Criteria; First Edition, New York 1986.

2. ESTC, London, Pamphlet on "Classification of Military Explosives", published in June 1987.

ANNEXURE - II

QUANTITIES OF PROPELLANTS VIS-A-VIS PACKAGES USED IN DIFFERENT TESTS

Sr. No.	Propellant Code	Test Type 6(a)	Test Type 6(b)		Test Type 6(C)		REMARKS
		Quantity per $0.15m^3$ volume of Card-board Carton. (Kg)	Package used	quantity Per Test (Kg)	Package used	Quantity used (kg)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1. 2.	NGB-051 NGB-221	135.00	C.27A Metallic containers (2Nos)placed inside one C26A Wooden package.	150.00	As in Test Type 6(b)	300.00	For Test Type 6(a), a Card-board Carton of Volume $0.15m^3$ was made as per stipulations contained in UN Recommendations, and for Test Types6(b) and 6(c) Original Service packages were used.
3. 4.	NGB-011 NGB-241	-do-		-do-		300.00	
5.	NGB-204	96.00	A pair of Card-board Cartons placed in a C27A metallic container which is placed in C26A wooden package.	96.00	-do-	160.00	
6.	NC-1140	150.00	C27A Container and C26A wooden package	180.00	-do-	300.00	
7.	NC-688	135.00		150.00	-do-	300.00	
8.	NC-1058	150.00	-do-	180.00	-do-	300.00	
9.	Ball Powder	160.00	Plywood rectangular container with alkathene liners.	240.00	-do-	200.00	
10.	Propellant T-28	160.00	C.128MK XIII cases with Alkathene	280.00	-do-	520.00	

SOME IMPORTANT OBSERVATIONS DURING TEST TYPES 6(a),6(b) & 6(c)

Propellent Code	Test Type(a)	Test Type 6(b)	Test Type 6(c)
(2)	(3)	(4)	(5)
NGB-051	No effect on MS witness plate.	Burning with hissing sound Material only in the initiated package burnt off leaving other packages unaffected.	After 8 minutes of exposure to flames, Ist package caught fire and entire material got burnt in six minutes. No fire balls etc. No effect on Aluminum Screens.
NGB-221	No detonation but material burnt-off with mild bang. Brilliant flames upto 10m height.		
NGB-011 NGB-241	-do-flame height upto 15 m.	-do-.	After 3½ minutes of flame exposure, the material started burning with bright flames.
NGB-204	No effect on MS Plate No detonation/No crater formation. Flames upto 10 m height.	-do- Flames with sparkling effect and hissing sound. Flame height upto 5m.	Brilliant sparkling flames. After 4½ minutes. Propellant burnt for about five minutes.
NC-1140	--do-- Flame height upto 20m.	Flames with hissing sound.	Ist package caught fire after 5minutes of exposure to external fire and thereafter propellant burnt with bright flames.
NC-688	-do-	-do-	Initial exposure of packages for two minutes. NO FIRE BALL.
NC-1058	-do-	-do-	-do- Initial exposure for 4 minutes.
Ball Powder	-do-	-do-Material only in the package which was initiated with G-12 burnt leaving others uneffected.	-do-
Prop.T-28	-do-	Material in all packages (6Nos.) burnt off with bright flames.	-do-Flame height upto 25m. No effect on Al.Screen.

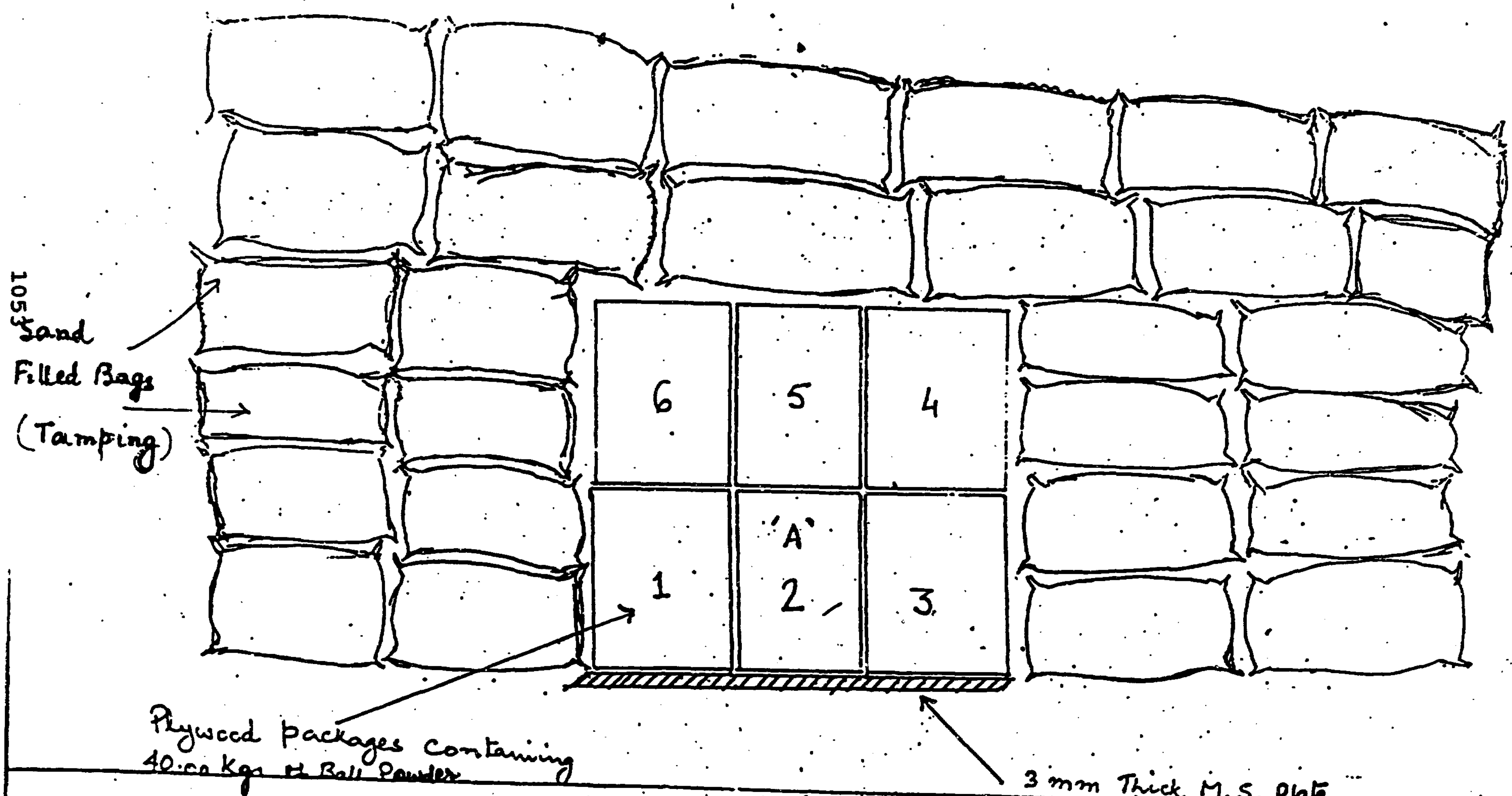
PROPELLANTS RECLASSIFIED USING U.N. [illegible]

Sr.No	Propellant Code	Used in	Composition Group	Physical characteristic.	Earlier classification	Reclassified as per U.N. Methods.	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1. 2. 3. 4.	NGB.051 NGB-221 NGB-011 NGB-241	81mm Mortar Ammn. 120mm Mortar Ammn.	Modified Yugoslav Comp. NCB; 57.5± 1.5 % NG; 40.5± 1.5 % + Others including Graphite	Flake Propellants	HD1.1	HD1.3	All the ten Propellants had behaved as HD1.1C with detonating impulse, however, with black powder in Test Type 6(a) and 6(b) and also in Test Type 6(c), they behaved as Mass Fire belonging to HD1.3C.
5.	NGB-204	84mm Carl Gustav Ammn.	Modified Swedish Comp. (as above) less Graphite	Strip Propellant	HD1.1	HD1.3	
6.	NC-1140	7.62 mm SAA	Swedish Comp. NC:97.0±0.5 % + others.	Cylindrical grains length : 1.14mm dia :0.84mm	HD1.1	HD1.3	
7.	NC-688	9 mm Ammn.	NC:98.5 % + others.	Cylindrocal Grains l:1.00mm d:0.50mm	HD1-1	HD1.3	
8.	NC-1058	30mm Aden GunAmmn.	NC:98.0 % + others.	Cylindrical grains l:1.3mm d:0.4mm	HD1.1	HD1.3	
9.	Ball Powder	7.62mm SAA	French Comp. NC:90% NG:9.0±2.0% (+) others	Ball/ Spheroids.	HD1.1	HD1.3	
10.	Propellent T-28	106mm A|T RCL Ammn.	NC:67.25±1.80% NG:25.00±0.75% (+) others.	Multitubular Cylindrical Grains of 12mm length.	HD1.1	HD1.3	

: Flames as seen under Test Type 6(c)

APPENDIX 'I'

ARRANGEMENT OF PACKAGES IN TEST TYPE 6(b).



Photoplate : 3mm THICK M.S. WITNESS PLATE BEFORE THE TRIALS.

Photoplate ... : EFFECT OF TRIALS ON WITNESS PLATE UNDER TEST TYPE 6(a).

An Alternative to Thermal Flux Measurements in UN Test 6(c)

By Richard W. Watson
Research Physicist
U.S. Bureau of Mines
P.O. Box 18070
Cochrans Mill Road
Pittsburgh, PA 15236

Abstract

In the United Nations' bonfire test (test 6c), thermal radiation measurements are used to determine the potential radiation hazards from transportation fires involving flammable substances. Currently, packaged substances are assigned to UN division 1.3 (propellants), if the irradiance from the bonfire test of the product exceeds 4 kw/m^2 at a distance of 15 m from the fire. The irradiance is measured over 5 seconds, during the period of maximum output. For substances, the value is corrected (scaled) to a mass of 100 kg net explosive content.

Thermal radiation measurements require complicated instrumentation, and are subject to significant errors introduced by wind, atmospheric attenuation, smoke obscuration, variation in source fire intensity, etc. Experience with UN test 6c, at the Bureau of Mines, indicates that the irradiance from bonfires involving typical test sample weights (10 to 100 kg) can be calculated to an acceptable degree of accuracy, from simple observations of the total burning time for the involved substance.

This paper discusses this simple approach, the current thinking of the UN Group of Experts on thermal flux measurements and criteria, and the impact of substituting burn times for thermal flux measurements on the classification of substances of interest.

Introduction

In conducting the United Nations external fire test (UN Test 6 (c)) it is necessary to make measurements of thermal radiation some distance from the bonfire. These measurements require complicated instrumentation, and are subject to significant errors introduced by wind, atmospheric attenuation, smoke obscuration, variations in source fire intensity, etc. In addition, radiation measurements of short duration fires are difficult to interpret in terms of the present criterion outlined in paragraph 44.4.4(c) of ST/SG/AC 10/11 (1). Paragraph (c) reads: if . . "the irradiance of the burning product exceeds that of the fire by more than 4 kW/m^2 at a distance of 15 m from the edge of the stack" . . . then the product, as packaged, is assigned to division 1.3 . . . "The irradiance is measured over 5 seconds, during the period of maximum output. For substances, the value is corrected to correspond to a mass of 100 kg net explosive content." For bonfire tests involving net explosives weights larger or smaller than 100 kg or for flux measurements made at distances other than 15 m a (mass)$^{2/3}$/(distance)^2 scaling law is ordinarily used to normalize (correct) the data. This scaling law is based on an assumed linear burning rate for the material under test with burning times scaling with the linear dimension of the stack or equivalently, the cube root of the mass. Size scaling presents no serious problem but it is likely that the assumption of a linear burning rate would break down for rapid burning propellants which ordinarily create fireballs and are consumed in very short times that do not strongly depend on the total involved mass. However, even in the case of very rapidly burning materials that produce fireballs, the radius of the fireball is, to a very good approximation, proportional to the cube root of the mass (2, 3). This again leads to a $m^{2/3}/R^2$ scaling law. The proper classification of rapid burning propellants is not a problem except when the observed burn time (for small samples) is significantly less than 5 seconds. In this case, averaging the flux over 5 seconds, as suggested in paragraph 44.4.4(c) results in a flux value well below the peak value and leads to some ambiguity in interpreting the test results. This has been pointed out in a recent paper submitted by the Netherlands for consideration by the United Nations Group of Experts (4). A proposal for reducing the thermal flux criterion in 44.4.4(c) from 4 kW/m^2 to 1.5 kW/m^2 at 15 m is also contained in this paper; adoption of the revised criterion could have significant impact on the current classification of some oxidizers and flammable solids.

The Bureau of Mines has been conducting research on the development of UN tests and criteria for a number of years under the sponsorship of the Department of Transportation and more recently under an agreement with the Department of Defense Explosives Safety Board. Some of this research involved measurements of thermal flux from burning propellants and flammable liquids and solids. Our experience in this area suggests that the irradiance from bonfires involving typical UN test sample weights (10 to 100 kg) can be calculated to an acceptable degree of accuracy from simple observations of the total burning time for the involved substance.

Experimental Results

Table 1 summarizes radiation measurements and observed burning times for a number of substances.

Table 1.--Measured and Calculated Values of Irradiance

Substance	Quantity kg.	Burn Time, s	Irradiance, kw/m^2 Measured	Irradiance, kw/m^2 Calculated
Nitrocellulose alcohol-wet	13.6	220	0.25 at 5 m	0.28 at 5 m
Nitrocellulose, plasticized	13.6	54	1.13 at 5 m	1.11 at 5 m
Pistol powder	13.6	15	3.4 at 5 m	4.0 at 5 m
Propellant mix	11.2	8	0.92 at 15 m	0.67 at 15 m
Nitrocellulose, plasticized	100	110	0.67 at 15 m	0.45 at 15 m

With the exception of the last entry (100 kg NC) the substances were contained in cylindrical cardboard containers having a length/diameter ratio of approximately 1.0; the 100 kg of plasticized nitrocellulose was contained in a standard 55 gallon (208 l) steel drum. All samples were ignited with 10 g of FFFg black powder placed just below the top surface of the substance. None of the containers were equipped with lids; so confinement was minimal.

Radiation measurements were made with heat flux gages obtained from Thermogage, Inc. (5). The irradiance values in table 1 represent average values obtained with three gages placed in a circular array (90° apart) at a ground height corresponding to the top of the sample containers and at the distances noted in table 1. Burning times were estimated from video camera records of the experiments. The burn times in table 1 correspond to the most intense burning and do not include the residual burning of the cardboard containers.

The values of irradiance listed in the right-hand column of table 1 were calculated from the equation:

$$I = \frac{C \cdot E}{4\pi R^2 t} \qquad \text{where,}$$

I = irradiance in kw/m^2,
C = constant = 0.33,
E = total energy content in joules,
R = distance from fire to gage position in meters,
t = observed burn time in seconds.

In applying the above equation, several assumptions were made. The first assumption involves calculating the total energy content of the test substance, E. The irradiance values in table 1 were calculated assuming a heat of combustion of 4186 J/g (1000 cal/g) for all the substances listed. This would appear to be a reasonable value for most substances capable of burning in the monopropellant mode. Other substances (coal, wood, liquid fuel) have much higher heats of combustion, but burn at much lower rates because of the limited availability of oxygen. These substances (flammable, solids or liquids) would not produce irradiance values high enough to be of concern here.

The second assumption involves the choice of the numerical value of the constant, C, in the above equation. This is the fraction of the total energy converted to thermal radiation. The vast majority of radiation measurements from combustion experiments indicate that the value of C lies between 0.2 and 0.4 (6); a value of 0.33 was chosen for the calculations in table 1. In applying the above equation it is also implicitly assumed that the mass consumption rate (E/t) is constant for a given material and packaging; for the experiments reported here, using a black powder igniter and minimal confinement, this was generally true.

With the exception of the last entry (100 kg NC) the substances were contained in cylindrical cardboard containers having a length/diameter ratio of approximately 1.0; the 100 kg of plasticized nitrocellulose was contained in a standard 55 gallon (208 l) steel drum. All samples were ignited with 10 g of FFFg black powder placed just below the top surface of the substance. None of the containers were equipped with lids; so confinement was minimal.

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REFERENCES

(1) United Nations recommendations on the Transport of Dangerous Goods, Tests and Criteria. First Edition, 1986.

(2) The Characterization and Evaluation of Accidental Explosions, Roger A. Strehlow and Wilford E. Baker, Prog. Energy Combustion Sci., Vol 2, pp 27-60, 1976.

(3) Measurement and Prediction of Heat Flux in Propellant Fires, J. P. Lucotte, 20th DOD Explosives Safety Seminar, Norfolk, VA.

(4) ST/SG/AC.10/C3/R-16, Radiation Criteria for Division 1.3/1.4, Netherlands, 1989.

(5) Model 2000-8, Circular foil heat flux gages, Thermogage, Inc., 330 Allegany Street, Frostburg, Maryland, 21532.

(6) Diffusive Burning of Liquid Fuels in Open Trays, D. S. Burgess et al, Fire Research Abstracts and Reviews, Vol 3, No 3, 1961.

(7) Ammonium Perchlorate Transportation Hazards Testing, E. I. Merril et.al., AFSC Astronautics Laboratory Report AL-TR-89-018, April 1989.

24th EXPLOSIVE SAFETY BOARD SEMINAR

HAZARD CLASSIFICATION OF LIQUID PROPELLANTS

BY

WILLIAM O. SEALS
ARMY RESEARCH DEVELOPMENT AND ENGINEERING COMMAND
PICATINNY ARSENAL, DOVER, NEW JERSEY

WILLIAM HERRERA
SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

CHESTER GRELECKI
HAZARD RESEARCH CORPORATION
ROCKAWAY, NEW JERSEY

INTRODUCTION

The lack of a formal protocol in the DoD safety community to evaluate liquid propellants prompted the establishment of a Hazard Classification of liquid propellants program. The DoD safety manual TB-700-2 has been used exclusively for the hazard classification of solid propellants and explosives in storage and transportation. A recent revision of this manual now addresses energetic liquids on a case by case basis. An examination of the UN document and NATO AOP-7 revealed deficiencies in making a final assesment for a Hazard Classification of energetic liquids. The Un document only addressed explosives in transportation; while the NATO AOP-7 provides no criteria for making a final judgement to a Hazard Classification. The tests, procedures, and criteria for making a final classification can be found in the TB-700-2. For this reason, the TB 700-2 was selected as the role model for developing the Hazard Classification of energetic liquids.

Since the tests and test procedures found in the TB-700-2 were designed to evaluate solid materials, it became apparent that modifications to these tests and test procedures would have to be made. The liquid propellants LP 1845 and LP 1846 are extremely sensitive to transition metals and nitric acid. Thus, containment of these liquids for a test evaluation would have to be made in a container compatible with these liquid.

This paper will address the events leading up to the selection of the TB 700-2 as the role model for the Hazard Classification of liquid propellants, establishment of the interim- classification tests, test procedures, modifications to the test procedures, and criteria for classifying liquid propellants. The recommended tests designed for a final classification will be contingent upon evaluating the liquid propellants in approved DoD packaging.

DISCUSSION

The UN document was initially examined for potential tests, test procedures, and criteria that might be beneficial in the establishment of a Hazard Classification of the liquid propellants. This initial examination was made based upon the Department of Transportation's acceptance of this document as their guideline for transporting explosives. As illustrated in Figures 1 and 2, the document determines the division of a Hazard Classification from a series of questions and answers. As seen in Figures 1 and 2, a material is considered for a Class I the answer is yes to the question "is the substance manufactured with the view of producing a practical explosion" Test series 1 is performed if the answer is no. Following this test series, if the answer is yes to the next question "is it an explosive substance?", then test series 2 is performed. Should the substance be considered as a Class 1 material, then test series 3 is conducted. When the results of test series 3 demonstrate that the material is thermally stable, test series 4 is conducted. The material is provisionally accepted into a Class 1 if packaged substance is considered not too hazardous for transportation.

The question now asked is "can the substance be considered for a Division 1.5?" If the answer is yes, then the test series 5 is performed. Should the results of this test indicate that the substance is an insensitive substance, then it is considered a Division 1.5 material. However, if the answer to the question above is no, then the packaged substance is subject to test series 6. Depending upon the series of questions asked depicted in Figure 2 and the answers given based upon test results will determine how the material will be characterized. Test series 1 through 6 can be found in Figures 3-8.

The NATO AOP-7 outlines the characteristic qualifications for liquid propellants in Fifure 9. Note that in Figure 10, the qualification guidelines follow those of the TB 700-2. Specific physical property tests call for density, melting point, boiling point, coefficient of thermal expansion, vapor pressure, and flammability/detonability. The required NATO AOP-7 qualification tests are given in Figure 11. Optional qualification tests are cited in Figure 11a. Unfortunately, these tests, spelled out for the NATO AOP-7, provide no criteria for assessing or designating a Hazard Classification.

In the TB 700-2, mandatory tests, shown in Figure 12, are required for an interim hazard classification for solid propellants and explosives. Alternate tests that may be required, depending on the application, are depicted in Figure 13. Criteria to establish the interim classification for a Class A or B explosive material are given in Figure 14. No criteria are given for an interim classification for solids as a Class C, explosive. To obtain a final classification, the single package, stack test, and external fire tests are required. As shown in Figure 15, additional tests, such as the bullet impact, fragment, package drop, and oblique drop tests, may be required before a final Hazard Classification can be rendered. The decision to conduct these tests will be determined by the appropriate safety group. The bullet impact and fragment tests are part of the requirements for an insensitive munition.

The criteria for arriving at a final Hazard Classification for a material are shown in Figure 16. Note that criteria for a Class C material are now given. Include in this criteria should have been that the material does not detonate under atmospheric conditions nor are fragments produced. Schemes for a large scale test analyses are cited in Figure 17 and 18. The single package, stack and external fire tests are the only required mandatory tests for a final Hazard Classification of a material.

Before initiating a test program, a methodology was presented to the safety community for approval. As depicted in Figures 19, 20, and 21, this methodology received the approval of the tri-services and DoD Explosive Safety Board. Note that for liquids, a Class C designation has been recommended. This differs from the TB 700-2 in that only a Class A or B is given as a result of the card gap test. When 70 or more cards are required to attenuate a detonation in the card gap, a Class A explosive is assigned to the material. If the test results are 70 cards or 0, the, the material is a Class B explosive. It is recommended that the material be considered a Class C material when 0 cards are used in the card gap test.

Utilizing the tests cited in the TB 700-2 manual, modifications had to be made to evaluate a liquid. As shown in Figures 22, 23, and 24, the liquid propellants were housed in compatible polyethylene sample test containers for testing. This precaution had to be taken since the liquid propellants LP 1845 and LP 1846 are decomposed by transition metals. Contact of these materials with compatible stainless steel containment had to be assured in the impact and critical diameter tests.

All the mandatory and auxillary tests were conducted for LP 1845 and LP 1846. The results of these tests are given in Tables 1-10. The test description of each test is presented below.

TEST DESCRIPTION

THERMAL

Decontaminate a two(2) inch diameter x 2-1/2 inch high x 0.5 mil thick polyethylene bottle filled with deionized water by placing in an oven at 70C for 24 hours. Weigh the dried bottle. Fill the decontaminated bottle with liquid propellant, weigh the bottle and liquid propellant and place in a constant temperature, explosion proof oven. Raise the temperature to 75C and maintain this temperature for a period of 48 hours. Remove and weigh the bottle and liquid propellant. Record the weight change and any reactions that may have occurred over this period of exposure.

CARD GAP

A typical card gap tester is shown in Figure 25. The test apparatus consists of a one piece 1.875 inch O.D. x 5.5 inch long mild steel tube. The ignition source consists of two pentolite pellets that weigh approximately 60 grams and a J-2 blasting cap. A 6 inch x 6 inch x 0.375 inch mild steel witness plate is used to determine if a detonation has occured. A detonation is indicated when a clean hole is cut into the witness plate. Cellulose acetate(or equivalent) cards 2 inches x 0.01 inches thick are used to attenuate a detonation. The greater the number of cards, the more sensitive the material. Four small pieces of plastic material cut into (0.0625 x 0.5 x 0.5 inches) pieces are used as shims to support the tube and maintain a 0.0625 inch air gap between the test sample and the witness plate.

A 0.5 mil thick polyethylene sleeve is placed inside the mild steel tube to prevent contamination of the liquid propellant. The liquid propellant is placed inside the tube and the first test is conducted. In the first test, the cellulose cards are omitted. Should no detonation occur in the first test, the test is repeated two more times. If a detonation occurs, then a test series given in Figure 26 will be followed with the cellulose cards placed between the tube containing the liquid propellent and the pentolite booster.

The first test performed in Figure 26 is with 8 cards. If a detonation occurs, then the number of cards is doubled (add 8 cards) for the next test. If a detonation occurs in this test, the number of cards is doubled again (add 16 cards). Continue doubling the number of cards until no detonation occurs. When no detonation occurs, then the number of cards is reduced by one half the preceding increment. As an example, if the test is run at 32 cards but not at 64, then the next test will be run at 48 cards. If a detonation occurs at this reduced number of cards, the number of cards will be increased by one half the preceding increment of 56 cards. This test procedure is continued to a point where no detonation is obtained. A 50% probability that a detonation has occurred is a measure of charge sensitivity at where a 50% probability that a reaction has occurred at a given attenuation gap length.

IMPACT

The standard JANNAF drop weight tester was used to establish the impact sensitivity of liquid propellants. A typical test sample holder for the apparatus is illustrated in Figure 27. The liquid propellant test sample is enclosed in a cavity formed by a steel cup, elastomeric "O" ring and a steel diaphragm. A 4.4 pound (2 kilogram) weight is dropped onto a piston from a height of 48 inches. If a positive result occurs, the weight is dropped from a height one half the original height.This adjustment of the drop weight to one half the distance is continued until no positive reaction occurs. A positive result has occurred when the steel diaphram is punctured with an accompanied loud report, severe deformation of the diaphragm or evidence that the sample is consumed. Data are reported at the height which yields 50% probability of initiation.

DETONATION

A lead cylinder, 1-1/2 inch diameter x 4 inches high, is placed upon a 12 inch square x 1/2 inch thick SAE 1010 mild steel plate. Fill a decontaminated polyethylene bottle (2.5 inches high x 2 inches in diameter) with a liquid propellant sample. A no. 8 blasting cap with the following requirements is placed perpendicular and in contact with the liquid surface:

1. A cap containing 0.4-0.45 grams of PETN base charge pressed into an aluminum shell having a bottom thickness not to exceed 0.03 inches.
2. A specific gravity not less than 1.4 grams/cubic centimeter.
3. Primed with standard weight of primer in accordance with the manufacturer's specifications.

In the center of a wooden block, drill a hole and position the blasting cap. Ignite the blasting cap and examine the lead cylinder for and deformation. Any deformation of the lead block that is 1/8 inch or more will be considered evidence that a detonation has occurred. Conduct a minimun of five tests more or until a detonation has occurred.

IGNITION AND UNCONFINED BURNING

Kerosene soaked sawdust is placed in a 12 inch x 12 inch x 4 inch stainless steel container with a 1/16 inch wall thickness. The sawdust is evenly filled to a level of 1/4 inch. A 2 inch diameter decontaminated polyethylene bottle is filled with a 2-1/2 inch height of liquid propellant. The polyethylene filled with test sample is placed in the center of the kerosene soaked sawdust and ignited with an electric match-head igniter. This test is repeated twice.

Four liquid propellant filled decontaminated polyethylene bottles are placed in the center of a container filled with kerosene soaked sawdust. The bottles are placed in a row with each bottle in contact with the next bottle. The sawdust is ignited at one end with an electric match-head igniter. The test is repeated two more times.

ADIABATIC COMPRESSION

The schematic of the U-tube compression ignition test set-up is illustrated in Figure 28. The following test parameters are r ved:

-tube radius	1.0 inch
Sample volume	3.0 cubic centimeters
U-tube height	9.0 inches
Ullage space	6.0 inches
Tubing material	304 stainless steel
Tubing diameter	0.25 inch O.D. x 0.035 thick
Pressure valve orifice	0.187 inches

The U-tube is closed at one end with a cap. A 3 ml. quanity of test fluid is placed in the curvature of the U-tube. The open end of the U-tube is connected to the discharge valve. A reservoir is pre-pressurized with nitrogen to 2000 psi. The test is conducted by a suddenly pressurizing the U-tube. The pressure surge forces the liquid in the curvature to violently compress the ullage space containing the liquid vapors into the closed end. This rapid rate of pressurization is sufficient to provide adiabatic compression. Rupture of the U-tube is an indication that an explosion or detonation has occurred. The test is repeated with nitromethane as a control and the test results are compared.

CRITICAL DIAMETER

A schematic of the critical diameter test setup is shown in Figure 29. Tests are conducted using different size diameter cylinders with L/D ratios of 2:1. The liquid propellant tests were conducted using 2,3,4 and 5 inch diameter cylinders. Each cylinder was welded to a 316 stainless steel 1/4 inch thick witness plate.This assembly was passivated with nitric acid to remove any potential contamination. An explosive C-4 charge is placed on top of the open end of the container filled with the liquid. A 0.5 ml thick polyethylene sheet separates the charge and liquid. As the size of the container increases from 2 to 4 inches, the explosive charge was increased proportionally to ensure that the same energy per unit area was maintained. The 2 inch tests were conducted with 160 grams of C-4, the 3 inch tests used 360 grams, the 4 inch tests used 640 and the five inch tests required 1000 grams for each test. These C-4 charge weights were chosen to produce a fixed energy input of 3.11 x 105 Joules/sq in. Detonation velocity probes were inserted into the cylinders to determine the shock wave velocity as it travels through the liquid. The explosive charge is ignited and any reaction is recorded on motion picture film.

FLASH POINT

The standard procedure for the ASTM-92-72 Cleveland Open Cup Flash Point Test Method was followed to evaluate the liquid propellants. The standard brass cup used in this procedure was replaced by a Pyrex cup that reduced the standard volume from

70 ml. to approximately 50 ml. The cup was filled with liquid propellant and placed in the test apparatus. The fluid filled cup was heated to 25C. A gas-fired flame was passed over the liquid. If no flash occurred, the temperature was raised in increments of 10C to a maximum of 75C. The lowest temperature where the pilot flame caused the vapors above the liquid to ignite was taken as the flash point.

MINIMUM PRESSURE FOR VAPOR PHASE IGNITION

A schematic for the pressure test vessel for vapor phase ignition is depicted in Figure 30. Water is used to calibrate the vessel. The vessel is evacuated and 2 ml. of distilled water is injected into the vessel. The temperature is slowly raised at a rate of 5C per minute. At the 5C intervals, pressure and temperature are recorded. A sample of n-propyl nitrate is used as a standard for comparison. A fuse wire, 3 inches in length, is installed in the vessel such that 1 inch is unsupported. The vessel is evacuated and 2 ml. of n-propyl nitrate is injected into the vessel. The temperature of the liquid is raised to a temperature of 160C (use caution). Reduce the pressure to 2.2 atmospheres (29 psia). Ignite the vapor with the fuse wire and record the voltage, current, and pressure. Repeat the test two more times.

The apparatus is cleaned with distilled water and 3 ml test sample of liquid propellant is injected into the vessel. The temperature is slowly raised at 5C per minute until 100C is reached and then an attempt at ignition is made. Record voltage, pressure and current at this temperature. If no ignition occurs, discontinue the test restart test with procedure cited above except raise the upper limit of the temperature 5 C and attempt ignition. If no ignition occurs, repeat the test until ignition or a reaction occurs. At each of these ignition points, record the voltage, current and pressure.

ELECTROSTATICS

Electrostatic energy stored in a charge capacitor is discharged to the sample material to determine whether the electrostatic discharge will cause a sample to decompose, flash, burn, etc. The liquid sample is placed in a stainless steel 316 sample holder or equivalent material compatible with the liquid propellant that will permit the discharge to pass through the sample. The capacitor has a 50000 volt potential. A discharge needle is lowered above the liquid until a spark is drawn through the liquid sample (20 mg.). The standard test interval ranges from 0.0001 microfarads (uf) and 0.00125 Joules at 5 kV to 1 uf and 12.5J at 5 kV. The test is initiated at 1 uf and 12.5 J level. If a negative result occurs, testing is at this level until 20 negatives are reported. If the result is positive, such as a spark, flash, burn, odor or noise other than the instrument noise, a lower discharge level is selected until

20 or more energetic results occur. The test voltage of 5 kV or less at ambient temperatures between 18.3C and 32.2C is used with a relative humidity not to exceed 40%.

DISCUSSION OF RESULTS

THERMAL

The thermal test (Table 1) is the test used by the Department of Transportation as a basis for "forbidden" materials for transportation. Had a detonation occured with the LP materials, the materials could not be shipped. Both materials indicated minimal loss in weight with no visible signs of a reaction having taken place.

CARD GAP

The card gap test results found in Table 2 indicated that zero (0) cards were used. This reflects the insensitivity of the liquid propellants, LP 1845 and LP 1846. It is felt that the length of the sample holder tube, 5.5 inches, may not provide enough residence time for the shock wave to cause a reaction. It is suggested that the tube length be increased to 16 inches. Another concern is the diameter of this sample tube. The diameter can be below the critical diameter and, as such, will not support the transmission of detonation wave.

IMPACT

Table 3 lists the impact test data for LP 1845 and LP 1846. Since LP 1846 has approximately 3% more water than LP 1845, the difference of only 1 inch between the two was to be expected, and LP 1845 more sensitive. Nitromethane, classified by the Department of Transportation as a flammable liquid is more sensitive than the liquid propellants.

DETONATION

Detonation test data are given in Table 4. As seen, no detonations occurred in LP 1845 or LP 1846. The Department of Defense Safety community considers this test as a mandatory critical test. A detonation by a material under this test requirement would immediately characterize the material as a Class A Division 1.1.

IGNITION AND UNCONFINED BURNING

The test results for ignition and unconfined burning are shown in Table 5. The transfer of thermal heat from sawdust soaked in kerosene to liquid propellant samples produced to reaction. This test simulates a fire that could develop during the storage of propellants. The question resolved is whether a detonation can occur of a fire hazard.

ADIABATIC COMPRESSION

Adiabatic compression test results are depicted in Table 6. When a pressurization rate of 260,000 psi/sec was applied to LP 1845 and LP 1846, no detonations or explosions occured. It is critical that the same test configuration be used for each test; otherwise, erroneous test data can be obtained. It has been found that a slight change, such as replacing the end cap with a pressure transducer cap, will have a pronounced effect upon the test results. The standard end cap which has a conical interior produced a detonation when tested with nitromethane. When a flat interior transducer cap replaced the standard cap, no detonation occured. Both tests were conducted at the same pressurization rate. It is theorized that there is a heat transfer problem associated with the conical interior cap. A bubble can be trapped in the conical space which can afford a hot spot for a reaction to occur.

CRITICAL DIAMETER

Critical diameter test data for LP 1845 and LP 1846 can be found in Table 7. The detonation probes indicated that no detonations occurred with LP 1845 in the 3 inch diameter test cylinders; but, a detonation was detected in the 4 inch diameter cylinder. LP 1846 proved to be less sensitive. Here no detonation was detected in the 4 inch diameter cylinder; however, a detonation wave was seen in the 5 inch diameter cylinder. This differential in the critical diameter can be attributed to approximately 3% more water in the basic LP 1846 stoichiometric formulation. The recommended 3:1 charge height to diameter was not followed from the standard test because the deviation in the planar wave across the diameter from the test charge used in this test would be negligible.

FLASH POINT

Table 8 records the flash point test data results for LP 1845 and LP 1846. LP 1845 and LP 1846 are stoichiometric formulations containing 16.8% and 20.0% water, respectively. The vapor above both these compounds is essentially water. Therefore, one would expect that there would be no flash point for both these materials, and this was the case for both materials.

MINIMUM PRESSURE FOR VAPOR PHASE IGNITION

LP 1845 and LP 1846 minimum pressure for vapor phase ignition data can be found in Table 9. As in the case for flash point, the vapor above the liquid phase is water. In this test, the LP materials began to decompose when the temperature reached 120C. Thus, there is no minimum pressure for vapor phase gnition as the material does not ignite under these conditions.

ELECTROSTATICS

The electrostatic test results for both liquid propellants evaluated can be seen in Table 10. Both materials proved negative to electrostatic ignition. Hydroxylammonium nitrate and triethanolammonium nitrate are nitrated salts that are completely ionized in the water portion of the basic formulation. Therefore, electrostatic charge build-up is readily dissipated through these formulations and can not materialize into a hazardous discharge.

SUMMARY

Based upon the results of the small scale interim classification tests, the safely community assigned a Hazard classification of Class B Explosive, Division 1.3C. The assignment of a compatibility Group C poses a problem for the logistics chain. The safety community has characterized these materials as oxidizers. This assignment is incorrect since the basic formula contains an oxidizer and a fuel component. As a Group C catagory, liquid propellants can not be stored with solid materials. However, they can be stored with other oxidizers. To place this under a Group J category which is designated for liquid propellants and gels would require that the materials be stored separately from any other material. One can see the dilemma. A program has been recommended to resolve this problem.

The problems associated with the HAN-based liquid propellants sensitivity to decompose in contact with transition metals and nitric acid can be resolved. Strict manufacturing practices and storage containers compatible with the liquid propellants can eliminate or greatly reduce the threat of contaminating the liquid propellant. The surveillance program, that is in progress, will greatly enhance the design of the containers for long term storage. Any pressure generated from the HAN-based propellant's decomposition can be relieved through proper venting techniques and avoid any safety hazards while in storage.

The results of various tests have shown that the HAN-based liquid porpellants are very insensitive to initiation. Destruction of armored vehicles has been the result of stored ammunition detonating when hit by a shaped charge. The need for insensitive munitions is critical for the preservation of the vehicle and more importantly the personnel. Successful gun firings of the HAN-based propellant in the 155mm regenerative gun scheduled for 1991 will usher in a new era for tactical weapons systems. The Hazard Classification program has paved the way for this attainment. This concludes the paper presentation.

UNITED NATIONS HAZARDOUS SUBSTANCE ACCEPTANCE PROCEDURE

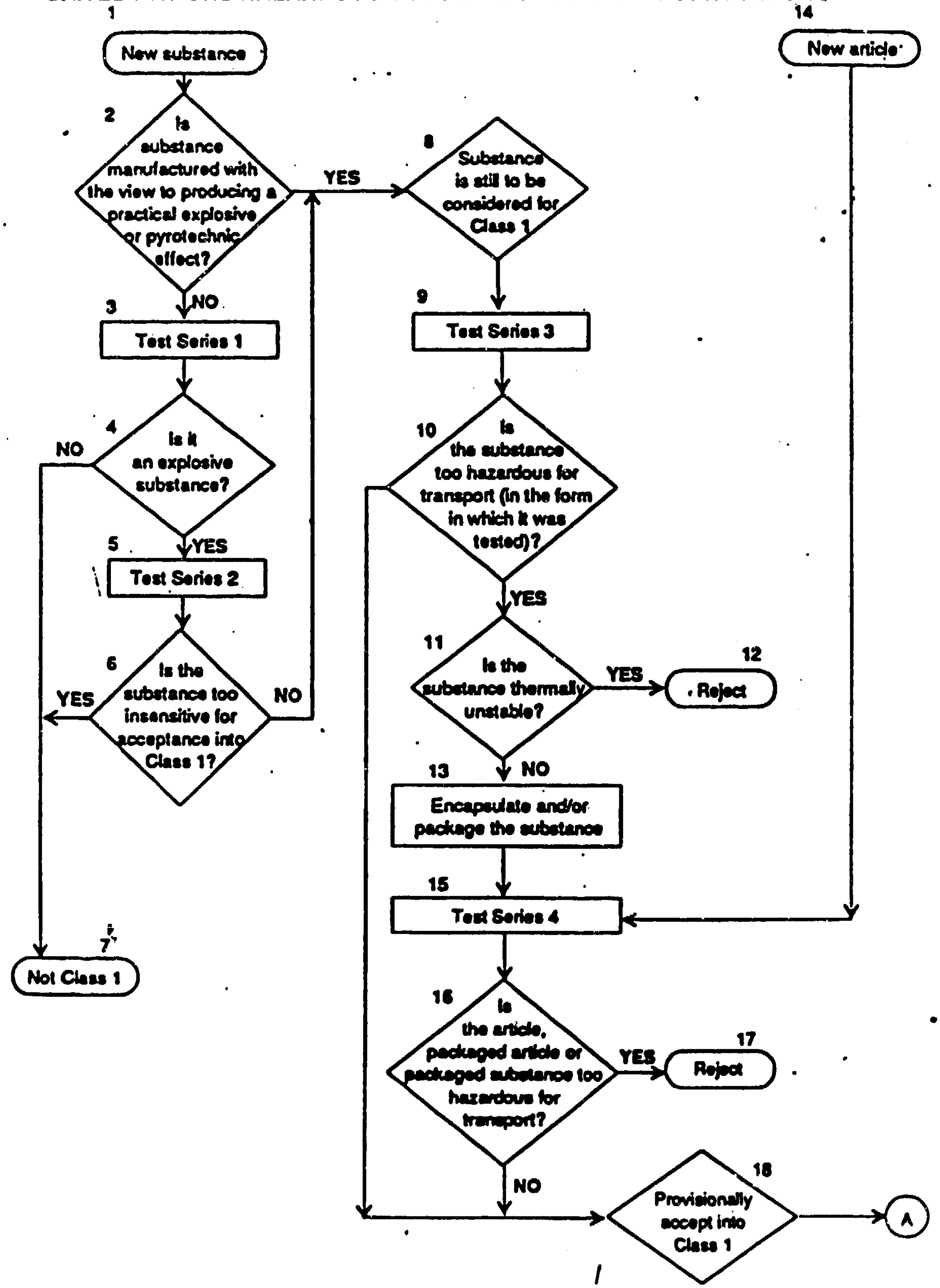


FIGURE 1

UNITED NATIONS PROCEDURE FOR ASSIGNMENT OF HAZARD DIVISION

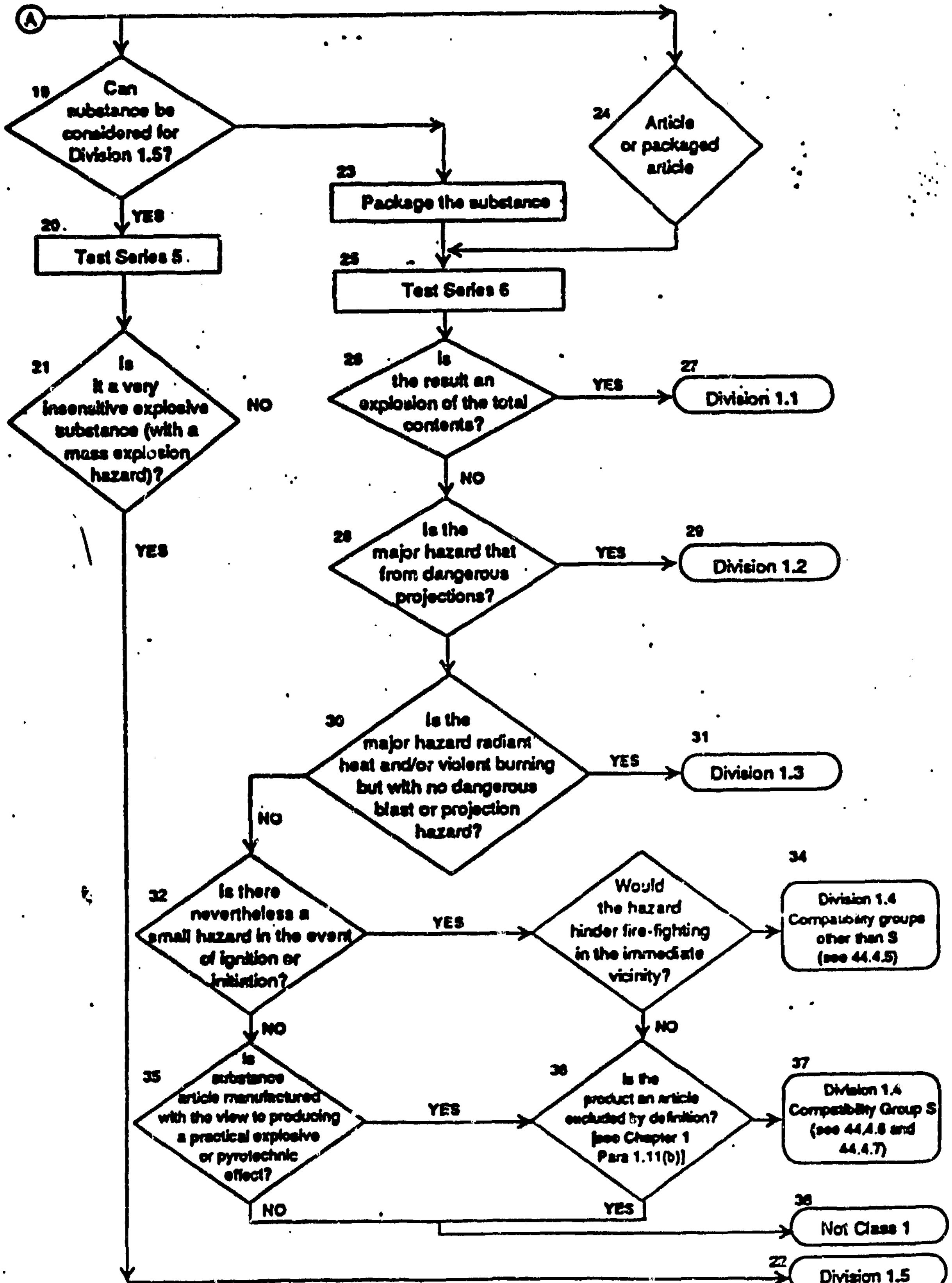


FIGURE 2

FIGURE 3

UN DOCUMENT
TEST SERIES 1

- TYPE 1 (a) TESTS: SHOCK TESTS WITH A DEFINED BOOSTER UNDER CONFINEMENT
  - TEST 1 (a) (i) BAM 50/60 STEEL TUBE TEST
  - TEST 1 (a) (ii) TNO 50/70 STEEL TUBE TEST
  - TEST 1 (a) (iii) CARD GAP TEST FOR SOLIDS
  - TEST 1 (a) (iv) CARD GAP TEST FOR LIQUIDS
- TYPE 1 (b) TESTS: COMBUSTION OR THERMAL TESTS
  - TEST 1 (b) (i) KOENEN TEST
  - TEST 1 (b) (ii) INTERNAL IGNITION
  - TEST 1 (b) (iii) SCB TEST

FIGURE 4

UN DOCUMENT
TEST SERIES 2

* TYPE 2 (a) TESTS: SHOCK TESTS WITH DEFINED BOOSTER UNDER CONFINEMENT
  * TEST 2 (a) (i) BAM 50/50 STEEL TUBE TEST
  * TEST 2 (a) (ii) TNO 50/70 STEEL TUBE TEST
  * TEST 2 (a) (iii) GAP TEST FOR SOLIDS
  * TEST 2 (a) (iv) GAP TEST FOR LIQUIDS
* TYPE 2 (b) TESTS: COMBUSTION OR THERMAL
  * TEST 2 (b) KOENEN TEST
  * TEST 2 (b) (i) INTERNAL IGNITION
  * TEST 2 (b) (ii) TIME/PRESSURE TEST
  * TEST 2 (b) (iii) SCB TEST

FIGURE 5

UN DOCUMENT
TEST SERIES 3

(A) SENSITIVITY TO IMPACT
- * BUREAU OF EXPLOSIVE MACHINE
- * BAM FALLHAMMER
- * ROTTER TEST
- * 30 kg FALLHAMMER
- * MODIFIED TYPE 12 IMPACT TOOL

(B) SENSITIVITY TO FRICTION
- * BAM FRICTION APPARATUS
- * ROTARY FRICTION
- * ABL FRICTION

(C) THERMAL STABILITY
- * THERMAL STABILITY TEST AT 75C

(D) RESPONSE TO FLAME
- * SMALL SCALE BURNING TEST (USA)
- * SMALL SCALE BURNING TEST (FRENCH)

FIGURE 6

UN DOCUMENT
TEST SERIES 4

* TYPE 4 (a) TEST: THERMAL STABILITY OF PACKAGED OR UNPACKAGED SUBSTANCES
  * TEST 4 (a) THERMAL STABILITY TEST FOR ARTICLES AND PACKAGES
* TYPE 4 (b) TESTS: EFFECT OF DROPPING THE EXPLOSIVE FROM A HEIGHT OF A FEW METERS
  * TEST 4 (b)(i) STEEL TUBE DROP TEST FOR LIQUIDS
  * TEST 4 (b)(ii) TWELVE METER DROP TEST FOR ARTICLES AND SOLID SUBSTANCES

FIGURE 7

UN DOCUMENT
TEST SERIES 5

- TEST 5(a): SHOCK TESTS-IGNITION BY STD. DETONATOR
  - TEST 5(a) CAP SENSITIVITY TEST
- TEST 5(b): THERMAL TESTS
  - TEST 5(b)(i) : DDT TEST- IGNITION BY HOT WIRE
  - TEST 5(b)(ii): DDT TEST- 5 GRAM IGNITER
- TEST 5(c): SUBJECT TO LARGE FIRE
  - EXTERNAL FIRE TEST
- TEST 5(c): IGNITION BY INCENDIARY SPARK
  - PRINCESS INCENDIARY SPARK TEST

** NOTE: HAZARD DIVISION 1.5 MUST PASS ALL TESTS

FIGURE 8

UN DOCUMENT
TEST SERIES 6

* TEST TYPE 6(a): TEST ON SINGLE PACKAGE
  * WHETHER INITIATION OR IGNITION CAUSES BURNING OR EXPLOSION
  * SURROUNDINGS ENDANGERED BY THESE EFFECTS
* TEST TYPE 6(b): TESTS ON STACK OF PACKAGES
  * WHETHER BURNING OR EXPLOSION IS PROPAGATED FROM ONE PACKAGE TO ANOTHER
* TEST TYPE 6(c): EXTENAL FIRE TEST
  * HOW PACKAGES IN STACK BEHAVE TO EXTERNAL FIRE
  * SURROUNDINGS ENDANGERED BY BLAST WAVES, HEAT RADIATION AND FRAGMENTS

FIGURE 9

NATO CHARACTERISTIC QUALIFICATION FOR LIQUID PROPELLANTS

1. GENERAL CHARACTERISTICS
   1.1 COMPOSITION
   1.2 TYPE\ROLE
   1.3 RELATED APPLICATIONS & COMPOSITIONS
   1.4 FABRICATIONS
   1.5 PHYSICAL PROPERTIES

2. CHEMICAL CHARACTERISTICS
   2.1 STABILITY
   2.2 COMPATIBILITY
   2.3 TOXICITY

3. PROPELLANT CHARACTERISTICS
   3.1 BURNING CHARACTERISTICS
   3.2 IMPULSE\IMPETUS
   3.3 HEAT OF COMBUSTION

FIGURE 10

QUALIFICATION (NATO) FOR LIQUID PROPELLANTS

* QUALIFICATIONS GUIDLINES
  * DOD TB 700-2
  * NAVSEAINST 8020.8
  * TO 11 A-1-47
  * DLAR 8220
* QUALIFICATIONS
  * PHYSICAL PROPERTIES
    * DENSITY
    * MELTING POINT
    * BOILING POINT
    * COEFFICIENT OF THERMAL EXPANSION
    * VAPOR PRESSURE
    * FLAMMABILITY\DETONABILITY
  * CHEMICAL PROPERTIES
    * COMPATIBILITY
    * TOXICITY

FIGURE 11

NATO QUALIFICATION TESTS FOR HAZARD CLASSIFICATION OF LP

* UNCONFINED BURNING (BONFIRE)
* IMPACT
* CARD GAP
* MINIMUM PRESSURE FOR VAPOR PHASE IGNITION
* FLASH POINT
* ADIABATIC COMPRESSION
* DETONATION VELOCITY

FIGURE 11A

NATO OPTIONAL QUALIFICATION TESTS FOR LIQUID PROPELLANTS

* ATTACK BY FRAGMENT
* HIGH VELOCITY IMPACT
* DROP TEST PACKAGE
* OBLIQUE IMPACT
* CRITICAL CONDITIONS FOR SELF HEATING

FIGURE 12

INTERIM HAZARD CLASSIFICATION TESTS FOR LIQUID PROPELLANTS

* THERMAL STABILITY
* IMPACT
* CARD GAP
* DETONATION TEST
* IGNITION AND UNCONFINED BURNING

MANDATORY

FIGURE 13

HAZARD CLASSIFICATION TESTS

* JANNAF THERMAL STABILITY
* ADIABATIC COMPRESSION
* CRITICAL DIAMETER
* FLASH POINT
* MINIMUM PRESSURE FOR VAPOR PHASE IGNITION
* ELECTROSTATICS

EVALUATION CRITERIA

SMALL SCALE TESTS (INTERIM)

DOT "FORBIDDEN"

- Thermal Stability: detonation, burning, marked decomposition

DOT CLASS A (DOD 1.1) - if one or more occurs

- Detonation Test: 1/8 inch or more deformation of lead cylinder
- Card Gap Test: detonation sensitivity of 70 or more cards
- Impact sensitivity: explosion at 4 inches, but not more than 10 inches
- Ignition and Unconfined Burning: detonation

DOT CLASS B (DOD 1.3) - if ALL occur

- Ignition and Unconfined Burning: deflagration
- Thermal Stability: no result
- Detonation test: no detonation AND Card Gap: detonation sensitivity less than 70 cards OR no reaction at zero cards
- Impact Sensitivity: no explosion at 10 inches or less

FIGURE 15

HAZARD CLASSIFICATION
LIQUID PROPELLANT END ITEM TESTS

* SINGLE PACKAGE TEST
* STACK TEST
* EXTERNAL FIRE
* BULLET IMPACT (50MM)
* PACKAGE DROP TEST
* OBLIQUE PACKAGE DROP TEST
* FRAGMENT TEST

FULL SCALE TESTS

EVALUATION CRITERIA

LARGE SCALE, PACKAGE TESTS (FINAL)

DOT CLASS A (DOD 1.1)

- Packages mass detonate
- Bulk materials with Card Gap of 70 or more cards

DOT CLASS A (DOD 1.2)

- Packages do not mass detonate
- Package tests produce hazardous fragments

DOT CLASS B (DOD 1.3)

- Packages do not mass detonate
- Bulk materials with Card Gap of less than 70 cards
- Radiant heat flux › 0.3 cal/sq cm-sec beyond 100 feet

DOT CLASS C (DOD 1.4)

- Hazardous fragment and firebrand density no more than one/600 sq ft beyond 100 feet
- Radiant heat flux no more than 0.3 cal/sq cm-sec beyond 100 feet

FIGURE 17

HAZARD CLASSIFICATION PACKAGE TEST ANALYSES

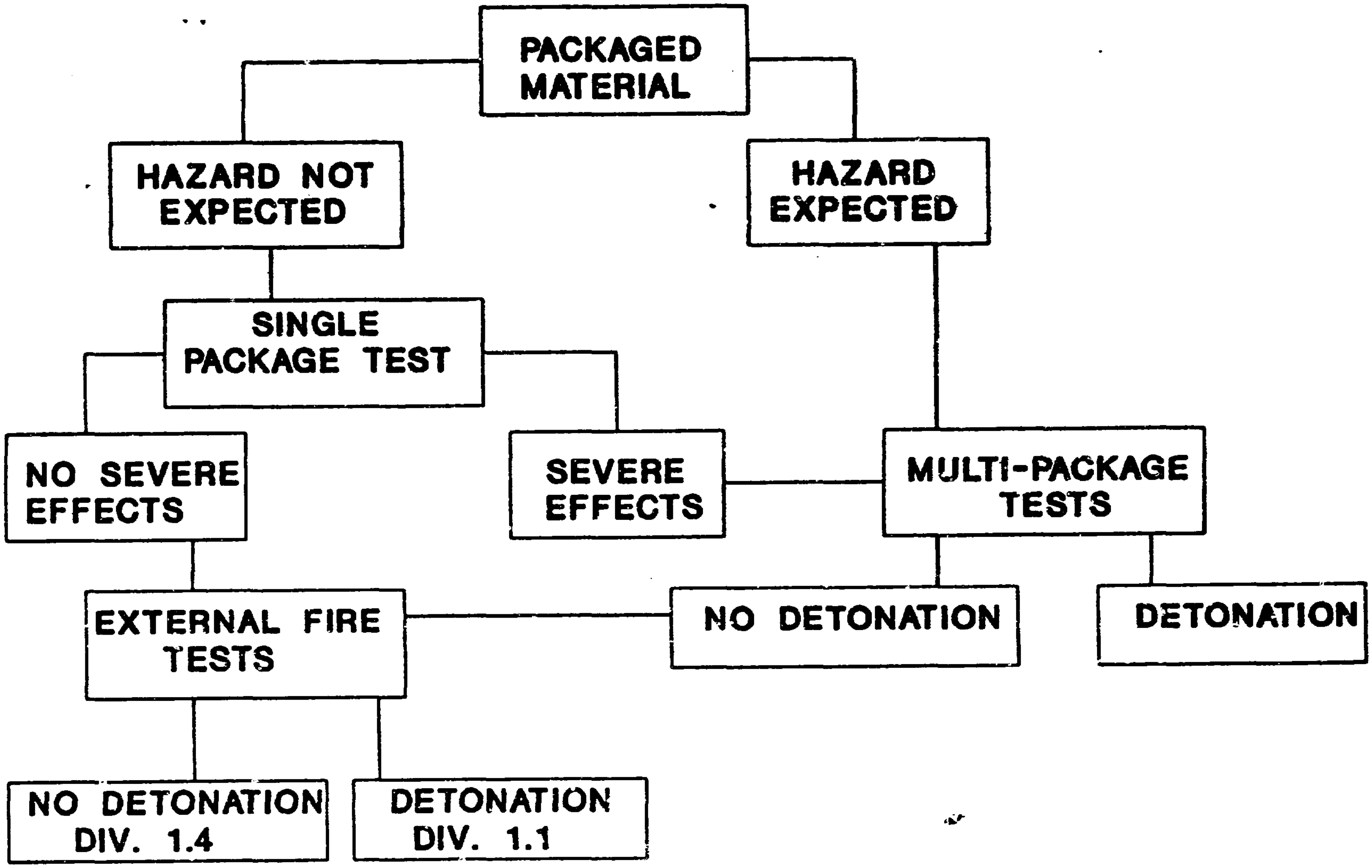


FIGURE 18

HAZARD CLASSIFICATION
PACKAGED MATERIAL ANALYSES

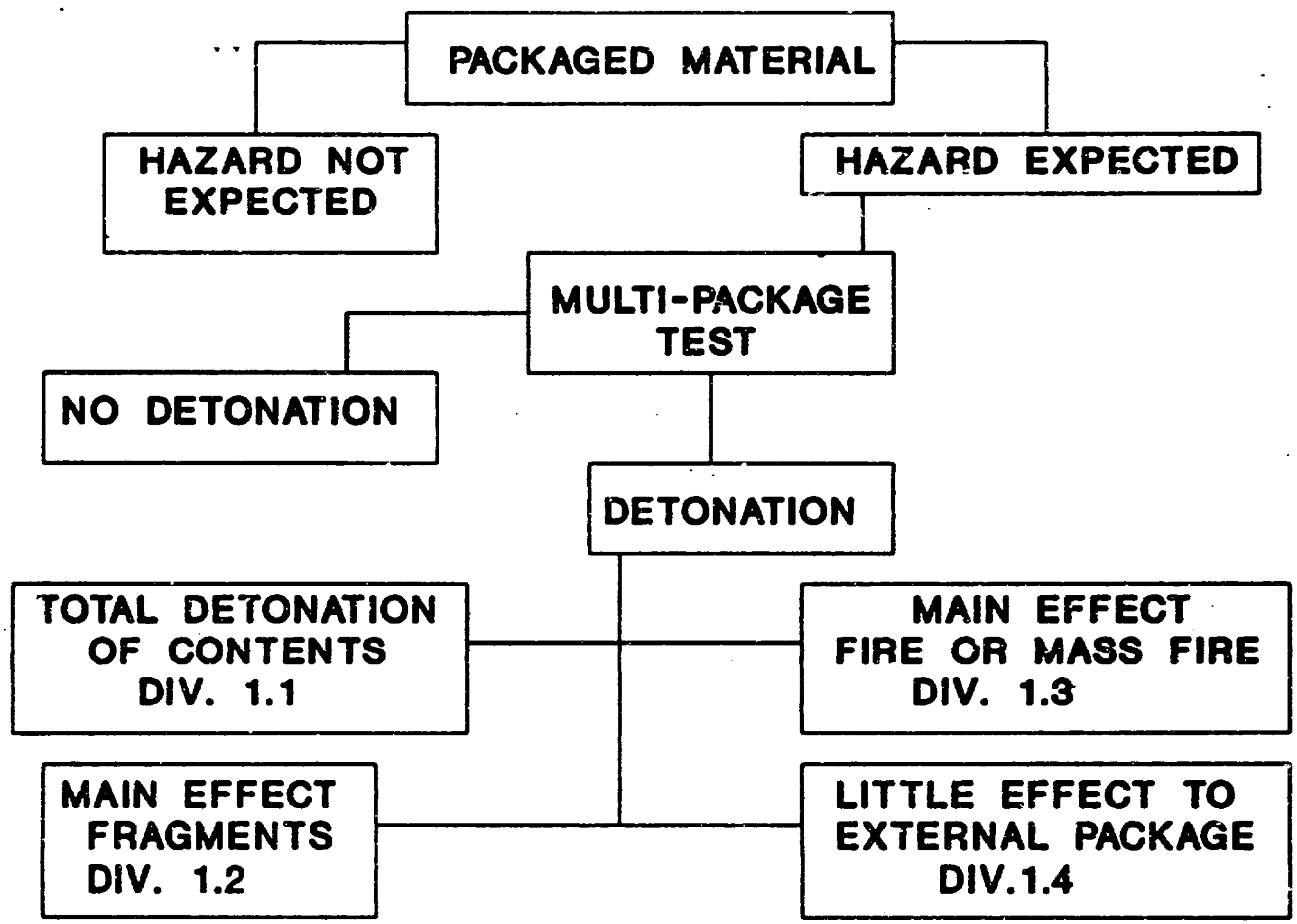
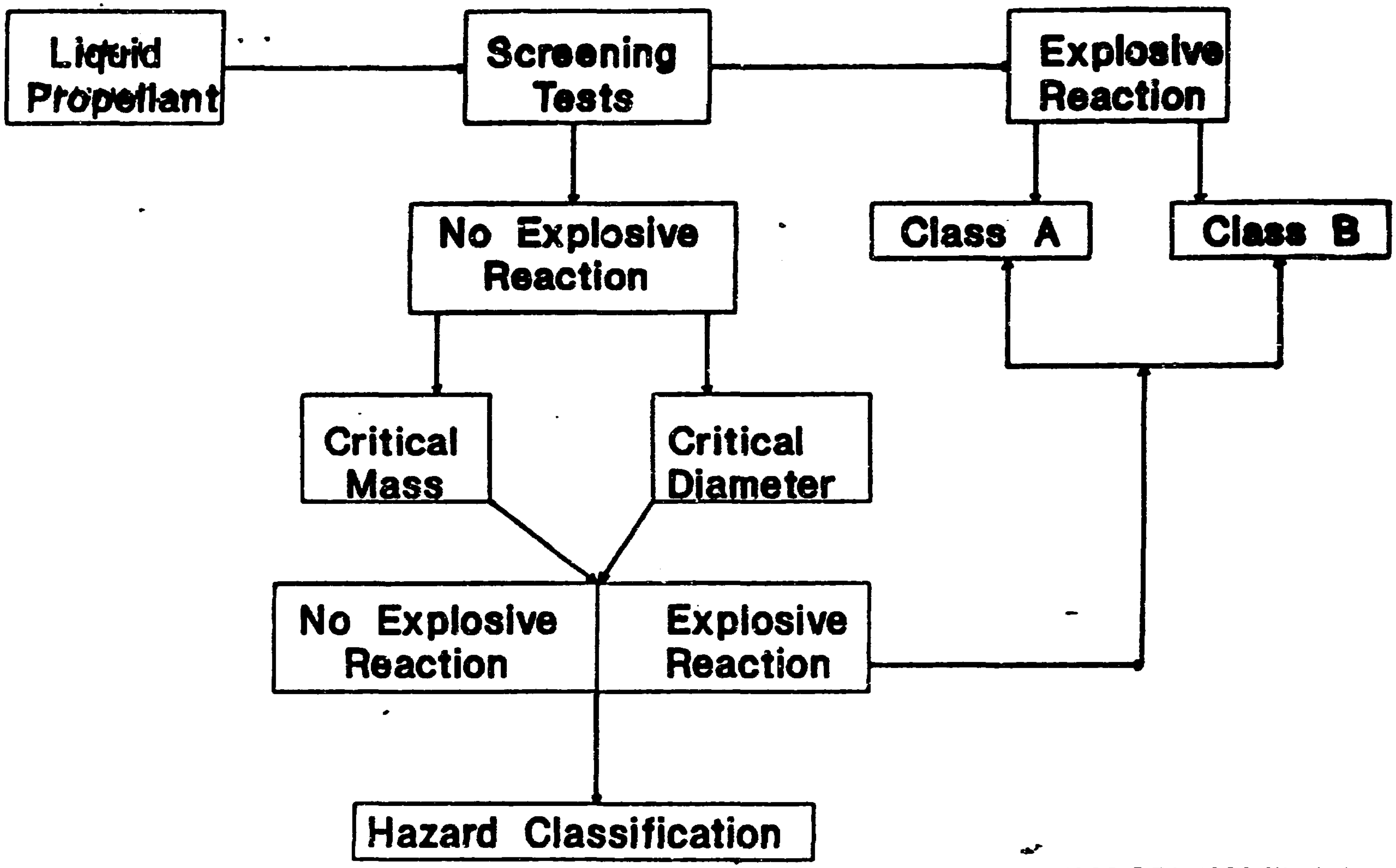


FIGURE 19

Hazard Classifioation Methodology



1988 DEA 1060 Workshop

ENCL. 5 PG. 2

FIGURE 20

No - Go Reaction Methodology

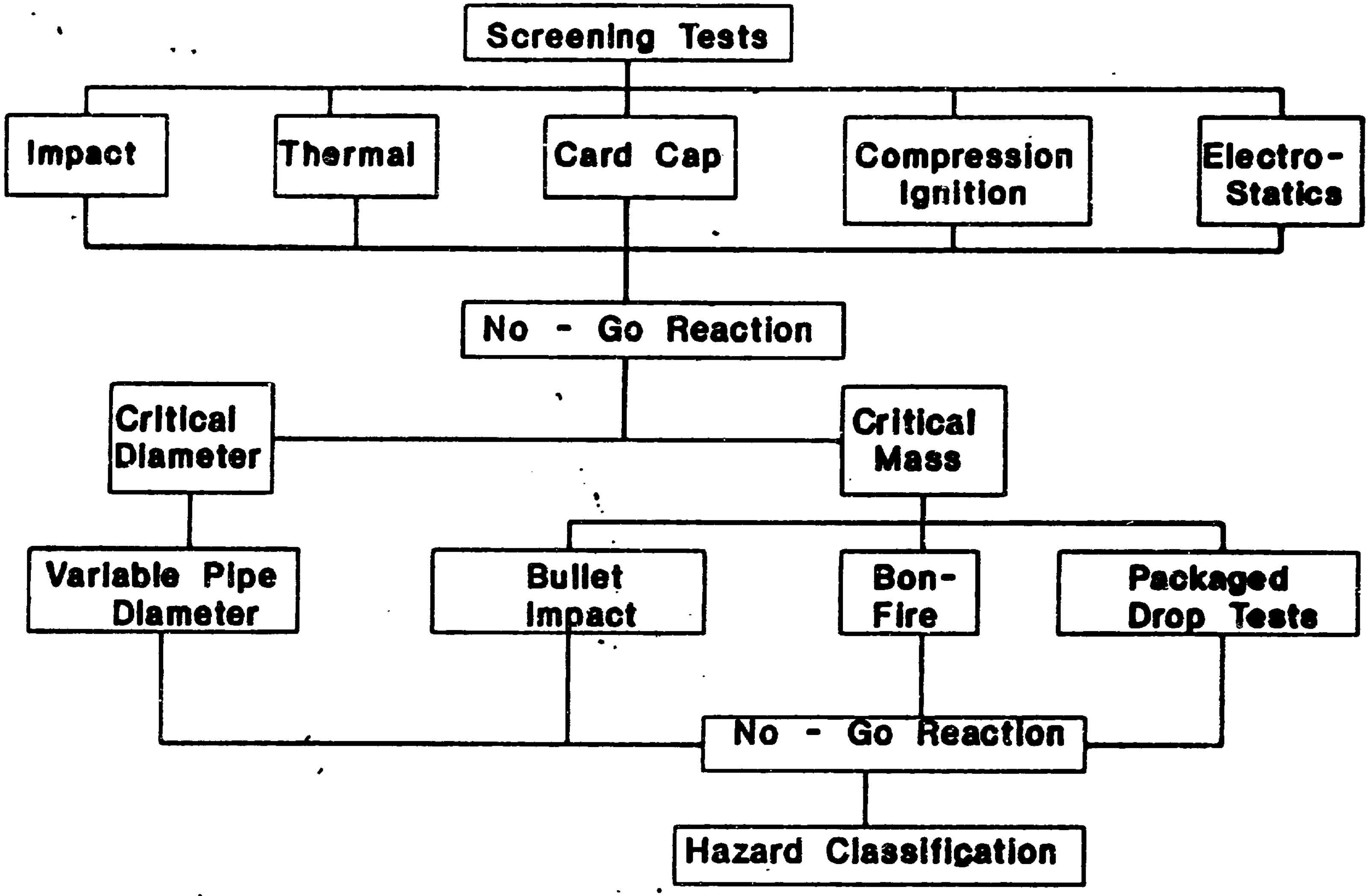


FIGURE 21

Explosive Reaction Methodology

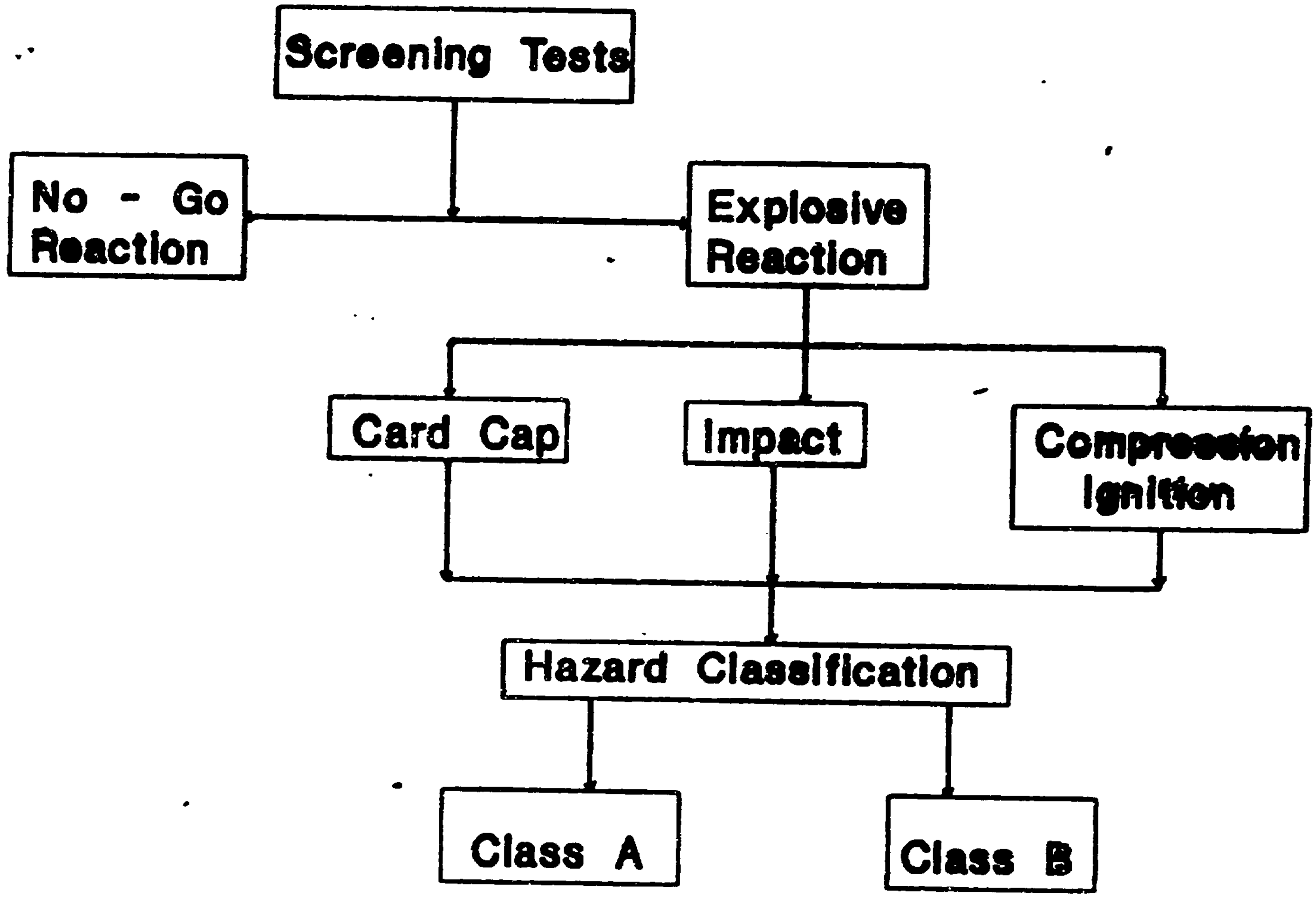


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FIGURE 22

TB 700-2 SOLID VS. LIQUID PROPELLANT TEST COMPARISON

Solid Propellant	Liquid Propellant
THERMAL STABILITY TEST REQUIREMENTS	
Constant temperature oven	Constant temperature oven
75°C for 48 hours	75°C for 48 hours
2-in. propellant cube	*8 cu in. of LGP in a 2-in. diameter polyethylene bottle*
CARD GAP TEST REQUIREMENTS	
Tubing 1-7/8 in. diameter, 5.5 in. long	Tubing 1-7/8 in. diameter, 5.5 in. long
Two pentolite pellets	Two pentolite pellets
Engineers blasting cap	Engineers blasting cap
Steel plate 6×6×3/8 in.	Steel plate 6×6×3/8 in.
Propellant sample machined or cast 1-7/8 in. diameter, 5.5 in. long	*Propellant in a 1.5-mil polyethylene liner 1-7/8 in. diameter, 5.5 in. long*

FIGURE 23

TB 700-2 SOLID VS. LIQUID PROPELLANT TEST COMPARISON

Solid Propellant	Liquid Propellant
DETONATION TEST REQUIREMENTS	
1.5-in. diameter lead cylinder	1.5-in. diameter lead cylinder
No. 8 blasting cap	*No. 8 blasting cap encased in 1.5-mil polyethylene film*
2-in. propellant cube	*8 cu in. of LGP in a 2-in. diameter polyethylene bottle*
IGNITION AND UNCONFINED BURNING TEST REQUIREMENTS	
Kerosene-soaked sawdust bed	Kerosene-soaked sawdust bed
Electric match igniter	Electric match igniter
2-in. propellant cube	*8 cu in. of LGP in a 2-in. diameter polyethylene bottle*

FIGURE 24

TB 700-2 SOLID VS. LIQUID PROPELLANT TEST COMPARISON

Solid Propellant	Liquid Propellant
IMPACT SENSITIVITY TEST REQUIREMENTS	
Bureau of Explosives tester	Bureau of Explosives tester
Sample placed in cup assembly	*Sample placed in stainless steel cup assembly modified to accept liquids*
Ten tests at 3-3/4 in. drop height	Ten tests at 3-3/4 in. drop height
Ten tests at 10 in. drop height	Ten tests at 10 in. drop height
CRITICAL DIAMETER TEST REQUIREMENTS	
Velocity probes	*Velocity probes*
Witness plate	*Stainless steel witness plate welded to tubing*
Pentolite explosive charge, 51 grams	C-4 explosive charge, 311 kJoules/in^2
E-99 detonator	E-99 detonator
Tubing, 1/8 to 1 in. OD	*Stainless steel tubing 2, 3, 4, and 5 in. OD with wall thickness of 0.0625 in. Welded assembly must be passivated with nitric acid prior to test*

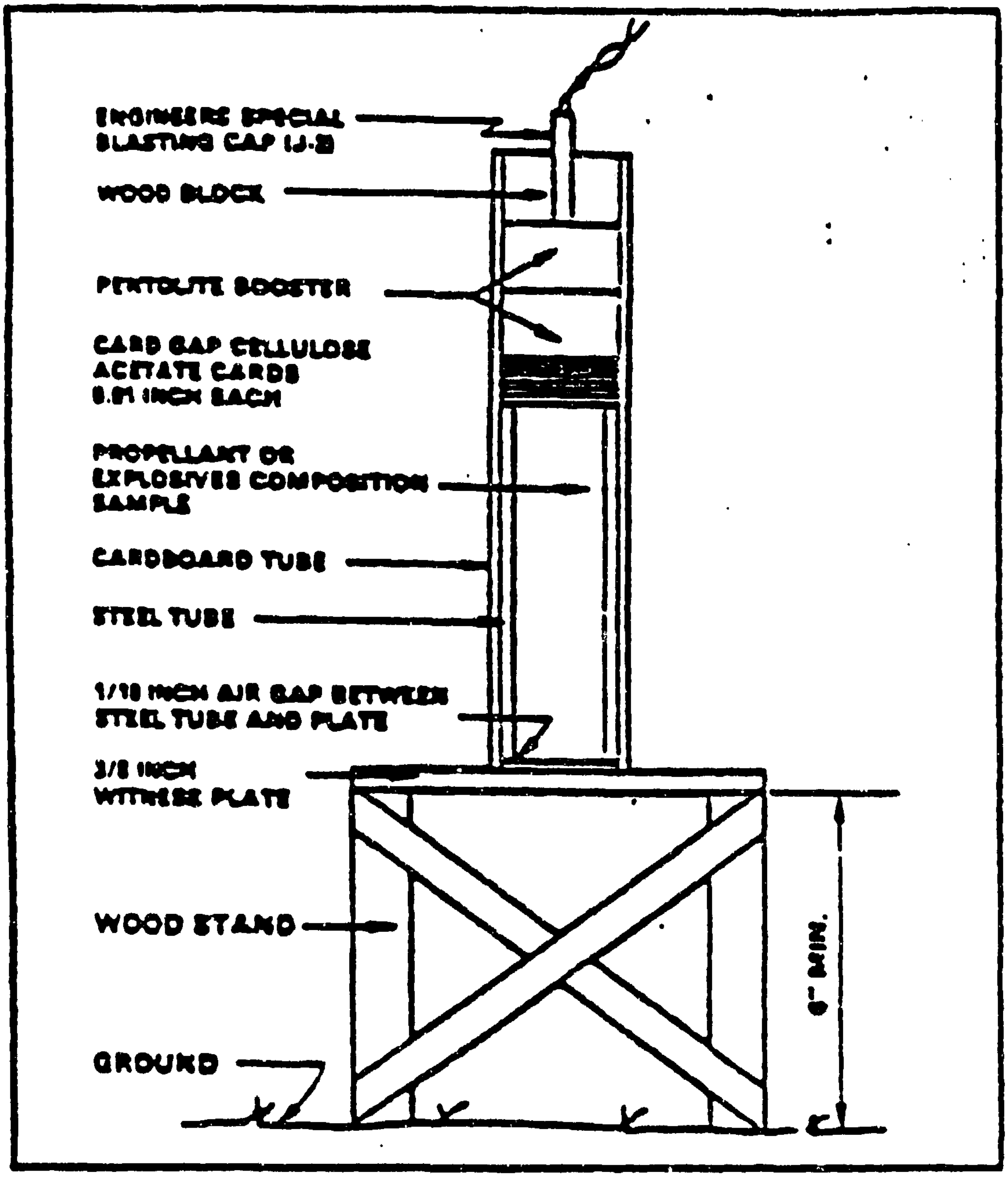
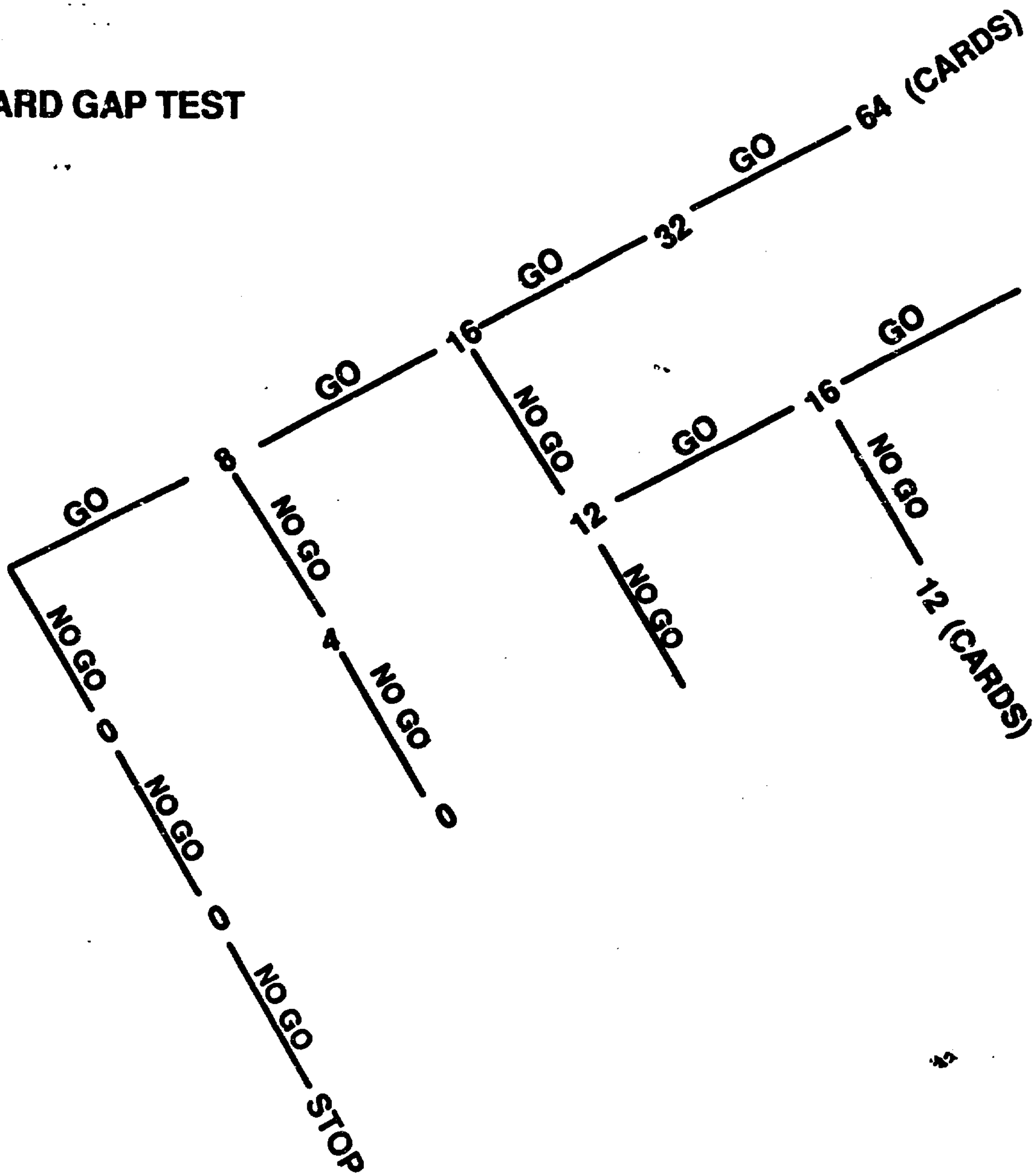


Figure 25. Card Cap Test Configuration

FIGURE 26

CARD GAP TEST



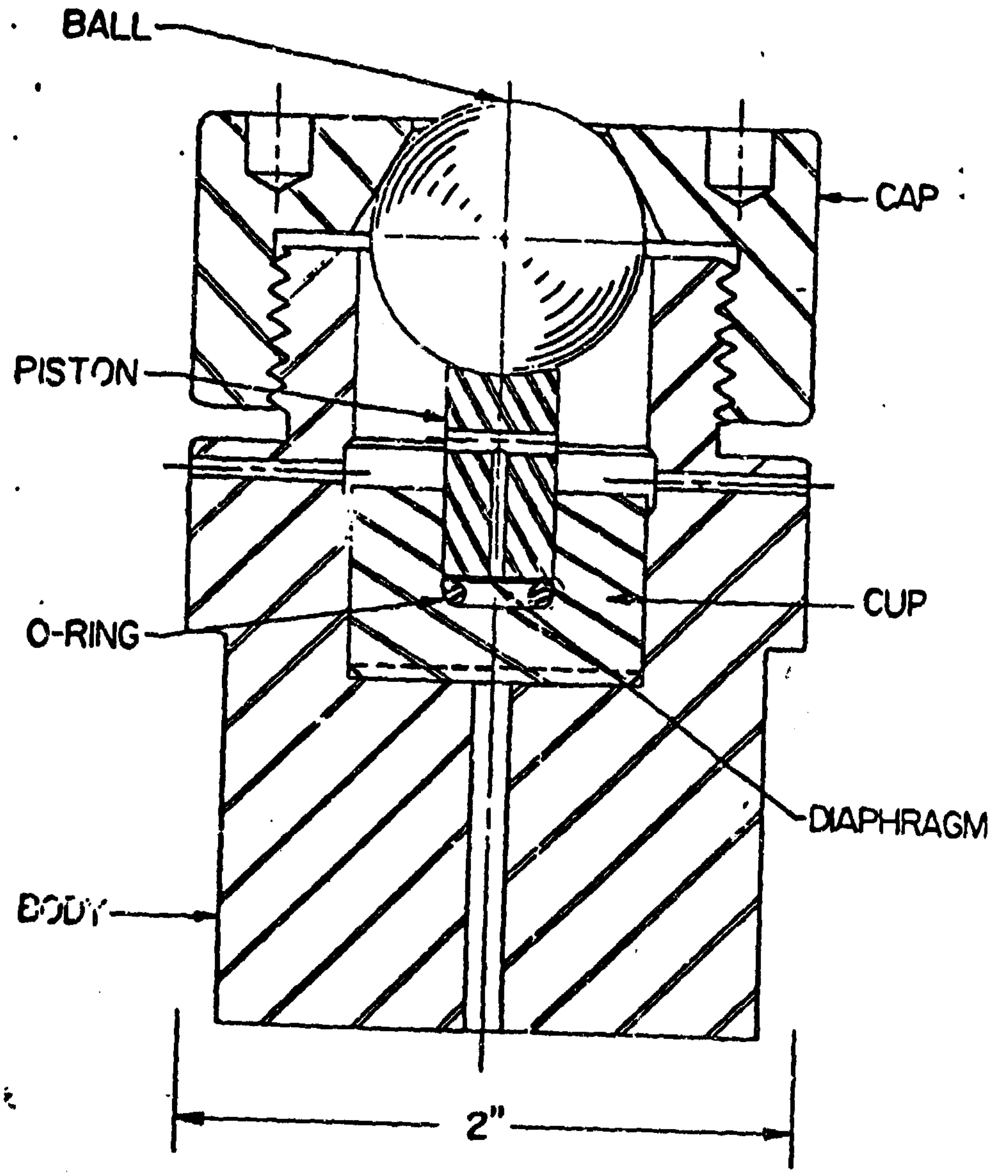


FIGURE 27 - SAMPLE CUP ASSEMBLY

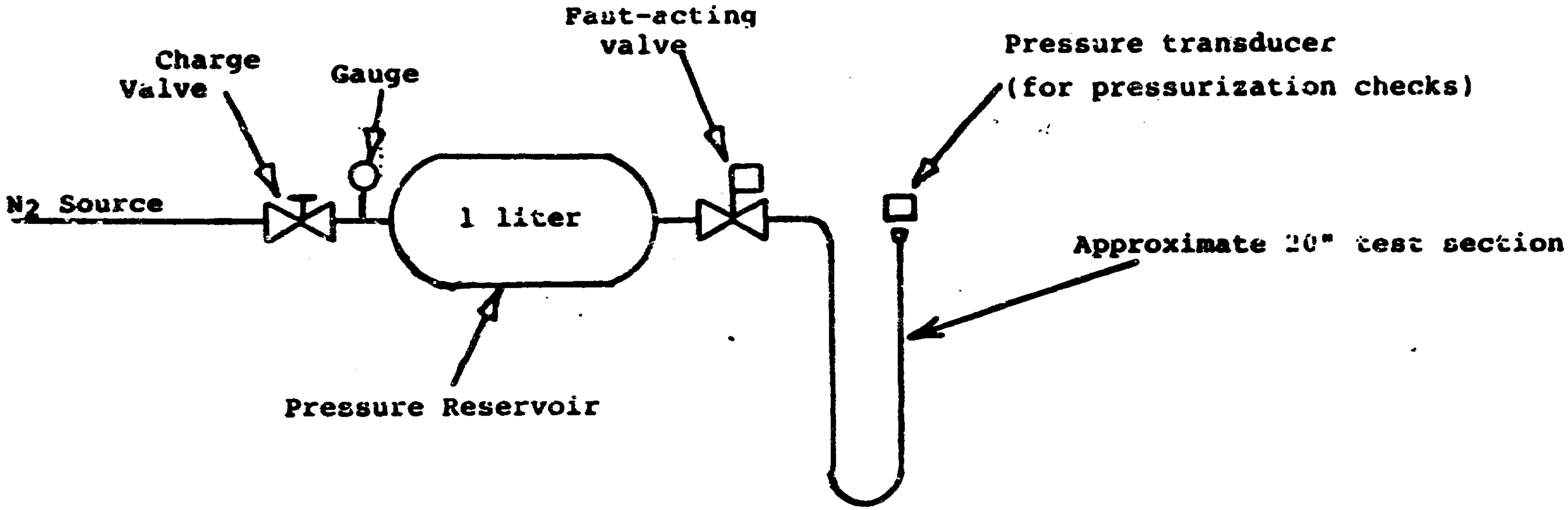
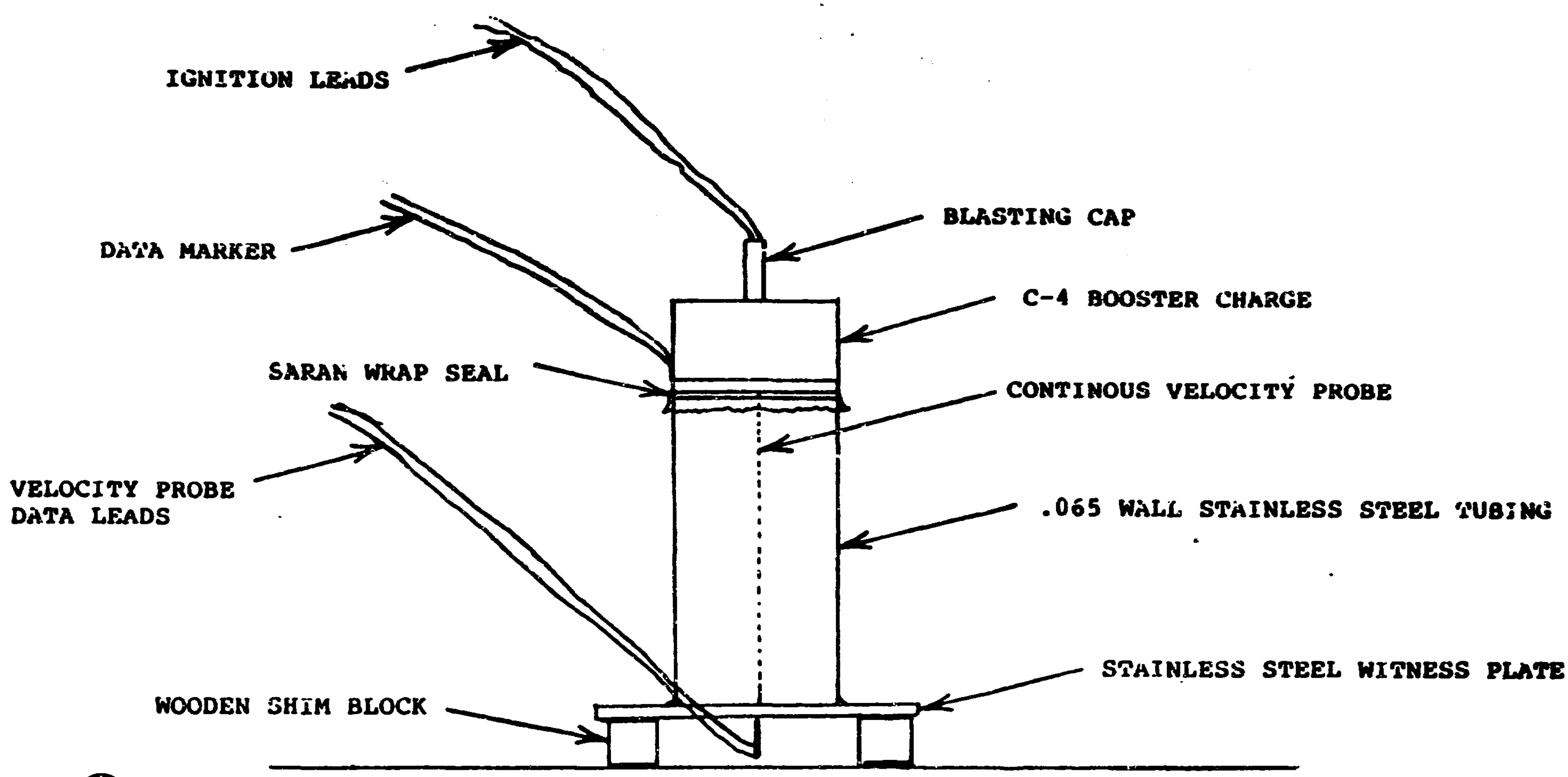

Charge
Valve
Gauge
Faut-acting
valve
Pressure transducer
(for pressurization checks)
N2 Source
1 liter
Approximate 20" test section
Pressure Reservoir

FIGURE 28

FIGURE 29

CRITICAL DIAMETER TEST SET-UP



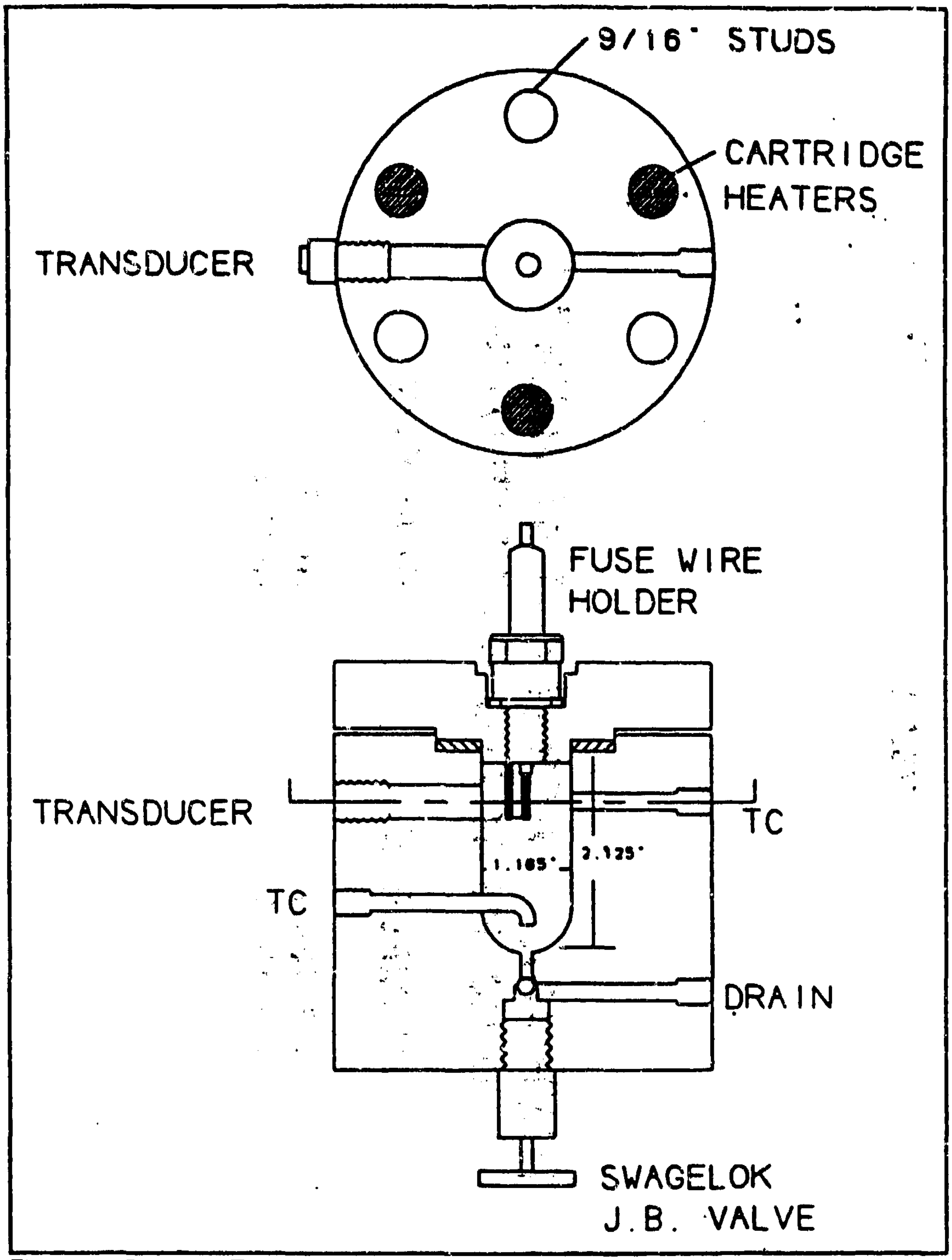


Figure 30 Pressure Test Vessel

TABLE 1

THERMAL STABILITY TEST RESULTS
48 HOURS AT 75°C IN VENTED OVEN

SAMPLE ID	REACTION
LP 1845	NONE
LP 1846	NONE

TABLE 2

CARD GAP DATA FOR LP 1845 AND LP 1846

SAMPLE IDENTIFICATION	NUMBER OF CARDS	VISUAL OBSERVATION
1. LP 1845	0	WITNESS PLATE DEFORMED NO HOLES IN PLATE
2. LP 1846	0	WITNESS PLATE DEFORMED NO HOLES IN PLATE

TABLE 3

IMPACT TEST DATA FOR LP 1845 AND LP 1846

SAMPLE ID	DROP HEIGHT (IN.) 0%	50%	100%
LP 1845	28	30	31
LP 1846	29	30.5	33

TABLE 4

DETONATION TEST RESULTS

SAMPLE ID	DETONATION REACTION
LP 1845	NONE
LP 1846	NONE

TABLE 5

IGNITION AND UNCONFINED BURNING TEST RESULTS

SAMPLE ID	DETONATION REACTION
LP 1845	NONE
LP 1846	NONE

TABLE 6

ABIABATIC COMPRESSION TEST RESULTS

SAMPLE ID	REACTION
CONTROL (WATER)	NONE
LP 1845	NONE
LP 1846	NONE
NITROMETHANE	DETONATION

TABLE 7

CRITICAL DIAMETER TEST DATA

SAMPLE IDENTIFICATION	BAFFLES*	DETONATION REACTION
1. LP 1845	NO	NO REACTION AT 3 INCHES REACTION AT 4 INCHES
2. LP 1846	NO	NO REACTION AT 4 INCHES REACTION AT 5 INCHES
3. LP 1845	YES	NO REACTION AT 3 INCHES REACTION AT 4 INCHES
4. LP 1846	YES	NO REACTION AT 4 INCHES REACTION AT 5 INCHES

* WHIFFLE BALL TYPE POLYETHYLENE SPHERES OCCUPYING APPROXIMATELY 12% OF THE CANISTER VOLUME.

TABLE 8

FLASH POINT
75°C (PROPANE FLAME)

SAMPLE ID	REACTION
LP 1845	NO REACTION
LP 1846	NO REACTION

TABLE 9

MINIMUM PRESSURE FOR VAPOR PHASE IGNITION

SAMPLE ID	REACTION
WATER (CONTROL)	NONE
LP 1845	NONE (MATERIAL DECOMPOSED)
LP 1846	NONE (MATERIAL DECOMPOSED)

TABLE 10

ELECTROSTATIC TEST RESULTS
1 MICROFARAD AND 12.5 JOULES AT 5 KV

SAMPLE ID	REACTION
LP 1845	NO REACTION
LP 1846	NO REACTION

PAPER ON
RECATEGORISATION TRIALS WITH
EXPLOSIVES AND AMMUNITIONS.

PRESENTED BY
SHRI S.K.SHIVLIHA,IOFS.
ADDL.GENERAL MANAGER
ORDNANCE FACTORY CHANDA
442 501
(INDIA)

SAFETY WITH EXPLOSIVES

The ammunitions and Explosives, although they constitute a major part of the military hardware and involve military personnel and are, in general,thought to be used and handed only by the soldiers in the warfield, they do, indeed, if viewed from a wider angle, involve quite a considerable percentage of the civilian population, whether directly or indirectly in so far as their process of manufacture, storage and transportations are concerned. They potentially pose a very high degree of risk to the process operatives, the Engineers, the people dwelling around the manufacturing units and also to the inhabitants in the surroundings of a storage area. During transportation over long distances innumerable people as well as country's valuable properties in various forms and publid utilities do get exposed to the severe hazards. Hence, there is an utter necessity for paying a judicious thought to the problem and an effective action needed in their management. The potency of the explosives has necessarily to be judged rightly and safety norms decided accordingly. Handling of ammunitions and explosives need involvement of as much high technology as it should involve an improved methodology. The Explosive industry is a growing one. The necessity of this industry, their progress and development cannot, in any way, be ruled out. Development of new explosive stores and their manufacture is an ever demanding affair. The purpose is not for any offensive action but is positively for the cause of defence. It is a guarantee towards the security of a country and her people. Considered in this perspective, safety with explosives is of paramount importance and it plays a titanic role in their handling thus making itself a subject of top interest and of human considerations. Scholars in the field, all over the Globe, have been showing keen interest in the subject, they have been putting their untiring efforts and conducting research works in formulating various safey norms and improving the standards of safety.

While much has been achieved in this direction, much more still remain to be done in this field.

Immediately after the IInd World War, there arise the necessity of holding large stocks of explosives in many countries. To do this tremendous task, efforts had been put up by experts to tackle the problem and achieve a desired level of safety. Based on available damage data, the devastating effects of explosions in the war and through conductance of planned and organised trials with large quantities of explosives, certain empirical formulae and desired safety standards in handling of explosives could be set up for the first time. These had in the subsequent years undergone several modifications in the hands of expertrs in the field after a careful study of the characteristics of different explosives stores. The explosivies were then grouped according to their hazardous behavious and characteristics for the purpose of storage and transportation and the norms thus set up were followeo by various countries. They were in vogue over a long interval of time until U N Experts felt the necessity of adopting a uniform policy and made an attempt to place them in proper system based on a scientific analysis.

The classifications of explosives thus brought out in the U.N system according to their hazard potential is considered to be a very progressive step and the norms adopted by many countries over the world. India has also adopted the same in a phased manner judging their merit over the old model of explosive groupings. Even though UN classification system of explosives and ammunitions presents store-wise distinct H.D and compatibility group label, Indian experts felt the necessity of conduting certain re-categorisation trials with various ammunition in order to find as to whether these can be placed further to lower hazard divisions, without ofcourse any compromise to safety. The purpose was mainly to accommodate more explosives stores in the storages and also in the process buildings and to find out substitute materials for packing and ascertaining correct H.D with these. Extensive work has been done in this specialised wing and several trials on recategorisation conducted in India with various types of ammn. and explosive components based principally on the procedures and norms prescribed in the literature published by the UN experts. Described below, in a nutshell, are a few illustrative cases. However, prior to elaboration of the cases, it is considered worth to have a glimpse on the advantages which also led to the thought for such a venture. The advantages are:-=

1) Direct verification of the already established H.D i.e. study of en-masse explositions or a sporadic explosion which may taken place with a particular type of ammn when held in considerable Qty. at one place or put in modified packages or otherwise.

2) Piece-meal study of the behaviour and characteristics of an ammunition in its nacked stage, in the containered stage and also in the stage of this being in finally packed conditions.

3) Observation of effects of explosions or damage caused to the distance from its explosion site, i.e a test of its potention or power of damaging or lethality due its known and calculated explosive content which add to direct knowledge owing to such a deliberate study/observation which otherwise is not possible in any accidental explosion.

4) A further verification of the Quantity distance criteria and fixation of revised explosive limit of an explosive building based on new data/observation of recategorisation trial designing of racks and stacks for different types of stores based on extent of detonation effects as observed in such trials.

5) Design improvement of packages, selection of new materials as packing substitutes and thereby improvement in value engineering and achieving economy in parallel with safety.

6) Understanding and predicting approximate HD of ammn.of similar type and the developmental stores.

7) Be-holding it as a media of learning through observation of the effects and influencing people for the necessity of adoption of safety norms through observation of these effects and discussions thereon.

8) Assessment of fire hazard character of the store and determi8nation of circle dia of such fire hazards due to flying of hot fragments from the site of explosion.

9) Determination of escape time for the operatives in an explosive building incase of an eventuality.

10) Incase of categorisation to lower H.D, advantages are had for fie fighting in regard to approach to the scene and availability of enhanced time at the disposal of fire fighting personnel, since the risk decreases with the increse in the numerial value of the H.D.

11) Re-categorisation to a lower H.D reduces the risk to the surroundings whether in storage or during transportation.

However, reverting to our earlier discussions, let the account of a few re-categorisation trials, so conducted keeping the above in view be placed here. It is once again reiterated that the object of such trial is to minimise the risk and to find out the guidelines as the solution to our problems.

TRIAL I.

1.	Propellent:	NGB 0[illegible]1 NGB 011	Double based flake propellents.
		NGB 688	Single based powder propellent.

The above propellants were under H.D 1.1

2. PACKING - These are first bagged in cambric cotton bags(15 Kgs. each) one such bag is placed inside a metallic C 27A container and finally two C 27A containers

are packed in one C 26 A wooden rectangular package. Thus each C 26 A package contains 30.00 Kgs. of the propellant material.

3. PROCEDURE.

A) SINGLE PACKAGE TEST:-

The card board cotton)vol.apx. 0.15 m3) was placed over a 3 mm thick M.S plate on the ground. The cotton was completely filled with th propellant. It contained a qty.of 135.00 Kgs. in case of all three propellants. A thin polythene tube containing 30.000 g of G 12 was placed in the mid-depth of the propellant. Fuze No. 11 (Length 2000mm) was inserted in the gun powder. The propellant container was tamped all around with sand filled bags to give a 500 mm thick confinement in all directions. The fuze was lit using a safety match.

OBSERVATIONS:

No detonation. Material burnt off with a mild bang and in other two cases without any bang.

B. STACK TEST.

Five Nos.of C 26 A packages containing propellants were arranged over the witness plates. One package at bottom was opened and in one of the C 27A containers inside this package, a polythene tube containing 30.00 gm of Gun powder and fitted with safety fuze 11 (2000 mm) was placed in the propellant material. This container and package was closed in the normal manner. All the packages were tamped with sand bags to give a confinement of around 1000 mm thick. Ignition was then initiated.

OBSERVATIONS:-

Burning with hissing sound and bright flames.

C) BON FIRE TEST:-

An iron grill was placed in four holes dug on a pre-selected site, with a clear space of about 750 mm available above the ground level. Three aluminium screens were placed in three different directions at distance of 4 mts. from the respective corners of the iron grills. These screens were erected at a height of about 700 mm above the ground level and the open space between two screens was kept from 3 to 3.5 metres. The 4th side was kept wide open.

Propellants packed in 10 Nos. of C26A packages (300.00 Kg in total) were placed on the Iron Grill in twor rows. Adequate quantity of fire wod was placed below the grill and all around the packages. Kerosene was sprinkled profusely on the fire wood. The fire wood was ignited usigng about 5.00 Kg of wastepropellant and safety Fuze No. 11 (4500 mm length).

OBSERVATION:

Propellant (360.00 Kgs) in 12 Nos.of C 26 A packages burnt off with very brilliant flames, with occasional hissing sound. No efect observed on Alu. screens. There was no detonation.

4. CONCLUSION.

Categorised as U.N.H.D 1.3 since all norms confirm to stipulations of U.N. H.D 1.3.

TRIAL II.

1. Hazard classification of fuze B 429 packed in wooden Box F1A.

2.PACKING;-

Fuze B 429 with exploder, assembled with adapter is packed in plastic container 59 A and 12 such containers are housed in wooden box F1A.

Fuzes containing exploder pellets are generally classified under H.D 1.1. Considering that the exploder pellet is housed in a metal adapter and mode of packing of fuze, it was felt that the fuze assembled with adopter may behave as hazard division 1.2 explosives. It was, however, necessary to confirm the correct hazard division by carrying out categorisation trials. Categorisation trials were carried out to ascertain the correct category of fuze B 429 assembledwith adopter containing exploder pellet.

1

3.PROCEDURE.

BOX TRIAL:-

The box containing 12 fuzes were placed in a pit dug in the ground. It was tamped with sand to provide thick barrier all around.

To facilitate initiation of the fuze in the centre, the exploder pellet in the adopter was removed. The closed end of the adopter was cut and a through hole was made in the adopter. The adopter was reassembled with fuze and CE pellet (about 10 gm) was inserted through this hole in the adopter. The above CE pellet, by using a small qty.of PEK 1, was connected with a double lead of prima cord. The free end of the prima cord was detonated using CE primer, safety fuze and detonator No.27. The trial was repeated three times.

OBSERVATION:-

The fuze initiated, detonated completely. The remaining fuzes were intact and were found scattered within a radius 10 m from the site of trial in all the above three cases

4.CONCLUSION:-

Since en-masse explosion did not occur in any of the successive box trials, it can be concluded that Fuze B 429 assembled with adopter containing exploder pellet, when packed in plastic container 59 A and 12 such containers housed in wooden box F1A, does not carry en-masse explosion risk.

Fuze B 429 assembled with adopter containing exploder pellet, when paçked in plastic container 59A and 12 such containers housed in wooden box F1A, is assigned hazard division 1.2.

TRIAL III.

1. Verification of the design of wooden racks for storages of unfuzed 81 mm HE mortor bombs in inter-stage storage buildings.

2. OBJECTIVE.

By providing adequate spacing (air gap) between HE filled shells the chances of sympathetic detonation can be avoided and unit risk principle can be applied to cater foor increased explosive holdings in buildings. This spacing can be further reduced by providing suitable partition of wood or metal between the shells. The spacing can be calculated from the following formulae reported in the literature:

S = 14.3 C2 W - 3/2

where S is spacing in cm.

C is the weight of HE filling in g

and W is the weight of filled shell in g

For HE filled shells, C = 0.7 Kg and W = 4.2 Kgs, value of S works out to 17.8 cm. From the literature,it is noted that a large No.of trials using 105 mm HE shells have been carried out in UK and it has been found that 10.8 cm air gap is equivalent to 1 .25 cm thick plywood partition between the shells. By providing extra margin fo safety wooden racks were fabricated with the following design features:

Spacing between the bombs + 9.5 cm

Thickness of wooden partition = 2.5 cm

Wooden racks to the above design have been provided for storage of 81 mm HE filled shells in inter-stage storage buildings, awaiting X ray examination results. With the above arrangements, it is considered that chances of sympathetic detonation from round to round are not likely/.

PROCEDURE.

(A) RACK TRIAL.

Wooden rack along with five bombs, was placed in a pit dug in the ground. It was tamped from all sides with sand bags to provide a thick barrier. All the rounds were facing in one direction and were without fuze and tail unit simulating the storage conditions in the inter-stage storage buildings.

To facilitate the initiation of the round at the centre of the rack, a CE pellet was inserted in the fuze housing. The CE pellet by using a little qty of PEK 1, was connected with the double lead of prima cord. The free end o the prima cord was detonated using GC primer, detonator No.27 and safety fuze. The trial was repeated three times.

OBSERVATIONS

The round initiated detonated completely. The remaining four rounds were found within a distance of 5 to 10 m from the site and these were not detonated. One of the rounds in one trial out of the three broke in two pieces from the middle with explosive filling intact.

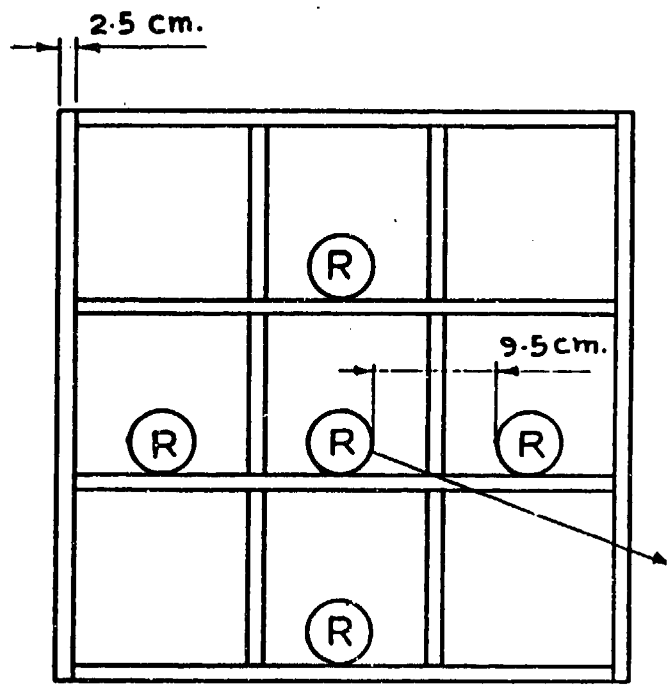
B. GAP TEST.

For the sake of data collection, a gap test was also carried out by keeping the two 81 mm HE Mortar bombs with fuze and tail unit assembly side by side. Axes of both the rounds were parallel to each other. They were ket 9 cm apart as shown in sketch II. One of the round was detonated to see the effect on the other. This trial was carried out only once. After detonation the second round was found within the pit with fuze intact.

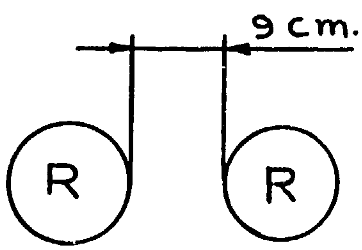
4.CONCLUSION

From the trial results, it was concluded that no explosion will be communicated to adjacent 81 mm bombs when stored in specially designed woodn racks as has been involved in this trial.

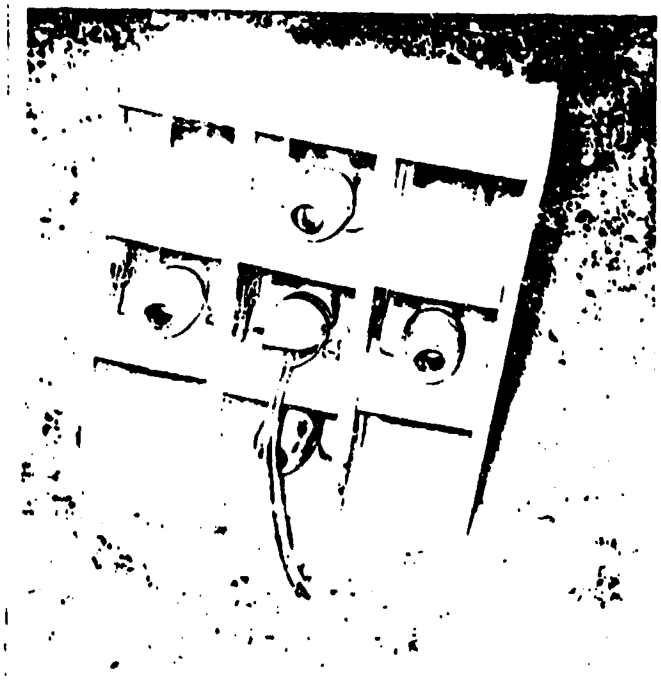
HE filled 81 mm Mortar Bombs, without fu? tail unit assembly can be stored in wooden racks of 2.5 cm thick wood and spacing of 9.5 cn round to round and there is no likelyhoo sympathetic detonation between the rounds ir arrangements.



SKETCH - I
RACK TRIAL



SKETCH - II
GAP TEST



Arrangement of Bomb 81 mm HE in a wooden rack with double lead of cordtex connected to CE Pellet for initiation of the central round.

HIGH EXPLOSIVE WASTES RECENT EXPERIENCES IN AUSTRALIA AND AVOIDANCE TECHNIQUES IN A NEW FACILITY

by

John Maher
Manager Chemical and Explosives Projects
Australian Defence Industries Ltd
Canberra, Australia

ABSTRACT

Australian Defence Industries Ltd (ADI) is managing the closure of a high explosive and propellant manufacturing facility in suburban Melbourne. The site is to be made available for housing, recreation and commercial purposes. A number of issues have arisen in relation to soil decontamination in an environment of changing Government and public perceptions.

In reconstructing the explosives and propellant processes at a new site in rural Mulwala in New South Wales, which is located in a sensitive water supply area, new approaches have been taken to address waste problems.

Introduction

ADI Ltd

The Australian ammunition and explosives industry has undergone significant change and restructuring in the past 18 months.

On 3 May 1989 the Government created a new Government owned Company to run the defence factories and dockyard previously part of the Department of Defence. This company, Australian Defence Industries Ltd, is now Australia's largest defence equipment manufacturing and services company, employing around 6000 people.

Its products and services include:

- Naval Engineering
- Electronics
- Weapons
- Ammunition
- Training Systems
- Clothing

ADI facilities are geographically widespread, including a regional office in Malaysia.

Prior to the creation of ADI, restructuring of Australia's munitions industry had commenced with the closure of the high explosives manufacturing capability at Albion Explosives Factory in Melbourne Victoria and the announced closure of one of the oldest explosives establishments, Explosives Factory Maribyrnong - to occur in a year or two.

The high explosives capability is being transferred to an existing propellant manufacturing facility at Mulwala NSW.

ADI's retains the management of the closure of both establishments.

For many of you the closure of such establishments, and the legacy as a result, is no novelty. For us, however, this has been a significant event and has raised some particular problems which may be of interest and wider relevance.

In this paper, I will describe issues which have arisen in relation to decontamination, the attitudes of Government and public perceptions towards this process for the Albion Explosives Factory closure, and then outline our approach to avoiding future environmental problems in the relocation of this capability at Mulwala, NSW, a site of significant environmental sensitivity (located on the river Murray, the largest river in Australia and a crucial source of water for many purposes).

The Closure of Albion Explosives Factory

Profile of Albion is as follows:

Site:
- 20 kilometres West of Melbourne
- now surrounded by residential properties
- about 500 hectares (1250 acres): 2km x 2.3km
- adjacent creeks (can affect 4 rivers which pass through heavily populated areas)
- 349 buildings at time of closing
- safeguarding problems (purple line incursions)

History of the establishment:

1939	Constructed by ICIANZ
1940	Manufacture TNT, NG, Cordite, chemicals
1948	Care and Maintenance
1954	Reopened (RDX plant added)
1957	Solvent less double base propellant plant added
1971	Continuous TNT plant installed
1975	A major effluent plant was constructed
1986	Closed

Capabilities:

The following products were being made at the time of closing:

High Explosives - TNT, RDX, Comp B, RDX/WAX, Plastic Explosive
2, 4 Dinitrotoluene
Nitrogylcerine
Gun, rocket propellants
Nitric, Sulphuric acid concentration and processing

Environmental

Aspects of environmental significance at Albion were:

- Major effluent plant not constructed until 1975 (lime slurry neutralisation plant)
- Concrete settling tanks, labyrinths (cracking problems)
- Earthenware drains (clay soil problems)
- Acidic effluents neutralised in old pits using limestone with discharge to creek systems
- Breaches of effluent discharge levels to sewer when sewer pipes failed
  - red water to sewer during the war; and to adjacent paddocks
  - red water spillages

- Asbestos burial
- Waste disposal (open ground burning), plant decontamination.

Once the traumas of the closure were overcome the key staff retained proceeded to carry out an orderly closedown. Using the knowledge of current and past members of the workforce areas of possible contamination were generally identified. A formal study of the Site was initiated and soil sampling began. The limits of allowable contamination in the soil after reclamation were sought from the Environmental Protection Agency (EPA).

The Government appointed a Steering Committee made up of community, municipal, State and Federal officers. A concept plan for Albion was developed and included proposals for:

- residential housing
- recreation land
- light industrial
- a possible lake and golf course

Unfortunately the political process does not work so smoothly and a sequence of events occurred which has created particular difficulties, as yet unresolved:

a. Government Housing summit: needing an electoral boost the Federal Government called a housing summit - land was needed - Albion was the 'jewel in the crown' of the Victorian parcel of Federal land to be offered up.

b. Community, Municipal and State Government hopes were further heightened.

c. An environmental issue concerning residential land heavily polluted with lead (old battery factory site) hit the airwaves. This site was very close to Albion. Other similar contaminated sites were identified (some in prime city areas)

d. Community, union, government pressures developed - some 50 contaminated sites were officially identified in Victoria by the EPA (all non Defence related)

e. This resulted in a focus on Albion and clamour for "total freedom from contamination". The attitude is typified in a quotation from a Union Spokesman (reference 7).

"... the union will only accept a level of contamination that will not present any increased risk to the future occupants of the site. They want the whole site cleared and not just the selected areas of contamination".

f. The EPA retreated to its bunker and we still await a statement of what the levels of contamination should be - zero?

Contamination levels

The results of the contamination study have indicated that the residual contamination was (as expected) localised and in general in relatively low levels. Based on 34.5 hectares surveyed of the 500 hectares and from 1000 excavations to at least 1 metre depth, only 1% (5 hectares) of the total area could be considered contaminated.

The levels and concentration varies from site to site and the bulk of contamination lies primarily in the south west **near the high explosives areas.** The contamination is however very scattered across the site but each site can be identified. The contaminants are primarily organics associated with high explosives manufacture. Of the total volume of soil covered by the survey about one sixth was found to be contaminated. The distribution of the contaminants is as follows:

Contaminant	% of the volume of the soil which contains these contaminants
Nitroaromatics (TNT, 2,4 DNT, 2,6 DNT)	40%
Heavy metals	20%
RDX	15%
Acids, Sulphates	20%
Mixtures	5%

Over 90% of the material contains from two to three times the recommended acceptance criteria (in the low parts per million range). The remainder contains up to several hundred times the recommended acceptance criteria (hundred to thousands ppm). These recommended criteria are levels we have evolved ourselves using risk assessment and available medical evidence. We have had a lot of difficulty in determining what limits are applied internationally.

Fortunately the soil is heavy basaltic clay with fractured basalt seams and the contaminants have been securely held. Bedrock is at about 3 metres and contamination is distributed down to this level. Groundwater contamination is also probable but the degree has not yet been quantified.

Hence we have a situation where there are localised levels of low contamination with occasional "hot spots" of relatively heavy contaminants.

As a consequence of all these factors, we now face a dilemma:

- Relatively low levels of contamination
- Difficulties in obtaining technologies to reduce low levels to even lower levels (current technology appears to address removal of gross levels)
- A tradeoff between cost of decontamination and the revenue expected for the land
- Community anxieties and fading aspirations.

We believe we will need a multiple treatment type approach. We are still exploring options such as thermal techniques, composting and biodegradation. Our options will be driven by the limits set by the EPA. We are confident that solutions can be found which are able to be operated successfully. Because of the high political interest, cost is becoming a lesser consideration to the achievement of a total clean up. The question is however, what does "clean" mean. We are working very closely with the EPA to obtain a resolution of these matters.

New High Explosives, propellant capability Mulwala NSW

In the second part of my paper I wish to outline the approaches we have taken in reconstructing this capability to avoid a future legacy of contamination for our successors. In line with the theme of this paper I will be focussing primarily on liquid effluent issues. I should point out that the processes described below are not to be run for extended periods, ie production will be staged using short runs.

The Site

The site of the existing Mulwala Explosives Factory was chosen for the new high explosive capability. This facility is located on the border in New South Wales and is about 1 kilometre north of the Murray River. The land is relatively flat, sandy agricultural land.

The Facility is located in a sensitive water environment. The Murray river, the largest in Australia flows halfway across the continent to South Australia and provides a vital agricultural lifeline. The salinity of the water is an ongoing and very significant national problem. At Mulwala the river has been dammed to form Lake Mulwala and two main irrigation supply channels are drawn from this to service NSW and Victoria. Continuous water quality monitoring is carried out downstream of the lake and is of a high quality. Also adjacent to the river are a number of billabongs or ponds.

The soil is an alluvial sequence of sands, gravels and clays down to 100M. Underground leakage from the Mulwala canal occurs and liquid contaminants could pass through the clayed upper zone to the water table.

Mulwala Facility's Products and Capabilities (present and planned).

Current products:

- extruded double base and single base propellants for small arms ammunition and medium calibre ammunition
- rocket propellants and casting powders
- nitrocellulose
- nitric acid
- nitroglycerine
- ether

The new capabilities now under construction (and scheduled to be completed in 2 years) are:

- TNT - we will be re-installing basically the same process used at Albion employing continuous multi stage counter current flow for the trinitration of toluene.

- RDX - again we are reinstalling the existing continuous Woolwich process to produce RDX by the nitrolysis of hexamine using 98% nitric acid and purification by recrystallisation from cyclohexanone.

- Propellants - new gun propellant facilities employing screw mixer extruder technology.

- Ancillaries - laboratory, bulk toluene storage, burning ground, acid concentration.

- Control system - one of the most significant changes has been the incorporation of a Distributed Control system to remotely monitor and control the RDX and TNT processes. This will ensure operator health and safety, improved product quality and increased safety. Needless to say, a well run process is basic to controlling environmental problems.

Addressing Environmental Issues

Basic principle

The basic principle is one of total containment of primary liquid effluents.

The existing factory does currently discharge process waters from the acid concentration plant to the river and we are developing ways to deal with this. I will enlarge on this later.

In broad terms containment will be achieved by:

a. Dedicated on site effluent treatment. The TNT and RDX plants will have an effluent treatment plant integrated with the process. I will discuss this below.

b. Above ground piping has been used extensively to allow ease of maintenance and inspection.

c. In the process buildings we have used open, accessible drains to catch any spillages or washings. Considerable effort has been expended in designing the floors so that wash waters are contained. We have used impervious concrete structures with particular attention to joints and taken care to reduce the likelihood of cracks. All open drains have continuous stainless steel liners.

d. Carbon columns are an integral part of the process effluent systems.

e. Some specialised processes have been incorporated to deal with or reduce effluent levels in the TNT process. We will employ a proprietary process for acid waste treatment (organic and nitrobody removal) and we have an incinerator process to deal with red water.

f. No formal system of stormwater collection is proposed for the new area. The potential for discharge from the area of contaminated stormwater will be minimised by:

- use of drains in the paving around process buildings which will drain to the effluent treatment system.
- bunding of tankage areas and tanker docks.
- bunding of manufacturing, handling and packaging areas. Such areas will be roofed.
- special procedures to deal with spills in unbunded areas. (Given the long distances to the boundary and the permeable nature of the soils, we consider the possibility of spilled liquids reaching surface waters to be negligible.)
- wastewater recirculation is a feature of the RDX plant and has been maximised in re-installing the process.
- final effluents from the two processes will be collected in evaporation ponds which have been designed with sufficient storage capacity. Evaporation is well in excess of rainwater on an annual basis. I will describe these ponds in greater detail later.

Process Effluents

These proposals can be illustrated by examining the main processes in turn:

a. TNT Process Effluents

Main effluents from this process are:

- red water, from the sulphiting purification process
- pink water, from general wash water and other sources
- fume scrubber waste.
- nitrous compounds and organics in the waste acid stream

The red water will be disposed of by complete incineration in a gas fired rotary hearth furnace which was developed at Albion. Ash arisings (95% sodium sulphate, the rest carbon) are accepted for land fill.

The pink water, ie the washings collected in drains and fume scrubber wastes are collected in a brick lined pit, neutralised (sodium sulphite), passed through an activated carbon column and the residual stream sent to the large TNT effluent evaporation pond.

Waste Acid Stream - the waste acid stream from the nitration process carries over nitro-organic contaminants and if we had retained our existing process to reconcentrate the weak sulphuric acid, we would have to deal with a contaminated effluent. Again, we considered incineration of the effluents, but a neater solution has been effected by purchase of a proprietary chemical extraction process from Italy for waste acid purification.

b. RDX Process Effluents

In relocating the plant we have attempted to maximise recirculation of the process water to minimise liquid effluents. Previously there was no recirculation.

Process waters will be neutralised and passed through carbon absorption columns and then returned to a storage water tank. Water from this tank will then be deployed back to the process, for cooling and wash down. Any overflow from this tank will flow to the evaporation pond and any drainage will again be captured in open building drains and also eventually pass to the evaporation pond. Cyclohexanone residues will be burnt.

c. Acid Concentration Plant Effluents
Propellant Complex Effluents

I mentioned our goal of total containment of liquid wastes. We still have one remaining problem to address as a result of the processes of the existing facility. This relates to the effluents from the acid concentration plants and the nitroglycerine plant already in operation. These effluents could also be marginally increased as a result of our new capabilities. We plan, for example, to truck effluents from the propellant process (mostly water slightly contaminated with nitroglycerine to the existing NG effluent treatment plant.) This treatment, ie neutralisation using sodium hydroxide, results in an effluent with a range of salts viz nitrates, nitrites, acetates and formate. This effluent currently goes to the river. To eliminate this we are looking at a novel solution. By the time the new capability is in place we aim to have resolved this problem.

Irrigated Forest Plantation

The option we are exploring is the use of tree plantings to deal with this effluent. One of the first projects to investigate waste water renovation by irrigating forest land was at Pennsylvania State University in 1963. A significant body of work has been done in the last decade in Australia mainly in the areas adjacent the River Murray.

The "green revolution" is of course giving a boost and encouragement to the exploration of such methods.

We are still at the feasibility study stage and we have not yet subjected this technique to rigourous analysis. A preliminary strategy plan (reference 4) has indicated there is potential for the system.

The likely problem areas are with:

- salinity
- reduced soil permeability
- toxicity to crops
- pollution of groundwater and adjacent surface waters due to the build up of chemicals.

Salinity is considered to be the most critical effluent quality parameter. The salinity of the effluent is high but it is believed by using selected planting material and careful irrigation that this is manageable. Sulphate and nitric ions, in contrast, are essential to tree growth and taken up by most plants.

The major species of tree recommended is appropriately, the flooded gum(Eucalyptus grandis). This is suitable for the climate, of proven vigour and is suitable for pulping. It recovers well from fire damage and can not only accommodate floods but can also withstand long periods of drought.

On the next slide I have shown some indicative cost estimates and this indicates the major elements of such a system. The analysis of input effluents and monitoring of the forest soils and waters is of course a crucial factor.

<u>Evaporation Ponds</u>

Finally I wish to mention the role of the evaporation ponds I have alluded to earlier in this paper which have some interesting features.

We were aware of the now widespread use of geotextile membranes for ground water protection, landfill encapsulation and evaporation pond liners. One such local example is the containment of Magnesium chloride brine solutions in Henderson Nevada (reference 6). We considered such a system for our original design. We are not sure if such a system has been used for effluents from explosives processes. Two HDPE (high density polyethylene) sheets would be layed on the bottom separated by a permeable geotextile membrane. Any leakage into the membrane would be monitored. Above this a 100mm (4 inch) reinforced concrete layer was proposed and on top of this a further layer of acid resistant polyester.

This design appeared to have some drawbacks. Cost was one problem. Secondly, it is impossible to ensure that a concrete base such as this would not crack and so expansion joints would be required. If a crack did occur the leak would not be immediately detected as the leaked material could channel some distance before detection.

Our attention was drawn to fly ash containment ponds at major power stations at Yallourn in Victoria. This design was much simpler and consisted of a 2.5mm HDPE lining covered with 500mm of a protective sand layer.

We have modified our design and it now consists of a layer of 2.5mm HDPE on the bottom, 500mm of sand and a further layer of 2.5mm HDPE above this, which will be the surface of the pond. Along the sides of the dam we have installed a geotextile liner to compensate for any problems in gaining an effective interface at the side wall. Near the access points a protective layer of polyester is provided. Our leak detection system consists of a agricultural type pipe in the sand layer feeding to a monitoring pit with alarms. We also have installed a network of bores to assist in detecting leaks.

Should the upper liner fail we can take quick action to pump out the compartment (each pond is subdivided), visually locate the tear and effect simple repairs by welding in a new section.

Consequently, not only was the construction cost cheaper, we believe maintenance and repair also will be more economical. The care taken in installing the liner and the associated warranties give us confidence of a twenty year life.

The ponds have been filled with water for some time and up to now have withstood the effects of many visitors, with the exception of two kangaroos!

<u>Summary and Conclusion</u>

In closing an explosive factory, what initially seemed a straightforward task, has resulted in a series of interesting technical, political and environmental interactions.

A heightening of local environmental awareness of the issues of land contamination, the unique nature of explosives contamination and a general dearth of reference data has produced a situation where very severe limits of residual contamination are likely to be set. Given that there appears to be a general lack of technologies in achieving marginal change at these lower levels, there are new challenges in selecting a decontamination technique.

In re-establishing similar facilities, a totally different approach has been taken to avoid such future problems. In a sensitive area we have adopted for a policy of total liquid effluent containment and turned to some novel technologies to achieve that end.

References:

1. Department of Defence - Gutteridge Hastins and Davey, Draft Environmental Impact Statement September 1987 "Relocation of Albion Explosives Factory to Mulwala NSW.

2. Report, Department of Administrative Services, "Relocation of Albion Explosives Factory to Mulwala NSW". Evidence for presentation to Parliamentary Standing Committee on Public Works,February 1988.

3. Department of Defence, Review of Explosives Factories W.F. Pheasant, July 1985.

4. Report, Department of Defence, Mulwala Explosives Factory, "Detailed Strategy Plan Re-use of MEF Wastewater on Irrigated Forest Plantation", prepared by Land Energy Pty Ltd, July 1989.

5. Forrests Commission of Victoria, "Effluent Treatment and Reclamation in Victoria using Tree Plantations by Stewart H., Craig F., Dexter B.

6. International Conference on Geomembranes, Denver USA 1984, various papers.

7. Age Newspaper, 3 May 1990 Melbourne, Victoria Australia.

Acknowledgments:

The help and contributions of Mr N. Tozer, Mr R. Smart and Mr B. Kathiravelu are acknowledged.

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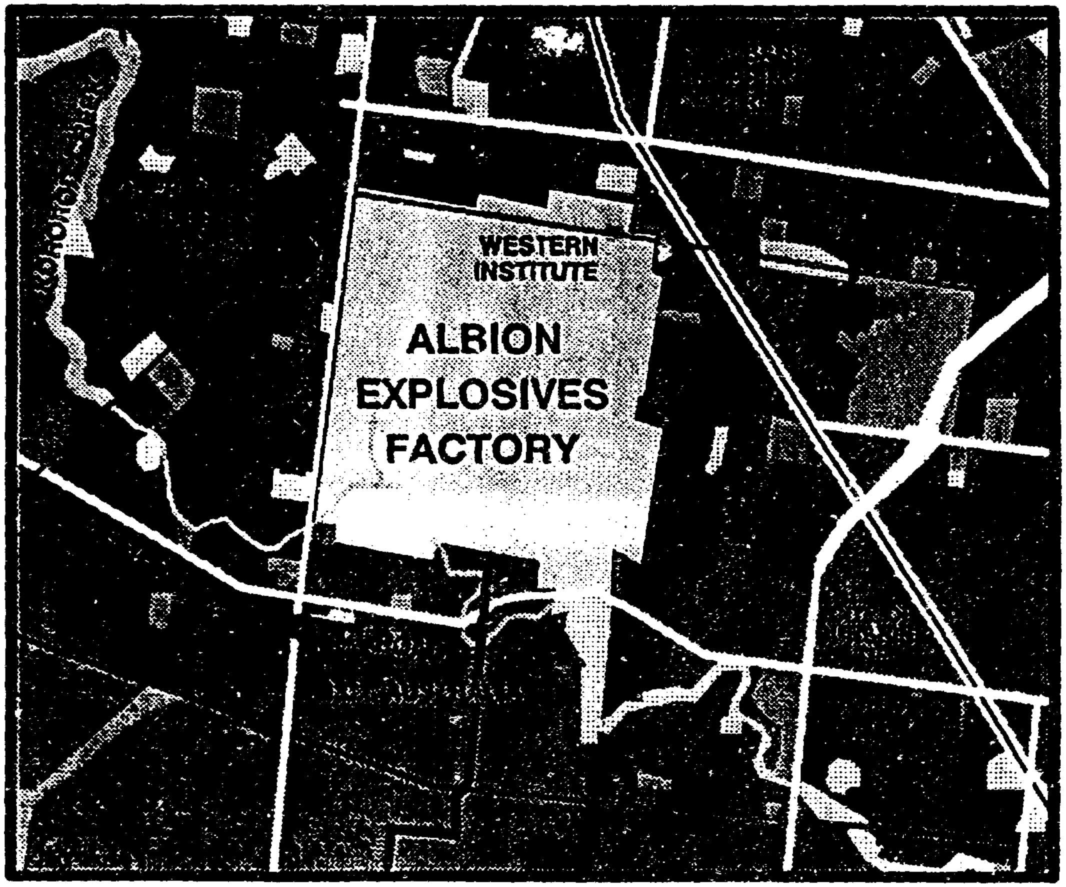

HISTORY OF ALBION EXPLOSIVES FACTORY

1939	CONSTRUCTED BY ICIANZ
1940	MANUFACTURED TNT, NG, CORDITE, CHEMICALS
1948	CARE AND MAINTENANCE
1954	REOPENED (RDX PLANT ADDED)
1971	CONTINUOUS TNT PLANT OPENED
1975	MAJOR EFFLUENT PLANT WAS CONTRUCTED
1986	CLOSED

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THE CLOSURE OF ALBION EXPLOSIVES FACTORY

PROFILE OF ALBION IS AS FOLLOWS:

SITE

- 20 KILOMETRES WEST OF MELBOURNE
- NOW SURROUNDED BY RESIDENTIAL PROPERTIES
- ABOUT 500 HECTARES (1250 ACRES): 2KM X 2.3KM
- ADJACENT CREEKS (CAN AFFECT 4 RIVERS THROUGH LARGE POPULATION AREAS)
- 349 BUILDINGS
- SAFEGUARDING PROBLEMS (PURPLE LINE INCURSIONS)

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CAPABILITIES AT ALBION EXPLOSIVES FACTORY

THE FOLLOWING PRODUCTS WERE BEING MADE AT THE TIME OF CLOSING

- HIGH EXPLOSIVES - TNT, RDX, COMP B, RDX/WAX, PLASTIC EXPLOSIVE
- 2,4 DINITROTOLUENE
- NITROGYLCERINE
- GUN, ROCKET PROPELLANTS
- NITRIC, SULPHURIC ACID CONCENTRATION AND PROCESSING

ENVIRONMENTAL ISSUES AT ALBION EXPLOSIVES FACTORY

ASPECTS OF ENVIRONMENTAL SIGNIFICANCE

- MAJOR EFFLUENT PLANT NOT CONSTRUCTED UNTIL 1975
- CONCRETE SETTLING TANKS, LABYRINTHS (CRACKING PROBLEMS)
- EARTHENWARE DRAINS (CLAY SOIL PROBLEMS)
- ACIDIC EFFLUENT NEUTRALISED IN LIMESTONE PITS
- BREACHES OF EFFLUENT DISCHARGE LEVELS TO SEWER WHEN SEWER PIPES FAILED
- - RED WATER TO SEWER DURING THE WAR; AND TO ADJACENT PADDOCKS
  - RED WATER SPILLAGES
- ASBESTOS BURIAL
- WASTE DISPOSAL (OPEN GROUND), PLANT DECONTAMINATION

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POLITICAL PROCESS - IMPACT ON ALBION CLEAN UP

- GOVERNMENT HOUSING SUMMIT
- COMMUNITY
- OTHER SITES
- PRESSURES
- ATTITUDE
- EPA

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Scramble for Albion

Contamination scare

Contamination on second site feared

Huge clean-up for poison site

Fire could have lit Albion "time bomb"

Albion doubt

Contamination is higher than expected

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CURRENT SITUATION

- RELATIVELY LOW LEVELS OF CONTAMINATION
- DIFFICULTIES IN OBTAINING TECHNOLOGIES TO REDUCE LOW LEVELS TO EVEN LOWER LEVELS (CURRENT TECHNOLOGY APPEARS TO ADDRESS REMOVAL OF GROSS LEVELS)
- A TRADEOFF BETWEEN COST OF DECONTAMINATION AND THE REVENUE EXPECTED FOR THE LAND
- COMMUNITY ANXIETIES AND FADING ASPIRATIONS

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CONTAMINATION LEVELS AT ALBION EXPLOSIVES FACTORY

- BASED ON 34.5 HECTARES SURVEYED OF THE 500 HECTARES AND FROM 1000 EXCAVATIONS TO 1M DEPTH (3000 SAMPLES), 1% OF THE TOTAL AREA (5 HECTARES) COULD BE CONSIDERED CONTAMINATED
- THE LEVEL VARIES FROM SITE TO SITE AND IS CONCENTRATED PRIMARILY IN THE SOUTH WEST NEAR THE HIGH EXPLOSIVE AREAS
- OF THE TOTAL VOLUME SURVEYED, ABOUT ONE SIXTH IS ESTIMATED TO BE CONTAMINATED

THE DISTRIBUTION IS:

CONTAMINANT	% OF THE VOLUME OF THE SOIL WHICH CONTAINS THESE CONTAMINANTS
(TNT, 2,4 DNT, 2,6 DNT)	40% BY VOLUME
HEAVY METALS	20%
RDX	15%
ACIDS, SULPHATES	20%
MIXTURES	5%

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CONTAMINATION LEVELS

GREATER THAN 90% OF MATERIAL

↓

CONTAINS ONE TO THREE TIMES RECOMMENDED ACCEPTANCE CRITERIA (LOW PPM)

LESS THAN 10%

↓

SEVERAL HUNDRED TIMES CRITERIA I.E. HUNDREDS TO THOUSANDS PPM

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MULWALA FACILITY's PRODUCTS AND CAPABILITIES

PRESENT

CURRENT PRODUCTS:

- EXTRUDED DOUBLE BASE AND SINGLE BASE PROPELLANTS FOR SMALL ARMS AMMUNITION AND LARGE CALIBRE AMMUNITION
- ROCKET PROPELLANTS AND CASTING POWDERS
- NITROCELLULOSE
- NITRIC ACID
- NITROGLYCERINE
- ETHER

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NEW CAPABILITIES
MULWALA

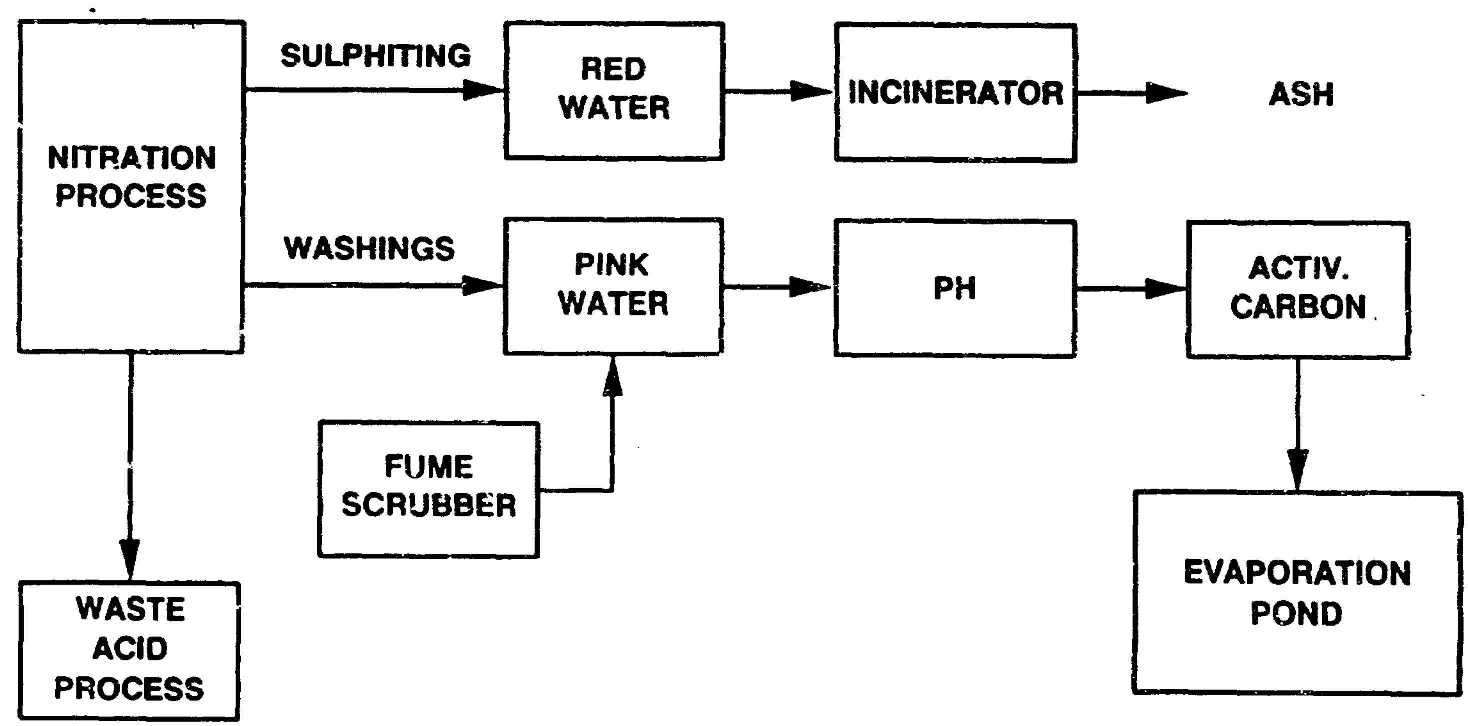
- TNT
- RDX
- PROPELLANTS
- ANCILLARIES
- CONTROL SYSTEM

ENVIRONMENTAL TECHNIQUES TO BE USED AT MULWALA

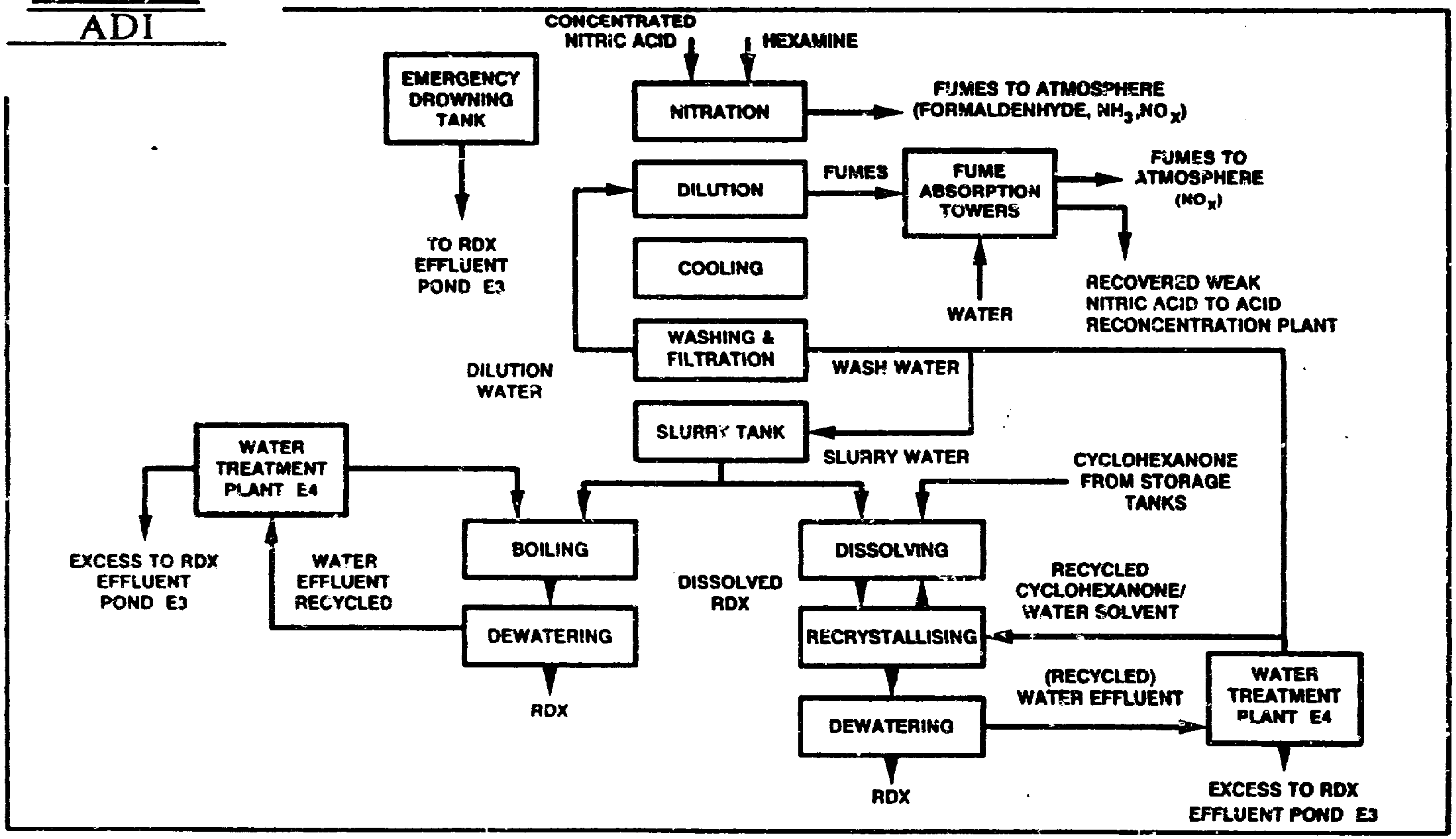
BASIC PRINCIPLE IS ONE OF TOTAL CONTAINMENT OF PRIMARY LIQUID EFFLUENTS

- DEDICATED ON SITE EFFLUENT TREATMENT
- ABOVE GROUND PIPING
- USE OF OPEN DRAINS
- ACTIVATED CARBON COLUMNS
- SPECIALISED TREATMENTS AND PRACTICES (INCINERATION, CHEMICAL)
- NO FORMAL STORM WATER SYSTEM (SAFEGUARDING MEASURES TO REDUCE POTENTIAL DISCHARGE OF CONTAMINATED STORMWATER)
- BUNDING, DRAINS WITH SAVE ALL PITS
- WASTEWATER RECIRCULATION
- EVAPORATION PONDS

TNT WASTEWATER MANAGEMENT



RDX MANUFACTURE



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COST ESTIMATES FOR PROJECT ESTABLISHMENT

INDICATIVE COSTING ESTIMATES. (RECEIVING SITE) 16/32 ha PLANTATION AREA

ITEM	ESTIMATED COST	(16ha/32ha)
DETAILED DESIGN AND PROJECT PLANNING		($15K/$20K)
LINED BALANCE STORAGE DAM. (23.3MI)	SUBJECT TO LOCAL QUOTATION	
3 PHASE POWER SUPPLY	AS ABOVE	
FILTRATION, CHEMICAL INJECTION PUMPING PLANT, HEADWORKS FACILITIES. (INSTALLED)		($30K/$50K)

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COST ESTIMATES OF PROJECT ESTABLISHMENT

INDICATIVE COSTING ESTIMATES. (RECEIVING SITE) 16/32 ha PLANTATION AREA

ITEM	ESTIMATED COST	(16ha/32ha)
MONITORING EQUIPMENT AND INSTALLATION		($12K/$18K)
RIPPING, WEED CONTROL ETC	$1,000/ha	($16K/$32K)
IN-FIELD DISPERSAL SYSTEM (INSTALLED)	$4,000/ha	($64K/$128K)
PROPAGATION, PLANTING AND ESTABLISHMENT OF TREES	$3,000/ha	($48K/$96K)
SYSTEM/SITE MANAGEMENT - 0.5 MAN YEARS	$15,000/year	($15K/$25K)
ANALYSIS - MONITORING	#3,000/year	($3K/$5K)

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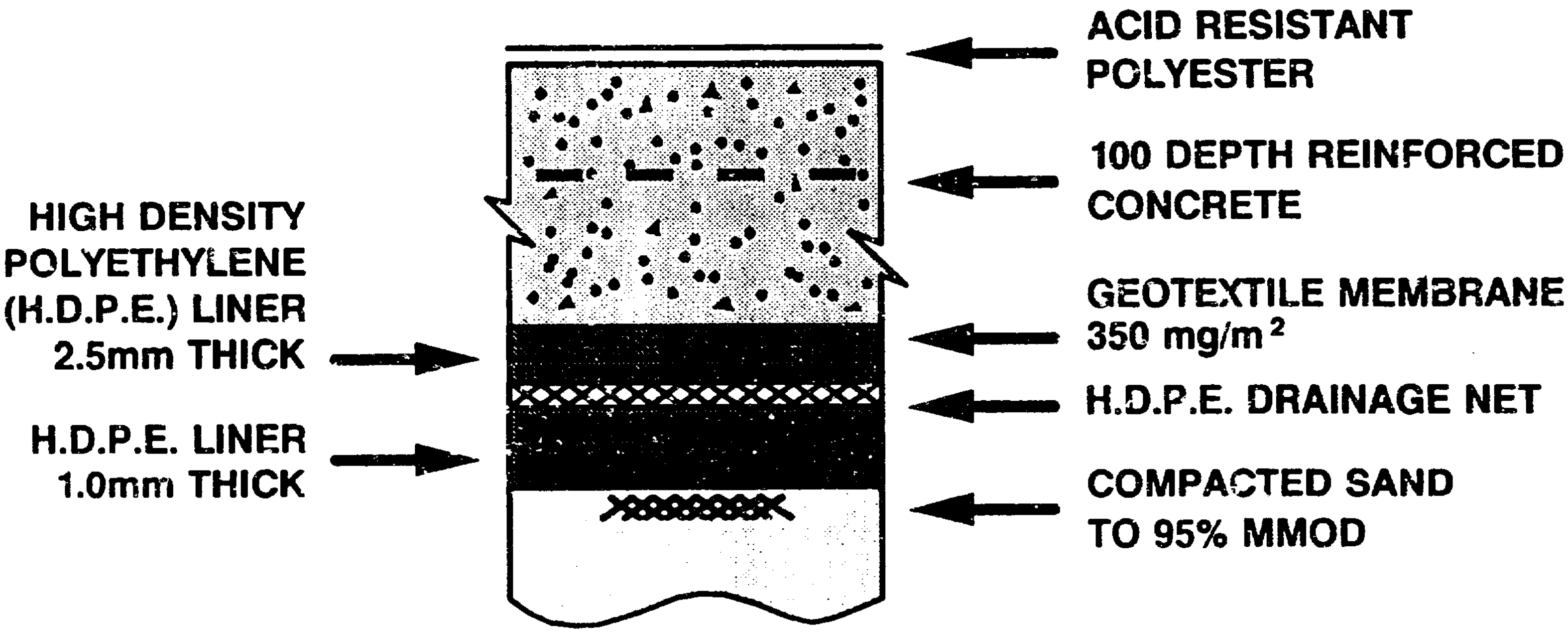
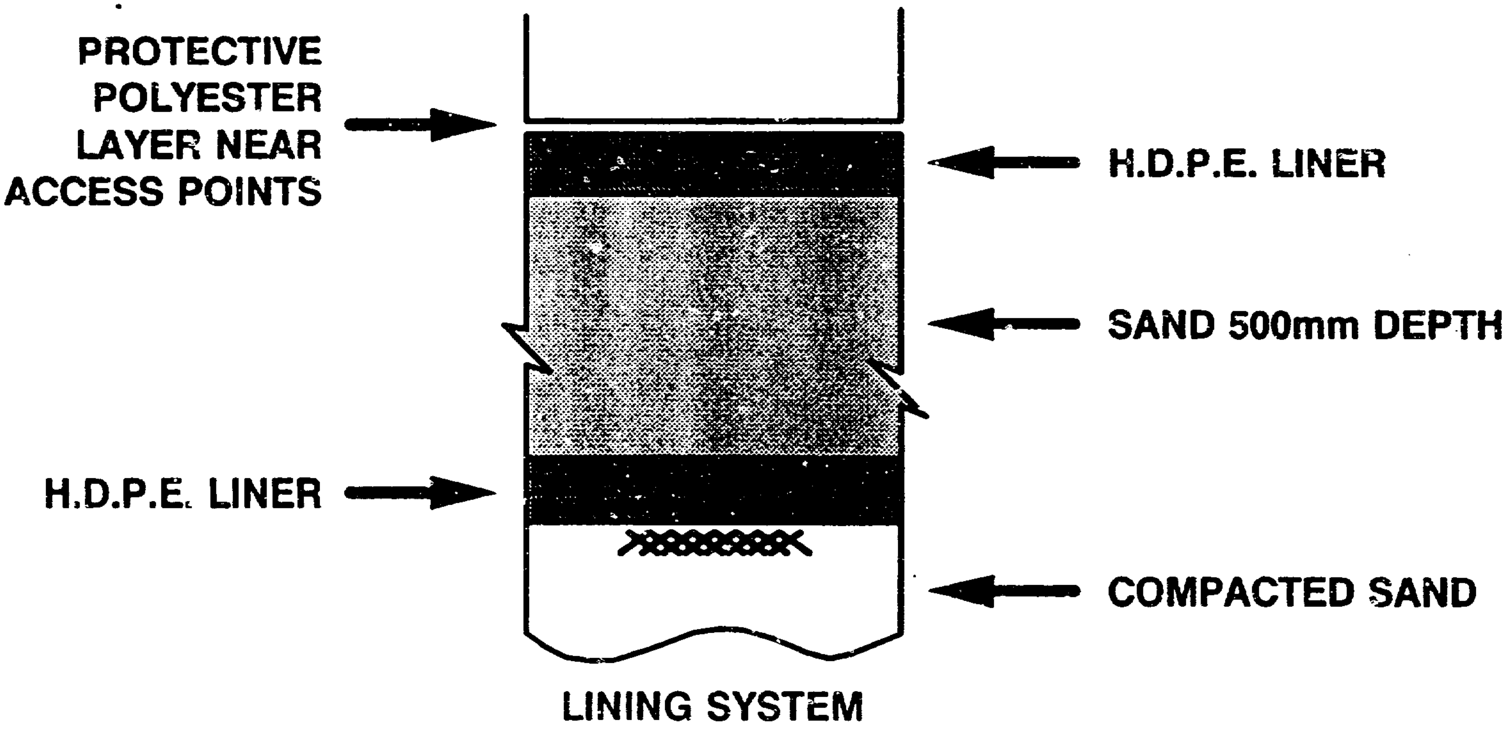
TYPICAL SECTION ORIGINAL DESIGN



LINING SYSTEM

ADI

TYPICAL SECTION REVISED DESIGN



1157

Title: Decontamination of Explosive Contaminated Structures and Equipment

Author: Paul W. Lurk and Wayne E. Sisk, U.S. Army Toxic and Hazardous Materials Agency, CETHA-TS-D, Aberdeen Proving Ground, Maryland 21010-5401, (301) 676-7610

As a result of past operations, the U.S. Army has numerous buildings and large quantities of process equipment which is contaminated with explosives. Recent changes in laws also require all detonation scrap to be free of explosive residue prior to recycle. Before these materials can be recycledor disposed of, the residual explosives must be removed. Removal of residual explosives is necessary to avoid creating safety and environmental hazards. If the process equipment is to be landfilled, residual explosives may migrate into the soil and ultimately contaminate groundwater. Building structures which have been used for explosives manufacture are usually slated for demolition and disposal of the rubble. Demolition of a building which has residual explosive can be dangerous. Disposal of contaminated rubble may contribute to soil and groundwater contamination.

Probably the two most common methods in present use for decontamination are steam cleaning and decontamination by fire (burn it to the ground). Steam cleaning is in most cases effective but provides only surface decontamination and is not effective on hard to access areas. It is difficult to completely decontaminate concrete with steam. Steam cleaning of complex items such as motors can not assure that interior areas are cleaned. Burning of structures contaminated with explosives is no longer an environmentally acceptable method of decontamination. Buildings with asbestos should not be burned. Since open burning of a contaminated structure can be viewed as an uncontrolled release of toxic substances, local or state regulators view intentional building fires in the same light as open detonation..

In 1982, USATHAMA began a project aimed at developing new, improved procedures for decontaminating structures and equipment contaminated with explosives. The goal of this on-going project is to develop a method which will be safe, produce little or no waste and will assure a high degree of decontamination. Target compounds for removal are all the major military explosives such as trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-s-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), nitrobenzene (NB), 1,3-dintrobenzene (DNB), 1,3,5-trinitrobenzene (TNB), 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), 2,4,6-trinitorophenylmethylnitramine (TETRYL), smokeless powder (nitrocellulose/nitroglycerin), ammonium picrate (Yellow D). The process to be developed would have to be effective at removing contaminants from metal, wood, painted concrete and bare concrete. An addition goal of the project was to develop a decontamination method which is universally applicable and, thus, could be used on large structures as well as process equipment. The first phase of this project was a review of existing techniques and the consideration of novel techniques.

Phase I of Development Program, Technology Screening

Under contract to USATHAMA, Battelle Columbus Laboratories performed an analysis of existing explosives decontamination techniques and also developed descriptions of novel concepts. Information was gathered from government and private industry manufacturers of explosives. Government facilities were visited to inspect contaminated structures and equipment. In a July 1983 report, Battelle documented the detailed analysis of the following technologies:

Thermal Decomposition Concepts

Flashblast	Contact Heating	Hot Plasma
Microwave Heating	Flaming	Hot Gases
Solvent Soak/Burn	Infrared Heating	CO_2 Laser
Burn to Ground		

Abrasive Concepts

Electropolishing	Acid Etch	Scarifier
Sandblasting	Demolition	Drill and Spall
Ultrasound	Cryogenics	Hydroblasting
Vacu-blast		

Extractive Removal Concepts

Solvent Circulation	Supercritical Fluids	Rad Kleen
Surfactants	Strippable Coatings	Manual Steaming
External Steam Generator	Vapor Phase Solvent Extract	

Chemical Concepts

Radical Initiated Decomp.	Base Initiated Decomp.	Decomp. with DS2
Molten Decomp.	Sulfur Based Reduct	Sodium Borohydride
Microbial	Reduction Cleavage	Reactive Amines
Ultraviolet and Cat.	Gamma Rad.	Chromic Acid
Nucleophilic Displacement	Ozone	Ascorbate
Solid State Hydrogenation	Gels	Foams

Various combinations of methods were also considered. Each technology was evaluated and rated based on destruction efficiency, mass transfer, safety, damage to buildings, penetration depth, applicability to complex surfaces, operating costs, capital costs and waste treatment costs.

Among the thermal decomposition concepts, hot gases received the highest ranking overall and received high scores in all categories. The hot gas process involves exposing contaminated materials to hot gasses in order to vaporize or decompose the contaminants. The hot gasses together with the vaporized explosives and break down products are discharged to an afterburner for complete destruction.

The burn to ground method received high scores in most categories but received the lowest possible scores for safety and building damage. The only thermal concept recommend for further development was hot gases.

All of the abrasive concepts received poor scores for waste treatment costs. The abrasive concepts also received low scores for penetration depth. None of the abrasive concepts were considered for further development.

External steam generator (pumping steam into the structure) scored the highest of the extractive removal concepts. However, the low solubility of some explosives in hot water prevents the steam method from being universally applicable. Vapor circulation was the only extraction technology selected for further development.

Three chemical decomposition techniques where selected for further development. The concepts selected were radical initiated decomposition, base initiated decomposition and sulfur based reduction.

In all, 55 technologies or combinations of technologies were considered. Six concepts were selected for further investigation. The selected technologies were hot gasses, combination chemical/hot gas, vapor circulation, radical initiated decomposition, base initiated decomposition and sulfur based reduction.

From the combination methods evaluated, only a combined chemical/hot gas concept was considered to be worthy of further development.

Phase II, Laboratory Tests

In Phase II, the technologies selected from Phase I were developed in more detail. Probably the most important aspect of the development work was the laboratory tests. Test coupons of steel, painted concrete and unpainted concrete were spiked with known quantities of 2,4 DNT, 2,6 DNT, TNT, TETRYL, RDX and HMX. The test coupons were then subjected to the processes under investigation. After appropriate treatment times, the coupons were inspected for residual explosives. Hot gases and the combination of chemical/hot gases yielded the highest degrees of explosives removal. In many cases, the residual explosive levels were below detection limits. Although each of the six processes evaluated in the laboratory phase of testing offered some advantages and disadvantages for particular operations, it was the hot gas process which had a greater range of applications and provided the most complete decontamination.

The laboratory tests did identify some potential problems with the hot gas process. During testing the formation of explosive crystals on the outside surface (originally uncontaminated) of concrete test coupons indicated that the hot gases may cause explosives to migrate through concrete. This raises the concern that during decontamination of a concrete structure the explosives may be driven out of the structure rather than destroyed. It was also noticed that the hot gas process dried out and, thus, weakened concrete.

Pretreatment of concrete with a caustic chemical led to quicker destruction of explosives and allowed hot gas decontamination to proceed at lower temperatures. Quicker destruction of explosives reduces the possibility of migration. Operating at a reduced temperature lessens the drying effects on ...rete. Thus, it was concluded that combination of chemical treatment and ...gasses would be the best route to complete decontamination without ...ation of explosives and with minimal damage to concrete.

The hot gas process, complemented by chemical pretreatment, emerged from the laboratory tests as clearly the most promising technology for wide spread application. The next step was to see how well the process would perform outside the laboratory on a contaminated building.

Phase III Pilot Tests

The Cornhusker Army Ammunition Plant (CAAP) Tests:

Pilot tests of the chemical/hot gas decontamination method were conducted at CAAP in 1987. The tests were conducted for USATHAMA by Arthur D. Little, Inc. The objectives of these first pilot tests were:

1. Determine the effectiveness of hot gas with and without chemical pretreatment.

2. Evaluate the effects of test conditions on the integrity of an actual structure.

3. Provide design criteria for full scale systems.

4. Provide test data for regulatory permitting of the process.

After numerous potential sites were considered, a projectile washout building at Cornhusker AAP was selected as the test site. The building had concrete walls, a concrete floor and a wooden ceiling. Dimensions of the building were 25' long, 25' wide and 11' high. So that two separate tests could be conducted, a dividing wall was constructed in the center of the building. Other modifications to the building included construction of a false ceiling to protect the wooden roof, replacement of the windows and doors with sheet metal and insulation of the outside of the building. Although inspection of the building revealed some TNT contamination, the level of contamination was too low to sufficiently challenge the decontamination method. This problem was resolved by placing TNT contaminated concrete blocks, which were removed from a sump cesspool, inside the test building.

Hot gas was supplied to the building through ductwork by a 3.0 million BTU/hr propane fired burner. Gasses exited the building into a propane fired afterburner. Gasses entering the building, exiting the building and exiting the afterburner were analyzed. In tests where chemical pretreatment was used, a solution of sodium hydroxide and dimethylformamide was employed. Theramocouples were used to monitor temperatures inside the building during treatment. Concrete samples were subjected to mechanical properties tests before and after hot gas treatment.

Conclusions drawn from the Cornhusker pilot tests were:

1. Hot gas decontamination of a building is safe and feasible.

2. Although treatment of surfaces with caustic chemicals did increase explosive removal on the surface of concrete, it had no effect on interior contamination. Further, longer treatment with hot gas alone should be capable of providing complete decontamination.

3. The hot gas decontamination process caused concrete block to loose 5% of its compressive strength and 20 to 30% of its bend (tensile) strength. The effects of this loss in strength would have to be judged on a case by case basis for each building treated. Of course, if the building is not going to be reused, the condition of the concrete after treatment is of no concern.

4. Initial design criteria and cost estimates for decontamination of small and large buildings were developed.

5. Process data, such as composition of effluent gasses from the afterburner, were collected and can be used for applying for regulatory permits for future operations.

The Hawthorne Army Ammunition Plant (HWAAP) Pilot Tests:

Further pilot tests of the hot gas process (without chemical pretreatment) began in July 1989 at HWAAP. These tests are being conducted for USATHAMA by Weston, Inc. This test series is directed towards the decontamination of process equipment used in explosives operations. The objectives were:

1. Test the process on a variety of materials (vitrified clay, steel, copper, aluminum) with a variety of contaminants (TNT, NC, NG, Ammonium Picrate, RDX, HMX).

2. Test the process on a variety of items including intricate equipment which has areas inaccessible to other treatment processes (pumps, pipes, ship mines, risers, transfer containers, motors).

3. Determine the temperatures and treatment times required to reduce contaminant levels to below detectable limits. Define a process that will render equipment items fit for unrestricted use or disposal.

4. Render large quantities of contaminated equipment fit for unrestricted use or disposal.

A flashing chamber at HWAAP was modified to accommodate the hot gas process. The same burner and afterburner that was used at Cornhusker AAP are in use at HWAAP. HWAAP has a large store of equipment and munition items which require treatment. Test items have been selected from HWAAP's stores, placed in the modified flashing chamber and treated with hot gas. Test samples also include highly contaminated clay pipe removed from what was once the West Virginia Ordnance Works.

Test items were sampled for explosives prior to testing. Because of low levels of contamination, some items were spiked with explosives. After testing, items were sampled for residual explosives.

Ten test runs were conducted: nine tests evaluated the feasibility of the process on TNT and smokeless powder; one test run evaluated ammonium picrate. The operating conditions of the test runs were selected to form a temperature-residence time matrix. Three temperatures were evaluated: 400°F, 500°F, and 600°F. The duration of tests evaluating TNT decontamination was 6 hours, 12 hours, 24 hours, or 36 hours (after reaching steady state). A residence time of 48 hours was used for evaluation of ammonium picrate; this extended residence time (and a temperature of 600°F) was selected to ensure the decontamination process would be completed and to avoid potential safety problems associated with partially decomposed ammonium picrate (picric acid). To demonstrate the destruction and removal efficiency (DRE) of the process, stack testing was conducted at the afterburner inlet and outlet. Stack tests were conducted during the first three test runs for explosives and smokeless powder.

The hot gas process is effective for treating items contaminated with TNT and ammonium picrate. Analytical results indicate that temperature is a key factor in explosives removal. It was determined that a minimum temperature of 500°F is required to remove TNT below measurable levels on the treated test items. Since relatively large temperature gradations were evaluated (±100°F), the minimum effective operating temperature may le somewhere between 400°F and 500°F. Test items that are treated for 6 hours at a minimum temperature of 500°F are not characteristically hazardous and are appropriate for disposal or potentially for resale as scrap. Items with contamination on external surfaces were generally the least difficult to treat; three failures were observed (one failure was associated with soil/debris in clay pipe). Test items with contamination on internal surfaces or within porous media proved to be more difficult to treat. Although three test items were observed to fail, residual concentrations were generally higher.

Generally, items constructed of steel or aluminum showed no signs of damage due to treatment. For clay, however, exposure to the hot gas resulted in cracks throughout the entire pipe sections. The clay became very brittle and was easily broken. The treated test items that are constructed of steel or aluminum and have not intricate of mechanical components should be appropriate for reuse in manufacturing or handling operations.

Due to the limited testing on smokeless powder and the variability in pre-test item contaminating, it is not possible to analyze trends in the data for smokeless powder. The sampling and analytical methods employed for determination of smokeless powder emissions in the stack gases (and presence of smokeless powder on test items) were determined to be inappropriate. The method did not allow NC and NG to be distinguished from one another or from other nitrated testers. The stack sampling protocol was also questionable; the sampling media may not have captured NC and NG.

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TNT emissions from the afterburner, as measured during the stack testing program were never above detectable levels. In cases where TNT inlet concentration was sufficiently high, the DRE exceeded 99.99 percent.

Combustion efficiency of the afterburner ranged from 99.9895 to 99.9933 percent during the stack testing program; efficiencies reflect the excellent performance of the afterburner.

The emissions of particulate from the afterburner, as measured during the stack testing program, ranged from 0.000017 gr/dscf to 0.00093 gr/dscf (corrected to 7 percent oxygen). Emissions are two orders of magnitude lower than applicable regulations.

Emissions of carbon monoxide and total hydrocarbons at the flash chamber inlet indicate that the existing air preheater at HWAAP is operating poorly. Emissions were one order of magnitude higher than emissions associated with typical gas-fired heaters. Combustion efficiencies for the air preheater ranged from 98.95 percent to 99.72 percent during the stack testing program.

Due to extended heatup and cooldown periods, it is difficult to evaluate the effects of the 600^{o} F test runs. During the 600^{o} F test runs, before the steady state temperature was achieved, the system had operated at conditions that were very similar to the 500^{o} F/6 hour test run. The results of the 500^{o} F/6 hour test run indicate decontamination of TNT. Therefore, during the 600^{o} F test run, the test items may have been adequately treated before the steady state temperature was even achieved.

Use of Waste Energetic Materials as a Fuel Supplement In Utility Boilers

Craig A. Myler
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

William M. Bradshaw
Oak Ridge National Laboratory
Operated by Marin Marietta Energy Systems, Inc.
for the U.S. Department of Energy under contract
No. DE-AC05-840R21400

Michael G. Cosmos
Weston Services, Inc.
West Chester, Pennsylvania

ABSTRACT

Waste energetic material produced during the manufacture of explosives has been considered a by-product waste which must be disposed of. Methods such as open burning or open detonation pose potential environmental risks while disposal in specially designed hazardous waste incinerators is costly. No current method capitalizes on these materials inherent energy capacity. Efforts to utilize these wastes as supplements to fuel oil are under way. Laboratory and bench scale operations verify the principle while economic analysis shows a positive advantage using this approach. Pilot scale testing is in progress to develop fuel mixing/feeding procedures and to determine fuel mixture energy parameters.

Introduction

Production and stockpiling of explosives by the U.S. Army results in the generation of waste energetic materials. Typically, these materials contain nitrated aromatic compounds which are classified as hazardous due to their inherent reactivity. Environmentally safe methods are used to dispose of these materials as hazardous wastes; however, they do not take advantage of the energy content of these materials. A program initiated by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) in conjunction with Oak Ridge National Laboratory (ORNL) and Roy F. Weston, Inc. is investigating the use of these waste materials as a supplement to fuel oil for use in standard industrial-type boilers. Using the energy stored in these wastes reduces fuel consumption while eliminating potential hazardous waste. Each of these benefits is a national priority item. The development of this technology is therefore highly desirable.

Nature of the Waste

To effectively treat the subject, a description of the nature of the wastes as well as their origin is in order. Energetics are separated into three classes:

(1) Propellants

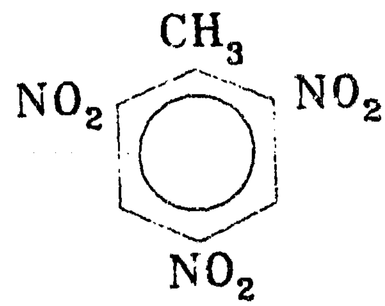
(2) Explosives

(3) Pyrotechnics

Propellants and pyrotechnics will not be included in this report. This does not preclude their use as fuel supplements and work has been initiated to investigate the use of propellants as fuel supplements, either as admixtures to fuel oils or as supplements to coal.

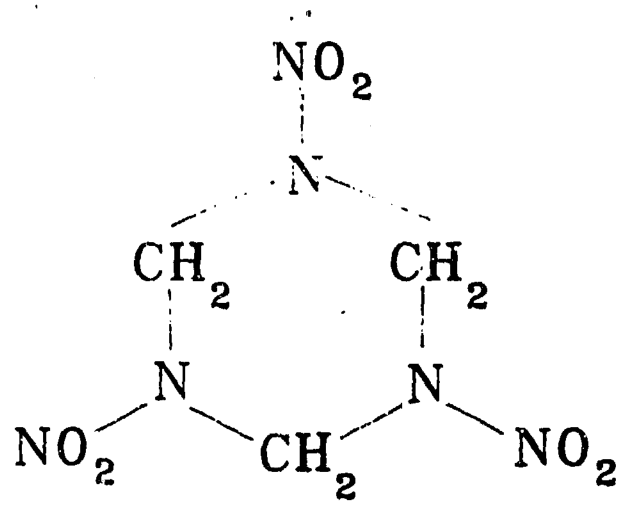
The two primary explosive wastes of concern are trinitrotoluene (TNT) and cyclotrimethylenetrinitramine (RDX). These are the most prevalent explosives in use today and constitute the greatest inventory of waste. The structures of these compounds along with pertinent physical data are given in Figures 1 and 2. Of particular note is the substantial amount of available nitrogen. This will be discussed in terms of expected combustion products later in this report. TNT and RDX are often combined (normally with a small amount of paraffin) to form a composite explosive. The most common is Composition B or simply, Comp B, which is a 40% TNT to 60% RDX mixture.

As class A explosives, both TNT and RDX constitute a reactivity hazard. Handling, storage and use require special care and attention to insure the safety of personnel. In addition to its reactivity, TNT also constitutes a toxicity hazard. The American Conference of Governmental Industrial Hygienists recommends a Time Weighted Average (TWA) maximum concentration of 0.5 mg/m^3 and indicates a dermal hazard with TNT.[1] The risk



Melting Point	80 to 81 °C
Color	Yellow, Crystalline
Boiling Point	345 °C
Density	1.654 gm/cm^3
Viscosity	0.139 poise at 85 °C
Specific Heat	251.8 J/mole-K at 27 °C
Heat of Combustion	809.18 to 817.2 kcal/mole
Solubility at 0 °C	57 gm/100 gm Acetone 28 gm/100 gm Toluene
Solubility at 50 °C	346 gm/100 gm Acetone 208 gm/100 gm Toluene

Figure 1: Structure and Physical Properties of Trinitrotoluene (TNT)[2]



Melting Point	**202 to 203 °C**
Color	**White, Crystalline**
Density	**1.806 gm/cm^3**
Specific Heat	**277 J/mole+K at 20 °C**
Heat of Combustion	**501.8 to 507.3 kcal/mole**
Solubility at 0 °C	**4.2 gm/100 gm Acetone** **0.016 gm/100 gm Toluene**
Solubility at 50 °C	**12.8 gm/100 gm Acetone** **0.087 gm/100 gm Toluene**

Figure 2: Structure and Physical Properties of Cyclotrimethylene-trinitramine (RDX)[3]

associated with this toxicity is generally small due to TNT being a solid under standard conditions as well as its low solubility in water. Even so, this toxicity cannot be ignored in any program utilizing TNT. Necessary precautions include safe explosives handling techniques, precaution against skin contact, and insurance against airborne contamination. Safe explosives handling including prevention against skin contact is commonly practiced and will not be discussed further.

The heating value of RDX is approximately 9 kJ/g while for TNT it is approximately 15 kJ/g. Each of these compounds burns easily and completely. The largest drawback to utilization as fuel supplements (outside of their reactivity) is the production of NOx. Combustion of these explosives produces some quantity of NOx above that which would be produced from the combustion of standard fuels. This NOx production was found to be approximately 0.54 g/MJ of fuel.[4] Current test objectives include the characterization of these emissions and determination of means to curtail or treat the production of NOx.

Sources of the Waste

Along with the preceding discussion on the chemical nature of the waste, a brief description of the source of the waste and its physical state is in order. Two sources contribute to the inventory of waste explosives. The first of these is the normal production process. The second source is that inventory which becomes either obsolete due to its packaging or unserviceable due to storage, damage, etc.

As in the production of most items, especially in batch- produced chemicals, off specification materials are sometimes produced. Due to the military nature of explosives, strict production specifications are enforced. Batches of explosives sometimes fail to meet specifications which leads to their classification as wastes. Lackey[5] provides an estimate of current energetic waste generation of 1.13×10^6 kg/yr. This estimate grows to 4.60×10^6 kg/yr during full scale production. It should be noted that no TNT is currently produced. Additionally, loading of munitions with explosives results in significant waste generation through equipment wash down procedures.

The second source of waste explosives is unserviceable stockpiles. If a weapon is no longer a part of the Army inventory, the munitions it uses may be classified as unserviceable or obsolete. Also, quality control of stockpiled munitions may determine that a particular munition is unable to meet requirements for military service and it will be classified as unserviceable. This may be due to the breakdown of the explosive itself, degradation of other chemical portions of the munition such as a propellant charge, or to a deterioration of the munition body (for example a corrosion of the casing). Table 1 provides an estimate of the amount of unserviceable explosives in the current Army inventory.

TABLE 1: Estimate of Unservicable Explosives Contained In U.S. Army Stockpile (1985)[6]

	COMP B (10^6 kg)	TNT (10^6 kg)
Munitions	2.535×10^6	1.496×10^6
Reclaimed Material	2.315×10^6	----
Total	4.850×10^6	1.496×10^6

Finally, current disposal practices will be discussed. Two methods are generally used, not including continued storage which by its nature is expensive and non-productive. The first is destruction by open detonation of the explosives. This practice is simple, relatively safe and expedient. It has recently come under environmental scrutiny and testing is currently in progress to determine the impact of this disposal method on the environment. Open detonation does not capitalize on the heating value of the explosives.

The second current method of disposal is by incinerating the waste explosives. Typically, the explosive is mixed to form a water-explosive slurry and fed to a rotary kiln. A fuel such as propane or fuel oil is used to maintain the kiln temperature at approximately 1200 ^{o}C. This process requires approximately 1.67 kg of fuel oil per kg of explosive destroyed. Although this process can be made environmentally acceptable, it is expensive in terms of capital cost and energy consumption.

Neither of the above disposal practices takes advantage of the energy contained in the explosives. With limited government resources a constant concern, a less costly alternative approach is desirable. In the case of mobilization for national defense, limited fuel reserves makes utilization of this energy source even more important.

Safety

Safety is of paramount importance in using explosives as fuel supplements. The very nature of explosives requires special handling during their intended use and even stricter controls during combustion in an industrial boiler. Three separate areas of concern will be addressed. First, the rheology of explosives-fuel oil mixtures will be discussed. Second, physical properties with impact on compatibility of the explosives with fuel oils will be described. Finally, the likelihood of detonations occurring is addressed. These three safety related areas are fully described by Lackey.[7]

Due to the physical state of the waste explosives (irregularly sized solid pieces) and the relatively low solubility of TNT and RDX in fuel oils, a solvent is used to bring the TNT and RDX into solution. At some concentrations the RDX and TNT form slurries, especially upon removal of the solvent. Also, mixtures of toluene, TNT and fuel oil were shown to produce multiphase liquid mixtures which are undesirable for feed to a boiler. An optimum composition for the supplemented fuel must be determined and has an upper boundary dictated by detonation potential which will be described later.

Proper combustion of fuel oils is dependent on the burner systems ability to atomize the fuel. Viscosity is a key design parameter in selection of an atomizing nozzle and burner. Viscosity data for TNT supplemented fuel oils is given in Table 2. As shown, the viscosity of a No. 2 fuel oil supplemented with TNT does not show a significant increase in viscosity due to the addition of the explosive.

Explosives/Fuel Oil Compatibility

Consideration was given to the chemical compatibility of TNT and RDX with fuel oil.[7] Differential thermal analysis, vacuum thermal stability and accelerating rate calorimetry all showed that neither TNT nor RDX undergo chemical reaction in the presence of fuel oil and/or solvents but act simply as solids in solution. A test to determine if TNT would plate out in solution over time was conducted as well. Plating was observed during this 6 month long test; however, the plating was only a thin layer which presented no hazard when removed with warm acetone. Plating of TNT in current tests will be prevented by frequent feed system washing with warm acetone.

TABLE 2: Viscosity (in centistokes) of TNT Supplemented Fuel oils at Various Concentrations[8]

	TNT (g/100 ml Fuel Oil)			
	0	10	15	20
No. 2 Fuel Oil at 38 °C	3.7	4.2	4.4	4.7
	TNT (g/100 ml Fuel Oil)			
	0	10	20	30
No. 5 Fuel Oil at 60 °C	37.0	56.0	75.0	106.0

Pilot Testing Using a Prototype Combustor

In 1987 a pilot scale (300 kW) combustor was operated using fuel oil supplemented with TNT, RDX and Comp B.[9] Testing was conducted at the Los Alamos National Laboratory. Mechanical problems with the equipment precluded completion of this test program but not before sufficient data were acquired to show that the use of explosives as fuel supplements was possible. The problems encountered consisted of the failure of the insulation used in the reducing section of the prototype combustor and the failure of the burner tip caused by RDX accumulation and subsequent burning. Enough data were taken to warrant a continuation of the pilot scale testing with careful attention given to selection of a combustion chamber and the feed system used to introduce the explosive supplemented fuel oil. A diagram of the prototype combustor is shown in Figure 3.

In addition to showing the feasibility of utilizing explosive supplemented fuels, stack emissions data were obtained from the prototype combustor. These data were collected and reported by the Army Environmental Hygiene Agency[4]. As only four data runs were performed in which stack sampling was conducted, only generalized conclusions could be reached. The first conclusion is that destruction and removal efficiencies (DRE) of 99.999 % were obtained for TNT combustion. Carbon monoxide and

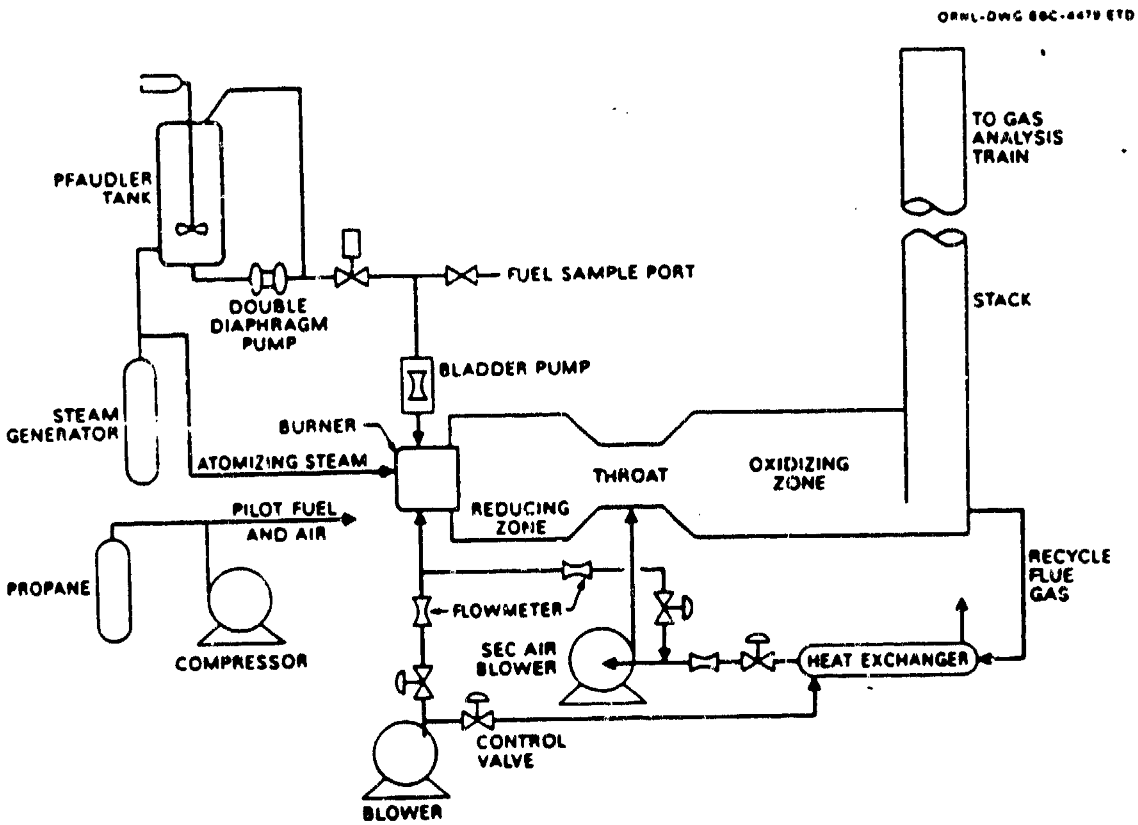


Figure 3: Prototype Combustor Used in Initial Pilot Scale Studies[9]

particulate emissions were described as controllable. Finally, and perhaps most important, increased NOx concentrations were found to be caused by the addition of the explosives to the fuel oil. With the limited number of data points obtained and the poor condition of the combustor it is premature to formalize estimates of NOx production for design of control equipment. It should be noted that the NOx emission rate was reported for total NOx as NO_2. For the two data points obtained during supplemented fuel burns, the total NOx emission rate was between 0.50 and 0.56 g/MJ. Methods to curtail this production rate as well as obtain definitive data to support design of abatement systems are key factors in current test plans.

Current Program

Using the foregoing information, USATHAMA's current program was developed to provide the data needed to specify requirements for a complete supplemental fuel system utilizing TNT or Composition B. Testing is scheduled to begin in June 1990. Three major items required engineering design and specification to obtain a working pilot system: (1) a boiler system which would approximate the anticipated full scale boilers that the supplemented fuels would be used in, (2) a system to safely mix and feed the explosives, solvent and fuel oil was needed which could safely mix and deliver the supplemented fuel, and, (3) a data acquisition plan was needed to obtain the necessary design information for both emission control design, the operating parameters for the burner and preliminary data needed for regulatory approval. A block diagram of the test system is shown in Figure 4.

The boiler is the central piece of equipment in the utilization of explosives supplemented fuels. The majority of currently installed oil burning Army steam boilers are of a water tube design. Various burners and nozzles are used. For the current tests, air atomization was selected to reduce the potential for flashing of the toluene in the supplemented fuel mixture. The boiler selected is designed for 47 boiler horse power and utilizes fuel at an input rate equivalent to 498 kW. A scale factor of ten would include the majority of process steam generation boilers in use today. Larger systems are used; however, more complex burner designs and fuel feed systems would likely require additional testing prior to use of supplemented fuels in these systems. This testing would likely include surrogate fuel mixtures synthesizing the viscosity and heating value of the supplemental fuel.

The second required piece of equipment for this test program is the mixing/feed system. This unit is currently in the design stage and will include provision

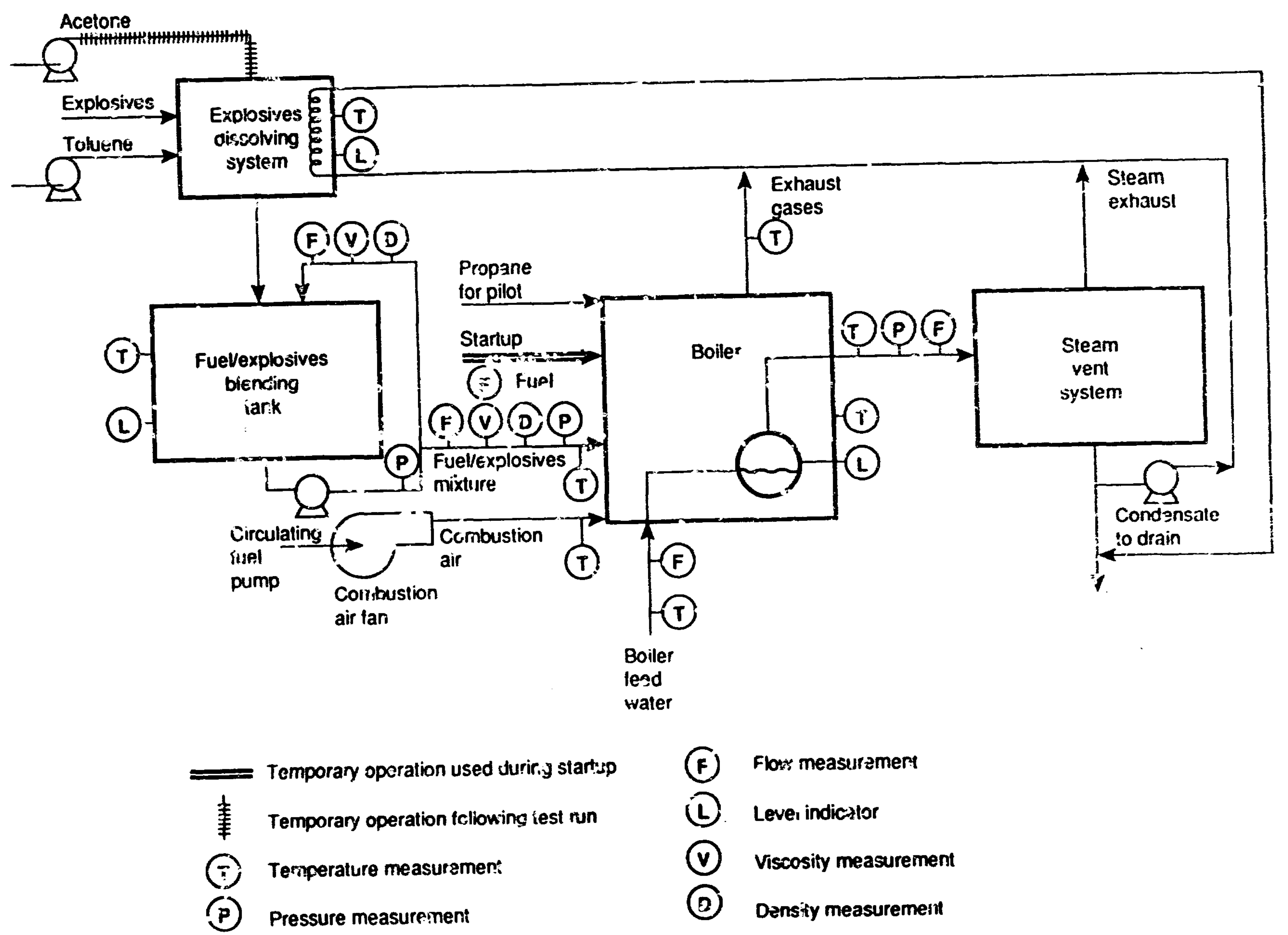


Figure 4. Block Diagram of Supplemental Fuel Pilot Scale System.

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for dissolving the explosives in a separate solvent tank, followed by remote addition of this solution to a fixed quantity of fuel oil. The system will mechanically agitate the fuel mixture as well as recirculate the mixture through the piping system. Once a test is completed (by exhaustion of the supplemented fuel mixture), the system will be flushed with acetone by remote control. The mixing/feed system would constitute the primary capital cost for implementation of a system to utilize waste explosives. Care in terms of scalability by utilizing standard equipment in the pilot scale design will assist in the scale up of this unit to a full production system.

Finally, the data acquisition plan was designed to obtain the necessary information for implementation of this technology. This includes flow properties of the selected feed mixtures, efficiency of explosive destruction within the system, heat balances over the system and measurement/characterization of emissions from the system. Eighteen total tests will be conducted. The sample matrices for supplemented fuel experiments are shown in Figure 5 and the expected test sequence is shown in Figure 6. In addition to the 14 tests shown in Figure 5, three tests will be performed using No. 2 fuel oil without the addition of explosives and one test will be performed as a duplicate test using supplemented fuel oil.

Weight Percent TNT in Feed

Percent Excess Air	1	10	15
20	●	●	●
25	●	●	●
30	●	●	●

Weight Percent Composition B in Feed

Percent Excess Air	1	4	8
20	●		●
25		●	
30	●		●

Figure 5: Test Matrices for TNT and Composition B Supplemented Fuels Pilot Scale Testing

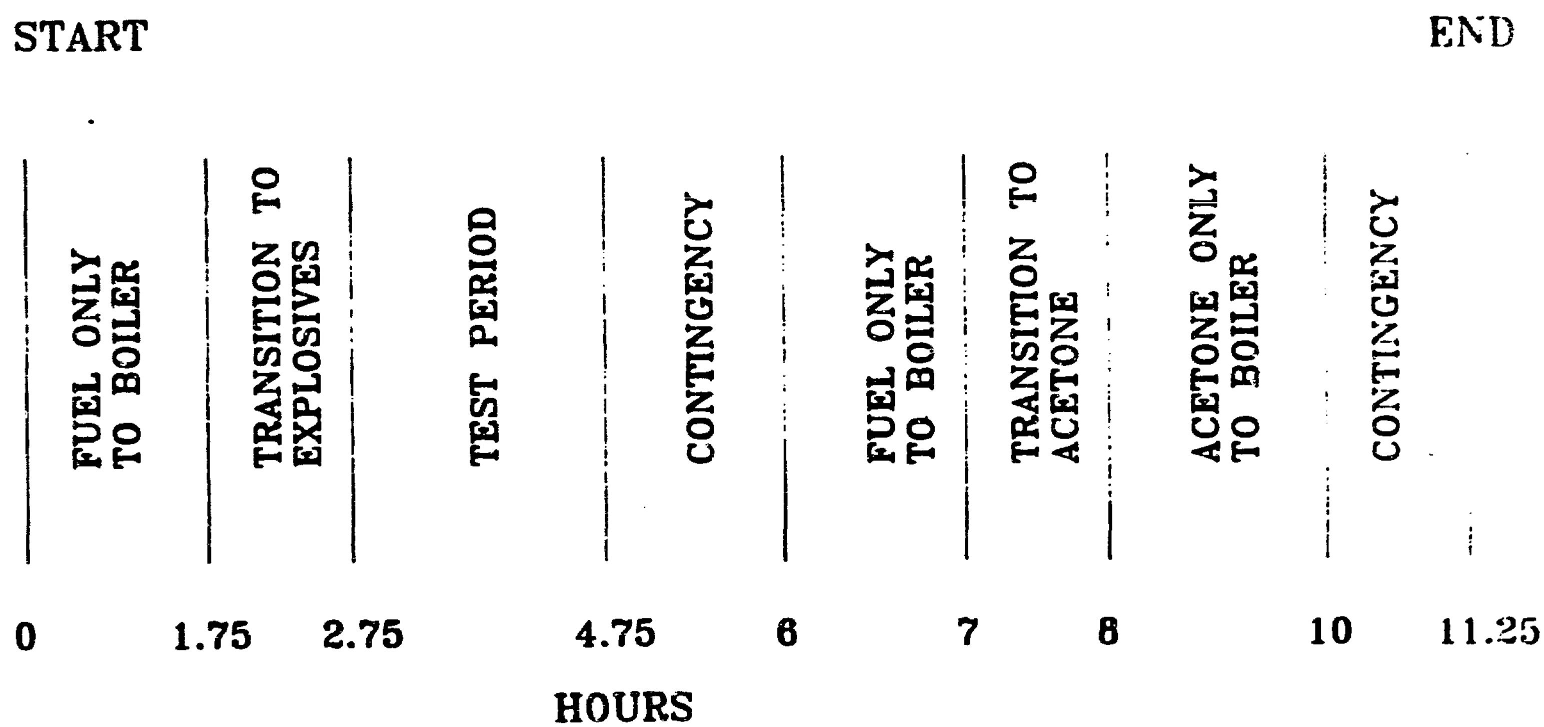

Figure 6: Expected Test Sequence for Explosive Supplemented Fuel Pilot Scale Testing

Detonation Testing

Finally, testing of the detonation characteristics of supplemented fuel oil was conducted.[7] Both static and dynamic tests were performed. Static tests were conducted in a horizontal .0504 m (2 inch, sched 40, 304 SS) pipe in which the explosive supplemented fuel was allowed to settle for a duration of 4 to 8 hours. Dynamic tests were conducted in a vertical pipe of the same diameter in which the mixture was agitated and then immediately tested for detonation potential. Single phase TNT-acetone-No. 2 fuel oil mixtures showed no propagation of detonation characteristics in static tests at TNT concentrations up to 78 wt percent. TNT-toluene mixtures showed no propagation in both static and dynamic tests at up to 65 wt percent TNT. RDX on the other hand did result in propagation of detonation for static testing at 5.3 wt percent. This was due to RDX particles settling and forming a trail on the bottom of the pipe. For dynamic testing, RDX concentrations up to 15 wt percent did not exhibit propagation of detonation. Supplemented fuels containing less than the concentration required to support propagation of detonation in the static mode will be used in testing.

Conclusion

The use of waste explosives as supplements to fuel used in steam boilers appears to be a viable means of using for fuel what would otherwise be a difficult to dispose of waste product. Previous work has shown the feasibility of using waste explosives as fuel supplements in terms of safety, hazardous waste elimination and cost. Current project plans are aimed at providing the necessary information to make this technology available for implementation at Army installations. By eliminating a hazardous waste through utilization of its energy potential, effective use is made of what is otherwise a costly environmental problem.

REFERENCES CITED

1. Threshold Limit Values and Biological Exposure Indices for 1988-1989, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1988, pg. 37.

2. Military Explosives, Department of the Army Technical Manual TM 9-1300-214, September, 1984, pg. 8-72.

3. IBID, pg. 8-30.

4. Stationary Air Pollution Source Assesment No. 42-21-0515088, U.S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, Maryland, January 1988, pg. 15.

5. Lackey, M.E., "Utilization of Energetic Materials in an Industrial Combustor", U.S. Army Toxic and Hazardous Materials Agency, Report No. AMXTHE-TE-TR-85003, Aberdeen Proving Ground, Maryland, June 1985, pg. 3.

6. IBID, pg. 2.

7. Lackey, M.E., "Testing to Determine Chemical Stability, Handling Characteristics, and Reactivity of Energetic-Fuel Mixtures", U.S. Army Toxic and Hazardous Materials Agency, Report No. AMXTH-TE-CR-87132, Aberdeen Proving Ground, Maryland, April 1988.

8. IBID, pgs. 7-8.

9. Bradshaw, W.M., "Pilot-Scale Testing of a Fuel Oil-Explosives Cofiring Process for Recovering Energy from Waste Explosives", U.S. Army Toxic and Hazardous Materials Agency, Report No. AMXTH-TE-CR-88272, Aberdeen Proving Ground, Maryland, May 1988, pg. 12.

Reactivity Testing of Explosives Contaminated Soil and Sediment.

by Wayne Sisk

Presentation was taken from: The Final Report to United States Army Toxic and Hazardous Materials Agency, January 1987

SUBJECT: "Testing to Determine Relationship Between Explosive Contaminated Sludge Components and Reactivity," by F.T. Kristoff, T.W. Ewing and D.E. Johnson for Arthur D. Little, Inc.

Reference: USATHAMA Reference AMXTH-TE-CR-86096