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MINUTES OF THE EXPLOSIVES SAFETY SEMINAR (16th), HELD AT THE DIPLOMAT HOTEL, HOLLYWOOD, FLORIDA ON 24-26 SEPTEMBER 1974. VOLUME I

Department of Defense Explosives Safety Board
Washington, D. C.

26 September 1974

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MINUTES

OF THE SIXTEENTH

EXPLOSIVES SAFETY SEMINAR

VOLUME I

DIPLOMAT HOTEL

HOLLYWOOD, FLORIDA

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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.

PF Klein
P. F. KLEIN
Captain, USN
Chairman

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WELCOME ADDRESS

Captain P. F. Klein, USN
Chairman
Department of Defense Explosives Safety Board

Ladies and Gentlemen

It is with considerable pleasure that I welcome you to this 16th Annual Explosives Safety Seminar. In the past, the sessions have been widely acclaimed in the explosives safety community of the United States and I sincerely hope that the results of this Seminar reflect previous standards. It is always our purpose to provide professionally stimulating and informative material for these gatherings. The agenda which we have drawn up for this year is a very good one.

I would also like to particularly welcome several of our professional friends from other countries.

Let me introduce the designated Members of the Explosives Safety Board: from the Department of the Army, Colonel Jerry Aaron; Department of the Navy, Captain Don Knutson; and Department of the Air Force, Colonel Jim Huffman.

The Department of Defense Explosives Safety Board and its Secretariat has completed a very successful twelve months since our last Seminar in which we moved forward to grapple with some of the explosives safety problems present in DoD installations around the world. We have conducted extensive explosives safety surveys of our air bases, ports, ammunition depots and magazines, sites and other munitions related facilities in the Mediterranean countries, Great Britain, Germany, in the East and our states and territories in the West, Hawaii, Guam, and Okinawa. These surveys revealed much that was good and also areas that need improvement. There are many lower ranking military officers and their corresponding lower ranking civil servant grade structure helpers out in the field who are hard working and enthusiastic about their jobs. They need your support - you military and civil servants at the various headquarters and staff levels. I emphatically recommend that you get away from your desks when possible and visit with them to learn their problems and give them your advice. The one thing they lack is the experience which you have gained over many years of first hand association with explosives. We must continue to build our cadre of knowledgeable explosives safety professionals in the Military Services and in the Civil Service.

Now when the visiting inspection team enters your reservation, the tired old cliche "we're only here to help you" usually is heard. I like to think that in our case the old cliche is not so tired. My Secretariat Safety Engineers have several hundred years of personal experience to back up their comments and recommendations. Additionally, and most important, they have been all over the world and have seen first hand similar problems and how they were solved. Your site plans for new construction in zones affected by explosives safety considerations receive a comprehensive review at our offices before they are approved or rejected. The DoD policy is that such construction should receive Explosives Safety Board approval before it is commenced. Therefore complete site plan submittal is a must in order to get a favorable review. We strongly endorse upgrading and improvement at our munitions facilities within reasonable explosives safety criteria and will do whatever is required to bring this about.

The Explosives Safety Board itself held six formal meetings on a variety of subjects during the past twelve months. First and foremost we approved a revised DoD Explosives Safety Standards Manual which is being printed now and will be distributed before the end of the year. It incorporates our newest policy on quantity-distance criteria and hazard group classification and we believe that it is now a better format. Accompanied by the various Board Members, we have climbed in and out of igloos, magazines, ships, and shore stations. I introduced Col Huffman to the six deck configuration of our Navy's destroyer and submarine tenders, of course, with the munitions on the bottom deck. With Col Aaron we prowled the back woods of the Army in Germany and wondered at the marvelous autobahns, especially when we got lost. Capt Knutson has just this month joined the Board and as yet we haven't had an opportunity to get him out in the field. The Board Members have looked at an air defense site, a large naval munitions handling complex, and an Army industrial type munitions facility. They have seen, first hand, the problems involved and as such were then in a better position to arrive at a reasonable decision.

Finally, as Chairman, I have flown over 80,000 miles since our last Seminar in quest of first hand knowledge of all Service's munitions facilities. I have frozen at Korean air bases in winter and sweltered at Tooele Army Depot in summer. Looking back it would appear that my scheduler is 180 degrees out of phase.

I have enjoyed my visits to our DoD installations and have come away convinced of several facts. We need more cross talk between the munitions communities of the various Services out in the field when they are in close proximity. My visits to several areas have engendered this concept. We need to upgrade and improve munitions facilities throughout the DoD Components. Although I attack this problem from the explosives safety viewpoint, the end result is a better operational capability for our Armed Forces along with a protection of our investment of millions of dollars in munitions of all types.

Summary Report

ESKIMO III TEST

Dr. T. A. Zaker
Department of Defense Explosives Safety Board
Washington, D. C.

ESKIMO III was the third in a series of full-scale tests of earth-covered magazines sponsored by the Department of Defense Explosives Safety Board and conducted at the Naval Weapons Center, China Lake, California. The test was executed on 12 June 1974. Principal findings have been summarized in a motion picture film report describing the test.

Background

The ESKIMO series of tests is directed primarily toward determining minimum separation distances required between earth-covered magazines, or igloos, at various orientations to one another. Intermagazine distances are intended to provide protection against explosion communication between magazines.

In ESKIMO I, minimum safe distances were determined for situations in which the headwall of a magazine faces the earth-covered side or rear of another (1)*. The explosion source in ESKIMO I consisted of an igloo filled with TNT-loaded 155mm projectiles. The performance of the one headwall design tested, while adequate at the distances determined in ESKIMO I, was considered to warrant confirmation at the same scaled distances from a still larger explosion source.

In ESKIMO II, several different door and headwall combinations, and modifications to those designs, were exposed to face-on explosive blast loading from an earth-barricaded aboveground stack of 750-lb bombs (2). The stack was designed to produce loadings equivalent to those in exposures at the required front-to-rear distance from an igloo containing 500,000 pounds of explosives, the most permitted in a single magazine. Strong directional blast effects were observed from the explosion source in ESKIMO II, resulting in impulse loads up to twice the design level on the headwalls exposed. While straightforward modifications to existing construction did not appear to be effective, a newly designed single-leaf sliding door withstood the blast very well. In combination with a sufficiently strong headwall, the door can be expected to provide a high degree of protection to stored ammunition.

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*Numbers in parentheses designate references.

Objectives and Layout

One of the test structures remaining from ESKIMO II was a corrugated steel arch magazine having a noncircular cross-section better suited to storage of unitized loads of rectangular block shape than is the semicircular arch. This igloo had been built to the full 80-ft length of a standard earth-covered magazine, anticipating an eventual test of it under lateral explosive blast loading. A principal aim of ESKIMO III was the full-scale qualification of the noncircular arch design at the minimum side-to-side spacing determined by tests in 1962-63 of semicircular steel arch magazines.

A new donor igloo, and a parallel acceptor flanking the donor on the side opposite the oval arch structure, were built with light-gage, deep-corrugated semicircular steel arch sections, a design recommended by one of the Military Departments for reasons of economy. In the process of qualifying these igloo designs, ESKIMO III was expected to demonstrate the effectiveness of earth cover in preventing explosion communication, and in suppressing blast effects from explosion of the donor charge, which consisted of 350,000 pounds of tritonal in 750-lb bombs. The layout of test magazines is shown in the accompanying figure.

Near-field instrumentation included pressure gages and motion transducers to determine, in considerable quantitative detail, the close-in blast loading and the dynamic response of the arch structures. The dynamic response of the arches flanking the donor magazine was observed by means of accelerometers, linear displacement transducers, and telescoping rod-and-pipe scratch gages at the mid-and quarter-sections of each structure.

Pressure gages were installed in the headwalls of the target igloos and at the ground surface immediately forward of each igloo. Other gages were emplaced at the surface of the earth cover over the midsections of the flanking igloos A and B in the accompanying figure, and to the rear of the donor at three positions bracketing the currently permitted front-to-rear magazine distance established in ESKIMO I.

Magazines shown in the figure remaining from previous tests and rebuilt for ESKIMO III permitted evaluation of intermagazine distances for orientations other than side-to-side. Igloo C, representing a front-to-side exposure at the minimum distance permitted for this orientation, was fitted with the single-leaf sliding door first designed for ESKIMO II. Notwithstanding some degree of unobstructed headwall-to-headwall exposure, Igloo D is at about twice the minimum side-to-side distance for which it qualifies under present standards. Igloo E represents a barricaded front-to-front exposure at a distance about two-thirds that permitted by standards for this orientation.

Wood frame cubicles with large glass windows were positioned at several distances in the far field, as in ESKIMO II (2). The cubicles, each 9 ft

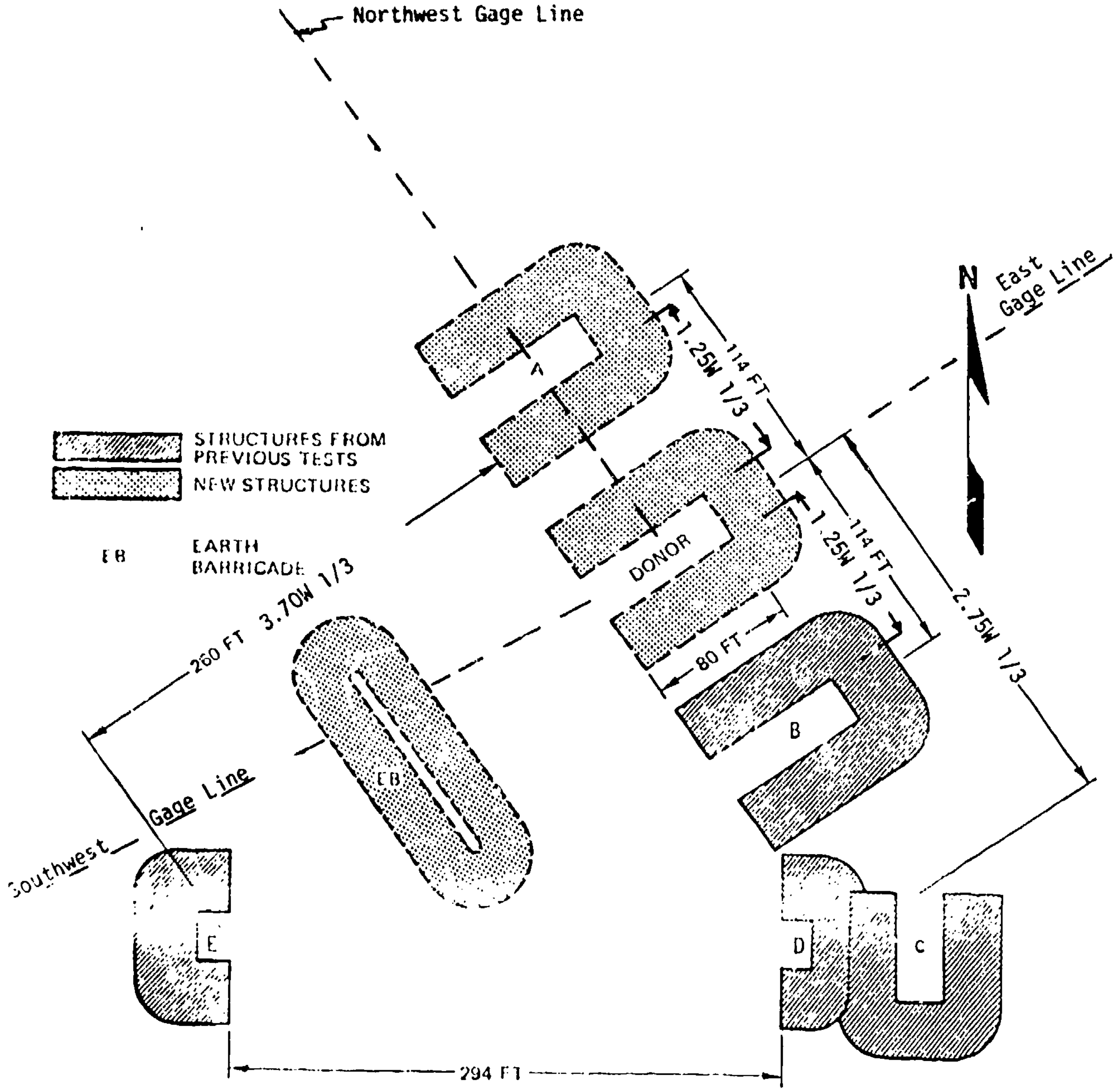


Figure 1 ESKIMO III Test Area Layout

on an edge, were placed in sets of three at the U.S. and NATO inhabited building distances, and at half again the NATO distance. A tenth cubicle, housing an anthropomorphic dummy, was located at the U.S. distance. In the other nine, foamed polystyrene boards were fastened to the rear wall to trap glass fragments for later analysis. Highway vehicles were positioned at the U.S. and NATO public traffic route distances, and at the NATO inhabited building distance. An anthropomorphic dummy was seated in one of the automobiles at the U.S. distance.

A B-29 airplane, previously exposed to low levels of blast in ESKIMO I and II, was located at about one-third the required distance required by standards for passenger aircraft.

Blast pressure measurements were made using self-recording gages placed in pairs at locations in the far field ranging out to the U.S. inhabited building distance. Motion picture coverage was extensive, including telephotography from ground stations to the south, west, and northwest, and coverage of door and headwall movement by cameras in each of the target magazines.

Film Report

A 22-minute, 16mm sound motion picture produced by the Naval Weapons Center, China Lake was shown.

Results and Implications

ESKIMO III demonstrated at full scale the effectiveness of both the noncircular structural steel arch igloo and the light gage, deep corrugated circular arch in resisting explosive blast forces at the minimum side-to-side distance permitted by standards. Significantly greater arch deformation occurred in the latter case, however.

The single-leaf sliding door appears to provide ample protection to magazine contents at the presently permitted front-to-side distance. On the other hand, no significant reduction of the present barricaded front-to-front separation seems justified.

The levels of damage to windows at the U.S. inhabited building distance, and to vehicles at the U.S. highway distance, appear acceptable and consistent with the protection afforded against smaller quantities than that involved in ESKIMO III.

Preliminary analysis of the pressure records from near field gages has confirmed that the earth cover on the explosion source reduces drastically the close-in peak pressure and the impulse as well. This result has important implications for storage arrangements involving both aboveground and earth-covered magazines.

The effect of earth cover in suppressing close-in blast is being investigated in detail at a small scale in a program of model tests sponsored by the Board at the U.S. Army Ballistic Research Laboratories. Also being conducted under the Board's auspices, in an effort to exploit the full-scale results of the ESKIMO series, is a finite-element numerical analysis of igloo headwall and door response to blast loading. This will eventually provide a tool for evaluating the performance of alternate designs, with less reliance on full-scale testing. These developments, as well as the data analysis for ESKIMO III accomplished thus far, are reported in specialist sessions at this Seminar.

A fourth test in the ESKIMO series is planned as a final confirmation of the effectiveness of the single-leaf sliding door at the minimum permitted front-to-rear magazine distance. In this test, the front of the noncircular arch igloo will be exposed face-on to blast from an aboveground explosive charge. Measurements to the rear of the donor magazine in ESKIMO III indicate that the free-field pressure and impulse observed there are the same as would be produced by a 37,000-lb TNT hemisphere about 150 ft away. Thus the near-field blast from ESKIMO III can apparently be simulated by an aboveground charge of little more than one-tenth the explosive quantity.

References

1. F. H. Weals, "ESKIMO I Magazine Separation," NWC TP 5430, April 1973.

2. T. A. Zaker, "ESKIMO II: Summary of Results and Damage Observations," Minutes, 15th DDESB Seminar, 139-148, September 1973.

AMERICAN DEFENSE PREPAREDNESS ASSOCIATION AND ITS RELATION TO NATIONAL SECURITY

Mr. John Alison
Vice President
Northrop Corporation
Alexandria, Virginia

I AM GRATEFUL FOR THIS OPPORTUNITY TO PARTICIPATE IN YOUR MEETING. THE ATTENTION GIVEN TO EXPLOSIVES SAFETY BY BOTH INDUSTRY AND GOVERNMENT AND THE LARGE ATTENDANCE AT THIS SEMINAR IS EVIDENCE THAT THIS IS AN IMPORTANT TECHNICAL GATHERING. IT IS THE KIND OF MEETING TO WHICH ADPA HAS TRADITIONALLY GIVEN ITS SUPPORT.

THE OBJECTIVE OF ADPA IS MILITARY AND INDUSTRIAL PREPAREDNESS OF THE UNITED STATES. WE WERE ORGANIZED AS THE ARMY ORDNANCE ASSOCIATION IN 1919 BY CITIZENS WHO HAD BEEN CALLED TO WASHINGTON BY PRESIDENT WILSON TO MOBILIZE AMERICAN INDUSTRY IN SUPPORT OF WORLD WAR I. THESE PUBLIC MINDED CIVILIANS WERE SHOCKED BY THE ABSENCE OF MOBILIZATION PLANNING AND INDUSTRIAL READINESS. THEIR GOAL WAS TO AVOID FUTURE COSTLY AND INEFFICIENT MOBILIZATIONS BY WORKING WITH GOVERNMENT, INDUSTRY AND THE COMMUNITY AT LARGE TO FOSTER DEFENSE READINESS IN TIME OF PEACE. AFTER WORLD WAR II WHEN THE DEFENSE FORCES WERE UNIFIED UNDER THE DEPARTMENT OF DEFENSE, THE NAME OF THE ORGANIZATION WAS CHANGED TO THE AMERICAN ORDNANCE ASSOCIATION, AND RECENTLY, THE NAME WAS CHANGED TO THE AMERICAN DEFENSE PREPAREDNESS

ASSOCIATION. ALTHOUGH THIS DESIGNATION IS LONGER THAN WE LIKE, IT DOES ACCURATELY REFLECT THE PURPOSE OF THE ASSOCIATION.

AS PRESIDENT OF ADPA I WAS FREQUENTLY CALLED UPON TO TALK TO OUR CHAPTERS AND TO OUTSIDE GROUPS INTERESTED IN NATIONAL DEFENSE. MANY OF THE OCCASIONS WERE DINNER MEETINGS AT WHICH LADIES AND GUESTS, NOT INTIMATELY FAMILIAR WITH THE PROBLEMS OF DEFENSE, WERE PRESENT. I WELCOMED THESE OPPORTUNITIES. WOMEN HAVE A HIGH STAKE IN OUR NATION'S DEFENSE. THEY GIVE THEIR HUSBANDS AND SONS IN TIME OF WAR, AND SHARE THE BURDEN OF PAYING FOR DEFENSE IN TIME OF PEACE. THEY PROFOUNDLY AFFECT THE COLLECTIVE THOUGHT OF DEMOCRACY. WE HAVE A MOST IMPORTANT MESSAGE FOR THEM AND FOR ALL WHO ARE SERIOUSLY INTERESTED IN REDUCING THE DANGERS OF WAR. TOO OFTEN OUR COMMUNICATION IS LOST BECAUSE WE ASSUME THAT WHAT IS OBVIOUS TO US MUST BE OVBIOUS TO ALL. NUMBERS AND STATISTICS DON'T CARRY THE MESSAGE. IN THE AGE OF MEGATONS, DEFENSE STATISTICS LOSE THEIR MEANING FOR MOST AMERICANS NOT DIRECTLY CONNECTED WITH THE BUSINESS OF DEFENSE.

IN TRYING TO COMMUNICATE THE IMPORTANCE OF DEFENSE TO THE AVERAGE AMERICAN, I FIND THE MOST EFFECTIVE APPROACH

IS TO REVIEW HOW WE GOT INTO OUR WARS; WHAT THEY COST US; AND THEN RELATE THIS TO POSSIBLE WAYS TO STAY OUT OF THE NEXT ONE. THERE ARE MANY COMPELLING EXAMPLES STILL FRESH IN THE MINDS OF MANY AMERICANS. THE CONSEQUENCES OF FAILURE MUST BE TOLD IN TERMS THAT THE NON-DEFENSE CIVILIAN WILL FIND RELEVANT. MY EFFORTS TO DO THIS MAY BE OF INTEREST TO YOU.

THERE ARE SEVERAL PRINCIPLE INGREDIENTS WHICH GO TOGETHER TO MAKE AN EFFECTIVE DEFENSE ESTABLISHMENT. THE REQUIREMENT FOR TECHNICAL EXCELLENCE NEEDS LITTLE EXPLANATION. HOWEVER, ANOTHER INGREDIENT THAT SUPERCEDES TECHNICAL EXCELLENCE IS MONEY, AND THIS IS A MATTER FOR CONSTANT DISCUSSION. WITHOUT IT WE CAN'T DO NECESSARY RESEARCH AND DEVELOPMENT; PUT WEAPONS INTO PRODUCTION; OR TRAIN THE PEOPLE NECESSARY TO MANAGE AND SUPPORT OUR COMPLEX DEFENSE ESTABLISHMENT. DEFENSE SPENDING IS NEVER POPULAR UNTIL THE NEED BECOMES A REALITY.

WE ARE LIVING IN AN ERA OF POLITICAL CONFUSION AND FINANCIAL UNCERTAINTY. THERE WILL BE EFFORTS TO REDUCE MILITARY SPENDING IN FAVOR OF MAINTAINING SOCIAL EXPENDITURES WHICH NOW EXCEED THOSE FOR DEFENSE IN OUR NATIONAL BUDGET. AS RUSSIA INCREASES HER MILITARY EXPENDITURES WE MUST REMIND OURSELVES THAT HISTORY HOLDS FRIGHTENING

LESSONS OF WHAT HAPPENS WHEN FREE MEN REDUCE THEIR SPENDING FOR ARMS WHILE A DICTATOR IS INCREASING HIS.

NO ONE CAN ARGUE AGAINST THRIFT IN OUR NATIONAL ACCOUNTS. IT HAS NEVER BEEN NEEDED MORE THAN IT IS NEEDED TODAY. IN ORDERING PRIORITIES HOWEVER, THIS NATION SHOULD UNDERSTAND THAT OUR PROSPERITY DEPENDS ON BEING ABLE TO DEFEND IT IN A WORLD WHERE ARMS ARE STILL THE FINAL ARBITER IN NATIONAL DISPUTES.

ADPA HAS BEEN IN BUSINESS FOR MORE THAN 50 YEARS AND HISTORY HAS GIVEN US REASON TO BELIEVE THAT MILITARY AND INDUSTRIAL PREPAREDNESS IS AMERICA'S SUREST GUARANTEE FOR LASTING PEACE. THERE ARE MANY HOWEVER WHO SAY THAT PREPAREDNESS INCREASES TENSIONS AND LEADS TO WARS. THIS FINDS EMOTIONAL POPULARITY IN A NATION SICK OF CONFLICT AND TIRED OF THE BURDEN OF TAXES TO SUPPORT A MILITARY ESTABLISHMENT. IN A RECENT BOOK, SUPREME COURT JUSTICE WILLIAM O. DOUGLAS STATED, "WE KNOW THAT PREPAREDNESS AND THE ARMAMENT RACE INEVITABLY LEAD TO WAR. THUS IT EVER HAS BEEN AND EVER WILL BE. ARMAMENTS ARE NO MORE A DETERRENT TO WAR THAN THE DEATH SENTENCE IS TO MURDER".

I DON'T KNOW HOW THE JUSTICE ARRIVES AT HIS CONCLUSION. HISTORY CERTAINLY REFUTES HIS POINT OF VIEW, AND WE DON'T HAVE TO GO VERY FAR BACK IN OUR HISTORICAL REFERENCES

TO REACH THE OPPOSITE CONCLUSION ---- THAT UNITED STATES DISARMAMENT HAS BEEN A SUBSTANTIAL CONTRIBUTING FACTOR TO WARS IN OUR TIME. A LONGING FOR PEACE WHICH DOES NOT TAKE INTO ACCOUNT THE FACTS OF LIFE CAN CAUSE MUCH HUMAN SUFFERING, ---- FOR IT INVITES AGGRESSION.

PRIOR TO WORLD WAR I, WOODROW WILSON WAS ELECTED PRESIDENT ON A PLATFORM WHICH HELD THE PROMISE OF KEEPING OUR COUNTRY OUT OF A WAR WHICH WAS RAGING IN EUROPE. WILSON WAS A LIBERAL AND ENLIGHTENED PRESIDENT, BUT UNDER HIS LEADERSHIP THE UNITED STATES DID NOT POSSESS EVEN ONE FULL-STRENGTH DIVISION. WE HAD NO AIR FORCE, AND OUR ARTILLERY COULD NOT MATCH THE EXCELLENCE OF GERMAN WEAPONS.

HOWEVER, WHEN DIPLOMACY FAILED, THIS DID NOT PREVENT OUR PRESIDENT FROM SENDING THE YOUTH OF THIS NATION ----- INADEQUATELY PREPARED AND INADEQUATELY LED ---- TO FIGHT IN A WAR FROM WHICH THOUSANDS DID NOT RETURN.

THEN CAME WORLD WAR II. ALTHOUGH A BIT TOO YOUNG FOR WORLD WAR I, I CAN ATTEST FIRST HAND TO OUR LACK OF PREPAREDNESS FOR WORLD WAR II. IF OUR COUNTRY HAD NOT BEEN MANUFACTURING AND SELLING ARMS TO COUNTRIES WHICH WERE LATER TO BECOME OUR ALLIES, OUR LACK OF PREPAREDNESS WOULD HAVE BEEN ALMOST COMPLETE.

WHEN DIPLOMACY FAILED AGAIN, OUR LACK OF PREPAREDNESS DID NOT DETER ANOTHER PRESIDENT ---- WHO HAD ALSO CAMPAIGNED ON A PLATFORM OF PEACE ----FROM CALLING ON THE YOUTH OF AMERICA TO GO OVERSEAS AND FIGHT. ---- WHO CAN FORGET PRESIDENT ROOSEVELT'S RINGING DENOUNCEMENT OF WAR AND HIS PROMISE AGAIN, AND AGAIN, AND AGAIN, NOT TO SEND THE SONS OF AMERICA OVERSEAS TO FIGHT.

I HAPPENED TO BE ONE OF THOSE WHO WAS ALREADY THERE WHEN IT STARTED. NOT ONLY DID I GO INTO COMBAT WITH INADEQUATE WEAPONS, BUT I DIDN'T EVEN HAVE A DOCTOR TO MINISTER TO MY TROOPS. THE FIRST TIME I WAS SHOT DOWN, I HAD TO FIND A MISSIONARY TO SEW ME UP. I SPENT THE FIRST WINTER OF THE WAR --- WITHOUT ONE WOOL UNIFORM FOR ANY OF MY TROOPS. WE POSSESSED THIRTEEN SWEATERS AMONG APPROXIMATELY 70 AMERICANS WHO WERE WITH MY ADVANCE UNIT, AND I'M NOT EXAGGERATING WHEN I SAY WE TOOK TURNS WEARING THEM.

WORLD WAR II WENT BADLY FOR US FOR A WHILE, BUT THEN THE INDUSTRIAL MIGHT OF OUR COUNTRY BEGAN TO TURN OUT THE SINEWS OF WAR ---- AND WE WON! BUT NOT BEFORE MANY YOUNG AMERICANS HAD PAID FOR OUR UNPREPAREDNESS WITH THEIR LIVES.

WHERE WAS THE ARMS RACE BEFORE WORLD WAR I, OR BEFORE WORLD WAR II? WE WEREN'T EVEN ON THE TRACK. FRANCE

HAD BUILT A MAGINOT LINE DEEP IN THE GROUND TO DEFEND ITSELF, BUT NEITHER BRITAIN NOR FRANCE WERE PREPARED TO MEET A GERMANY THAT WAS ARMED TO THE TEETH. THE RECORDS SHOW THAT 15 MILLION MILITARY MEN WERE KILLED IN WORLD WAR II, AND SEVERAL TIMES THAT NUMBER OF CIVILIANS LOST THEIR LIVES IN THAT TERRIBLE CONFLICT.

IF AMERICA HAD BEEN IN A STATE OF READINESS THERE IS THE POSSIBILITY THAT WORLD WAR II MAY NEVER HAVE BEEN FOUGHT. THERE IS CERTAINLY NO QUESTION THAT IF WE HAD HAD THE ARMS AND LEADERSHIP AT THE BEGINNING OF THAT WAR ---- THAT WE POSSESSED ONLY TWO YEARS LATER ----- WE WOULD HAVE ENDED IT IN HALF THE TIME WITH A SAVING OF BILLIONS IN NATIONAL TREASURE --- INSTEAD WE PAID AN EXHORBITANT PRICE TO CREATE AN ARMY IN THE SHORTEST POSSIBLE TIME. AND THOUSANDS OF AMERICANS --- AND OUR ALLIES LOST THEIR LIVES WHILE THEY HELD THE LINE WAITING FOR ARMS NECESSARY TO FIGHT AN ENEMY WHO WAS PREPARED AND WHO THOUGHT HE COULD WIN BEFORE THE FREE WORLD COULD ORGANIZE AN OPPOSITION.

AFTER THE WAR I BECAME ACQUAINTED WITH THE SWEDISH INDUSTRIALIST, AXEL WENNERGREN. HE WAS WELL ACQUAINTED WITH THE TOP NAZIS BECAUSE HE HAD EXTENSIVE BUSINESS INTERESTS IN GERMANY PRIOR TO WORLD WAR II AND WAS

BLACKLISTED BY THE UNITED STATES FOR THESE ASSOCIATIONS. HE TOLD ME THAT DURING THE GERMAN BUILD UP, HE HAD ADVISED HERMANN GOERING NOT TO INITIATE A WAR AS THE UNITED STATES WOULD EVENTUALLY COME IN AND OUR INDUSTRIAL MIGHT WOULD PRODUCE THE ARMS WHICH WOULD RESULT IN GERMANY'S DEFEAT. DR. WENNERGREN SAID THAT GOERING LAUGHED AND CALLOUSLY STATED THAT - "GERMANY WOULD HAVE THE WAR OVER AND DONE WITH BEFORE THE WHEELS OF AMERICAN INDUSTRY COULD BEGIN TO TURN."

AFTER WORLD WAR II, OUR COUNTRY DISBANDED THE GREATEST ARMED FORCE THE WORLD HAD EVER SEEN. WITH THE EXCEPTION OF A LIMITED NUMBER OF NUCLEAR WEAPONS, WE DISARMED OUR NATION AND THE TIDES OF HISTORY CARRIED US ALONG FOR 6 YEARS BEFORE DIPLOMACY FAILED AGAIN ---- AND AGAIN, A PRESIDENT OF THE UNITED STATES SENT AMERICANS ABROAD TO FIGHT. THOUSANDS OF OUR YOUNG MEN DIED IN KOREA BEFORE WE COULD BRING ENOUGH MILITARY PRESSURE TO BEAR TO FORCE THE ENEMY TO THE CONFERENCE TABLE.

PRIOR TO THE KOREAN WAR, WE REDUCED OUR DEFENSE BUDGET TO LESS THAN 14 BILLION DOLLARS, AND THE SECRETARY OF DEFENSE STATED THAT WE WOULD REDUCE IT EVEN FURTHER. WITHIN A MATTER OF MONTHS, WE WERE AT WAR AGAIN. WE HAD

NO TACTICAL AIR COMMAND, AND OUR ARMY WAS EQUIPPED WITH WORLD WAR II WEAPONS WHICH WERE NO MATCH FOR EVEN THE NORTH KOREANS WHO HAD BEEN EQUIPPED BY THE RUSSIANS WITH MODERN WEAPONS OF WAR.

ONCE AGAIN OUR ARMS FACTORIES WERE GEARED FOR PRODUCTION, BUT WEAPONS DID NOT REACH OUR MEN IN THE FIELD UNTIL MANY LIVES HAD BEEN SACRIFICED ON THE ALTAR OF AMERICAN UNPREPAREDNESS.

AFTER KOREA, OUR NATION CREATED A POWERFUL NUCLEAR FORCE, AND OUR FOREIGN POLICY WAS BUILT ON A FOUNDATION OF MASSIVE NUCLEAR DETERRENCE AGAINST ANY AGGRESSOR. THERE IS NO DOUBT THAT THIS NUCLEAR POWER HAS BEEN A DETERRENT TO MAJOR EXCURSIONS BY THE COMMUNIST WORLD AGAINST FREE NATIONS AND HAS PROTECTED US AND OUR ALLIES FROM NUCLEAR BLACKMAIL. IN THE FACE OF THIS POWER, THE COMMUNISTS HAVE BEEN UNABLE TO LAUNCH FRONTAL ATTACKS ON THE FREE WORLD, SO THEY HAVE DEVELOPED WHAT THEY CHOOSE TO CALL "WARS OF NATIONAL LIBERATION". DIPLOMATICALLY, WE DON'T SEEM TO KNOW HOW TO COPE WITH THIS COMMUNIST TACTIC, EXCEPT TO SEND THOUSANDS OF YOUNG AMERICANS OVERSEAS TO FIGHT.

ALTHOUGH OUR COUNTRY IN 1964 POSSESSED MORE MILITARY MIGHT THAN EVER BEFORE IN OUR HISTORY, WE WERE NOT PREPARED

TO USE IT NOR TO FIGHT THE KIND OF WAR THAT OUR TROOPS WERE DIRECTED TO WAGE IN THE JUNGLES AND SWAMPS OF VIETNAM.

THE PRICE OF VIETNAM WAS HIGH. WE DID IT THE HARD WAY. WE NOT ONLY SPENT OUR MONEY AND SACRIFICED OUR SONS BUT WE DIVIDED OUR COUNTRY AS IT HAS NEVER BEEN DIVIDED BEFORE.

* * * *

THIS HAS BEEN AN OVER-SIMPLIFIED COMMENTARY, HOWEVER IT BRINGS ME TO THE FOLLOWING OBSERVATIONS:

WARS ARE NOT CAUSED BY ARMS RACES. WARS ARE CAUSED BY PEOPLE WHO WANT WHAT THEIR NEIGHBOR HAS AND FEEL THAT THEY CAN TAKE IT FROM HIM BECAUSE HE IS EITHER UNPREPARED OR UNWILLING TO DEFEND HIMSELF. IF THIS IS TRUE, THEN A FAILURE TO JOIN THE ARMS RACE BECOMES A PRIMARY CAUSE OF WAR. DISARMAMENT HAS NEVER KEPT THE UNITED STATES OUT OF WAR, AND THE PRICE OF UNPREPAREDNESS IS HIGH WHETHER MEASURED IN DOLLARS OR THE LIVES OF OUR CHILDREN.

FOY KOHLER, OUR RETIRED AMBASSADOR TO RUSSIA WHO IS BOTH A DIPLOMAT AND A SCHOLAR MAY HAVE GIVEN US A CLUE AS TO WHY THIS COUNTRY CONTINUES TO GET INTO WARS. HE SAID RECENTLY, "A DIPLOMAT IS NO BETTER THAN THE POWER BEHIND HIM." AFTER EACH OF OUR WARS THIS NATION HAS DISBANDED A MIGHTY MILITARY FORCE. COULD IT BE THAT WE

DELIBERATELY STRIP OUR DIPLOMACY OF ITS POWER AND DOOM IT TO FAILURE? IF SO, NEGLECTING OUR ARMS NOW WHILE RUSSIA IS EXPANDING ITS MILITARY STRENGTH IS A GRAVE MISCALCULATION.

PEACE AT ANY PRICE IS A DANGEROUS COMMODITY. WE SHOULD HAVE LEARNED THIS FROM THE AGGRESSIONS OF HITLER, MUSSOLINI AND THE MILITARY DICTATORS OF JAPAN. HOWEVER, THE NEW DICTATORSHIPS, MASQUERADING UNDER THE BANNER OF "PEOPLE'S DEMOCRACY" HAVE US CONFUSED. PERHAPS IT'S NOT WHAT WE DON'T UNDERSTAND ---- PERHAPS WE ARE JUST HOPING THAT THIS NEW NIGHTMARE WILL GO AWAY. HOWEVER WE SHOULD REMEMBER THAT IT WAS THE DEMOCRATIC REPUBLIC OF NORTH KOREA THAT ATTACKED THE SOUTH KOREANS WITH RUSSIAN ARMS. IT IS THE DEMOCRATIC REPUBLIC OF NORTH VIET NAM WHICH IS STILL ATTACKING SOUTH VIETNAM WITH ARMS MADE IN THE COMMUNIST WORLD, AND EGYPT AND SYRIA HAVE BEEN DEDICATED TO THE ELIMINATION OF ISRAEL WITH ARMS MADE IN THE SOVIET UNION.

GENERALS WIN OUR WARS AND STATESMEN LOSE THE PEACE. THIS OVER-SIMPLIFICATION CAN LEAD TO THE CONCLUSION THAT GENERALS ARE SMARTER THAN DIPLOMATS. THE TRUTH IS THAT THE ART OF STATESMANSHIP IS MUCH MORE DIFFICULT THAN WINNING BATTLES. IT TAKES TWO TO MAKE PEACE, BUT ONLY ONE

TO MAKE WAR. WHEN DICTATORS ADOPT AN EXPANSIONIST POLICY BACKED BY THE FORCE OF ARMS, SOMEBODY GETS CAUGHT WHETHER THEY LIKE IT OR NOT. GENERALS AND ARMIES ARE THE TOOLS OF STATESMEN. DECIDING WHEN TO USE THEM IS A HEAVY RESPONSIBILITY.

OUR NATION BELIEVES FERVENTLY IN A STABLE AND PEACEFUL WORLD, BUT WE AREN'T ABLE TO AVOID THE WORLD'S WARLIKE ACTIVITIES. I HAVE INTELLECTUAL FRIENDS WHO BELIEVE WE CAN KEEP OUT OF TROUBLE IF ONLY WE WILL STAY OUT OF OTHER PEOPLES QUARRELS. THERE ARE THOSE OPPOSED TO FIGHTING AS A MATTER OF PRINCIPLE. THESE ATTITUDES IGNORE THE REALITY OF THE WORLD WE LIVE IN. IN SPITE OF THE RHETORIC THERE IS A POINT IN MAN'S AFFAIRS WHEN HE WILL FIGHT.

PRIOR TO WORLD WAR II THE OXFORD UNION PASSED A RESOLUTION NOT TO FIGHT FOR KING AND COUNTRY. HOWEVER WHEN THE WORLD GAVE THEM A HITLER TO HATE, THEY FOUGHT AND DIED JUST LIKE LESSER MEN.

THE PRESIDENT AND SECRETARY OF DEFENSE IN POSTURE STATEMENTS TO CONGRESS, HAVE POINTED OUT THAT THE SOVIET UNION IS RAPIDLY EXPANDING ITS MILITARY FORCES. THEY NOT ONLY HAVE PASSED US IN THE NUMBERS OF INTERCONTINENTAL MISSILES, SUBMARINES AND SHIPS WHICH THEY POSSESS, BUT THEY

ARE RAPIDLY IMPROVING THE ADVANTAGE WHICH THEY NOW HOLD. THEY ARE SPENDING MORE OF THEIR GROSS NATIONAL PRODUCT ON ARMS THAN WE ARE, AND THEY ARE INVESTING MORE IN THE DEVELOPMENT OF FUTURE WEAPONS THAN WE ARE.

AFTER WORLD WAR II, GENERAL GEORGE C. KENNEY WAS THE SENIOR UNITED STATES MILITARY REPRESENTATIVE AT THE UNITED NATIONS. GENERAL KENNEY IS A GREGARIOUS AND INTELLIGENT MAN AND ALWAYS MADE IT A POINT TO KNOW HIS PEERS. HE TOLD ME THAT IN THE COURSE OF HIS OFFICIAL DUTIES AND SOCIAL CONTACTS AT THE UNITED NATIONS, HE GOT TO KNOW THE SENIOR RUSSIAN MILITARY OFFICER QUITE WELL. ONCE OVER COCKTAILS AND DURING A MOMENT OF INFORMALITY, HIS RUSSIAN COUNTERPART REMINDED HIM THAT ALTHOUGH THE UNITED STATES POSSESSED THE ATOM BOMB, WE DIDN'T KNOW HOW TO USE IT. HE STATED THAT THE TIME WOULD COME WHEN RUSSIA WOULD ALSO POSSESS SUCH WEAPONS, AND SAID, "REMEMBER GENERAL KENNEY, WE WILL KNOW HOW TO USE THEM".

WE ARE NOW APPROACHING THE TIME WHEN RUSSIA NOT ONLY HAS MORE NUCLEAR WEAPONS, BUT BIGGER ONES THAN WE DO. IT REMAINS TO BE SEEN WHAT THE RUSSIANS INTEND TO DO WITH ALL OF THIS NUCLEAR MIGHT. SUPPORTED BY RUSSIAN ARMS THE ACTIONS OF BELLIGERENTS IN THE MIDDLE EAST, SOUTHEAST

ASIA AND KOREA HOLD LITTLE ENCOURAGEMENT. THE RUSSIANS HAVE NOW ENTERED THE INDIAN OCEAN, AND INDIA ONCE ALLIED WITH THE WEST, IS NOW EQUIPPED WITH RUSSIAN WEAPONS PLUS A NUCLEAR CAPABILITY.

IN A SANE AND RESPONSIBLE WORLD, NUCLEAR ARMAMENT IS AS UNBELIEVABLE AS THE RANTING, RAVING AND BOASTING OF ADOLPH HITLER PRIOR TO WORLD WAR II. BUT HITLER WAS REAL, AND SO IS THE NUCLEAR ARMS RACE --- HISTORY TELLS US WE HAD BETTER WIN IT.

I HAVE TWO SONS AND THE LAST THING IN THE WORLD THAT I WANT TO SEE FOR THEM IS A WAR, ---- NUCLEAR OR OTHERWISE, IN WHICH THEY WILL HAVE TO PARTICIPATE. I WISH THAT THOSE WHO CRY LOUDLY FOR PEACE, COULD ASSURE US THAT NO AMERICAN PRESIDENT WILL EVER AGAIN CALL ON OUR YOUNG MEN TO GO OVERSEAS AND FIGHT. UNTIL THIS IS DONE HOWEVER, WE CAN'T TAKE THE CHANCE THAT THE YOUTH OF THIS GENERATION WILL BE ASKED TO MARCH INTO BATTLE INADEQUATELY ARMED AND LED BY AMATEURS. THE STAKES ARE NOT ONLY THEIR LIVES ---- BUT, OUR SURVIVAL.

THE NATO DRESTC TRIAL SERIES

Bryan G. Laidlaw

Defence Research Establishment Suffield
Ralston, Alberta, Canada

INTRODUCTION

The topic of this session is the NATO DRESTC Test Series results. This series of four trials, a one-ton calibration shot and three fifty-five ton shots, was carried out this past summer at the Defence Research Establishment Suffield. The code name DRESTC, is a contraction of the titles Defence Research Establishment Suffield (DRES) and the Explosive Storage and Transportation Committee (ESTC) of Great Britain.

DRES is a Department of National Defence Research Establishment with facilities consisting of a central laboratory and several smaller laboratories having a total floor area of 120,000 square feet and a field test range of 220 square miles. DRES is located 150 miles south-east of Calgary, Alberta, Canada (Fig. 1). As you can see, our test area is part of the 1000 square miles of barren, semi-arid prairie known as the Suffield Military Reserve. The purpose of DRES is to conduct applied research in a number of fields of defence interest. Under the auspices of the military engineering program, a number of free-field shock and blast trials which ranged in charge size from 8 lbs to 500 tons have been carried out at DRES since 1956. In a related area, research assistance has been given to the Department of Energy, Mines and Resources, Explosives Division to evaluate the hazards of slurry explosives when destroyed by fire in a simulated transportation accident environment.

Through the Department's affiliation with NATO Group AC/258, which is a group of experts dealing with the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives, a proposal evolved that a trial series would be sponsored and conducted by the United Kingdom and Canada with DRES, due to its background and facilities, chosen as the trial site. The office of the Director General of Ammunition at National Defence Headquarters, Ottawa, Canada, co-ordinated the Canadian and United States participation.

The overall objective of this series was to obtain scientific data that would allow a reduction in the storage separation distance requirements for NATO Hazard Class 5 explosive magazine storage, which had been indicated as possible in earlier results of smaller scale tests carried out by the British.

The current NATO inside quantity distances, that is, separation between stacks of explosive or between magazines containing explosives, are based upon the results of ESTC trials carried out just after World War II in Germany.

PROCEDURE

The four ground zeros were within 2000 feet of each other (Fig. 2). The basic soil characteristics, namely soil composed of soft silts and fine sands, were the same for all trials.

DRESTC 1 was a one-ton calibration trial for the series and provided information and data so that the planning for the larger trials could be finalized.

On DRESTC 2, 3 and 4, the donor charge had an earthwork barricade on three sides. (Slide 1) The double-sloped traverses, with regard to key dimensions, were constructed in compliance with NATO specifications. It should be noted that the particular closeness of the traverse to the donor charge for DRESTC 2 was by design. There is an approximate 3 foot space between the toe of the traverse and the stack. (Slide 2) DRESTC 3 and 4 had a 25 foot spacing between the charge and the toe of the traverse. The traverses were constructed in November 1973 to allow them to settle. The only compaction they received was from the machinery used in the building. After settling, the traverses still obeyed the "two degree rule" necessary to contain high velocity projectiles originating in the donor.

DRESTC 2 and 3 donor charges were constructed using wooden-cased palletized UK tetrytol demolition slabs which had been in storage in West Germany. An interesting discovery was made when we looked into a sampling of these cases in order to determine the composition of the donor stack: the 1 lb demolition charges weighed only 0.84 lb. As a result, additional pallets of tetrytol slabs were added to the charge to bring the weight up to fifty-five tons, which is 50 metric tons. As the Canadian inventory contained no demolition charges stored in wooden boxes, DRESTC 4 trial used 11.25 tons of metal clad TNT demolition charges to realize the fifty-five ton donor charge requirement.

OBJECTIVES

The main areas of interest on this trial are: (Fig. 3)

1. Blast Physics Program
2. Crater Studies
3. UK Acceptors
4. UK Caravans (holiday trailers)
5. UK Reinforced Concrete Structure
6. Slurry Explosive Acceptors
7. US Window Test Modules.

The objectives of the blast physics program were:

1. To determine the detonation wave velocity through the charge using ionization probes.
2. To document the free-field air blast environment to which the various targets were subjected using high-speed cameras, air blast time-of-arrival detectors and pressure-time gauges.
3. To estimate the fireball size using ion probes, and high-speed cameras.

RESULTS

Up to 21 ionization probes were placed throughout each charge to record the rate of detonation. These probes were placed through the centre of the charge, along the front edge of the charge and diagonally to one corner. All measurements started at the point of initiation which was in the middle of each layer on the open side of the barricade (Fig. 4). The data for the three charges illustrate that all three had a similar detonation rate, the average velocity of which was 17,310 ft/sec. The detonation velocity of a pure tetrytol explosive is between 22,500 and 23,500 ft.sec.

An additional forty ionization probes extended from the back edge of the charge out to 200 feet from ground zero. These produced little reliable data. (Fig. 5). You can probably see why the data were unreliable and spotty. The traverse causes the fireball to funnel upwards away from the ionization probes. Our high-speed camera coverage illustrates nicely the effect of the traverse on the DRESTC 2 and 3 explosions. (Fig. 6) At zero + 30 msec, the rear portion of the fireball still had not reached the ground. Measurement of the maximum fireball diameter gave the following values; DRESTC 2: 220 to 230 feet; DRESTC 3: 270 feet, and DRESTC 4: 260 feet.

Air Blast Time of Arrival Detectors are probably the least expensive but most reliable part of our instrumentation. (Fig. 7) Time versus distance curves drawn from the ABTOAD data show initial conditions were the same for the three charges but if one extends the velocity curves back to this point (Fig. 7), one will find that the location of the earth barricade is a deciding factor in airblast velocities. DRESTC 2 had lower velocities than those in DRESTC 3 although both charge weights were similar.

Analysis of the incident overpressure data indicates that the presence and location of the barricade (Fig. 8) also has an effect on overpressure. These overpressure results are presented along with an extrapolated TNT pressure curve. DRESTC 2 had lower pressures in the high pressure region and slightly higher pressures in the low pressure region - a phenomenon that was observed in the earlier British small-scale tests. DRESTC 3 and 4 had pressures higher than the predicted curve.

The normal profile of the pressure gauge signal was not found in the high pressure region. Again, high-speed cameras show the probable reason for this. (Fig. 9) Instead of a plane wave approaching the structure in DRESTC 4, we have a Mach Stem beginning to form at +40 msec after zero. Thus, pressure gauges in this vicinity would see the incident and reflected waves.

From the above results, it would seem that current techniques for predicting quantitively the detonation wave and airshock in a real storage situation using data accumulated from hemispherical and spherical "idealized" TNT charges are seriously limited. It has also been revealed that more investigations remain to be done if one is to fully study a realistic storage situation.

Crater Study

The objectives of the crater studies were to:

1. determine the diameter and depth of the apparent crater;
2. define the dimensions of the true crater;
3. compare the results with those from hemispherical and spherical charges detonated on the ground surface.

(Slide #4) DRESTC 2 had an almost circular crater with smoothly sloping sides, an apparent diameter of 113 feet and a depth to the deepest point of 21.2 feet. A mound, 9 feet wide and 4 feet high, formed in the centre of the crater. The earth traverse, with the exception of the corners was destroyed completely (Slide #5). In DRESTC 3, the crater was similar to 2, but it had gentler slopes and the centre mound was wider; 15 feet, but not as high - 2 feet. This crater penetrated the water table. The apparent crater diameter was 143 feet while the deepest point was 21.8 feet. The remainder of the traverse was clearly visible on two sides.

(Slide #6) DRESTC 4 had a strikingly different crater than DRESTC 2 and 3. There was no central mound, the sides were extremely steep and the apparent crater diameter much less. This diameter was 89 feet while the depth was 23.4 feet to the deepest point. The traverse was basically intact.

Upon comparing results with predictions based upon the NATO formula, that is, the radius in metres is equal to 1/2 times cube root of the net weight in kg, it was found that this formula seems to be sufficiently accurate to give a working estimate of the apparent crater radius.

The UK Acceptors

The main purpose of these trials was to expose simulated storage piles of NATO Hazard Class 5 explosives and a widely-used commercial explosive, also classed as class 5, Forcite 75, which is a nitroglycerine based mass detonating explosive, to varying blast parameters in order to determine a storage spacing factor of safety to prevent sympathetic detonation.

Up to 15 acceptor stacks composed of either wooden and metal cased tetrytol demolition slabs or cardboard boxes containing Forcite 75, were placed at 95 feet, 144 feet, 289 feet, and 443 feet from the face of the donor (Fig. 10). These are 2, 3, 6 and 9 w^3. The layout for DRESTC 3 shows that the acceptors were placed behind the earth barricade and in the open sector (Slide #7). The acceptors, including the 2400 lb tetrytol acceptor shown in the slide were partially dug into the ground with the spoil banked behind them to restrict translation.

(Slide 8 - DRESTC 4 detonation fireball; Slide 9 - smoke). Although several of the tetrytol acceptors were severely damaged by shock stimuli ranging from incident pressures from 10 to 300 psi, none was sympathetically detonated. (Slide 10) An acceptor at 300 psi immediately behind the berm suffered little damage but was buried by throw-out material in DRESTC 3. (Slide 11) This slide shows the acceptor on DRESTC 4 which you saw earlier in slide 7. It is now broken up and the contents of some cases scattered. (Slide 12) Another metal acceptor exposed to the same overpressure as the previous two burned completely. I might add it was on the open end of the barricade.

(Slide 13) Metal fragments such as these were found in the general area of this acceptor which appear to have penetrated the ends of the metal containers. (Slide 14) Also the lids of the containers were torn off by the blast but, unlike the wooden container which completely broke up and scattered the contents of the case, the metal container remained, leaving the exposed tetrytol slabs vulnerable to hot projectiles. DRESTC 4 had metal fragments caused by the metal in the metal clad TNT demolition charges in the donor charge, plus the metal pallets. Sympathetic detonation of all Forcite 75 acceptors exposed on DRESTC 3 took place some 2 milliseconds after the arrival of the shock front. (Fig. 11) A camera running at 1000 frames per second recorded the sympathetic detonation of a 600 lb stack of Forcite 75 located behind the traverse at 95 feet from the face of the donor.

Acceptors behind the double-sloped traverses were protected from high velocity fragments. Both tetrytol and Forcite 75 are NATO Hazard class 5 explosives. The Forcite detonated sympathetically while the tetrytol was shattered and burned but did not detonate. It does not seem practical to store these together. From these trials, it appears the current NATO formula of $S.D. = 2.4Q^{\frac{1}{3}}$ or $6w^{\frac{1}{3}}$, where S.D. is in m and weight in kilograms, for storing open stacks of NATO Hazard class 5 military explosives is unduly conservative for tetrytol stored in conventional wooden or steel packages as stacks tested at these distances showed little change. Although the explosive is rendered unserviceable in closer stacks through scorching and breakage, it would appear some reduction in storage separation distances could be considered.

UK Caravans

Nine caravans (holiday trailers) were exposed to free-field blast waves in both the side-on and end-on configurations in an attempt to determine the hazards to trailers parked near a storage site at the time an accidental explosion occurs. The worst hazard is from flying glass fragments. (Slide 15) This slide shows 3 caravans that were later exposed to a 0.6 psi blast wave. The window area in the UK trailers is larger than that in Canadian trailers which are of heavier construction. It was felt that the fragments produced by the windows shattering in the trailers at the 0.8 psi level some 1770 feet from GZ on DRESTC 2 would have injured the occupants. According to the current UK rule, caravan sites must be 1-1/2 times as far away as the inhabited building sites must be, which, for NATO, is 4020 feet from GZ. This seems unduly conservative as, at this distance, there is no structural damage to the caravan nor any danger of flying glass.

US Window Test Modules

A similar type of project was the US window test modules. This project is an extension of the window project carried out by the Naval Weapons Center, China Lake, California on the Eskimo series. Canadian standard, residential windows were used to provide additional data for the assessment of the current US Inhabited Building Safety Distances.

(Slide 16) This is the standard target which is three test modules bolted together. Painting of the windows is, of course, to aid in the post-shot identification of the source of all fragments. This turned out to be a large job (Slide 17) as all the windows were destroyed and broken into many fragments. An evaluation of the data accumulated confirms the need for a comprehensive review of the dangers from flying glass in the context of accidental explosions. The present Canadian data are not sufficient to predict these dangers.

UK Reinforced Concrete Structure

A test section of a reinforced concrete structure designed for magazine storage was tested on DRESTC 4. (Fig. 12) This is a plan view to give you an indication of the size. It was 50 feet long, 18 feet high and 12 feet wide. The roof slab was 7 inches thick. (Slide 18) This slide shows the structure in the construction stage - the front timbers are nominal 10 in. x 10 in. timbers. Slide 19 shows the completed structure and its placement relative to DRESTC 4.

Slide 20 and 21 show the damage to the front face and rear face respectively. As I mentioned and we saw earlier, the pressure wave had a triple point with the Mach Stem barely starting to form just before it hit the structure. This resulted in a lower loading than expected which can be directly attributed to the double-sloped traverse. A detailed study of the results and conclusions are now being carried out by the Department of the Environment, the UK sponsors of the project.

Slurry Explosive Acceptors

As part of a continuing program of study on slurry explosives at DRES, with particular emphasis on the effect of thermal shock and sympathetic detonation, two types of slurry were exposed to blast loading on these trials.

Slurry A was 40% TNT sensitized slurry while slurry B had aluminum added to it as well as being 9% TNT sensitized. (Slide 22) Here is a typical slurry acceptor at 95 feet from GZ. (Slide 23) Almost all slurry acceptors were torn apart and scattered. Those that did remain in place had slurry extruded from the confining plastic bag. Some cardboard boxes around the slurry were charred but no burning or sympathetic detonation occurred. The worm-like forms here are the remains of the two slurry acceptors exposed on DRESTC 4.

Here is a brief summary:

1. The DRESTC trial series provided data on blast measurements close to explosions in realistic storage situations. These data are particularly important as other data are unavailable.

2. From the results of the reported trials, the required present separation storage distances for wooden and metal cased NATO Hazard class 5 military explosives are unduly conservative.

3. The classing of the more sensitive mass detonating explosives such as Forcite should have further study and evaluation.

4. Additional tests may be warranted to determine if there is an optimum spacing between stored explosives and barricades to lessen blast effects.

5. The barricade between storage sites should be retained.

6. The accumulation of data on flying glass fragments should continue in the context of accidental explosions and Inhabited Building Safety Distances.

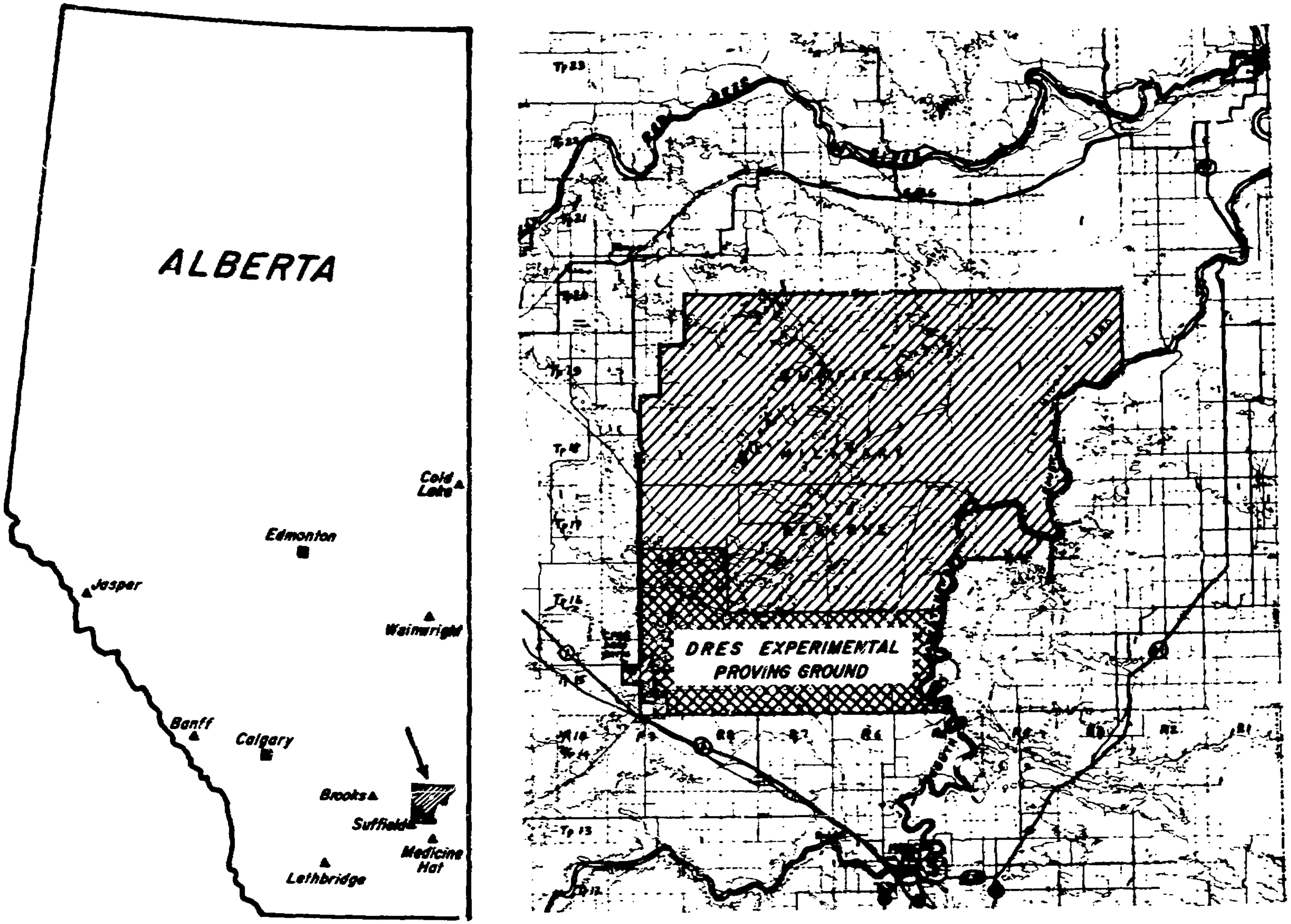

ALBERTA
Cold Lake
Edmonton
Jasper
Wainwright
Banff
Calgary
Brooks
Suffield
Medicine Hat
Lethbridge
DRES EXPERIMENTAL
PROVING GROUND
Tp 23
Tp 13

FIGURE 1

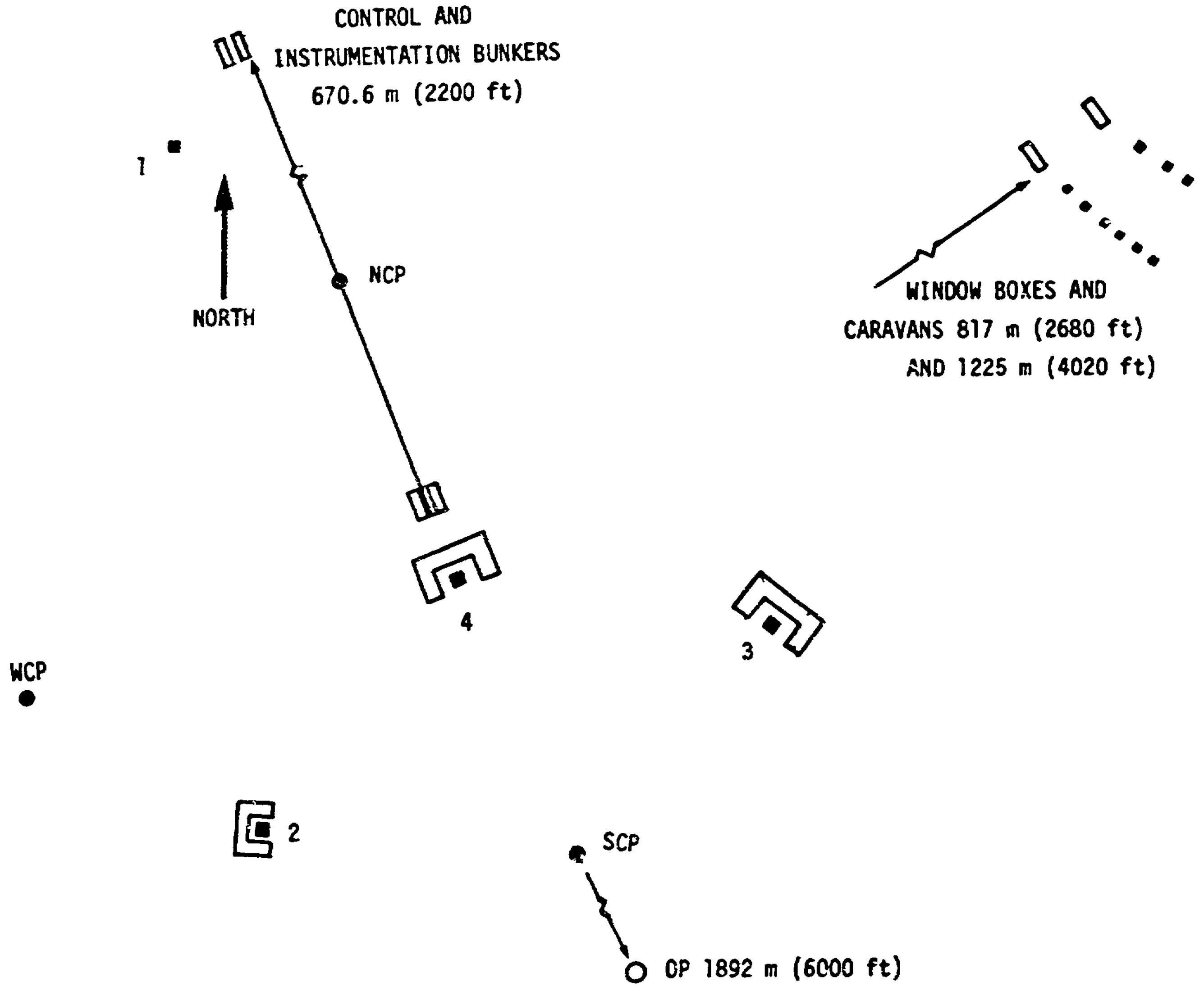
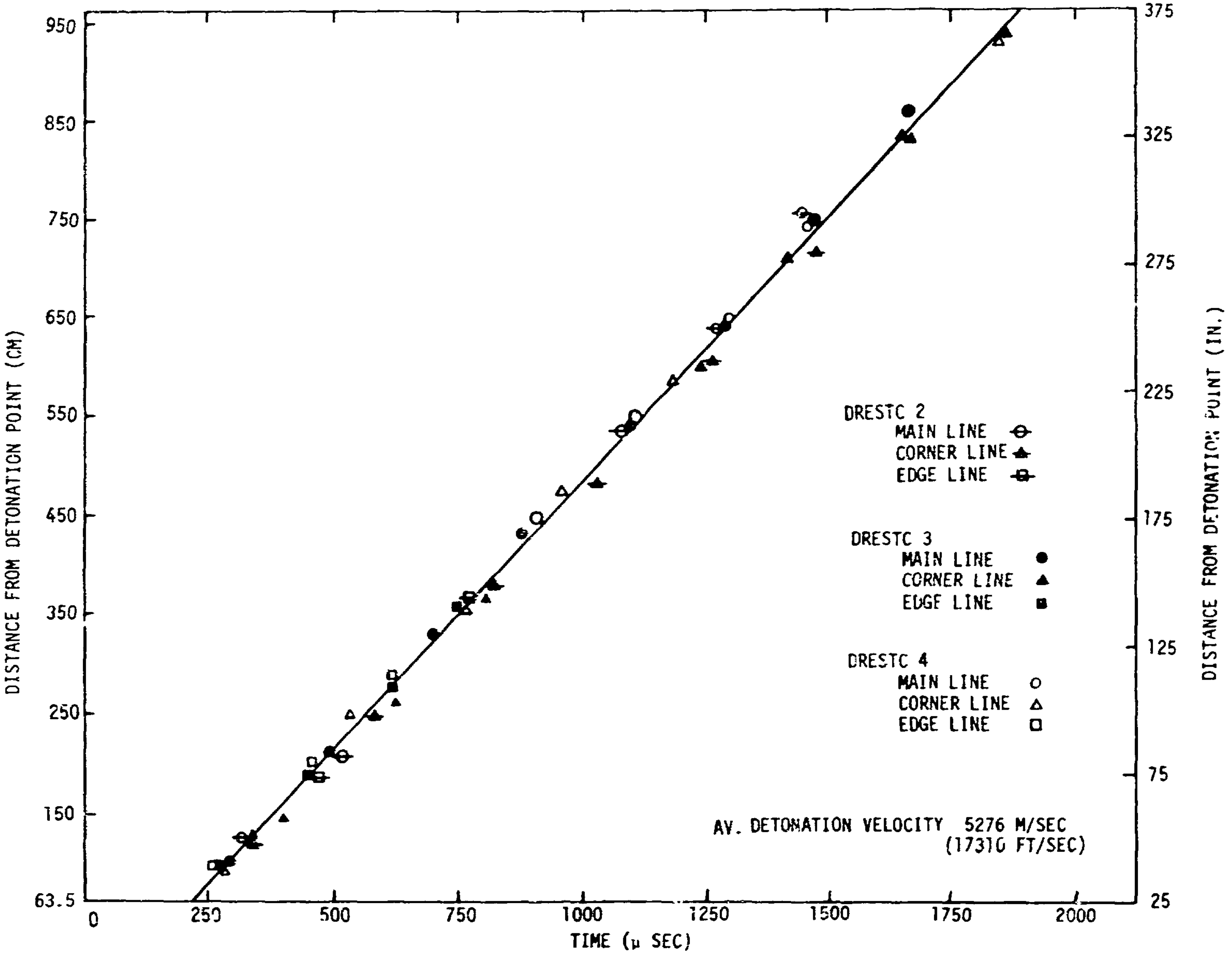


FIGURE 2 DRESTC TRIAL G.Z. LOCATIONS

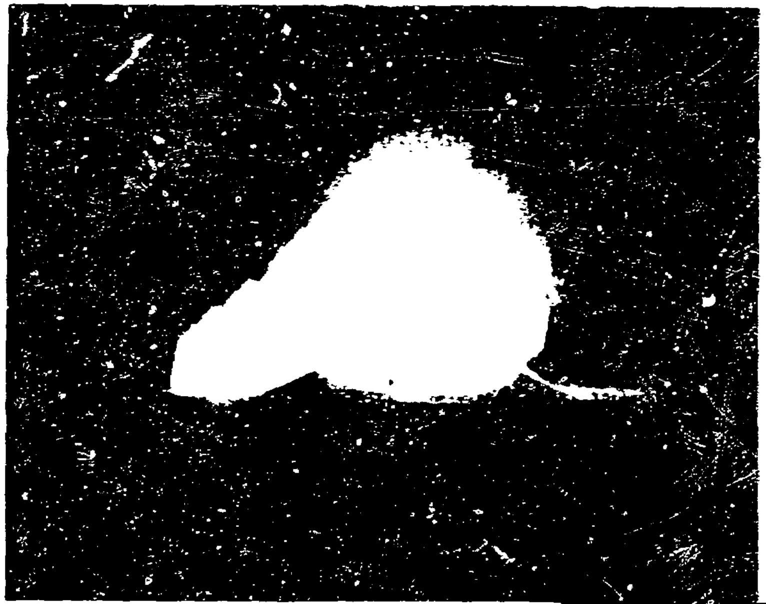
1. BLAST PHYSICS PROGRAM
2. CRATER STUDIES
3. U.K. ACCEPTORS
4. U.K. CARAVANS (HOLIDAY TRAILERS)
5. U.K. REINFORCED CONCRETE STRUCTURE
6. SLURRY EXPLOSIVE ACCEPTORS
7. U.S. WINDOW TEST MODULES

FIGURE 3



CHARGE IONIZATION PROBES

FIGURE 4



DRESTC 2
+10 msec

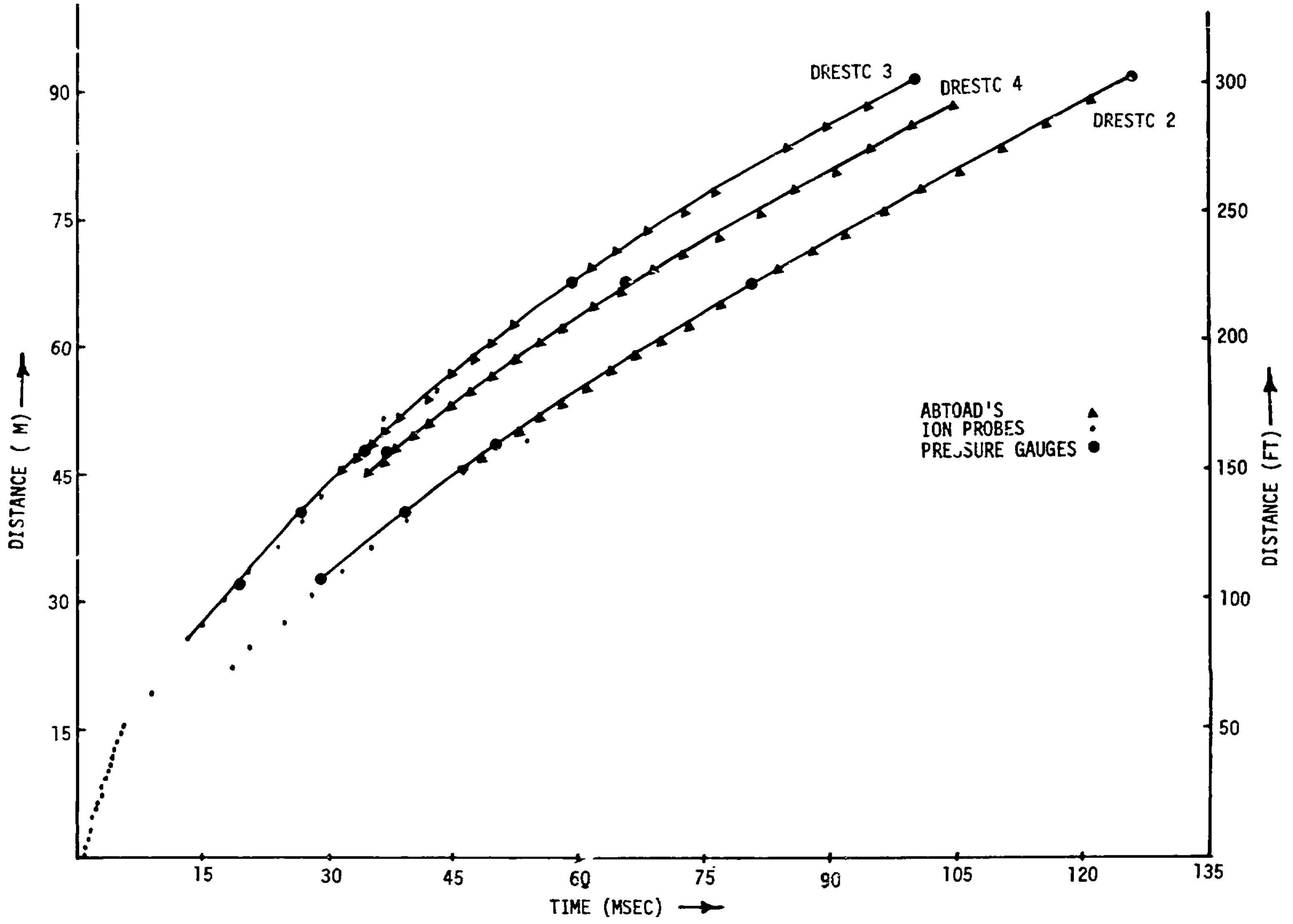
DRESTC 3
+ 10 msec

FIGURE 5

DRESTC 2
+30 msec

DRESTC 3
+ 30 msec

FIGURE 6



VELOCITY MEASUREMENTS

FIGURE 7

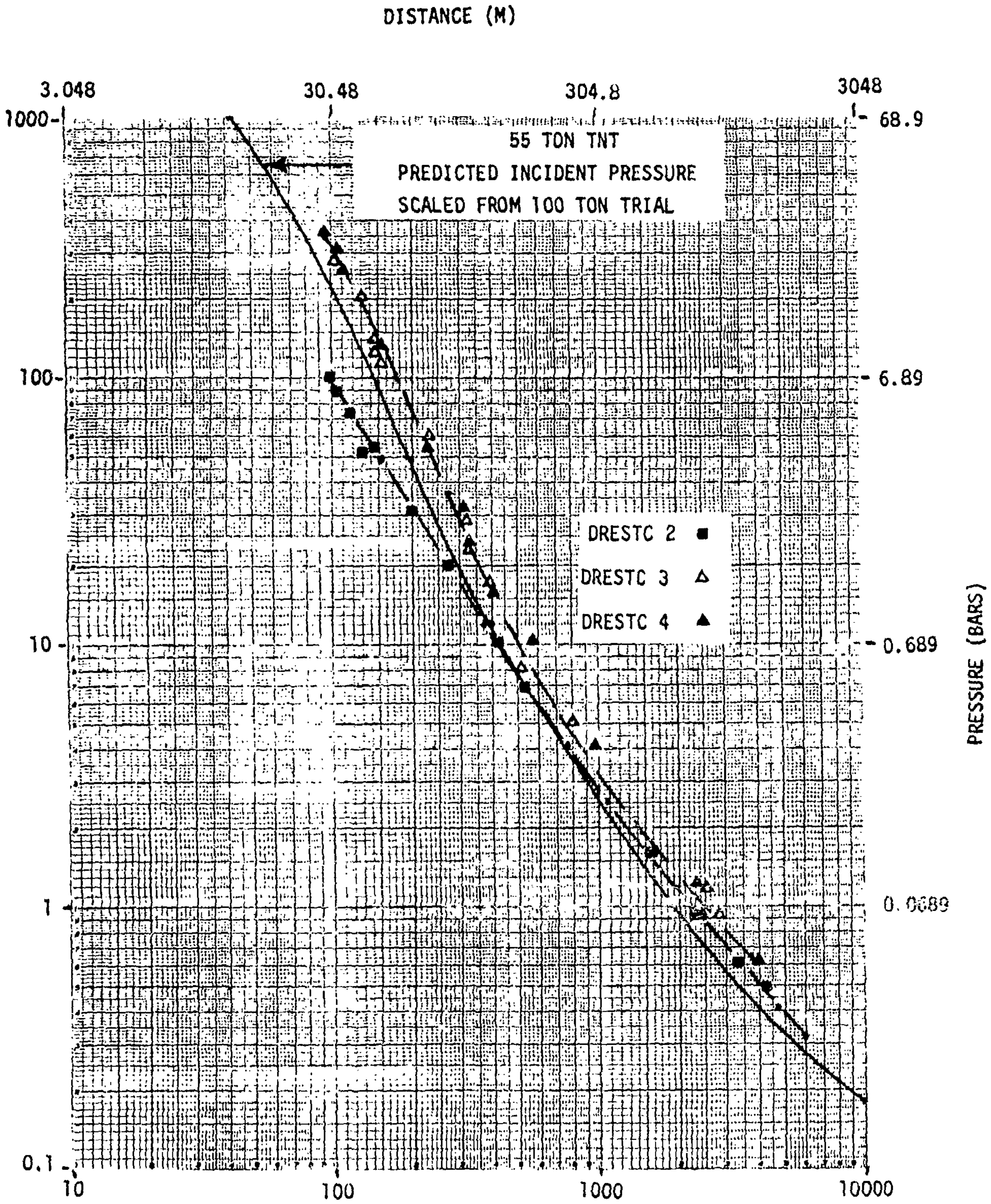

DISTANCE (M)
3.048
30.48
304.8
3048
1000
100
10
1
0.1
68.9
6.89
0.689
0.0689
55 TON TNT
PREDICTED INCIDENT PRESSURE
SCALED FROM 100 TON TRIAL
DRESTC 2 ■
DRESTC 3 △
DRESTC 4 ▲
PRESSURE (BARS)
10
100
1000
10000
DISTANCE (FT)

FIGURE 8

FIGURE 9

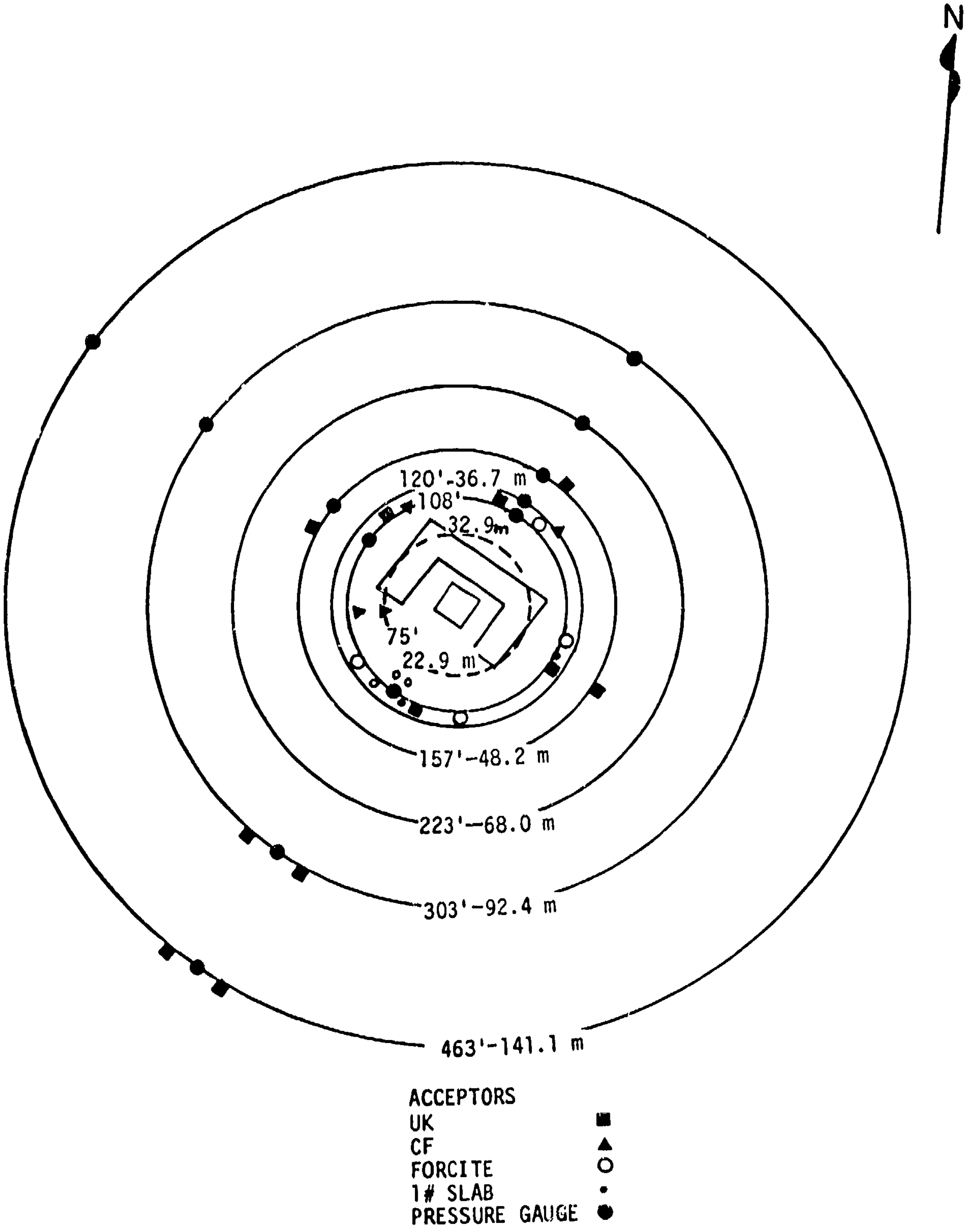


FIGURE 10 DRESTC 3 LAYOUT

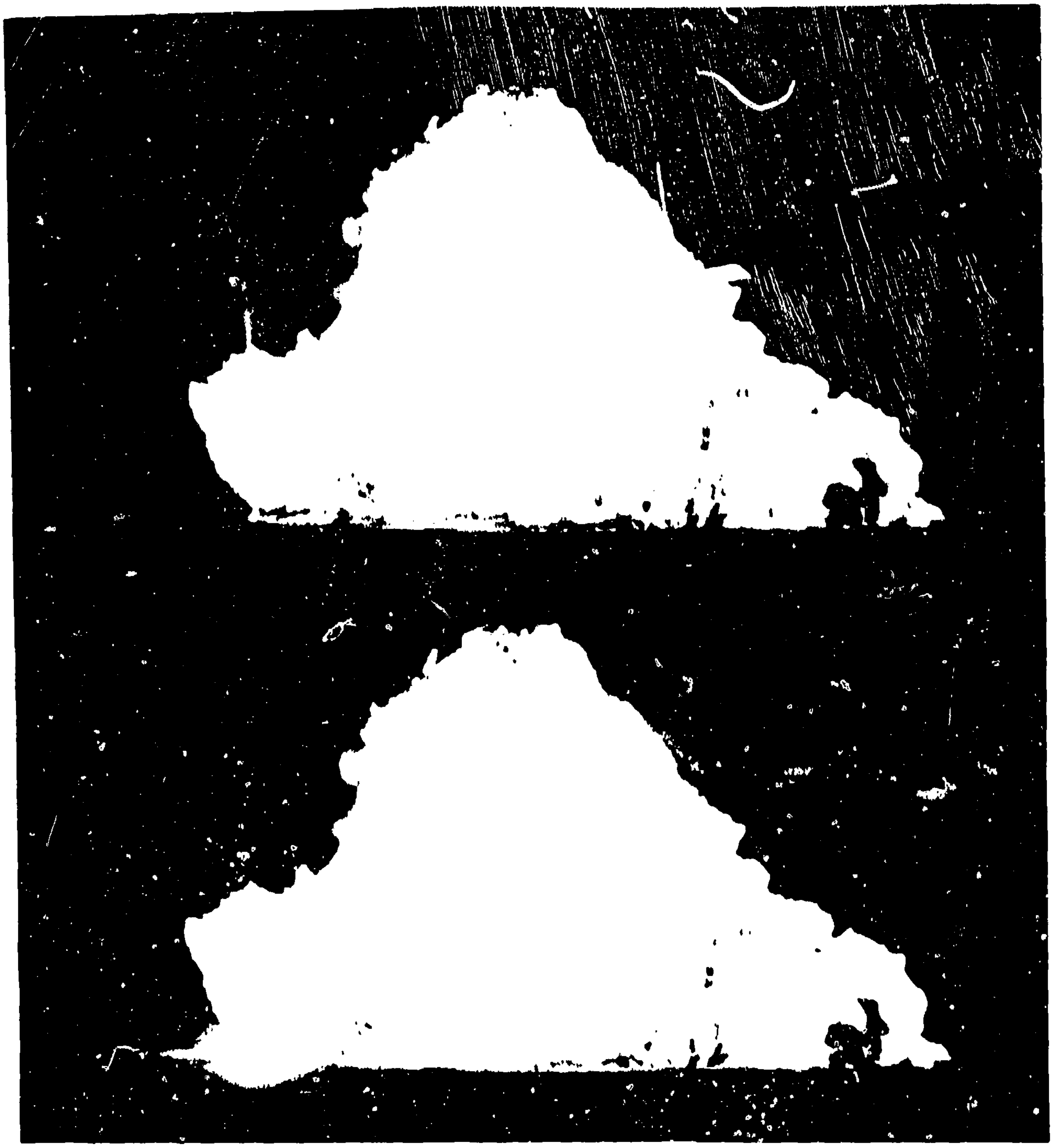
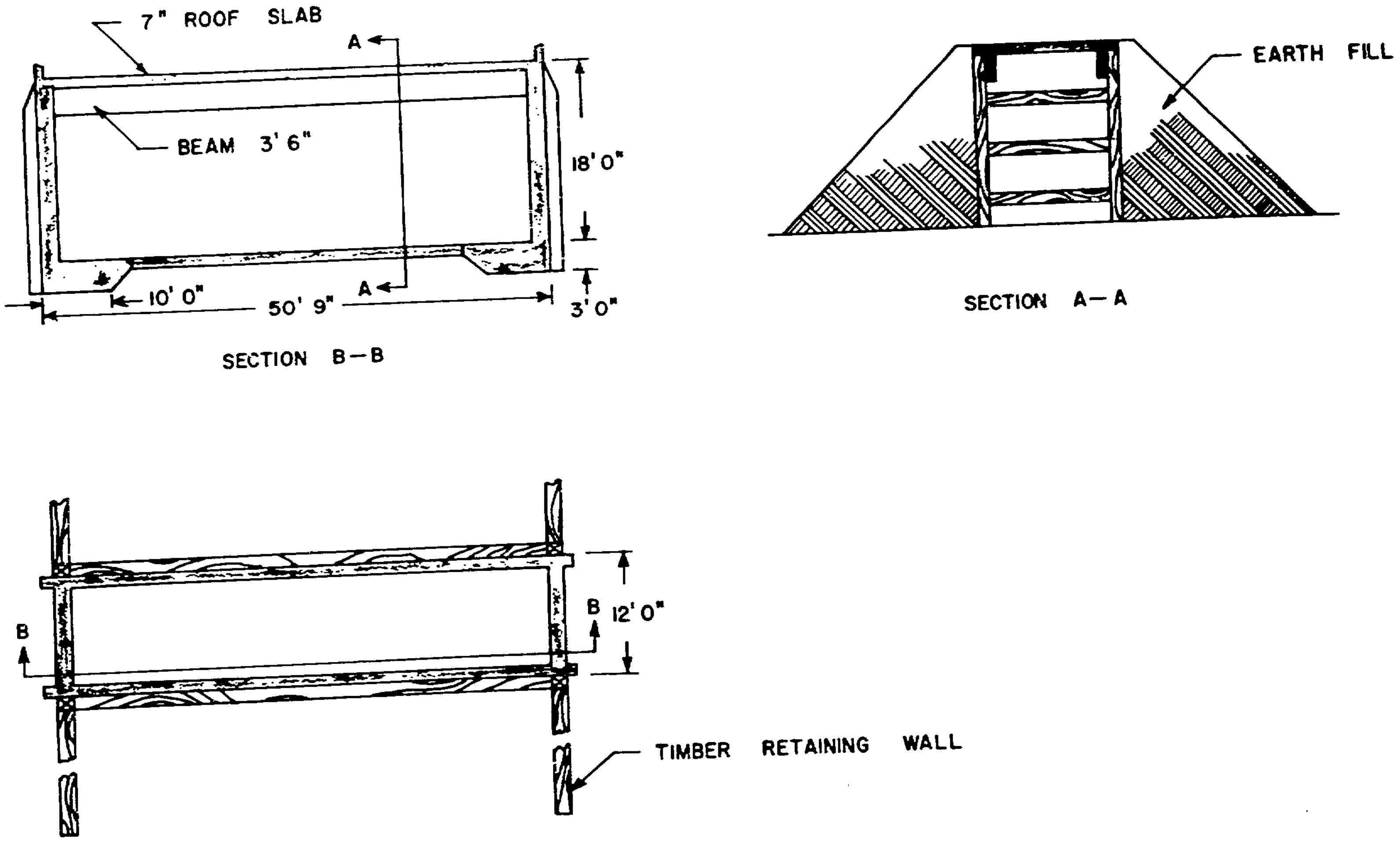


FIGURE 11



SECTION B—B

SECTION A—A

PLAN

REINFORCED CONCRETE TEST STRUCTURE

FIGURE 12

SAFETY IN THE EXPLOSIVES BUSINESS

G. A. Chandler
President, Winchester Group
Olin Corporation
New Haven, Conn.

Thank you Captain Klein. It is a great pleasure to be here with you and meet a number of old friends. I've run across a few old friends, there are a number of Olin people here, also some former Olin people are here that I haven't seen for quite a while. Also, I am delighted to meet the distinguished military guests at the head table.

I think we are intimately interested in the subject that you're considering for these several days, and that is the primary reason that I am here. Olin has been involved in this kind of business for many, many years. This is the basic Olin family business--when I say this, I am talking the powder, explosives type business. The company has been in the ammunition business for many, many years. Many of you knew the original company, the Western Cartridge Company in East Alton, Illinois. Winchester has been involved in arms and ammunition for more years than most of you are old. Certainly more than I am. Winchester became a part of Olin in 1932; of course, the company itself was started in 1866 and there is a great deal of history as far as Winchester is concerned.

We operate those facilities today and we also operate several other facilities. One is the Badger Army Ammunition Plant in Baraboo, Wisconsin, which has been operated by Olin since World War II. We have another military semi-explosives plant in Marion, Illinois where we make pyrotechnics and assemble 20mm ammunition, and a powder manufacturing plant in St. Marks, Florida. I've seen your agenda for the meetings; they are very highly technical. I would be presumptuous of me to try to talk about what some of your speakers have talked about today.

However, I would like to make several comments when it comes to safety in the explosives business. You know it is very easy for us in the explosives industry to be smug about our safety record. It is one of the best in all of industry. Unfortunately, however, inherent in the raw materials and finished products is the hazard of explosion, and therefore, when we do have an accident, there is often the possibility of multiple deaths and serious injuries from fire or explosion. Because of this potential, it is not enough that we are better than the rest of industry; we must stand head and shoulders above everyone else. There is really no margin for error.

How do we achieve this kind of a status? We can do this by moving ourselves ahead into the 21st century, let's say. We must change explosives technology from an art to a science. Captain Klein and I were discussing a few minutes ago the difference between art and science when it comes to explosives and there is merit in each side of it. We cannot throw out the art, yet we have to move into the science side. What would be more appropriate than for us whose products and devices can be propelled to a destination half way across the world, to use this technology to prevent explosions and to safeguard our workers. Certainly, if we can remotely control a vehicle on the moon, we are capable of controlling our manufacturing processes from 200 or 300 feet away with our people safely behind heavy barricades.

I was talking with an old friend, Norl Hamilton, who runs the Volunteer Army Ammunition Plant, and he described today their very highly automated TNT plant. Perhaps he was reading my speech before I wrote it. I am certain that you--and I am certain that Norl, like Olin--have made increasing use of TV camera and the remote operation of explosives handling equipment, but we have only scratched the surface. We are still only modernizing old techniques and old equipment.

It seems to me that it is theoretically possible for us to design an explosives plant which requires only a few employees to maintain the equipment, feed the raw material and remove the finished product. We must develop new methods, new devices, new apparatus which are designed specifically for computer-controlled automation. This must be our goal. This is the science, this is the technology which I believe is absolutely essential and absolutely possible. So much for the improvements in technology. Let me talk about another subject which I think is equally important.

We must also improve our communications. Almost every physics class has pondered the question of the tree that falls in the woods when no one is around to hear it. The question is: Did the fall create a noise? I will not discuss the philosophical or scientific principles involved in the answer; however, I do submit that an accident and an investigation that is confined to the plant where it occurs is like a tree that falls in the woods and there is no one to hear. There must be no boundaries, no company interests, no secret processes when the safety and the lives of people are involved.

Financial successes which result from a disastrous explosion of a competitor which we could have prevented is not the kind of success that any of us wants. I will say this, that information on any Olin explosives accident is always available. Usually a telephone call will suffice; sometimes a letter is involved; but we will always find a way to give you an answer which will allow you to safeguard your people from a similar accident.

The various accident reports which are presently circulated throughout industry can provide vital information for all of us. However, sometimes

I am reminded of the story of the psychiatrist who when passing a colleague on the street is greeted with a cheery "good morning" and the psychiatrist asks himself suspiciously, "What could he have meant by that?" Let's not write our accident reports so that our colleagues in other companies have to ask themselves, "What could he have meant by that?" Nor should you assume that because you are the only manufacturer of a certain product, that an accident report is not necessary. It is a rare accident or near miss that has no message for someone else. Sometimes a near miss is more significant than a lost time accident. Just to refer to that specifically, I can recall as a plant manager a number of years ago, near misses were, most of the time, more dangerous than lost time accidents. For example, we had coils of metal weighing 10,000 lbs. each, and the pile fell over one day. Ten coils of metal and no one was hurt. In my judgment, this was far more dangerous than the cuts on the fingers that we report as accidents. So that near misses are, many times, more dangerous than the accidents themselves.

Explosives, chemicals, apparatus and people all have similarities. An honest, in depth report spares no man's feelings. Most analyses and most good analyses of an accident will reveal the true cause and lesson and lead the way to preventive measures that can possibly save a life.

The goal of "open covenants openly arrived at" may never be attained in world politics, but "truthful investigations truthfully reported" is not beyond the explosives industry's abilities or at odds with its interests.

It is not just external communications that must be improved. Communications internally between top management and the first line supervision must be better. Often, I remind myself that the verbal message I give to my key staff may be misleading. It is very deflating to the ego, to myself, and perhaps, Captain Klein to find out that once in a while the instructions that I have given have not been passed on down the line. The foreman and the worker will judge me only on my actions and only on what they hear from their supervisors. I must make it abundantly clear at every level of management, that I mean it when I say that safety, quality and production are equally important. In my judgment, actions speak a great deal louder than words.

Let me describe just briefly what I believe the key elements of a good safety program are: I think that the first and most important element is that the top man has to say, "I want a good safety program." If the top man does not say that and support the people involved, he will not have the program. This is absolutely essential. As a matter of fact, I practice this, I preach it all the time and when some of my associates said, "George, you must come down to Florida, and meet with the people at this explosives meeting and speak to these people," I really couldn't say no, and I am delighted to be here.

The second key factor of a good safety program: you must have the basic elements of the program for that particular operation. And if you don't know that yourself, personally, there are many able consultants around who can help. I have used an older gentleman who was with our company 30 or 40 years whom I consider to be one of the best safety men I have ever known and he was most helpful to me in many, many operations. He helped establish the basic rules and the basic operating procedures in the various plants that we operate.

Number three, and equally important, is the housekeeping program. You must have good housekeeping. I consider this to be essential to a good safety program. I can walk into a plant, and many of you can also, and you can tell what kind of an operation it is by what the housekeeping is like. If it's in good shape, generally speaking, other things are good also. Generally, when housekeeping is bad, other things are in trouble.

Number four, you must have follow-through at all levels. You must make sure that things are happening as you expect they should be. And that means getting out into the plant, out into the operations to see what is happening.

And I think, finally, for a good safety program, you have to merchandise the program. Merchandising is a term that I use in the commercial side of the business quite often. Perhaps you don't hear it in the safety side of the business. It is very good to merchandise your product, whatever it may be.

And there are all kinds of ways to do this. We have a number of examples which I find to be a lot of fun. One of our plants that I used to visit in Burnside, Louisiana had a safety award dinner and I would go there every year to be with the troops. When they had this party, it was a real wing-ding. But it was a safety party and there was a message, and everybody came and we had a lot of fun. We give away glasses for safety programs, drinking glasses with some kind of a special emblem on them. People like to be proud of the place they work in; if you put some kind of an emblem on glasses, they will take them home and serve drinks (whether they be strong drinks or mild drinks, it really doesn't matter) and they're proud of it. They get these glasses if the safety record is good. TV stamps--some plants and some operations have a TV stamp program where you get so many points for a good record, lack of accidents.

Now, I have had safety people say to me, "George, that's not a proper way to promote a safety program because those are gimmicks." No, they're not gimmicks. They are merchandising. They are very important when I sell products commercially. We merchandise them. Why not sell projects internally and merchandise the same way. So a safety program, in my judgment, has to have all these things. Again, the top man has to say, "I want a good safety record," and then he has to go and get it.

In Olin, we demonstrate this principle by placing safety as the first item on our staff meeting agendas; by giving safety appropriations top priority; by requiring immediate reporting of disabling injuries and accidents all the way up to the President. We have a system now where the top man in charge of any operation that I am responsible for (we have about 15 in this country and 7 overseas) is to notify me immediately when there is a lost-time accident--not in writing, but in person or by phone, so we have direct contact. We make good safety performance a requirement for a bonus or for a raise. And it's amazing when youtalk about money, how well people listen.

These are far better demonstrations of our interest in safety than words spoken at some safety awards ceremony. I think ceremonies are very important, but I think actions speak a great deal louder than words.

Communications and technology--these are the tools that will achieve for the explosives industry a low severity to go along with a low frequency and place us head and shoulders above the rest of American industry.

In conclusion, let me say that as far as we are concerned, we are very willing to share with you our information on safety. All of us are faced with many new processes or changes in our production lines that raise a question as to the safety of a particular element. You may know of a certain Winchester individual or plant that has had the same problem. If any of you have any such problems in the future, I invite you to pick up the phone and directly call the safety manager at one of our plants in East Alton, Illinois; Marion, Illinois; or St. Marks, Florida; and of course our GOCO plant in Baraboo, Wisconsin. We feel that this kind of information is important for us to share with you and hopefully, for you to share with us. I think that passing the information around will provide a lesson for all of us to learn, and I think it can be helpful to us.

My thanks for the invitation to come down here. I am delighted to be with you. I think that the Captain has discussed with me the intent of this program. It is a most worthwhile project. It is essential to the success of your business; it is essential to the success of our business; and I wish you well in the future. Let's not have any explosions.

Thank you very much.

THE UK ORDNANCE BOARD AND ITS ROLE YESTERDAY AND TODAY

Major General P.J.M. Pellereau
Vice-President (Military)
Ordnance Board
United Kingdom

Today I shall endeavour to give you a brief insight into the origins, history and present day organisation and working of the Ordnance Board, culminating in our current endeavours to foster wider international agreement on the philosophy and principles involved in the assessment of the safety and suitability for service of armaments, and their safety in peace-time training conditions.

The Blazon of the Board

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Introduction

The Ordnance Board have established a tradition for the independent and unbiassed appraisal of the safety and suitability for service of weapons and weapon systems in which explosives are involved. We are proud of this tradition and endeavour to maintain it unimpaired, even though our present day methods of working have to be in accord with current procurement procedures.

The Board Yesterday

The association of the Board and its predecessors with ordnance and explosives goes back over 560 years. In 1414, King Henry V of later Agincourt and Harfleur fame, appointed one Nicholas Merbury as the first recorded Master of Ordnance, with a John Louth as his Clerk. In the letter patent of appointment the King authorised Merbury to "take and provide, by yourselves or by your sufficient deputies, as many stonecutters, carpenters, sawyers, smiths and labourers as may be necessary for the work of engines, guns and ordnance aforesaid........."

From these very practical beginnings grew what was eventually to become a great and powerful Department of State. It may be of interest to glance quickly at the vicissitudes of the successors of Nicholas Merbury and his band of artisans over the intervening 500 years of history.

Initially the Masters of Ordnance were men from relatively humble origins, in the merchant or scholar class, who had the good fortune to receive royal patronage, for in England in medieval times all commerce and craft activities were controlled by royal warrants, or charters. This placed almost monopolistic control of various trades and crafts into the hands of individuals like Nicholas Merbury or of groups of men formed into guilds. As time went by the arms industry prospered in England. It was centred on the Tower of London.

Then (as shown in this contemporary view) in the early 19th century, surrounded by open spaces. In these spaces, a cottage industry of charcoal burning, foundry work, and the manufacture of sulphur and saltpetre supported the main work in the Tower workshops. No doubt the activities of the Master of Ordnance or his deputies entailed witnessing events such as shown on this slide.

Because of the troubled, warring times of the 15th and 16th centuries, the arms trade was brisk and Masters of Ordnance prospered. Soon it was the nobility who held the job, many of whom were great names in the land. Among these was Sir Philip Sidney: 1585-86, the Elizabethan scholar, statesman and soldier of immortal fame following his chivalrous action at the Battle of Zutphen when, mortally wounded, he passed his water bottle to a common soldier, also dying, with the words "thy necessity is yet greater than mine."

King Henry V

The Tower of London (early 19th century)

The Business of the Board.

Board Member Witnessing a Trial (circa 1500)

Sir Philip Sidney

However, all was not well with the Office of Ordnance. Profiteering and fraud on a large scale had been carried out at the expense of the Exchequer. In 1590, Queen Elizabeth I set up a commission to investigate the manner and method of working of the Master of Ordnance and this commission ran the Ordnance Office for the next 7 years.

Queen Elizabeth I

In 1597, under the Queen's warrant a Board of Ordnance was set up under a great master to provide ordnance and warlike stores for use both on land and at sea. The first Great Master of Ordnance was the royal favourite, Robert, Earl of Essex.

Robert Earl of Essex

His appointment was for life - but in his case this was arbitrarily cut short by the executioner's axe some four years later.

During Stuart times, the Board under its great master prospered, becoming second in importance only to the Treasury. Its responsibilities included the design and development of armament, their manufacture and storage and the raising and equipping of trained bands of artillery when so required in time of war.

During the struggle between King Charles I and Parliament, and the ensuing civil war, the Board came in for the attention of Oliver Cromwell. There were very good reasons for this. The Great Master was appointed by, and owed allegiance to the King, not Parliament! Since the Great Master ran the Board, he had at his disposal all the cannon and warlike stores without which an Army was becoming very vulnerable. It was essential for the Parliamentary cause therefore that the Board be subject to Parliament, and during the period of the Protectorate the Board was run by a parliamentary commission.

After the restoration of the monarchy, King Charles II reconstituted the Board, and renamed it in 1683, the Great Board of Ordnance, placing it under the direction of a Master General and his Deputy, the Lieutenant General. As a part of the reorganisation and in recognition of the fact that artillery and military engineering were then a necessary part of any standing military force, the King also authorised the raising of two new permanent military corps; now existent as: The Royal Regiment of Artillery and The Corps of Royal Engineers, gunners and sappers as we know them.

The Master-General and his deputy then were both military commanders, as well as being head and deputy head of a Department of State. To add further to the prestige and dignity of the office, the Master-General was brought into the cabinet and became a principal adviser on military matters to the Government of the day.

The Board's responsibilities then covered not only the development, testing and manufacture of ordnance and warlike stores, but also the raising of professional bodies of soldiers to use these arms and to carry out the construction and maintenance of barracks, hospitals, fortifications, storehouses, etc. and all the administration for their efficient operation. Also the Board had the responsibility for geological and geographical survey - this responsibility is still reflected in the title of the Government agency doing this work today - The Ordnance Survey. Perhaps because of this early start the UK can now fairly claim to be the best mapped country in the world.

During the early part of the 19th century the Great Board went from weakness to strength. The armorial bearings which you have seen were granted in 1806 and the Board in its operation was one of the most powerful Government organisations in the land.

As an old print of a Board meeting shows, the business of the Board was carried out in a highly satisfactory manner.

King Charles II

A Board Meeting (circa 1800)

The Duke of Wellington

At about this time the great Duke of Wellington of Peninsular War and Waterloo fame became Master-General. However there was a great envy and resentment building up - with some good reason - in the War Office. The two principal support arms - Artillery and Engineers - were not under the command and control of the Commander in Chief, nor subordinate in any way to the Secretary of State for War.

Matters drew to a head when the War Office came under severe public criticism for alleged inefficiency and maladministrations during the Crimean War. The opportunity was taken in 1855 during the absence of the new Master-General, Lord Raglan, away on a visit to get first hand experience of conditions in the battle zone, to attack the Great Board during a Parliamentary debate on Army administration. The Board was made out to be the prime offender and the attack was pressed home. But only, as one contemporary spokesman recalled, "over the dead body of the 'Iron Duke'" who had died a year or two earlier. An order by Queen Victoria in May 1855 revoked the letters patent of the Master-General and the Lieutenant General of Ordnance and at the same time passed to the Secretary of State for War the responsibility for ordnance matters and the military component of the Great Board.

Lord Raglan

For some time previous to this, the technical control and evaluation of ordnance development had been in the hands of various committees set up within the Great Board. There was thus still an experience within the military component which could be put to good use. However within three years an ordnance select committee was constituted with an Army officer as President and a Naval officer as Vice President. Its members included professionally qualified Artillery men, both Army and Naval, and sappers, as well as representatives from the ordnance and explosive factories, and scientists and mathematicians from academic institutions.

The Committee was charged to carry out and report on all questions relating to experiments and inventions connected with ordnance and small arms. Between 1858 and 1881 there were several such committees in succession similarly tasked.

In 1881 the Ordnance Committee was revised and strengthened and in 1908 several other committees were joined to it to form an Ordnance Board again. The organisation of this new Board followed the same lines as the Ordnance Committee with both Navy and Army being represented along with distinguished civilian scientists. One important difference however was that responsibility for the design of land and sea ordnance material was placed elsewhere.

The new service, the Royal Air Force, became represented on the Board in 1921, and since that day the Board and its work have been essentially tri-service. This aspect was finally sealed in 1945 by the appointment of the first RAF officer as President of the Board.

The Board Today

And so we come to 1974. The present day Ordnance Board is firmly established as a joint service organisation whose main duties are:

1. To appraise weapons and weapon systems containing explosives for safety and suitability for service, having arranged or having been associated with trials on these and assessed the results.

2. To advise service staffs, establishments, technical and logistic directors on matters referred to the Board or on matters coming to the Board's notice, particularly where inter-service coordination is required.

3. To make appropriate recommendations to service staffs on safety matters affecting the use of weapons during training in peace-time.

4. To report and publish in printed proceedings:

Programmes and results of tests and trials.
The corporate opinion and recommendations of the Board.
Board statements of policy and other decisions as appropriate.

In carrying out these duties the Board act without fear or favour, with the aim of achieving the highest possible standards of safety, not only from the viewpoint of the users be they sailors, soldiers, or airmen, but also that of the general public by watching out that no one is exposed during storage, transportation and use of explosives or the operation of other hazardous equipments during service training.

Direction of the Board

Officially, the work of the Board is sponsored collectively by the three Service Procurement Controllers. I use the word procurement in its UK military sense and include the acquisition phases in this term as well. The Controllers are:

a. The Controller of the Navy,

b. The Master General of the Ordnance - a name you will recognize from history and now held by the Army Board Member responsible for the procurement of Army equipment, and,

c. The Controller of Aircraft.

However, by tradition the Board considers itself answerable to humanity at least, if not to God.

Usually the bulk of the Board's work arises out of requests from subordinate authorities of the respective Controllers - in UK parlance these are the approving authorities for their section of the equipment spectrum.

In accepting such requests and in giving subsequent advice, the Board are professionally independent, although they are empowered to seek assistance, should they wish to, from a very wide range of sources in industry or universities as well as from Government agencies. In particular the Board ensure that any trials with which they are associated are appropriate to their assessment and that they are carried out in accord with the Board's standards. This independence and the ability to resist outside pressure are the bases of the unique position of the Ordnance Board.

Tasks of the Board

At this stage it may be useful to look quickly at the wide range of weaponry the Board are asked to consider from time to time.

Even abbreviated our tasks spread to two tables. The first lists the stores with which we are concerned: guns, mortars, small arms and associated ammunition; weapon mounting and fire direction equipment; Naval mines and torpedoes; Army mines and demolition stores, unguided rockets and aerial bombs; guided weapons; pyrotechnic stores; power cartridges.

The second lists the facets of interest to the Board: explosives and incendiary compositions; electrical hazards to weapon systems; applied ballistics; attack of armour; ship magazine safety; nuclear weapon safety; range safety; and safety of laser devices.

Board Organisation

At present it comprises a President and two Vice Presidents, collectively known as 'The Bench,' a Secretary and 14 full Members and a number of associate and ex officio associate members (among the latter are four members from the US Armed Forces and the US Naval Ordnance Laboratory currently serving on the US Embassy staff in London).

The Board are directly supported by a number of technical staff officers from the three UK Armed Services and the scientific Civil Service.

The bench are all two-star officers, one from each of the three Armed Services. They each serve a two-year appointment as a Vice President and in their turn assume the office of President during their third and final year. The Secretary and fourteen full Members are either Captains RN, Colonels or Group Captains or an equivalent grade in the scientific Civil Service. The work of the Board is distributed by Service interest and by weapon technology between the Members, all of whom are technically competent in their particular fields. Each then assumes a special responsibility within the Board as the Member most concerned for his particular share of the work load. He and his group of technical staff officers form what is in effect a sub-committee of the Board although the official nomenclature for such a group is a division. The bulk of the detailed work of the Board is carried out by these groups; however, the results and findings if they are of adequate gravity are presented to the whole Board sitting in formal session in order that all Members may exercise a corporate responsibility for collective advice and recommendations. As briefly mentioned earlier, the formal business of the Board is always published in printed form, and the Board is fortunate in having its own press and printing staff. The printed form of the Board's work appears as a proceeding, known, fondly I hope, throughout most of our circle of colleagues as the OB PROC. Over the years these procs have recorded an impressive collection of factual data and wise comment.

Committee Work

In addition to formal Board sessions and the detailed work in divisions of the Board, several other committees are associated closely with or are the responsibility of the Board. The more important of these are:

a. The Explosives Storage and Transport Committee is responsible for prescribing the safety conditions to be observed during the storage and conveyance of all explosives by land, sea or air. Although it is under the chairmanship of one of the Vice-Presidents of the Board and is served by a small secretariat located in and administered by the Board, several other non Defence Departments such as the Home Office and the Department of the Environment are also involved. This is the committee which has perhaps the greatest measure of interest in the DoD Safety Board Seminar, which is why I as Chairman of ESTC was very glad to be able to accept the invitation to attend.

b. The Attack of Armour Committee is under the chairmanship of the Army Member of the Bench (strangely enough, me again!) and its members are drawn from the Ministry of Defence, members of the Board and R&D establishments. It arranges trials concerned with attack of armour, the results of which are assessed and published in Board proceedings.

c. The Ships Magazine Safety Committee contains members of the Board but is under the chairmanship of Director General Ships.

d. The Electrical/Explosives Hazards Committee is responsible for establishing design philosophy, developing trials techniques and arranging Board trials relating to electronic radiation and in-system electrical hazards to explosive stores.

e. The Nuclear Warhead Safety Committee is chaired by a member of the Board and its recommendations are published in Board proceedings (though on a limited distribution).

f. The Aircraft Safety Committee co-ordinates all studies of the risk of damage to aircraft arising from their own conventional weapons, after release. Board Members sit in this committee.

g. The Work of the Joint OB/Aircraft/Nuclear Weapon Safety Committee is self explanatory.

h. The Standing Committee on Range Safety works in conjunction with military training establishments.

j. The Military Laser Safety Committee acts as a focus for this new and perhaps most interesting advance in technology, which unfortunately brings some hazards with it.

International Standardisation

Over the years, as a course of normal working, the Board has had occasion to devise and collate a wealth of criteria such as:

a. Principles of safety mechanism and fuze design.

b. Philosophy of environmental testing and associated experimental test conditions and test methods, and

c. Principles of safety philosophy.

to name but a few. Based on these collected data, the Board has enunciated, from time to time, on desirable standards to be attained within the three British Armed Services, in relation to the safety and suitability for service of explosive components of weapons and weapon systems. We have not been alone in this type of work and we appreciate that other countries have been engaged in parallel activities. Unfortunately there is not always a coincidence of purpose, or result, when respective criteria are examined.

It is both militarily desirable and economically sensible for all forces in an alliance to be similarly armed. Greater effectiveness is created in the first instance, and a better use made of wealth and resources in the second.

However, if the full benefits are to be reaped from international collaboration in armaments, it is important that policies on weapon safety and suitability for service are gradually harmonised. Whether weapons are developed multi-nationally, bought from or sold to other countries or merely follow basic principles of inter-operability, problems can arise which need to be settled in good time. During training complex situations may arise affecting personnel safety which are better approached calmly in advance.

Some aspects, such as the transport and storage of explosives for example are already being considered within NATO countries but many other matters seem ripe for examination. At the very beginning, for instance, it would be helpful to agree to the techniques which are used to provide the data from which it may be possible to assess whether a weapon is safe and suitable for service.

In an attempt to provide the impetus to a more coherent approach on this wider issue, the UK is seeking to get active NATO involvement in discussions on a three Service basis. This approach is being made through the NATO military agency for standardisation.

Within the UK, the focus for the initiative is the Ordnance Board. As a suggested starting point we have instanced the following areas which we think are ripe for standardisation agreement.

a. The definition of climatic, mechanical and electrical environmental conditions (some work is already in hand - in the form of draft STANAG 2831 covering temperature and humidity conditions for ground equipment but it is clear that shock and vibration also merit consideration).

b. The principles for the design of fuzes and/or safety and arming mechanisms (STANAG 3525A is already in existence covering aerial weapons and would, we think, be readily extended across the ammunition and gun field).

c. Range safety. Very little official standardisation has been achieved on the difficult problem of range safety which vitally affects the use of one anothers training areas, and weapons.

d. Criteria concerning the behavour of weapons in a liquid fuel fire such as on the deck of an aircraft carrier, are perhaps much needed.

e. Criteria for the safe use of military lasers, which I have already mentioned as a topic much on our minds today.

May I now conclude this presentation on the Ordnance Board with the hope that this brief glimpse at our past and present aspirations will encourage and foster the many excellent exchanges and the good will we enjoy with our American colleagues in the explosive and ordnance business. I hope that those present today will assist in the process of agreement on standardisation by spreading the news of the approach through NATO and explaining its long term benefits.

THE ORDNANCE BOARD

1. The Ordnance Board have established a tradition for the independent appraisal of the safety and suitability for service use of weapons and weapon systems in which explosives are used. This short note describes the Board's aims, functions and *modus operandi*.

HISTORICAL NOTE

2. The Ordnance Board trace their history back to 1414 when Henry V appointed Nicholas Merbury as the Master of Ordnance and John Louth as his clerk to " take and provide, by yourselves or by your sufficient deputies, as many stonecutters, carpenters, sawyers, smiths and labourers as may be necessary for the works of engines, guns and ordnance aforesaid, together with sufficient timber, iron and all other things likewise necessary for the works aforesaid, and also with carriage for same when there is reasonable need for it, so long as you shall continue in your said offices. And we shall therefore direct you to busy yourselves diligently about the premises and perform and execute them in the form aforesaid .....".

3. Modern history starts in 1855 with the creation of the Ordnance Select Committee, which was managed solely by the Army until a Naval Vice-President was included in 1858. This Committee continued to function under various titles until 1908, in which year it became known as the Ordnance Board. An RAF Member was included in 1919 and the first RAF President was appointed in 1945.

PRESENT FUNCTION

4. With the passage of time the executive role of the Board in respect of weapon research, development and procurement has passed to other authorities and the Board are now solely an advisory body. In essence, they advise the Controllers, usually through the Approving Authority, on the safety and suitability for service of any weapon or part of a weapon system in which explosives are used. The term " suitability for service " is used in the context of the Board's assessment of the weapon to function safely and satisfactorily in its service environment. Except in so far as it may affect weapon safety, such an assessment does not necessarily include either a quantitative assessment of functional reliability or the ability to meet all the Staff Requirements; these latter aspects are, rightly, the responsibility of the R & D Authorities.

5. The advice of the Board, given without fear or favour, is aimed at obtaining the highest possible standards of safety not only from the viewpoint of the users, be they sailors, soldiers or airmen, but also that of the general public, by ensuring that they, too, are not exposed to any avoidable hazards during the storage, transportation and use of explosives.

CONTROL

6. The work of the Ordnance Board is functionally directed, collectively, by the Controller of the Navy, Master General of the Ordnance and Controller of Aircraft. The bulk of the Board's work comes as requests for advice from the Approving Authorities of the Procurement Executive, who are directly responsible to the 3 Controllers for ensuring that weapons being developed meet the service requirements.

7. Professionally, the Board are independent and give advice on standards of safety and suitability for service and ensure that associated trials are conducted in accordance with Ordnance Board standards. It is this independence from outside pressures which is the very core of the unique value of the Ordnance Board.

COMPOSITION

8. The present Board comprise a President and 2 Vice-Presidents (The Bench), the Secretary, full Members and Associate and *ex-officio* Members, supported by a number of Technical Staff Officers from the Military and Civilian Services.

9. Members of the Bench, consisting of 3 two-star officers, one from each service, each serve a 2-year appointment as Vice-President and take it in turn to be President for their final third year. The posts of Secretary and Deputy-Secretary are currently filled by a Captain, RN; and a retired Squadron Leader. The 14 Members of the Board include 3 Captains, RN; one Colonel, RM; 5 Colonels; 3 Group Captains and 2 Senior Principal Scientific Officers of the Civil Service. Each Member of the Board is supported by 2 or more Service Technical Staff Officers, normally in the equivalent rank of Major, and by civilian scientific grades.

ORGANISATION

10. Members and their staffs are organised in Divisions grouped broadly to deal with conventional weapons, guided weapons and nuclear weapons, together with a Support Division which is manned by scientific staff to advise on Explosives Chemistry, Nuclear Physics, Environmental Testing and Statistical Analysis.

11. Located within the Board is the Applied Ballistics Department, headed by a Superintendent, who is a full Member of the Board. The Department has modern computing facilities and, in addition to Range Table production, is largely concerned with assessment of risk to the service user arising from fragmenting projectiles. Another important task is the study of the risk of fragment damage to aircraft from their own weapons.

OPERATION

12. Advice given by the Board must be based on factual data. To this end, the Board are associated with R & D Trials and may also call for any additional trials which they may consider necessary to ensure that the production version of any explosive store is safe for transportation, storage and use, and that it functions satisfactorily when used in a service environment. In the first instance, the results of trials are assessed by the Member most concerned, who then presents his assessment to a weekly meeting of the entire Board for critical examination and discussion. The results of these deliberations are published in a document known as an Ordnance Board *Proceeding* (OB *Proc*), which include the corporate opinions, recommendations and advice of the whole Board. This method of operation not only ensures meticulous attention to detailed aspects of safety and suitability for service but also makes full use of the widely experienced Members, whose appraisal is essentially objective, informed and constructively critical.

13. The early involvement of the Board in any new requirement is essential in order to influence design for safety, to allow preliminary appraisals to be completed before production commences, and to avoid duplication of subsequent R & D and OB trials of the production store so as to save time, money and effort. The latter point is particularly important in the light of the increased cost of weapons and the limited range facilities now available for trials.

COMMITTEE WORK

14. The Board are responsible for, or associated with, a number of committees, which include the following:—

a. *Explosives Storage and Transport Committee.* This is a Government inter-Departmental Committee responsible for prescribing the safety conditions to be observed during the storage and conveyance of Government explosives by land, sea or air. It is under the chairmanship of one of the Vice-Presidents of the Board and is served by a small Secretariat, located in and administered by the Board.

b. *Attack of Armour Committee.* This Committee is under the chairmanship of the Army Member of the Bench and its members are drawn from DGW(A), DGFVE, DA Arm, Army, RAF and Scientific Members of the Board and R & D Establishments. It arranges trials concerned with attack of armour, the results of which are assessed and published in Board *Proceedings*.

c. *Royal Navy Magazine Safety Committee.* The Board provide members of this Committee, which is under the chairmanship of DG Ships.

d. *Electrical/Explosives Hazards Committee.* This Committee is responsible for establishing design philosophy, developing trials techniques and arranging Board trials relating to electronic radiation and in-system electrical hazards to explosive stores.

e. *Nuclear Warhead Safety Committee.* This Committee is under the chairmanship of a Member of the Board and its recommendations are published in Board *Proceedings.*

f. *Aircraft Safety Committee.* The function of this Committee, sponsored by DA Arm, is to co-ordinate all studies of the risk of damage to aircraft arising from their own conventional weapons, after release. Board Members sit in this Committee.

g. *Joint OB/A & AEE Aircraft/Nuclear Weapon Safety Committee.* This Committee is responsible for investigating the safety of nuclear weapons and their associated aircraft control and release systems. It is under the chairmanship of a Board Member and its members are drawn from the Ordnance Board, A & AEE, RAE and AWRE.

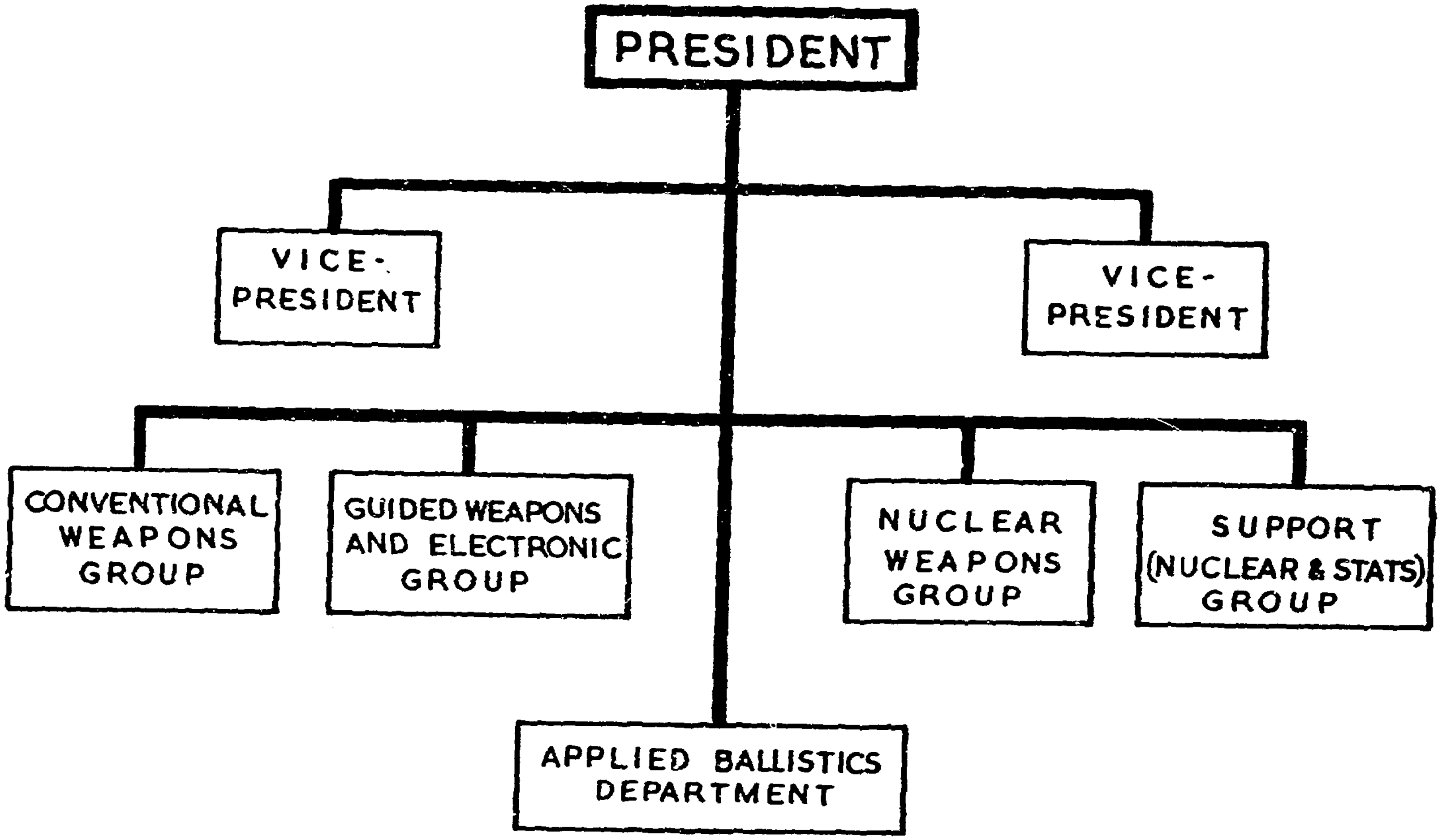
h. *Standing Committee on Range Safety.* The Board provide a member of this Committee, which is under the chairmanship of the Director of Army Training. It lays down the policy for Range Safety during practice firings on Army Department Ranges.

THE FUTURE

15. The increasing cost, complexity and lethality of new weapons and weapon systems, coupled with their increasing inter-service and multi-national employment, reinforces the need for a truly independent professional organisation able to look objectively at a weapon through the eyes of the User. The aim of the Ordnance Board is to continue to meet this need. The achievement of the aim will be directly related to the confidence and efficiency with which the Services are able to employ their weapons and weapon systems; and inversely related to the number of hazards and incidents experienced with explosives in these equipments.

Note. It is an established custom to treat the "Board" as a plural noun; *e.g.* "the Board are" or "the Board have".

THE ORDNANCE BOARD



NATO STANDARDISATION

ARMAMENT SAFETY AND SUITABILITY FOR SERVICE

Introduction

1. It is both militarily desirable and economically sensible for NATO Forces to be similarly armed. Greater effectiveness is created in the first instance and greater wealth in the second. As has recently been emphasised by the Eurogroup Defence Ministers in their Declaration on Principles of Equipment Collaboration in May 1972 and echoed by CNAD's Guidelines for Improved Equipment Collaboration in March 1973, this is an ideal which none disputes.

The Problems

2. However, if the full benefits are to be reaped from international collaboration in armaments it is important that policies on weapon safety and suitability for service are gradually harmonised. Whether weapons are developed multi-nationally, bought from or sold to other countries or merely follow basic principles of inter-operability, problems can arise which need to be settled in good time. During training complex situations may arise affecting personnel safety which are better approached calmly in advance.

3. Some aspects, such as the transport and storage of explosives are already being considered within NATO HQ but many other matters seem ripe for examination. At the very beginning, for instance, it would be helpful to agree on the techniques which are used to provide the data from which it may be possible to assess whether a weapon is safe and suitable for service.

4. It is, therefore, highly desirable to stimulate the collection and building up of internationally agreed principles, criteria and test procedures for the safety and serviceability of military weapons.

Aspects for possible NATO Standardisation

5. Some examples of aspects which might prove fruitful for NATO standardisation are given below. Others might well occur during preliminary examination:—

   a. Definition of Climatic and Mechanical Environment Conditions.
   b. Principles for the Design of Fuzes and/or Safety and Arming Mechanisms.
   c. Criteria covering the behaviour of Weapons in a Fuel Fire.
   d. Criteria for Range Safety.
   e. Criteria for Safe Use of Military Lasers.

6. Although rules for the storage and transport of explosives are already being continuously evolved by a Specialist Group they will still benefit from dissemination as standardisation documents in harmony with other weapon matters.

Action within the UK

7. A paper has been introduced by the UK through its representative on the Army Board of the NATO Military Agency for Standardisation proposing that the suggested standardisation topics should be studied by a suitable NATO Inter-Service forum. The Ordnance Board has already nominated a small Inter-Service focus for expert contributions to the UK input to a NATO forum.

8. It is hoped that all concerned with armaments will assist by spreading news of this approach and explaining its long-term benefits.

CCB/197/06

July 1974

THE UNITED NATIONS SYSTEM OF CLASSIFICATION OF EXPLOSIVES

R R Watson, Ministry of Defence, United Kingdom

SUMMARY

1. The paper describes the United Nations and NATO Groups of Experts on Explosives Safety and the system of classification of explosives which they have evolved. It provides an encouraging example of the type of international harmonisation, to promote safety and reduce costs, which General Pellereau advocated earlier in the Seminar. The status of the system is discussed. The hope is expressed that the United States will implement the system fully in the near future.

INTRODUCTION

2. In his talk on the UK Ordnance Board, General Pellereau mentioned the Explosives Storage and Transport Committee of which he is the Chairman and I am the Technical Adviser on Explosives. It is through representation of this Committee at international meetings in recent years that I have become enthusiastic about the ability of international groups to work well together to overcome national differences and to achieve a really worthwhile step forward. In the process they can create such good personal relationships that many incidental benefits accrue.

3. It may be useful to outline British interests and representation on these two Groups of Experts. Figure 1 shows the three main fields of responsibility for explosives safety. All powers and exemptions derive from the Explosives Act of 1875 which is due for major revision next year or very soon afterwards. Mr E G Whitbread, Her Majesty's Chief Inspector of Explosives, leads the UK team at the UN where he is assisted by the Secretary and Technical Adviser (Explosives) of the Explosives Storage & Transport Committee (ESTC). This Committee is the nearest British equivalent of the DoD Explosives Safety Board. The Secretary ESTC leads the British team at the NATO Group of Experts on Explosives Safety; the Technical Adviser (Explosives) leads at various sub-groups on storage matters. There is close collaboration between the military and civil sides on all matters of mutual interest, to ensure that both the UN and the NATO prescriptions are workable throughout the UK explosives field.

THE UNITED NATIONS GROUP

4. Figure 2 outlines the links of the UN Group of Experts on Explosives. The success of this Group since 1967 owes much to Mr W Byrd of the Office of Hazardous Materials, US Department of Transportation, who as Chairman directed its work so ably through a period when the diversity of national views seemed to present an insurmountable barrier to progress on international harmonisation. Since 1973 Mr E G Whitbread has taken the Chair. He is well known to many of you present today through his earlier work in the Explosives Research and Development Establishment at Waltham Abbey.

5. France, the Federal Republic of Germany, the US and the UK were the active members while representatives of international authorities such as IATA (International Air Transport Association), IMCO (Inter-governmental Maritime Consultative Organisation) and OCTI (which makes agreements on European Rail Transport) have kept careful watch in order to implement the UN Recommendations when opportune. This year Canada has become a member which is significant in relation to future regulations for the shipment of explosives through the North American ports.

6. The Group meets twice a year to consider papers proposing changes to the published Recommendations in "Transport of Dangerous Goods". This set of volumes is printed by the UN European Office of Geneva. The 1966 edition setting out a rather crude system for international agreement on the classification and carriage of explosives was supplanted in 1970 by a much more workable system. This was further refined by a Supplement in 1973 reflecting ideas from IMCO, NATO etc. The aim is to give general recommendations applicable to all modes of transport and to leave it to particular regulatory authorities to take account of safety requirements peculiar to each mode. Although progress may seem slow, it having taken from 1966 to achieve a system worthy of implementation in national regulations, it is good for international work where so much depends not only on technical criteria but also on negotiation and compromise.

7. In order that the Recommendations may apply to military as well as civil explosives, the four teams working since 1966 have included military advisers. Significantly these have included members or close associates of a NATO Group of Experts on Explosives Safety.

THE NATO GROUP

8. Figure 3 shows the constitution of the NATO Group of Experts on Safety Aspects of Storage and Transportation of Ammunition and Explosives. In view of this unwieldy title and the fact that it was set up by the NATO Armaments Committee, it is known as AC 258 Group.

9. The original purpose of the Group was to formulate criteria for Quantity-Distances Tables to be used by NATO Infrastructure for planning. The estimated cost of an ammunition depot varied enormously according to the country in which it was sited, because of national vagaries in Q-D requirements. It was found impossible to agree a common set of criteria suitable for a STANAG (Standardisation Agreement) because traditionally national Q-D standards are based on judgement as much as on technical evidence. Although the Group could pool its data it could not standardise the judgements. Therefore the NATO Manual on Explosives Storage and recent documents on transport set out to present an eclectic to serve as a basis for negotiations between a Visiting Force and a Host Nation.

10. It soon became apparent that the broadly based criteria of the NATO Manual on Storage (AC/258-D/70) were technically superior to many nations' systems of regulation. It was also realised that by co-operating in the planning and execution of costly trials, nations could tap a greater source of ideas and could avoid duplication of effort and expenditure. Examples are the British and US tests on stacks of aircraft bombs, the Anglo-American test series on 155mm shell stacks, the model and full-scale tests on Igloos, the British/Canadian tests on sympathetic detonation reported elsewhere in this Seminar, and several trial series on underground storage involving Norway and Germany.

11. Over the last four years members of the Group have striven to make the NATO prescriptions suitable as a basis for national regulations on the storage of explosives and NATO countries have been invited formally to adopt them in whole or in part. The majority of participants has now committed itself to adoption. The most important single factor which achieved this was the decision to incorporate the UN system of classification in the manuals.

THE UN CLASSIFICATION SYSTEM

12. The UN system of classification of dangerous goods, for purposes of control during normal transportation, divides and lists them in nine classes: explosives, gases, inflammable liquids, inflammable solids, oxidising substances, poisons and infectious substances, radioactive materials, corrosives, and finally miscellaneous dangerous substances not otherwise specified. Each class is further divided and items are grouped as necessary to provide a framework for national and international regulations.

13. A key feature of any successful system of classification is that the substances should be specified at an appropriate level of detail. If they are specified in too minute detail, the system becomes unworkable through a plethora of sub-divisions, sub-sub-divisions and groups. If on the other hand the system is too general, then it cannot be used to discriminate among significantly different substances.

14. Figure 4 shows the level at which substances and articles are specified in the UN system for explosives. It is emphasised that this level is appropriate for normal transportation but further information may well be necessary for clearing up operations after an accident. For this reason the UN system may be complemented by, or be incorporated into, some international system of marking or placarding such as the "Hazardous Information System", "Hazardous Chemicals System" etc. These systems are under active consideration at the UN at the moment but they are different in purpose.

15. Figure 5 shows the four divisions into which Class 1 is divided. A fifth division is under consideration for slurry explosives and others which do have a mass explosion hazard but whose sensitiveness is so low that the probability of initiation during transport is very small. The aim is to specify the dominant hazard once an accidental ignition or initiation has occurred either through internal causes or, more commonly, through involvement in an external fire. These divisions can be made the basis of a system of Fire Fighting classifications and this has already been agreed in NATO.

16. Compatibility is defined as the ability of explosives (packaged or otherwise as offered for transport) to be stowed or carried together without increasing either the likelihood of an accident or, for a given quantity, the consequences of an accident. Most nations have embodied some concept of compatibility in their regulations. The UN Group has tried to select the best criteria without deviating too much from simple, definable characteristics. In the past purely administrative factors have been included as reasons for additional groups in national regulations. The UN has tried to minimise the groups.

17. Figure 6 is presented primarily for reference in the Seminar Minutes. There is too much detail for assimilation on a screen. However this slide does give a useful overall view of the classification system. It shows how combination of the hazard division and the compatibility group yields a simple Classification Symbol such as 1.1 D. In practice not all the divisions occur in each group.

18. Figure 7 presents the same combination of divisions and groups in a different manner. This shows the thirty Classification Symbols. At its last meeting in August 1974 the Group recommended the elimination of the two subdivisions within Division 1.4; they were useful in 1966 before Compatibility Groups were devised but now they are superfluous. Safety explosives will be given the simpler symbol 1.4 S. The chart indicates how Division 1.1 was originally subdivided to distinguish certain substances (1.1 A) and articles (1.1B, 1.1 E). This corresponded to the former distinction between US DoD Quantity-Distance Classes 9 and 10. In both systems all mass detonating items are now considered together.

USE OF THE UN SYSTEM

19. The intention of the UN system for explosives is that it should be regarded as a broad framework of "building blocks", in standardised terms, to be adapted or amplified to suit the requirements of particular users, be they national regulatory bodies or international authorities. The NATO Group has ensured by its input that the system is suitable for storage regulations too although this is not stated in the UN publications which address themselves only to transportation. There is no intention to force authorities to accept standard conditions of transportation (or storage). Insofar as there is a consensus of safety requirements for many modes of transport, these are given in the Recommendations but without prejudice to the right of the regulatory body to waive or modify them as it thinks fit. As an example, Compatibility Group A has been devised with the intention that most bodies will prohibit transportation of primary explosives in bulk. The purpose of defining this group is to facilitate identification of the prohibited substances.

20. The use of the alpha-numeric Classification Symbol will simplify problems of language and translation, as well as being simple to communicate by telephone and to insert on labels and shipping papers. It is hoped that current requirements for long technical names may eventually disappear in favour of this simple Classification Code. It is a key feature of the IMCO explosives label and the new label for British military explosives, to be introduced from mid-1976 (Figure 8).

IMPLEMENTATION OF THE UN SYSTEM

21. IMCO adopted the UN Recommendations in its own Code for the safe carriage of explosives in ships in 1971. Many useful criticisms were fed back to the UN Group and were incorporated in the 1973 Supplement. Many nations have already based their national regulations for ships on the IMCO Code. In the Federal Republic of Germany this is now in force, despite certain minor problems of translation from the original English and French texts of IMCO. The UK regulations are broadly in line with the IMCO Code but implementation of the fine detail awaits the revised IMCO edition now in draft, which includes the improvements in the 1973 UN Supplement. France has indicated its commitment to adopt the UN system in the near future. Canada appears to have decided to follow the IMCO Code on its waterfronts.

22. The NATO Group adopted the UN system in 1972 for its storage manual and for subsequent manuals on transportation. This innovation has greatly increased the appeal of the NATO Recommendations which have been requested by several countries outside the Treaty Organisation (Austria, Australia, India, Switzerland).

23. Figure 9 is a flow chart used for planning the changeover to the UN system in the UK. There is a firm commitment now, with a target of mid-1976. Revision of statutory regulations and printing of labels (Figure 8) is well under way. The aim is to phase the change in accordance with the revised IMCO and revised NATO Storage Recommendations, both due in 1975. If these publications are delayed then the mid-1976 target might slip to 1977.

24. The UN Recommendations on labelling seem to have been well received everywhere. Most transport authorities now incorporate the basic features in their own mandatory labels even though they don't yet use the whole of the UN system of classification. The US labels introduced from January 1, 1974 are basically in line with the UN Recommendations although the old ICC Class (A, B or C) has been maintained, presumably as a temporary compromise to facilitate recognition. Conversion will be easier in the US (Figure 10, 11) than in the UK (Figure 12).

CONCLUSION: IT'S TIME THE USA DECLARED ITS INTENTIONS

25. At this point you will realise that the paper is aimed at propaganda. After so many declarations of intent and firm commitments by various nations, the question is being asked frequently: "What is the USA doing about adoption of the UN system of classification of explosives?"

26. There are major economies to be gained if everyone uses the same system of classification, labelling and shipping papers world-wide for both military and civil explosives. Many administrative frustrations and inconveniences will disappear. The use of inter-modal containers such as the US MILVANS highlights the absurdity of having different classifications and labels for different modes of transportation.

27. Members of the NATO and UN Groups are confident that the US will implement the UN system in due course. After all, it was formulated under a Chairman from the Department of Transportation, as noted earlier! It is understood that the Department of Defense set up a working party which recommended back in July 1972 that the Services should adopt the UN system when the Department of Transportation does so. There are now rumblings from over the border to the North that Canada is ready for the change, starting with the IMCO Code, but obviously truck and railroad regulations must be co-ordinated with those South of the border.

28. In a few years Mr Chairman, you will be out of step with everyone else if you don't adopt the UN system for explosives. If you can't beat us, will you not join us?

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EXPLOSIVES SAFETY IN THE UNITED KINGDOM

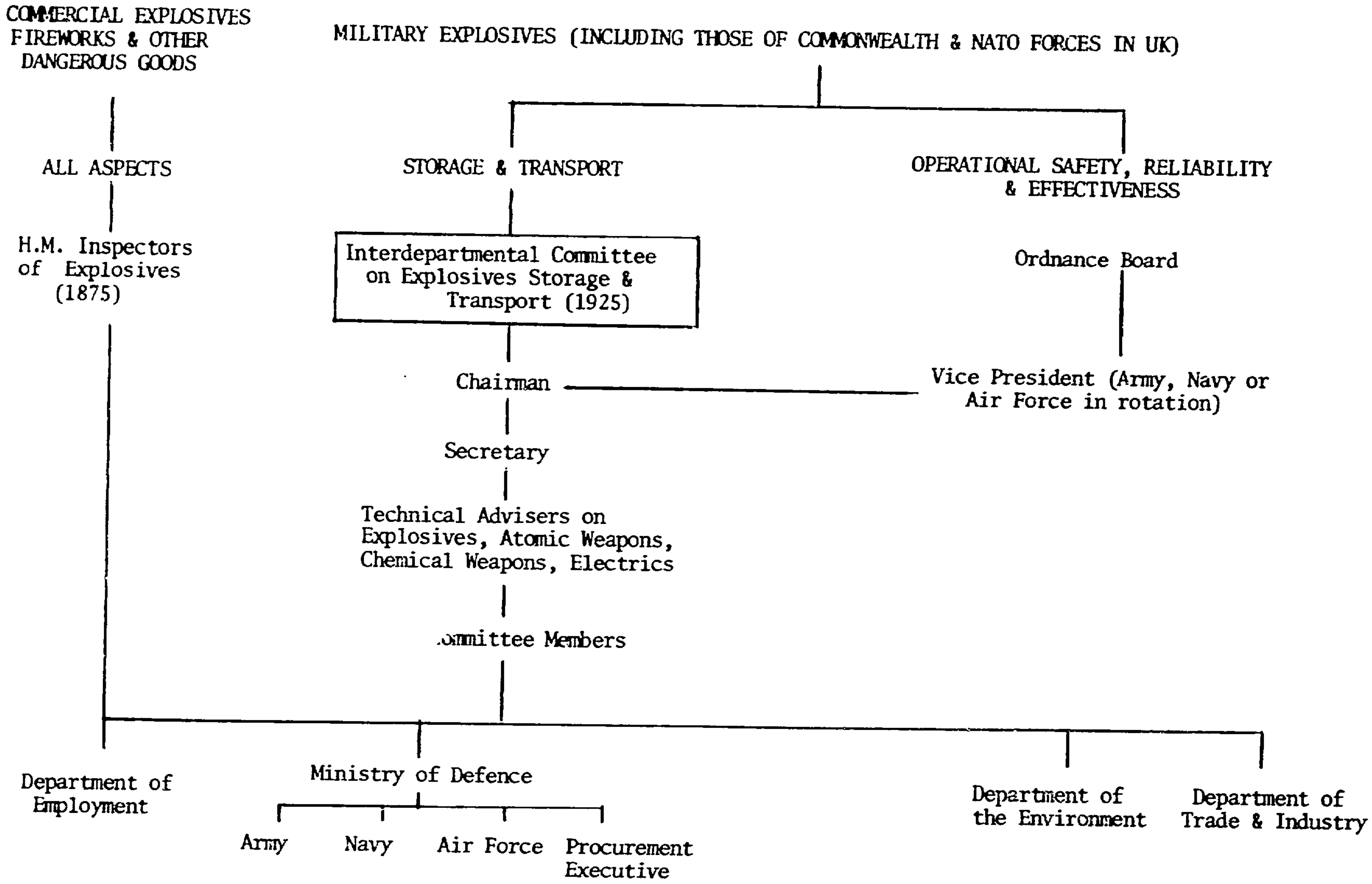


Figure 1

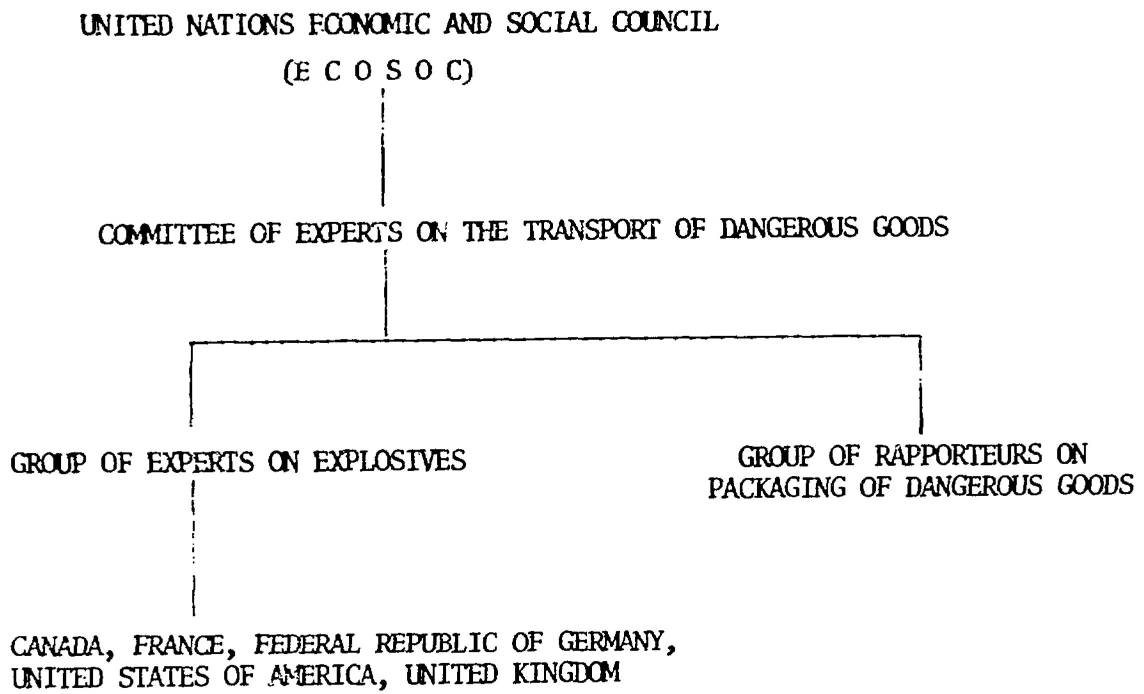

UNITED NATIONS ECONOMIC AND SOCIAL COUNCIL
(E C O S O C)
COMMITTEE OF EXPERTS ON THE TRANSPORT OF DANGEROUS GOODS
GROUP OF EXPERTS ON EXPLOSIVES
GROUP OF RAPPORTEURS ON PACKAGING OF DANGEROUS GOODS
CANADA, FRANCE, FEDERAL REPUBLIC OF GERMANY, UNITED STATES OF AMERICA, UNITED KINGDOM

Figure 2

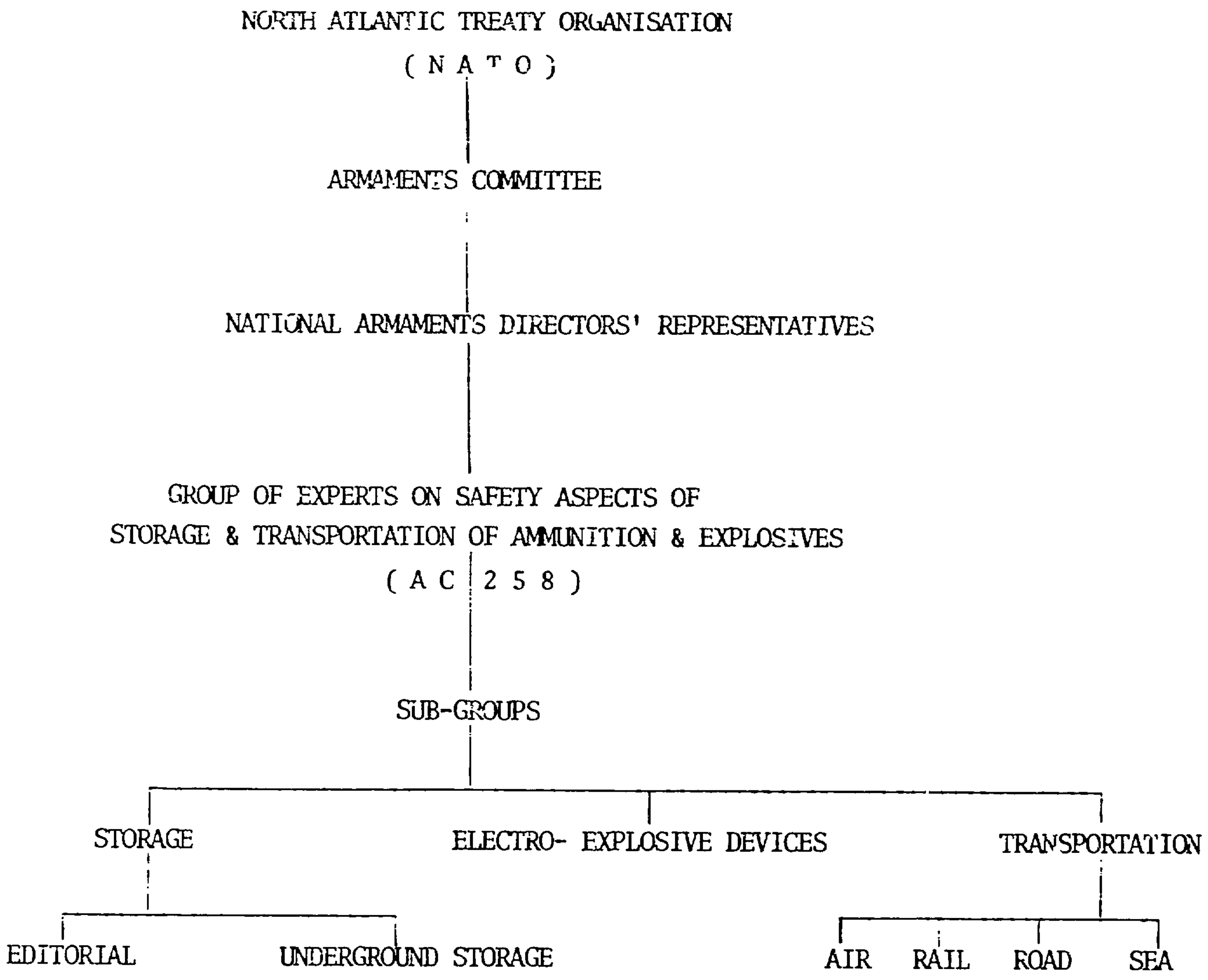

NORTH ATLANTIC TREATY ORGANISATION
(N A T O)
ARMAMENTS COMMITTEE
NATIONAL ARMAMENTS DIRECTORS' REPRESENTATIVES
GROUP OF EXPERTS ON SAFETY ASPECTS OF
STORAGE & TRANSPORTATION OF AMMUNITION & EXPLOSIVES
(A C 2 5 8)
SUB-GROUPS
STORAGE
ELECTRO- EXPLOSIVE DEVICES
TRANSPORTATION
EDITORIAL
UNDERGROUND STORAGE
AIR
RAIL
ROAD
SEA

Figure 3

LEVELS OF CLASSIFICATION

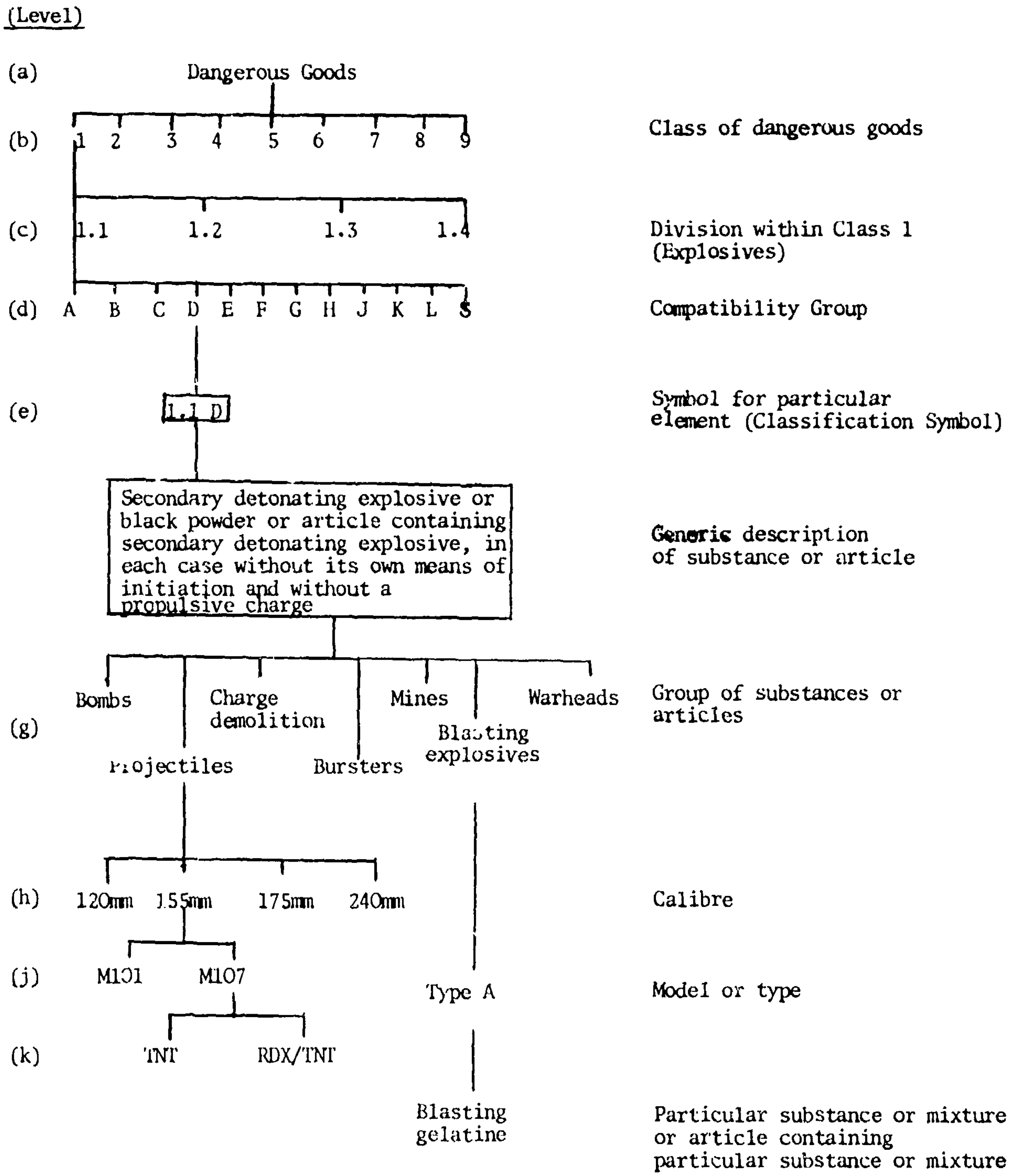


Figure 4

CLASS 1	EXPLOSIVES
	SUBSTANCES & ARTICLES (PACKAGED OR OTHERWISE AS OFFERED FOR TRANSPORTATION)
DIVISION 1.1	EXPLOSIVES WHICH HAVE A MASS EXPLOSION HAZARD
DIVISION 1.2	EXPLOSIVES WHICH HAVE A PROJECTION HAZARD BUT NOT A MASS EXPLOSION HAZARD
DIVISION 1.3	EXPLOSIVES WHICH HAVE A FIRE HAZARD AND EITHER A MINOR BLAST HAZARD OR A MINOR PROJECTION HAZARD OR BOTH BUT NOT A MASS EXPLOSION HAZARD
DIVISION 1.4	EXPLOSIVES WHICH PRESENT NO SIGNIFICANT HAZARD

Figure 5

United Nations Classification Code for Explosives

Description of substance or article to be classified	Compatibility Group	Classification Code
Primary explosive	A	1.1 A
Article containing primary explosive	B	1.1 B 1.2 B 1.4 B
Propellant explosive or other secondary deflagrating explosive or article containing such explosive	C	1.1 C 1.2 C 1.3 C 1.4 C
Secondary detonating explosive or black powder or article containing secondary detonating explosive, in each case without its own means of initiation and without a propulsive charge	D	1.1 D 1.2 D 1.4 D
Article containing secondary detonating explosive, without its own means of initiation, with a propulsive charge	E	1.1 E 1.2 E
Article containing secondary detonating explosive, with its own means of initiation, with or without a propulsive charge	F	1.1 F 1.2 F 1.3 F 1.4 F
Pyrotechnic substance, or article containing pyrotechnic substance, or article containing both an explosive and an illuminating, incendiary, lachrymatory or smoke-producing substance (other than a water-activated article or one containing white phosphorus, phosphide or flammable liquid or gel)	G	1.1 G 1.2 G 1.3 G 1.4 G
Article containing both an explosive and white phosphorus	H	1.2 H 1.3 H
Article containing both an explosive and a flammable liquid or gel	J	1.3 J
Article containing both an explosive and a toxic chemical agent	K	1.2 K 1.3 K
Article containing explosive and presenting a special risk needing isolation of each type	L	1.1 L 1.2 L 1.3 L
Package of explosive or article containing explosive, so packed or designed that any explosive effect during storage or transport is confined within the package or article	S	1.4 S

Figure 6

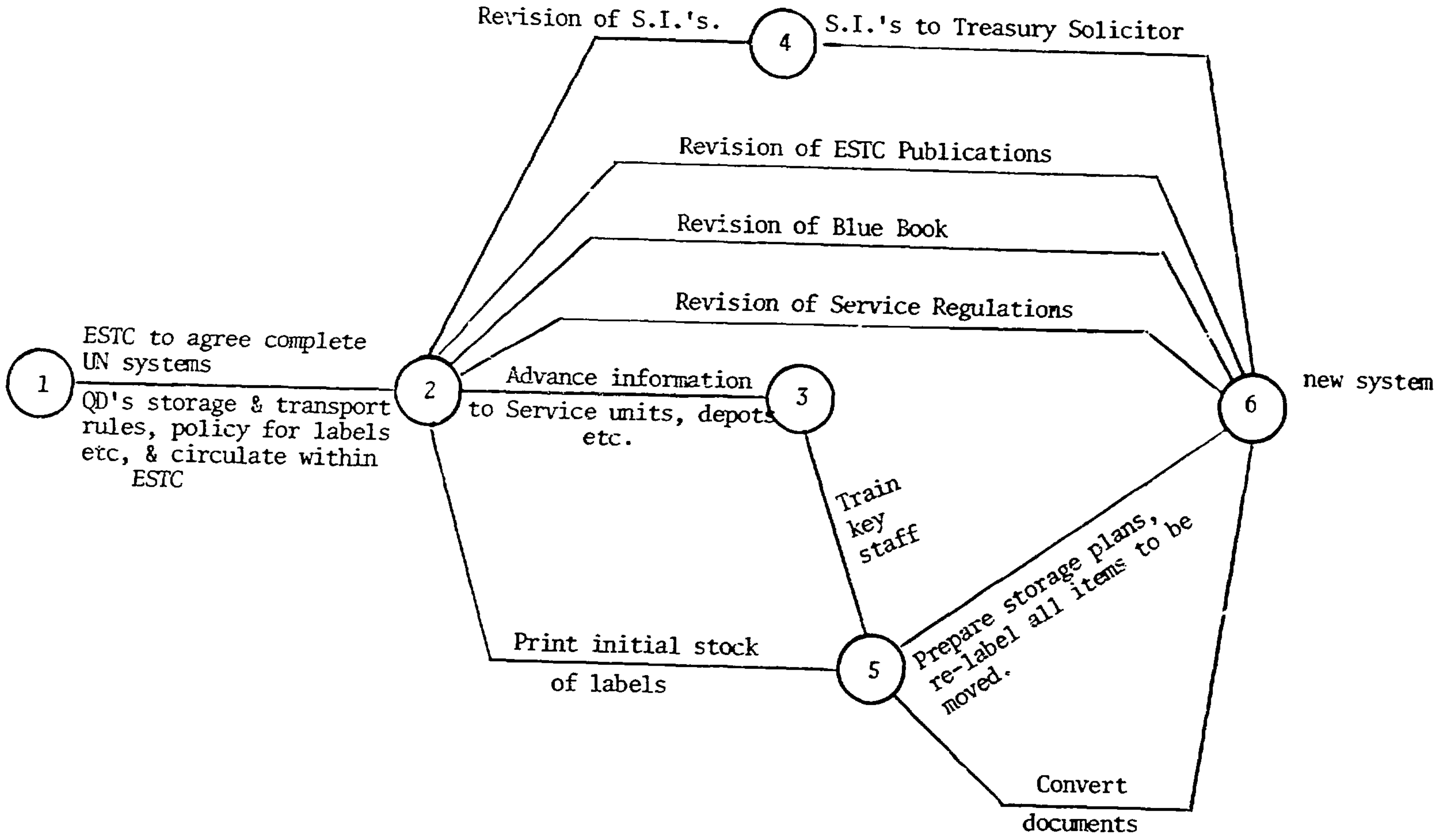
UN Transport Classifications

UN	A	B	C	D	E	F	G	H	J	K	L	S
1.4.2												1.4.2S
1.4.1		1.4.1 B	1.4.1C	1.4.1D		1.4.1 F	1.4.1G					
1.3			1.3C			1.3 F	1.3 G	1.3 H	1.3 J	1.3 K	1.3 L	
1.2		1.2 B	1.2C	1.2 D	1.2E	1.2F	1.2G	1.2H		1.2 K	1.2L	
1.1	1.1A		1.1C	1.1D		1.1F	1.1G				1.1 L	
		1.1 B			1.1E							

Figure 7

Figure 8

OUTLINE INTRODUCTION OF UN CLASSIFICATION



NOTES

1. MARKING OF NEW PRODUCTION AMMUNITION COULD START DURING EVENTS 2-5.
2. THE EXPLOSIVES ACT. 1875. MAY BE REVISED WITHIN THE TIMESCALE ENVISAGED ABOVE.

Figure 9

NATO Storage and UN Transport Classifications

Correlation with US Department of Defense Quantity-Distance Classes

DoD	UN	A	B	C	D	E	F	G	H	J	K	L	S
1	1.4.2												1.4.2S
	1.4.1		1.4.1 B	1.4.1C	1.4.1 D		1.4.1 F	1.4.1G					
2	1.3			1.3C			1.3 F	1.3 G	1.3 H	1.3 J	1.3 K	1.3 L	
3 4 5 6	1.2		1.2 B	1.2C	1.2 D	1.2 E	1.2 F	1.2G	1.2H		1.2 K	1.2L	
7	1.1	1.1A		1.1C	1.1D		1.1 F	1.1G				1.1 L	
			1.1 B			1.1E							

Figure 10

NATO Storage and UN Transport Classifications

Correlation with US Department of Transportation Classes

DoT	UN	A	B	C	D	E	F	G	H	J	K	L	S
G	1.4.2												1.4.2S
	1.4.1		1.4.1 B	1.4.1C	1.4.1D		1.4.1 F	1.4.1G					
D	1.3			1.3C			1.3 F	1.3 G	1.3 H	1.3 J	1.3 K	1.3 L	
A	1.2		1.2 B	1.2 C	1.2 D	1.2 E	1.2 F	1.2 G	1.2 H		1.2 K	1.2 L	
	1.1	1.1A		1.1 C	1.1 D		1.1 F	1.1 G				1.1 L	
			1.1 B			1.1 E							

Figure 11

NATO Storage and UN Transport Classifications

UK ESTC'71	UN	A	B	C	D	E	F	G	H	J	K	[illegible]	S
X1	1.4.2												1.4.2S
	1.4.1		1.4.1 B	1.4.1C	1.4.1 D		1.4.1 F	1.4.1G					
Y	1.3			1.3C			1.3 F	1.3 G	1.3 H	1.3 J	1.3 K	1.3 L	
X 3	1.2		1.2 B	1.2C	1.2 D	1.2 E	1.2 F	1.2 G	1.2 H		1.2 K	1.2 L	
X 4													
ZZ	1.1	1.1A		1.1C	1.1 D		1.1 F	1.1 G				1.1 L	
Z			1.1 B			1.1 E							

Figure 12

AN OVERVIEW OF THE SUPPRESSIVE SHIELDING PROGRAM

Mr. P. V. King
Edgewood Arsenal, MD

1. INTRODUCTION:

AT THE PAST TWO SEMINARS WE HAVE DISCUSSED OUR EFFORTS IN THE DEVELOPMENT AND APPLICATION OF SUPPRESSIVE STRUCTURES. AS YOU MAY REMEMBER, OUR DEFINITION OF A SUPPRESSIVE STRUCTURE IS ONE THAT IS DESIGNED FOR TOTAL ENCLOSURE OF A HAZARDOUS OPERATION, AND WORKS ON THE PRINCIPLE OF PROVIDING A COMPLETELY AND HOMOGENEOUSLY VENTED STRUCTURE WHICH WILL PERMIT THE SHOCKWAVE TO ESCAPE, AFTER GIVING UP A CONSIDERABLE PORTION OF ITS ENERGY, BUT WHICH IS DESIGNED FOR COMPLETE RETENTION OF ALL FRAGMENTS AND A HIGH DEGREE OF ATTENUATION OF FLAME, AEROSOL AND COMBUSTION PRODUCTS. OUR DESIGN OBJECTIVE IS TO PROVIDE A SAFE ENVIRONMENT AT A STATED DISTANCE FROM THE STRUCTURE, WHICH MAY IN SOME CASES (OPERATIONAL LINE PROTECTION) BE THE ADJACENT OPERATOR'S POSITION AND FOR LARGER EXPLOSURES, E.G., FOR MELT LAB OPERATIONS, BE IN THE INTRALINE DISTANCE FOR THE QUANTITY OF EXPLOSIVES INVOLVED.

Title Slide

IN OTHER WORDS, WE ARE AIMING AT ABSOLUTE, RATHER THAN ORDER OF PROBABILITY, PROTECTION AT THE DISTANCES OF CONCERN. THIS CONCEPT, OFFERING A NEW DIMENSION OF EXPLOSIVES SAFETY HAS BEEN TESTED FOR A VARIETY OF APPLICATIONS DURING THE

PAST TWO AND A HALF YEARS, BUT WE WILL CONCERN OURSELVES WITH OUR ACCOMPLISHMENTS AND FINDINGS SINCE OUR LAST SEMINAR.

2 - 6
5 Slides Suppressive Shield Operation

IN SUMMATION, WE FEEL WE HAVE, DURING THE PAST YEAR, DEMONSTRATED THE FEASIBILITY OF OUR CONCEPTS, AND THAT THERE ARE A VIRTUALLY UNLIMITED NUMBER OF APPLICATIONS THROUGHOUT THE EXPLOSIVES INDUSTRY AND, IN FACT, IN ANY OPERATION WHERE EXPLOSION HAZARDS EXIST. WE HAVE MUCH TO LEARN ABOUT THE WAY THESE STRUCTURES OPERATE. AND HOW THEY MAY BE OPTIMIZED, AND WE ARE ENGAGED, WITH THE HELP OF A NUMBER OF SCIENTIFIC ESTABLISHMENTS BOTH WITHIN AND WITHOUT THE GOVERNMENT, IN A COMPREHENSIVE PROGRAM TO PRODUCE PROTOTYPE STRUCTURES FOR CURRENT PRODUCTION BASE MODERNIZATION OPERATIONS, AND CULMINATING IN A DESIGN HANDBOOK TO OPTIMIZE (WITHIN PRACTICAL LIMITS) THE APPLICATION OF THESE STRUCTURES FOR THE GAMUT OF HAZARDOUS OPERATIONS RANGING FROM PRODUCTION THROUGH TRANSPORTATION TO STORAGE AND ULTIMATE DISPOSITION OF THE MUNITION.

Slide 15 Danger Radius Hardwall
Slide 15 Suppressive Shield
Slide 2500# Melter P.K.

2. PROGRESS:

DURING OUR LAST MEETING WE TALKED ABOUT OUR FORTHCOMING TESTS WITH THREE DISTINCTIVELY DIFFERENT TYPES OF STRUCTURES; LISTING THEM IN THE ORDER OF COMPLETION AND TESTING THEY ARE AS FOLLOWS:

Slide Radford P.K.

NAVY EOD PORTABLE STRUCTURE: AS SHOWN IN THE SLIDE A STRUCTURE WAS DESIGNED AND BUILT FOR THE NAVAL EXPLOSIVES ORDNANCE DISPOSAL FACILITY AT INDIAN HEAD, MD,

Photo EOD 2 Slides

FOR USE IN DISPOSING OF CLANDESTINE DEVICES, PRINCIPALLY OF TWO TYPES: SATCHELL CHARGES CONTAINING UP TO THREE POUNDS OF EXPLOSIVES AND PIPE BOMBS, CONTAINING UP TO ONE POUND OF HE. THE DESIGN CONSTRAINTS GIVEN WERE TO MAKE IT LIGHT ENOUGH TO BE USABLE ON TO&E EQUIPMENT (TRAILER WITH 7000 LBS CAPACITY, COMPLETE RETENTION OF FRAGMENTS, AND MODERATION OF BLAST TO THE EXTENT POSSIBLE WITH THE WEIGHT AND SIZE LIMITATION.) THIS STRUCTURE HAS BEEN TESTED TO THE DESIGN LIMITS, AND IS NOW BEING TESTED TO CAPACITY BY THE NAVY. AT THE LAST REPORT, 20 LBS HAD BEEN FIRED SUCCESSFULLY IN THIS STRUCTURE. PRESSURE MEASUREMENTS OUTSIDE THE STRUCTURE DURING THE THREE POUND TEST INDICATED AN OPERATOR SAFE DISTANCE AT 22 FEET (2.3 PSI OR BELOW SIDE-ON).

AS SHOWN, THE STRUCTURE WAS QUITE SIMPLE IN CONSTRUCTION, FEATURING AN INNER LAYER OF 1/4" ANGLE IRON AND TWO LAYERS OF PERFORATED MILD STEEL 3/16" THICK, AND SEPARATED BY 1/2". STRUCTURE WAS BUILT, AS SHOWN IN TWO MONTHS AT A COST OF 36K.

OUR SECOND STRUCTURE (THE 81MM MULTIPLE APPLICATIONS STRUCTURE) CAMDS WAS TESTED DURING THE PERIOD NOVEMBER THRU JULY 1974. EARLY IN THE DESIGN CYCLE THE STRUCTURE WAS ADAPTED TO THE DEMILITARIZATION OF CHEMICAL ROUNDS AND THE OVERALL DEMIL SYSTEM WAS CONSTRUCTED OF THE FOLLOWING COMPONENTS:

A. A SUPPRESSIVE STRUCTURE WAS BUILT TO CONTAIN FRAGMENTS FROM CHEMICAL ROUNDS UP TO 8" IN SIZE TO ATTENUATE BLAST TO THE EXTENT NECESSARY TO MODERATE

Photo CAMDS

THE LOAD ON THE PLENUM BUILDING, AND TO ATTENUATE, TO THE EXTENT LIMITED BY OTHER DESIGN CONSTRAINTS, THE AEROSOL DISPERSION.

Slide or Photos

Cut Away of CAMDS

B. THE PLENUM STRUCTURE AS SHOWN IS A LIGHTWEIGHT FLEXIBLE STRUCTURE BUILT TO CONTAIN THE COMBUSTION PRODUCTS AND EXHAUST THEM THROUGH A FILTER SYSTEM.

C. THE THIRD BUILDING IN THE SYSTEM IS MERELY A BUTLER TYPE BUILDING, ERECTED TO PROVIDE AN ATMOSPHERE SUFFICIENTLY STABILIZED TO SAMPLE POTENTIAL LEAKAGE FROM THE PLENUM BUILDING, AND TO PROVIDE PROTECTION FOR SNOW LOADING. THESE THREE MODULES CONSTITUTE A SYSTEM FOR DEMILITARIZATION OF ALL CHEMICAL ROUNDS UP TO 8" IN SIZE.

Photo - Int CAMDS

TESTS HAVE INDICATED THAT THE STRUCUTRE AS DESIGNED, WAS ADEQUATE FOR M55 CHEMICAL ROCKETS. HOWEVER, IN FIVE TESTS WITH THE 8" ROUND, FRAGMENT PENETRATION OCCURRED ON FOUR TESTS, INDICATING THE NEED FOR A MINOR MODIFICATION OF THE SUPPRESSIVE STRUCTURE.

Photo Frag Damage CAMDS

IT APPEARS THAT OUR PROBLEMS WITH THE CHEMICAL ROUNDS HAVE BEEN DUE TO A PAUCITY OF DATA CONCERNING THE FRAGMENTATION CHARACTERISTICS OF CHEMICAL ROUNDS GENERALLY, AND THAT THE EXTRAPOLATION OF DATA FROM HE ROUND TESTING (ARENA TESTS AND SIMILAR) DID NOT PERMIT ADEQUATE PREDICTION IN TERMS OF MASS AND VELOCITY OF THE CHEMICAL ROUND FRAGMENTS, WHICH RANGED IN SIZE UP TO SEVEN POUNDS.

81MM SUPPRESSIVE SHIELD

The third suppressive shield developed and tested during the past year was a shield approximately 20 x 15 x 13 as shown, constructed as follows (from the inside out), 1/8" Z bar, 2 - 3/16" perforated plates, 1 - 1/8" perforated plate, and 2 - 1/16" louvers. This shield was designed as a prototype to withstand the detonations of two 81MM HE rounds, in a fuze insertion/torqueing station.

Photo 81MM

Design constraints were as follows:

1. Minimum weight and ease of erection.
2. Complete primary and secondary fragment protection.
3. Reduction of incident overpressure to 2.3 psi, 3' from the shield.

In tests at National Space Technology Laboratories, Mississippi, 81mm fragments were demonstrated to penetrate 1" of mild steel. Since our spaced armor principles applied to suppressive shielding have shown approximately 1/2 the penetration of solid steel, our panels were constructed to provide a total thickness of 3/4" of metal. Results of six tests showed penetration of less than three of our six panel elements or approximately 7/16". This shield is of particular interest to us since we attempted to incorporate limit

DESIGN CONCEPTS, THAT IS TO DESIGN THE STRUCTURE TO OBTAIN PLASTIC DEFORMATION, THUS ABSORBING MORE ENERGY PER POUND OF STRUCTURE, WITHOUT FAILING. AS SHOWN, THE DESIGN PROVED PRACTICABLE. SOME DISTORTION WAS NOTED WITH TWO ROUNDS AS SHOWN. GREATLY INCREASED DISTORTION WAS NOTED WITH SIX ROUNDS, AND AFTER REPAIRS, THE STRUCTURE WAS TESTED TO FAILURE AT 35 LBS, YIELDING VALUABLE INFORMATION REGARDING DESIGN OF FUTURE STRUCTURES. IN SUMMARY, LAST YEAR WAS FOR US AN EVENTFUL ONE IN WHICH WE DEMONSTRATED THE APPLICABILITY OF SUPPRESSIVE SHIELD TO A NUMBER OF OPERATIONS, WE HAVE, AS SHOWN PREVIOUSLY ATTAINED SIGNIFICANT MODERATION OF THE DAMAGE PARAMETERS OF CONCERN IN EXPLOSIONS, HAVE MADE CONSIDERABLE ADVANCES IN REDUCING THE COST OF THE STRUCTURES IN TERMS OF MATERIAL AND LABOR. AS AN EXAMPLE, THE FIRST STRUCTURE WAS BUILT WITH A HEAVY FRAME AND WELDED PANELS WITH THE PANEL FRAME ASSEMBLIES WELDED IN PLACE. IN THE 81MM STRUCTURE WE CONSTRUCTED THE PANELS IN LARGER SIZES, PLACED THEM IN AN ANGLE IRON FRAME, AND WEDGED THEM IN THE STRUCTURAL FRAME WITH FOUR WEDGES, WHICH WERE TACK-WELDED IN PLACE. AT THE END OF THESE EFFORTS, OUR LEARNING CURVE WAS AS FOLLOWS: COST OF FABRICATION IN TERMS OF MAN HOURS/SQUARE FOOT OF STRUCTURE SURFACE WAS REDUCED FROM 5.5 PER SQ FT FOR (CAMDS) TO 2.5 PER SQ FT (81MM). IN TERMS OF DOLLARS PER SQ FT/PER POUND OF EXPLOSIVES OUR LEARNING CURVE LOOKED SOMETHING LIKE THIS.

Slide Limit Design Concepts

Slide Learning Curve

IN SUMMARY, WE HAVE HAD A BUSY YEAR, BUT I THINK WE HAVE DEMONSTRATED THE FEASIBILITY OF SUPPRESSIVE SHIELDING FOR A VARIETY OF OPERATIONS. HOWEVER, AS MR. JUNKIN EXPLAINED LAST YEAR, WE ARE REALLY JUST BEGINNING AS A REVIEW OF OUR CURRENT PLANS AND ACTIVITIES WILL REVEAL.

3. CURRENT PROGRAM:

Slide
Applications of Shields

AS DISCUSSED PREVIOUSLY, WITH FUNDING PROVIDED BY THE PRODUCTION BASE MODERNIZATION PROGRAM, WE ARE ENGAGED IN A THREE PHASED ACCELERATED PROGRAM ARRIVED AT MAKING THE MAXIMUM IMPACT ON THE PRODUCTION BASE MODERNIZATION PROGRAM, IN THE MINIMUM TIME FRAME CONSISTENT WITH ECONOMIC FEASIBILITY. SINCE AN ECONOMIC ANALYSIS PERFORMED SOME SIX MONTHS AGO INDICATED THAT SUPPRESSIVE STRUCTURES WERE, AT THEN PRESENT STATE OF THE ART, COST COMPETITIVE WITH OTHER TYPES OF CONSTRUCTION, AND IN ADDITION OFFERED A NUMBER OF POTENTIAL ADVANTAGES, WE ARE WELL ON OUR WAY IN A PROGRAM WHICH WILL PROVIDE IN ONE PHASE, COST EFFECTIVE SHIELDS FOR SOME 367 POTENTIAL OPERATIONS IN SEVEN CATEGORIES, AND IN THE SECOND PHASE, IN CONDUCTING AN APPLIED TECHNOLOGY PROGRAM WHICH WILL PERMIT OPTIMIZATION (WITHIN THE RANDOMNESS OF PREDICTED ACCIDENTS) AND APPLICATION OF SUPPRESSIVE SHIELDING FOR ALL APPLICATIONS THROUGH THE MEDIUM OF A DESIGN HANDBOOK. BY CONDUCTING THESE PROGRAMS CONCURRENTLY WE HAVE BEEN ABLE TO DEMONSTRATE SIGNIFICANT SAVINGS SINCE THERE IS AN INSTANT FEEDBACK OF DATA FROM ONE PROGRAM TO THE OTHER. WORK IS CURRENTLY UNDERWAY IN THE FOLLOWING CATEGORIES OF STRUCTURES.

AS SHOWN, THE CATEGORY SHIELD PROGRAM WILL BE COMPLETED BY FY76. THIS MEANS, BASICALLY, THAT COST EFFECTIVE BUT NOT OPTIMIZED, STRUCTURES WILL BE AVAILABLE FOR ALL DESIRED OPERATIONS ON THE PRODUCTION BASE MODERNIZATION PROGRAM, SHOWN IN OUR CHART, AND FOR RELATED OPERATIONS AT OTHER LOCATIONS, SUCH AS INCINERATION, DEFUZING, ETC.

Slide Category Shield Schedule and APP Tech Schedule

HOWEVER, IT IS IMPORTANT TO REALIZE THAT THE OPERATIONS WE HAVE BEEN CONCERNED WITH IN THE CATEGORY SHIELD PROGRAM ARE FOR THE MOST PART, THOSE WHICH ARE DESIGNATED CATEGORY THREE OR FOUR SAFETY HAZARDS, WHICH REPRESENT ONLY ABOUT 15% OF THE OPERATIONS IN A TYPICAL LAP LINE.

Slide Conventional Structure

WITH THE COMPLETION OF THE APPLIED TECHNOLOGY PROGRAM, AND PUBLICATION OF THE DESIGN HANDBOOK, IT WILL BE ECONOMICALLY FEASIBLE TO APPLY SUPPRESSIVE SHIELDING OF AN ENTIRE FACILITY, PERMITTING US TO ACHIEVE NEW STANDARDS OF COST REDUCTION AND PROTECTION.

Slide Suppressive Shield Facility

FOR EXAMPLE, IN OUR SINGLE PARAMETER STUDIES, THE EFFECT OF VENTING AREAS, GEOMETRY, NUMBER OF PLATES, ETC., ON ATTENUATION OF BLAST WILL BE STUDIED AND OPTIMIZED. AT THE SAME TIME SIMILAR EFFORTS ARE BEING CONDUCTED FOR OPTIMIZATION OF PANEL PERFORMANCE AGAINST FRAGMENTATION AND FIRE, FINALLY, SELECTED COMBINATION OF THE PARAMETER WILL BE EVALUATED AND SO FORTH. GENERALLY SPEAKING THE PROGRAMS WILL ALL INCLUDE THE FOLLOWING ELEMENTS:

1. REVIEW OF PAST EXPERIENCE.
2. DEVELOPMENT OF MATHEMATICAL MODEL.
3. CONDUCT OF R&D TESTING.
4. FIELD VERIFICATION TESTING.
5. MODEL REFINEMENT AND RETENTION AS NECESSARY.

THIS EFFORT WILL CULMINATE IN A DESIGN HANDBOOK BY THE 3RD QUARTER. FY77. RETURNING TO OUR PRESENT TIME FRAME. ONE OF THE MOST CHALLENGING OF OUR PROBLEMS IS THE DESIGN AND CONSTRUCTION OF A CATEGORY 1 SHIELD, TO CONTAIN THE EXPLOSION OF A 2500 LB MELTER. IN ORDER TO GET THE NECESSARY DESIGN INFORMATION, AS ECONOMICALLY AS POSSIBLE, A 1/4 SCALE STRUCTURE WILL BE CONSTRUCTED AND TESTED BY THE 3RD QUARTER, FY75, FOLLOWING WHICH THE FULL SCALE STRUCTURE (FUNDING WILLING) WILL BE CONSTRUCTED AND TESTED DURING 3RD QUARTER FY76. SO FAR IN OUR EFFORTS WE ARE CONVINCED THAT GIVEN SOME FREEDOM TO TRADE OFF BULK OF EXPLOSIVES AND DIMENSIONS OF THE STRUCTURE, WE CAN BUILD SUPPRESSIVE STRUCTURES FOR ALL PRODUCTION BASE MODERNIZATION OPERATIONS.

CURRENT STUDIES:

AS PART OF OUR PREAPARATION FOR THE PROGRAMS WE HAVE DESCRIBED, A NUMBER OF STUDIES HAVE BEEN, AND ARE BEING CONDUCTED TO FORM A SOUND BASIS FOR DESIGN AND TESTING EFFORTS. SOME OF THESE WILL BE REPORTED ON IN MORE DETAIL IN THE SPECIALIST SESSIONS THIS AFTERNOON, AND ARE BRIEFLY OUTLINED HERE.

Slide - Support Engineering

IN THE CONDUCT OF OUR PROGRAM WE HAVE PLANNED TO USE THE EXPERTISE OF A

NUMBER OF GOVERNMENT ACTIVITIES AS SHOWN ON THE VUGRAPH (FUNCTION MANAGEMENT). IT IS OUR HOPE THAT BY UTILIZING KNOWN SPECIALISTS IN THE AREAS OF CONCERN, WE CAN SAVE CONSIDERABLE TIME AND MONEY, AND BE ASSURED OF A HIGHER QUALITY PRODUCT.

Function Management
Vu Graph

IN CONCLUSION, I WOULD LIKE TO ADDRESS BRIEFLY, SOME OF THE QUESTIONS THAT ARE MOST FREQUENTLY ASKED CONCERNING SUPPRESSIVE STRUCTURES.

DECONTAMINATION:

ONE OF THE MOST PREVALENT QUESTIONS IS THE SUBJECT OF DECONTAMINATION WHEN THE SHIELD IS EXPOSED TO DUST OR VAPORS OF A COMBUSTIBLE NATURE. OUR PROPOSED SOLUTION IS TO EQUIP SHIELDS IN SUCH LOCATIONS WITH LIGHTWEIGHT PLASTIC LINERS OF MYLAR, POLYETHYLENE OR SIMILAR MATERIALS WHICH CAN EITHER BE WASHED DOWN OR STRIPPED OFF AND DISPOSED OF.

Slide 2 Liner Tests
Before & After

WE HAVE CONDUCTED A LIMITED NUMBER OF TESTS INDICATING THE FEASIBILITY OF THIS APPROACH. AS AN EXAMPLE A 0.0004", 0.0006" NYLON LINING WILL NOT PRODUCE A MEASUREABLE DIFFERENCE IN THE RESPONSE OF THE STRUCTURE, AND WILL CONTINUE THESE TESTS DURING OUR CURRENT PROGRAM.

SHELF LIFE:

IN A NORMAL OPERATING ENVIRONMENT THE SUPPRESSIVE SHIELD SHOULD MAINTAIN ITS INTEGRITY THROUGHOUT THE NORMAL LIFE OF THE RELATED FACILITIES AND EQUIPMENT, SINCE IT UNDERGOES NO STRESS EXCEPT IN THE EVENT ON AN ACCIDENT. IN THIS CONNECTION, WE ARE DESIGNING THE STRUCTURES TO SURVIVE ONE MAXIMUM

CREDIBLE INCIDENT WITHOUT FAILURE, BUT WITH THE NEED FOR REPLACEMENT OR REPAIR AFTER SUCH AN ACCIDENT, DEPENDING ON THE APPLICATION, AND AS DICTATED BY ECONOMIC FEASIBILITY. THERE IS AN OVERDESIGN INHERENT IN ALL SHIELDS, DUE TO THE NEED TO COVER A RANGE OF ACCIDENTS, THEREFORE MINOR DEGRADATION DUE TO OXIDATION, ETC., WILL NOT BE A PROBLEM, AGAIN, SINCE THE STRUCTURE WILL BE IN A CONTROLLED ENVIRONMENT THESE FACTORS WILL BE MINIMIZED. WHERE IT IS DESIRED THAT SUPPRESSIVE SHIELD BE USED FOR FREE STANDING OR SEPARATE FACILITIES, AS IN MELT OPERATIONS, THEY MAY BE PROTECTED FROM THE ELEMENTS BY THE INCORPORATION OF ANOTHER PLASTIC LINER, MAKING TWO IN ALL, AND THE FRAMEWORK CAN BE PAINTED OR RUST-PROOFED, ACCORDINGLY. OTHER QUESTIONS HAVE BEEN RAISED AS TO THE MEANS OF PROVIDING ENTRY AND EXIT FOR MATERIAL AND OPERATORS. AS FAR AS WE CAN DETERMINE IT IS PROBABLY SUFFICIENT TO SAY THAT THE MEANS OF EGRESS, ACCEPTABLE FOR CONVENTIONAL HARDENED STRUCTURES WILL BE ACCEPTABLE FOR SUPPRESSIVE SHILEDING, EXCEPTING THAT IN MOST CASES WE WOULD PREFER TO MAKE THEM OF SUPPRESSIVE RATHER THAN SOLID MATERIAL SINCE THEY WILL HELP THE SUPPRESSIVE SHIELD PERFORM BETTER. HOWEVER, THE REALTIVELY SMALL REFLECTING SURFACES PROVIDED BY GUILLOTINE DOORS, ETC., WILL PERMIT US TO USE DEVICES TESTED AND APPROVED FOR CONVENTIONAL HARDENED STRUCTURES, IF DESIRED, ALTHOUGH

WE ARE NOW PLANNING TO CONDUCT OUR OWN DEVELOPMENT TESTS OF DOORS AND INTERLOCKS. SIMILARLY: ENTRIES FOR UTILITIES WILL BE MORE EASILY PROVIDED FOR THAN IN A CONCRETE STRUCTURE, AND WOULD BE LESS LIKELY TO BECOME A FAILURE POINT, AS IS SOMETIMES THE CASE WITH COMPLETE CONTAINMENT STRUCTURES (BLAST CHAMBERS, ETC.), SINCE THERE IS NO REQUIREMENT FOR PRESSURE-PROOF SEALS.

LIMITS OF APPLICATIONS:

BASED ON OUR TESTS TO DATE, WE FEEL THAT THE SUPPRESSIVE SHIELD CONCEPTS CAN BE APPLIED TO AT LEAST AS EXTREME A SET OF ENVIRONMENTAL PARAMETERS AS CAN OTHER FORMS OF PROTECTION, AND IF DESIGNED PROPERLY, THEY SHOULD BE CAPABLE OF PROTECTING ANY OF OUR EXPLOSION HAZARDS, ON AN ECONOMICALLY JUSTIFIABLE BASIS, GIVEN THE FREEDOM OF SOME DEGREE OF TRADE OFF OF SIZE OF STRUCTURE AND BULK OF EXPLOSIVE FOR CONSIDERATIONS OF ECONOMIC FEASIBILITY. THIS FLEXIBILITY DERIVES FROM OUR BASIC DESIGN CONSIDERATION, NAMELY. THAT SINCE WE DO NOT HAVE TO WITHSTAND THE EXTREMES OF REFLECTED AND STATIC PRESSURES THAT HARDENED STRUCTURES MUST WITHSTAND, OUR CONSTRUCTION CAN IN THE LONG RUN BE MORE ECONOMICAL.

IN CLOSING, LET ME DISCUSS VERY BRIEFLY THE MOST RECENT WORK WE HAVE BEGUN IN THE UTILIZATION OF SUPPRESSIVE SHIELD CONCEPTS TO PREVENT PROPAGATION BOTH WITHIN OPERATING BAYS (PALLET CONFIGURATIONS) AND IN STORAGE/TRANSPORTATION APPLICATIONS.

Slide Transport Module

OUR CONCEPT HERE, IS THAT WE CAN PROVIDE, ON AN ECONOMICALLY FEASIBLE BASIS, NON-PROPAGATIVE PALLETS, WHICH WILL MINIMIZE THE DEGREE OF RISK IN ALL LAP OPERATIONS, THUS PERMITTING COMPLETELY PROTECTED (SUPPRESSIVE SHIELD) FACILITIES, AS DISCUSSED PREVIOUSLY. IN A SIMILAR MANNER, A NON-PROPAGATING TRASNPORT/STORAGE MODULE CAN BE BUILT, WHICH CAN SERVE AS AN ALL PURPOSE CONTAINER DESIGNED TO PREVENT PROPAGATION FROM MODULE TO MODULE. ELIMINATE THE NEED FOR MAGAZINES, OFF LOADING, ETC. THESE MODULES CAN BE DESIGNED TO STACK IN STANDARD MILVAN CONFIGURATIONS, ON DIMENSIONS SUCH MODULES WILL PROBABLY NOT BE FEASIBLE FOR ALL ROUNDS, HOWEVER, OUR TESTS TO DATE INDICATE THAT THEY ARE FEASIBLE FOR SOME.

Slide Transport Concepts

Slide Mag Storage

IN OUR TRANSPORT CONCEPT THE SHIPPING CONTAINER WOULD BE DESIGNED AS A SUPPRESSIVE EGG CRATE, WITH THE ROUND SUPPORTED IN A HOT SEALED PLASTIC BAG, SEPARATED FROM THE PERFORATED SHIELD BY PLASTIC STANDOFFS. IN THE EVENT A ROUND DETONATES. FRAGMENT ENERGY WILL BE ABSORBED BY PENETRATION OF THE SHIELD TO THE POINT WHERE THEY WILL LACK THE ENERGY TO DETONATE OTHER (ACCEPTOR) ROUNDS. IN THIS CASE WE ARE DISTINGUISHING CAREFULLY BETWEEN A DETONATION AND AN EXPLOSION, SINCE WITH THE LATTER, THE REACTION WILL DEGRADE, SO THAT THE ACCEPTOR ROUND FRAGMENTS ACTING NOW AS DONORS, WILL BE UNABLE TO DETONATE THE NEXT LAYER OF ROUNDS. IN THIS CONFIGURATION PREPARED FOR 81MM ROUNDS AND IN THE PHOTOS TO FOLLOW THE PERFORATED LINES OR SLEEVES WILL BE OF 1/16" OR 3/32" THICKNESS, SEPARATED FROM EACH OTHER BY SPACERS OF APPROXIMATELY 3/8".

THE TRANSPORT MODULE WILL CONSIST OF A DOUBLE WALL PERFORATED STRUCTURE COMPOSED OF TWO 1/16" THICKNESS OF MATERIAL WITH A THIN PLASTIC LINER (OR POSSIBLY TWO) FOR WEATHERPROOFING AND INSULATION. THE MODULE WOULD HAVE A DOOR, AND WOULD BE EQUIPPED WITH SPACERS FOR STACKING PURPOSES. THE FOLLOWING PHOTOS SHOW THE RESULTS OF VERY RECENT TESTS TO EVALUATE THE FEASIBILITY OF THE NON-PROPAGATING PALLET CONCEPT.

Slides

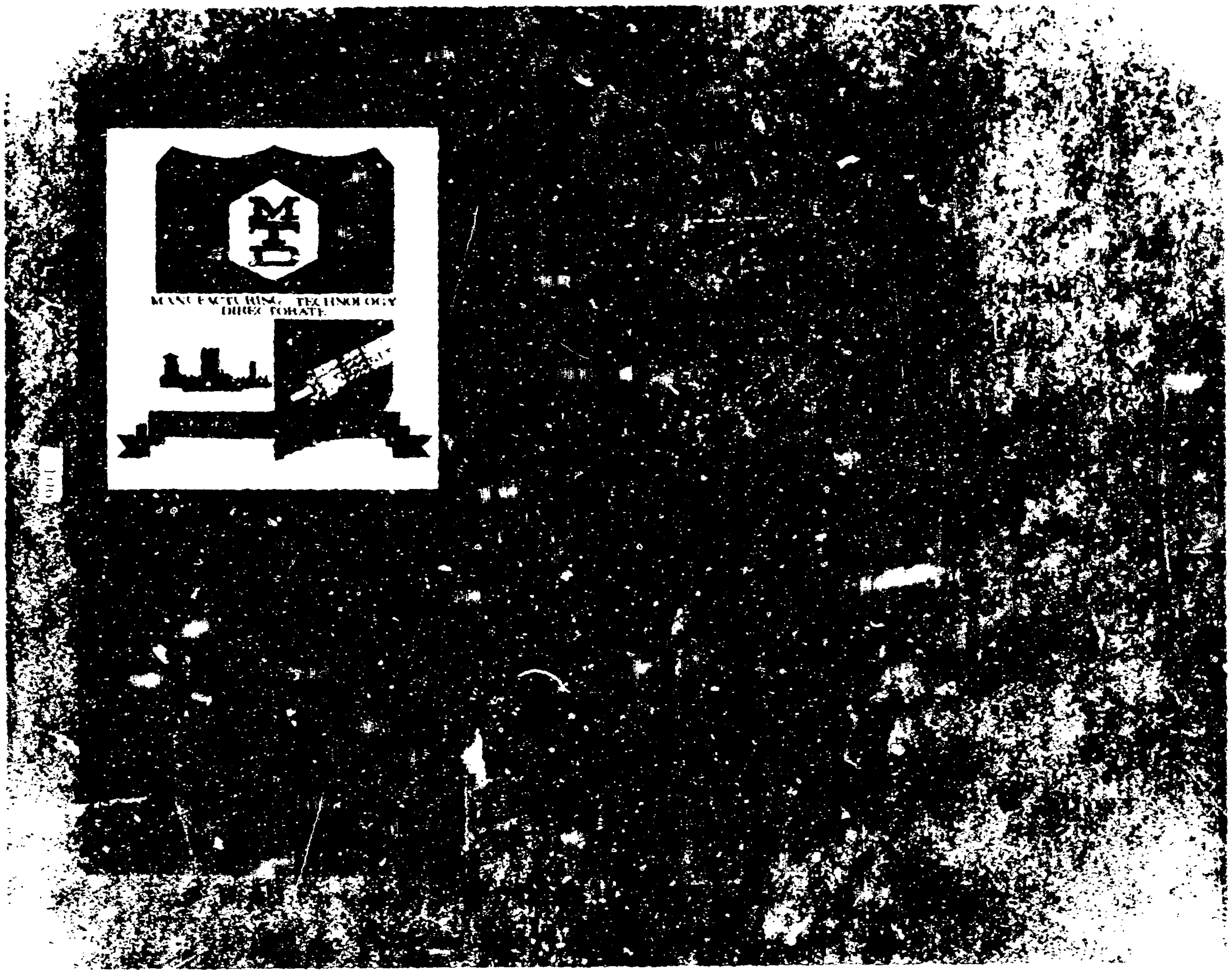
Trial No. 5

Trial No. 6

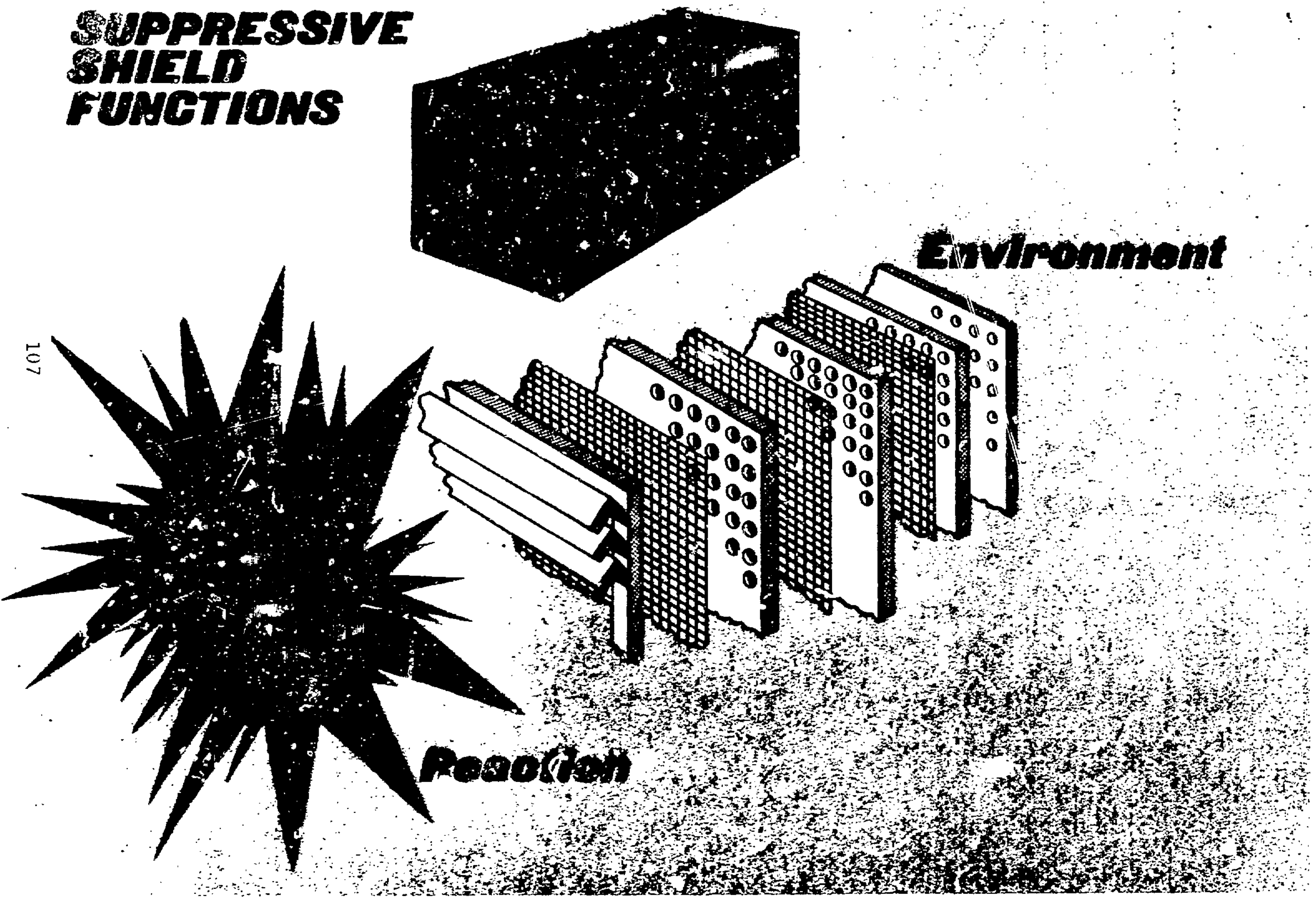
AS YOU CAN SEE, ROUNDS SURROUNDING A DONOR PROTECTED BY 1/8" OF METAL AND SPACED 2" OR GREATER FROM THE SUPPRESSIVE SHIELD MATERIAL DID NOT DETONATE, WHEREAS IN FREE AIR, ACCEPTOR ROUNDS SPACED UP TO EIGHT INCHES DID. ADMITTEDLY, THESE TESTS ARE INCOMPLETE REPRESENTING NINE TRIALS, BUT THEY CONFIRM RESULTS WITH APPROXIMATELY THE SAME NUMBER OF TESTS OF AN OLDER PRODUCTION VERSION OF THE 81MM ROUND TESTED PREVIOUSLY. AS REGARDS TO FEASIBILITY, WE HAVE CALCULATED THAT A STANDARD MODULE, BUILT TO DIMENSIONS SUGGESTED AS OPTIMAL BY SAVANNAH ARMY AMMUNITION DEPOT, WILL PROVIDE A NON-PROPAGATING UNIT OF 1440 ROUNDS STORED IN INDIVIDUAL MODULES OF 96 ROUNDS, EACH OF WHICH IS ITS OWN MAGAZINE, FOR A TOTAL WEIGHT, INCLUDING THE MILVAN OF 43,000 LBS. THIS COMPARES WITH A STANDARD PACKAGE OF 33,000 LBS, ALSO INCLUDING THE MILVAN. SINCE WE PLAN TO USE A SKELETONIZED FRAMEWORK OR SLING, RATHER THAN THE MILVAN, WE SHOULD BE ABLE TO REDUCE THE WEIGHT DIFFERENTIAL SIGNIFICANTLY. IN ADDITION FURTHER REFINEMENTS OF DESIGN ARE EXPECTED TO REDUCE THE WEIGHT PENALTY FURTHER.

CONSIDERING THE SAVINGS TO BE REALIZED BY ELIMINATION OF STORAGE MAGAZINES, TRANSHIPMENT, OFFLOADING, AND THE AVOIDANCE OF MASS REACTIONS IN MANUFACTURING, STORAGE AND TRANSPORT, WE FEEL THE PRICE IS MODEST.

THANK YOU FOR YOUR ATTENTION.


MANUFACTURING TECHNOLOGY
DIRECTORATE

SUPPRESSIVE SHIELD FUNCTIONS



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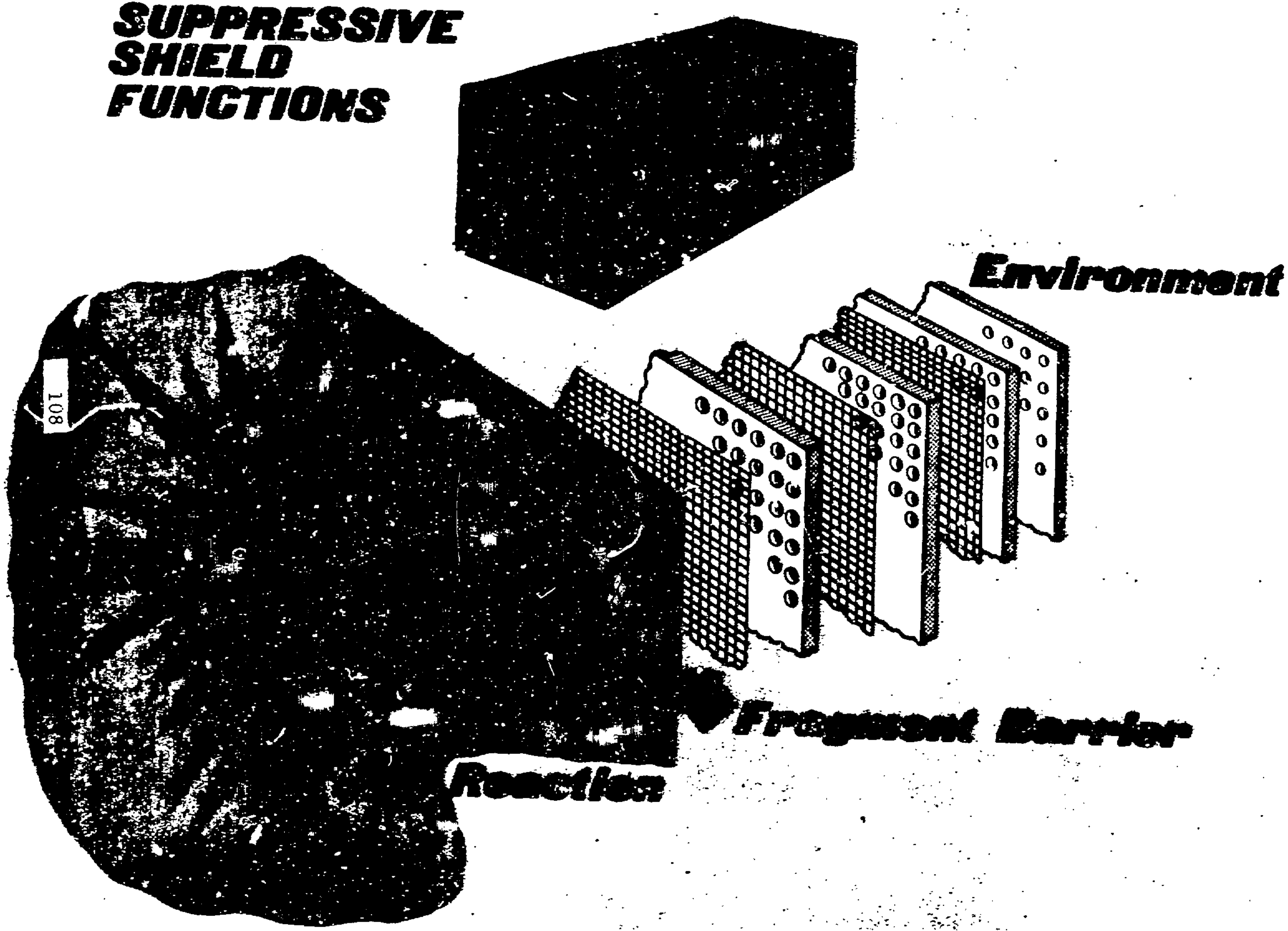

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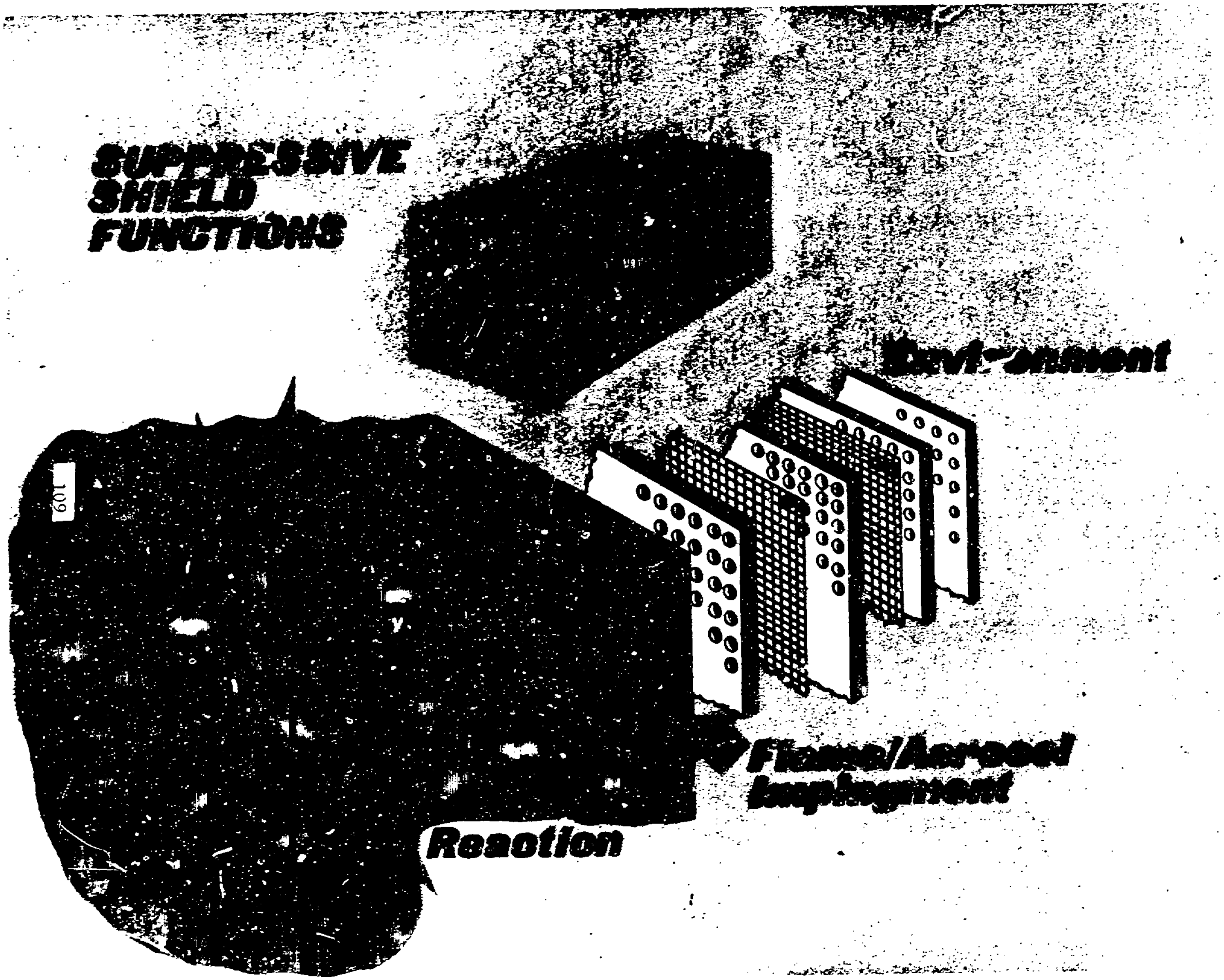
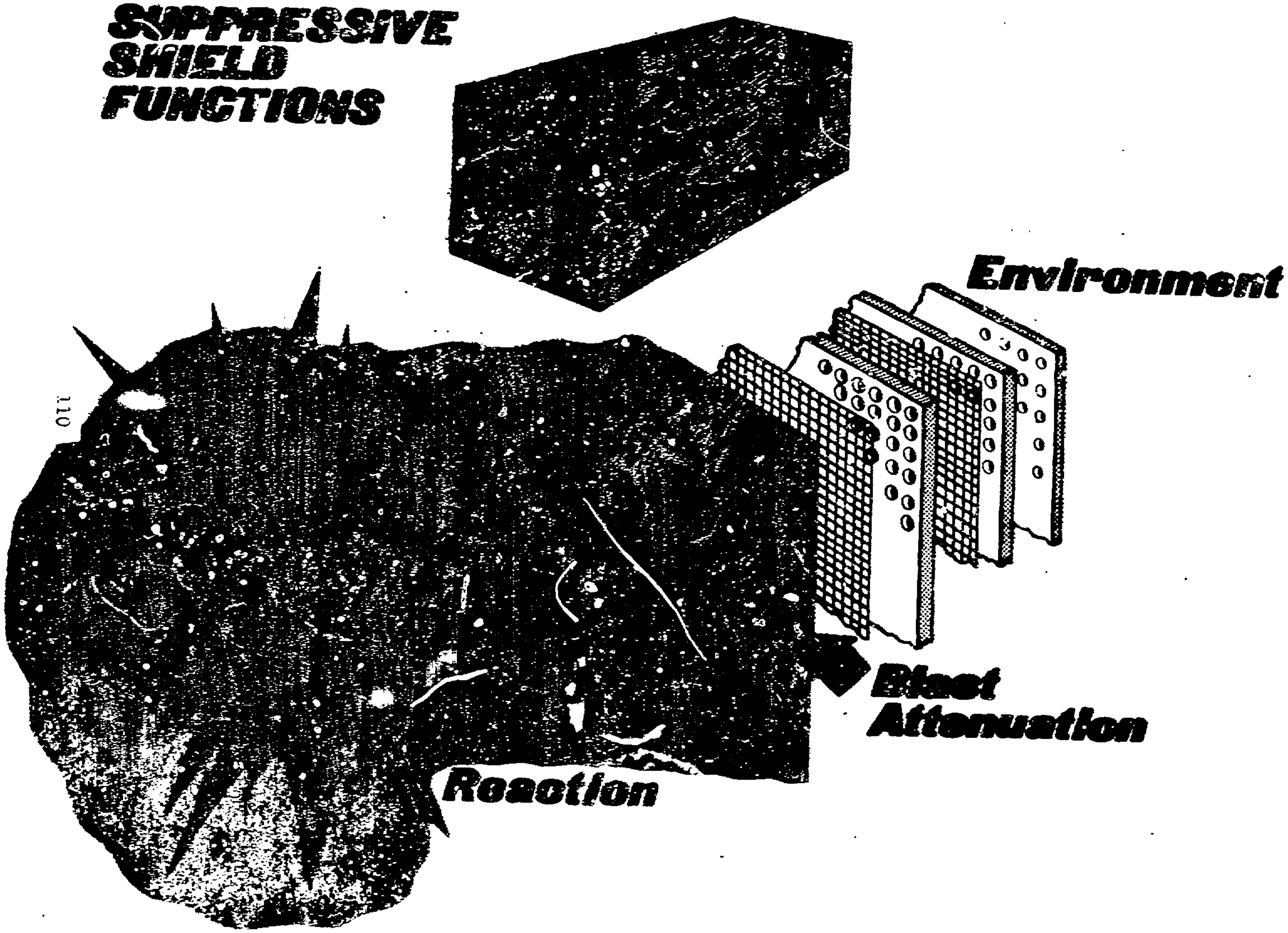


SUPPRESSIVE SHIELD FUNCTIONS



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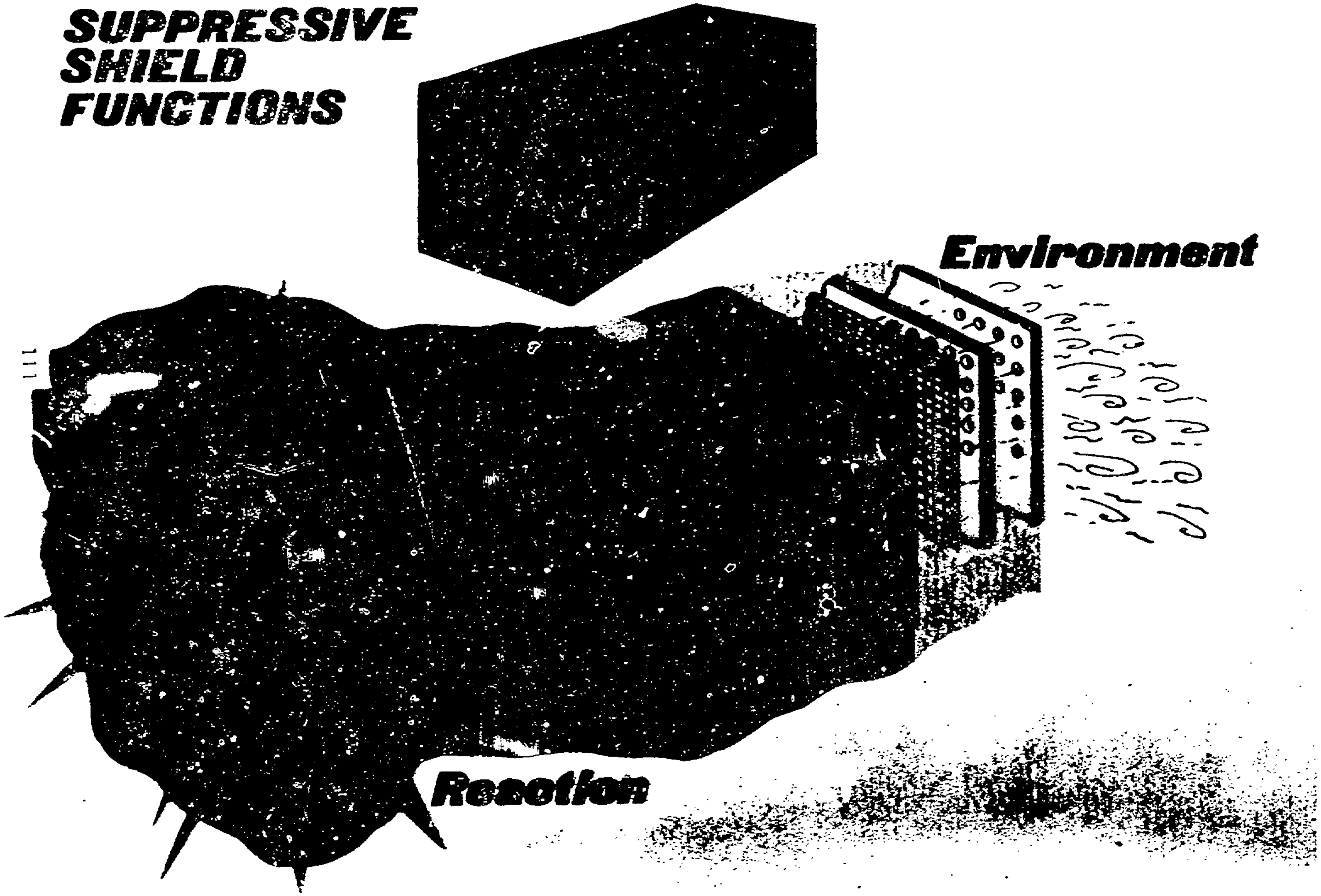
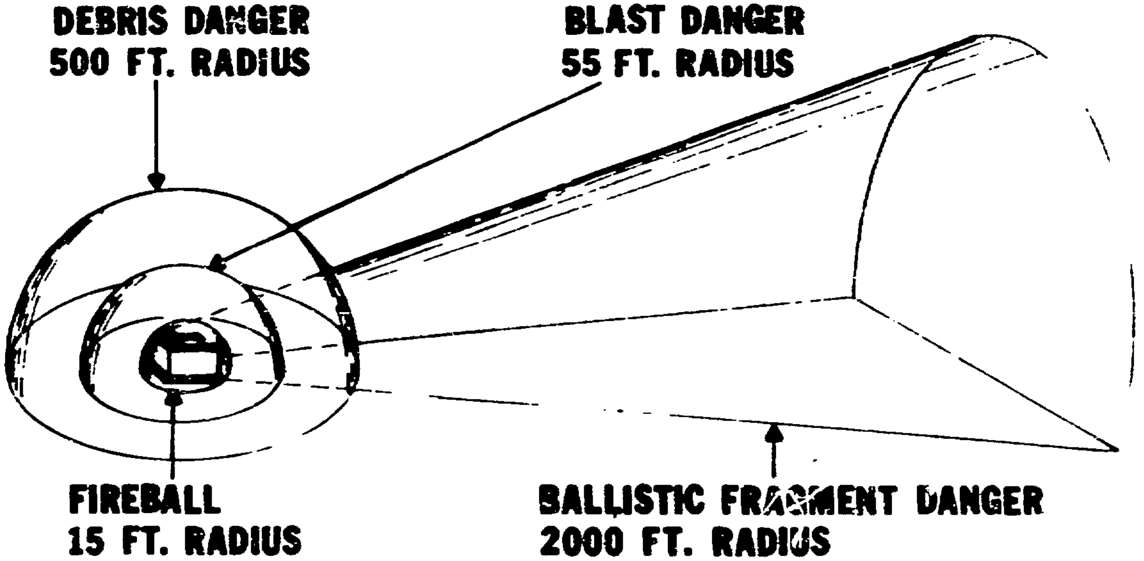
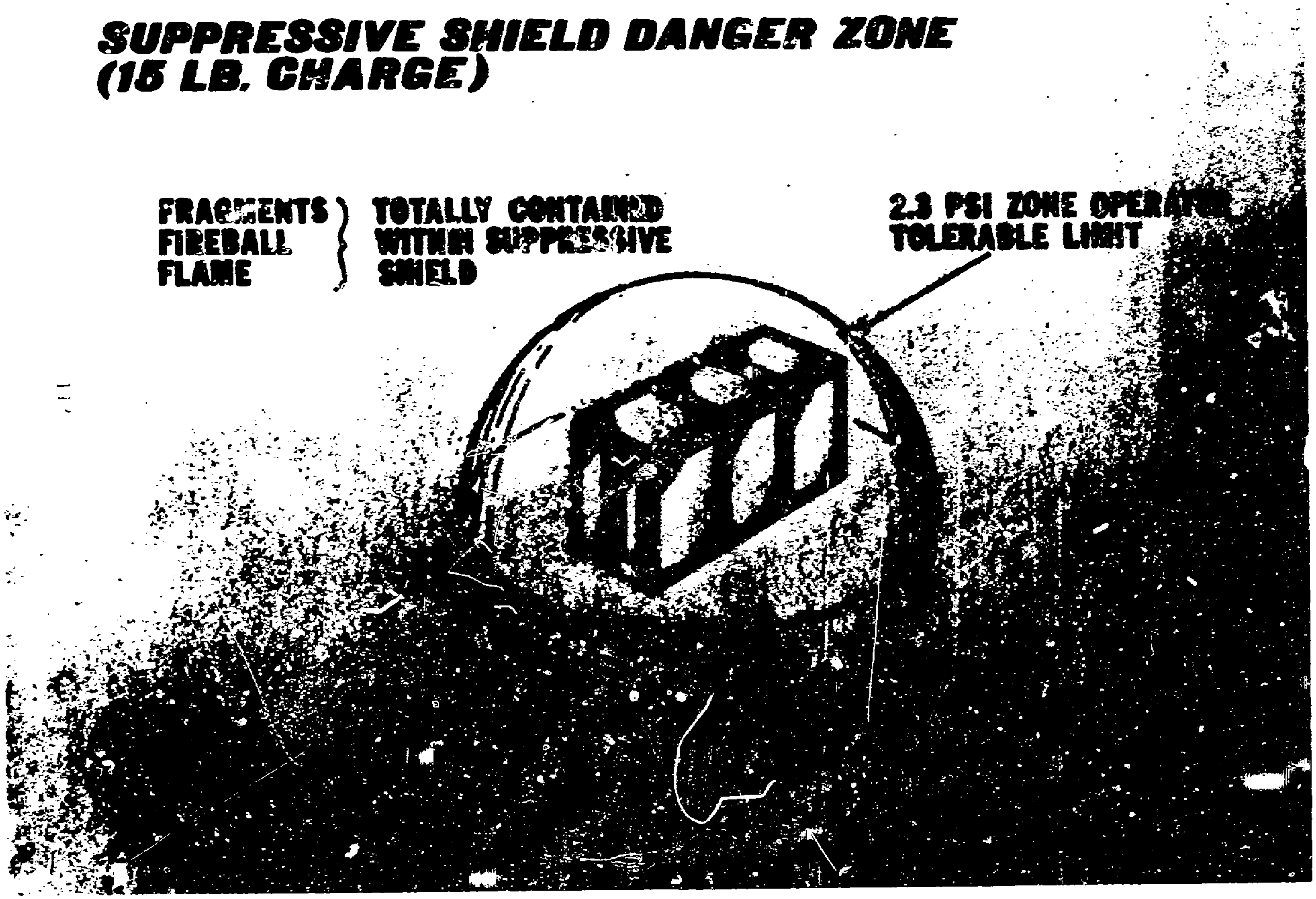


HARDWALL CUBICLE DANGER ZONES (15 LB CHARGE)



SUPPRESSIVE SHIELD DANGER ZONE (15 LB. CHARGE)



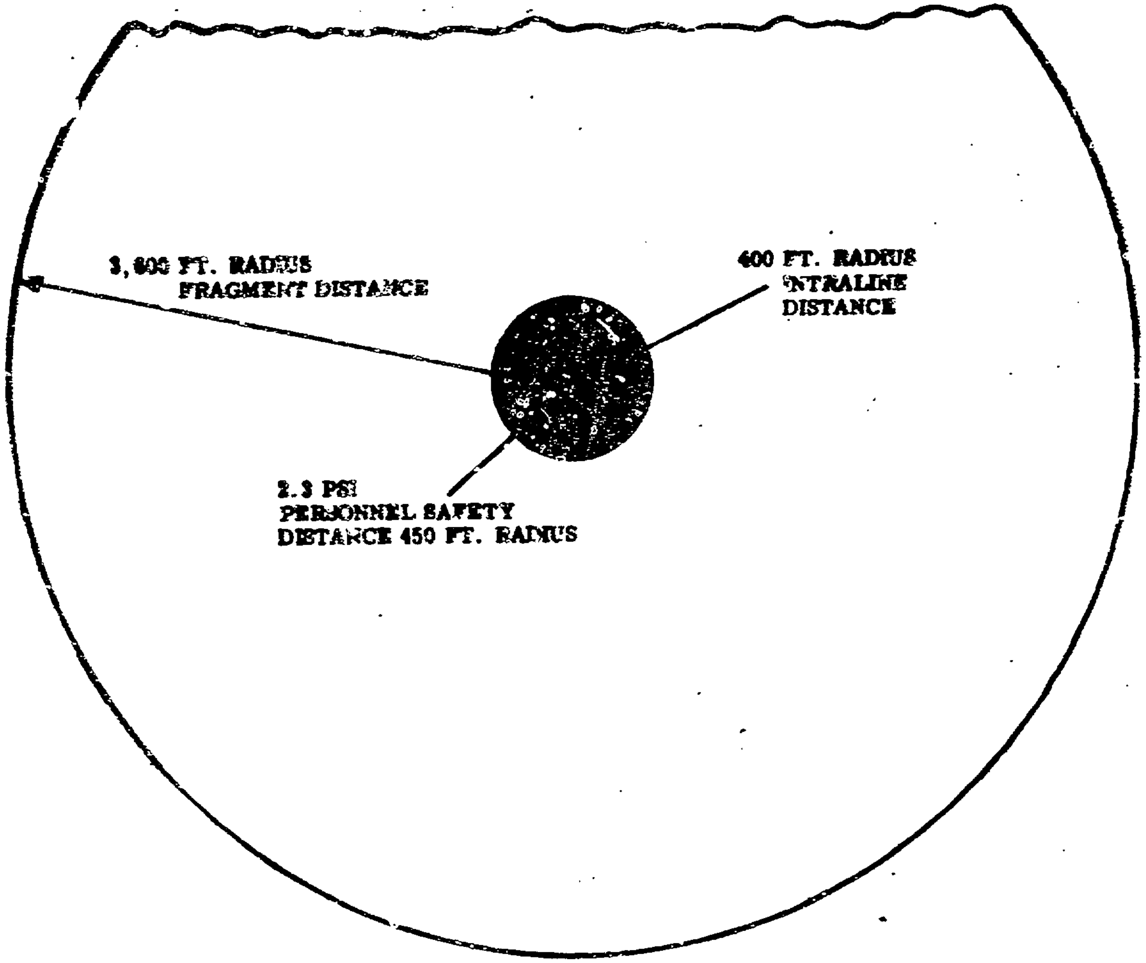
FRAGMENTS } TOTALLY CONTAINED
FIREBALL } WITHIN SUPPRESSIVE
FLAME } SHIELD

2.3 PSI ZONE OPERATOR
TOLERABLE LIMIT

PROPOSED CATEGORY 1 STRUCTURE

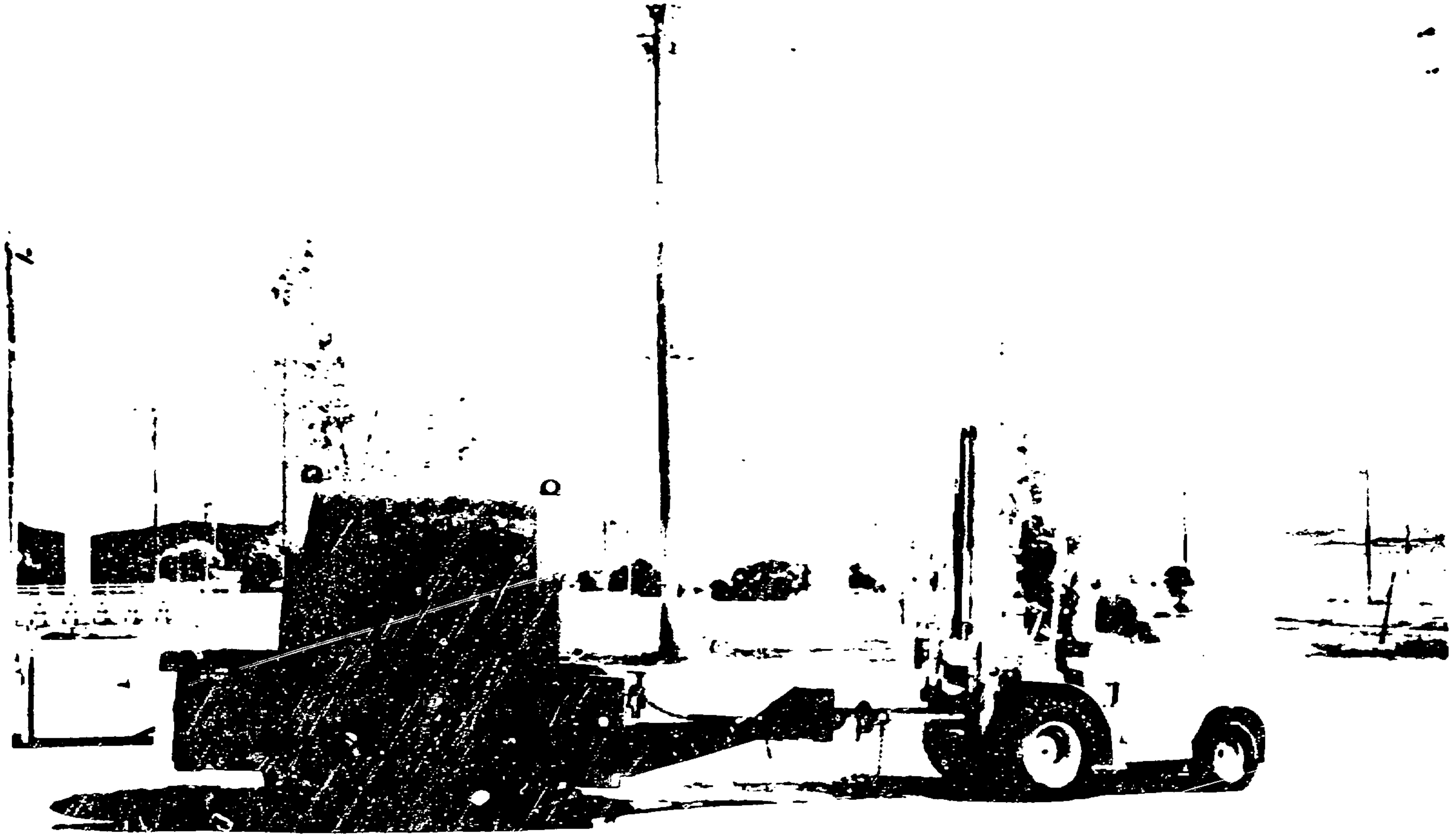
BLAST ATTENUATION FOR LARGE HE CHARGE WEIGHTS

RADFORD ACCIDENT - 10,000 LB HE CHARGE



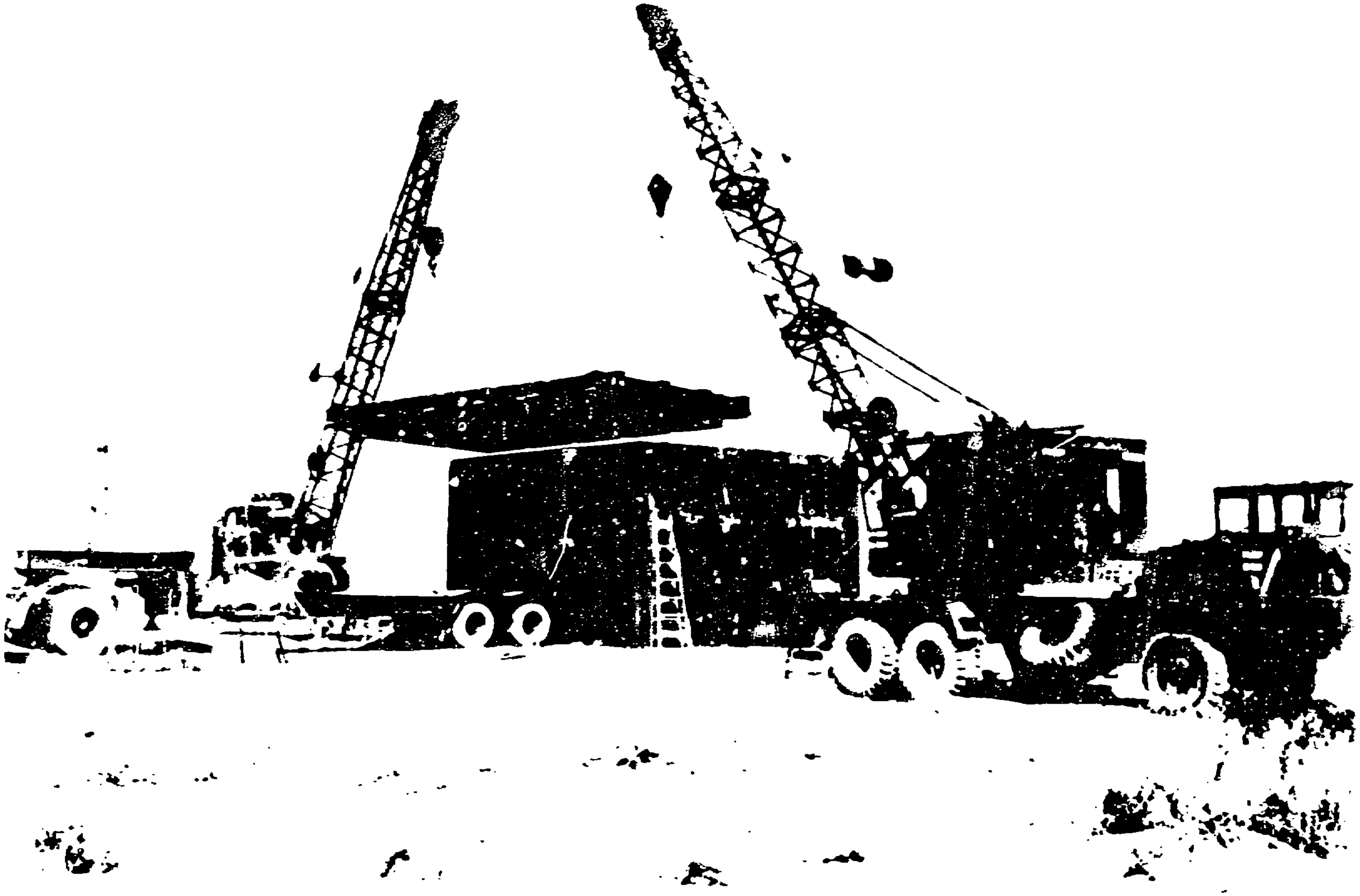
NAVY EOD

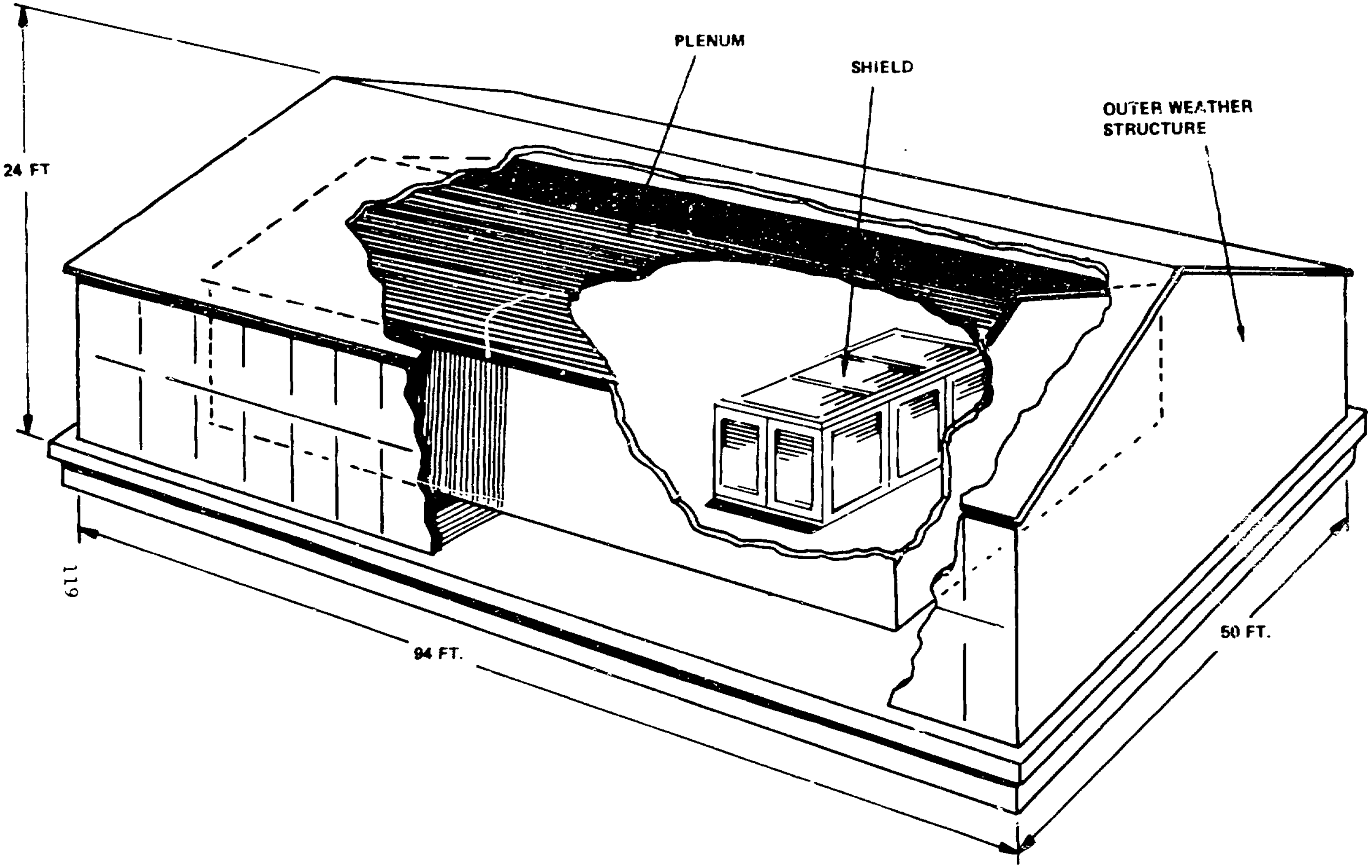
CAPACITY - 1# PIPE BOMB
CHARGE SIZE - 3# HE (BARE)
DESIGN/TEST CYCLE - 4 MONTHS



CHEMICAL AMMUNITION DISPOSAL SYSTEM

SUPPRESSIVE ENCLOSURE





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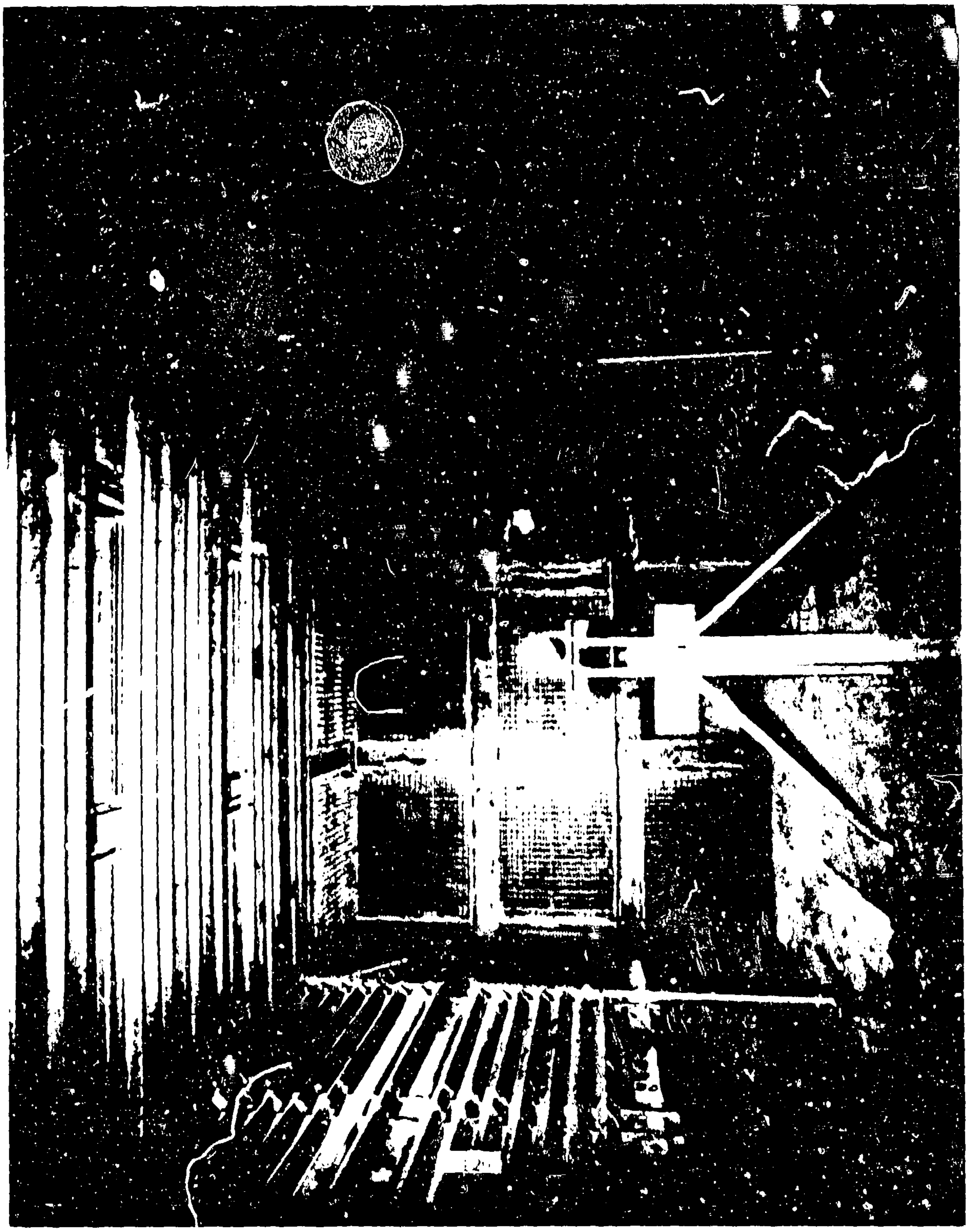
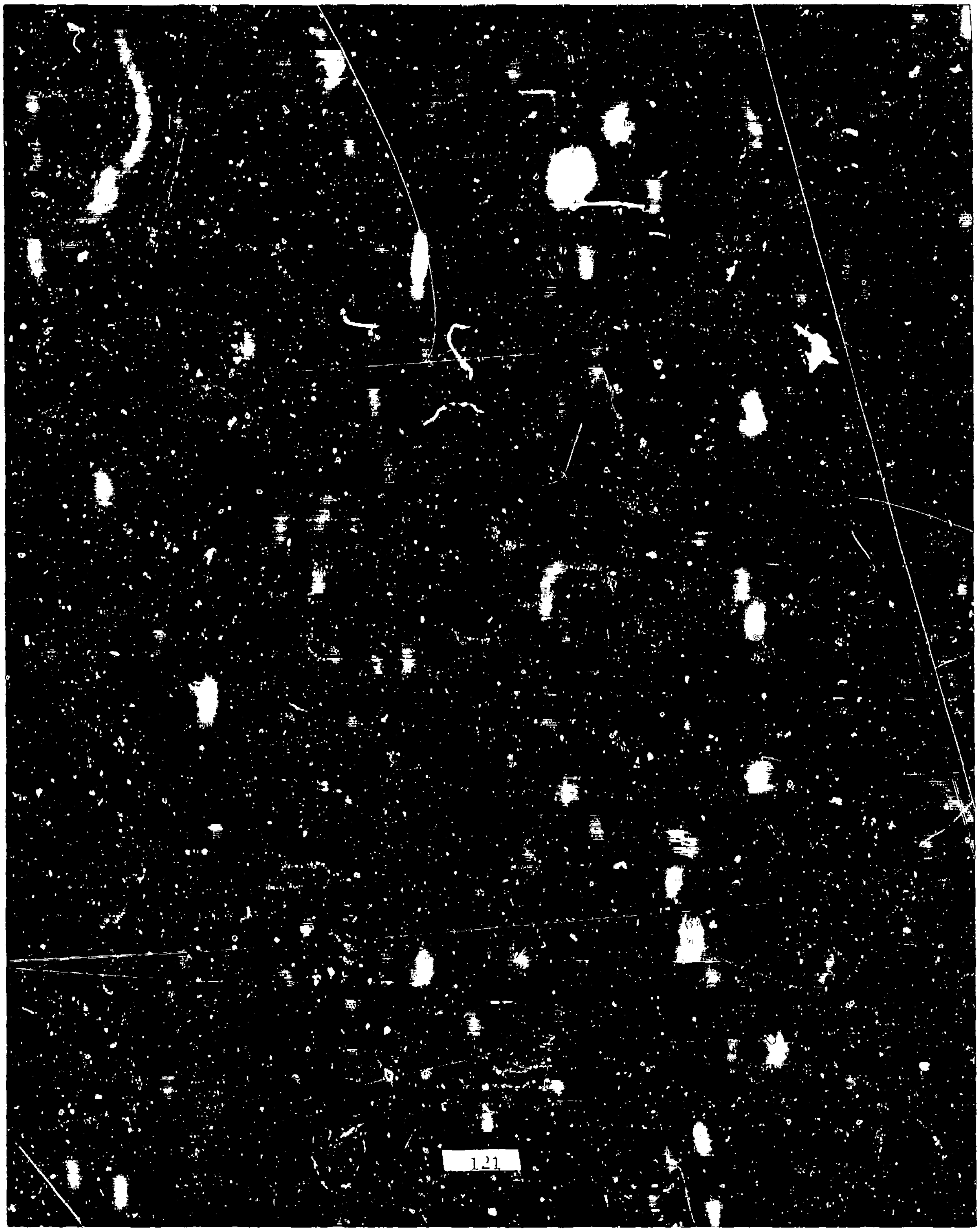
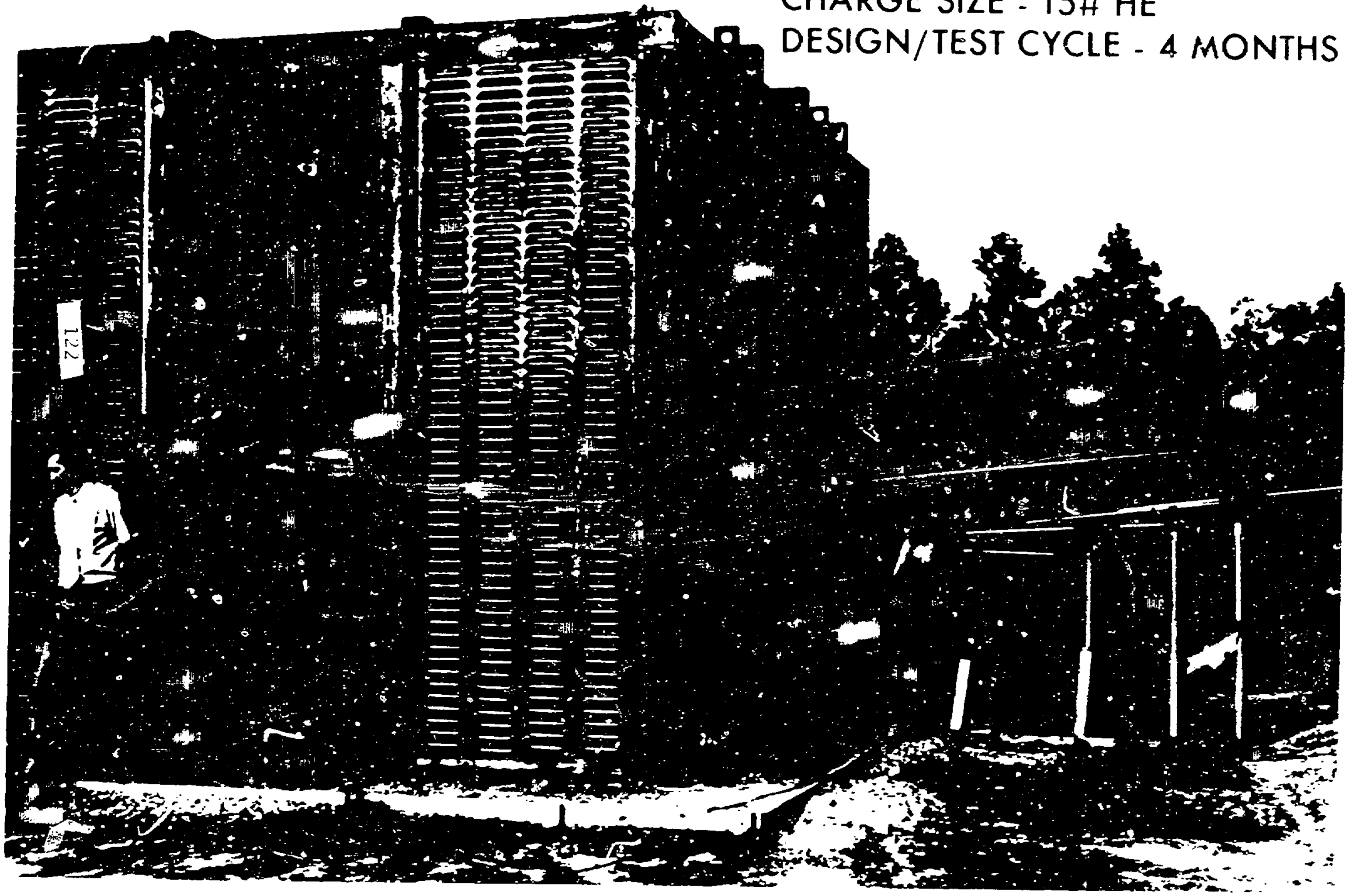
CHEMICAL AMMUNITION DISPOSAL SYSTEM (CAMDS) TEST PROTOTYPE



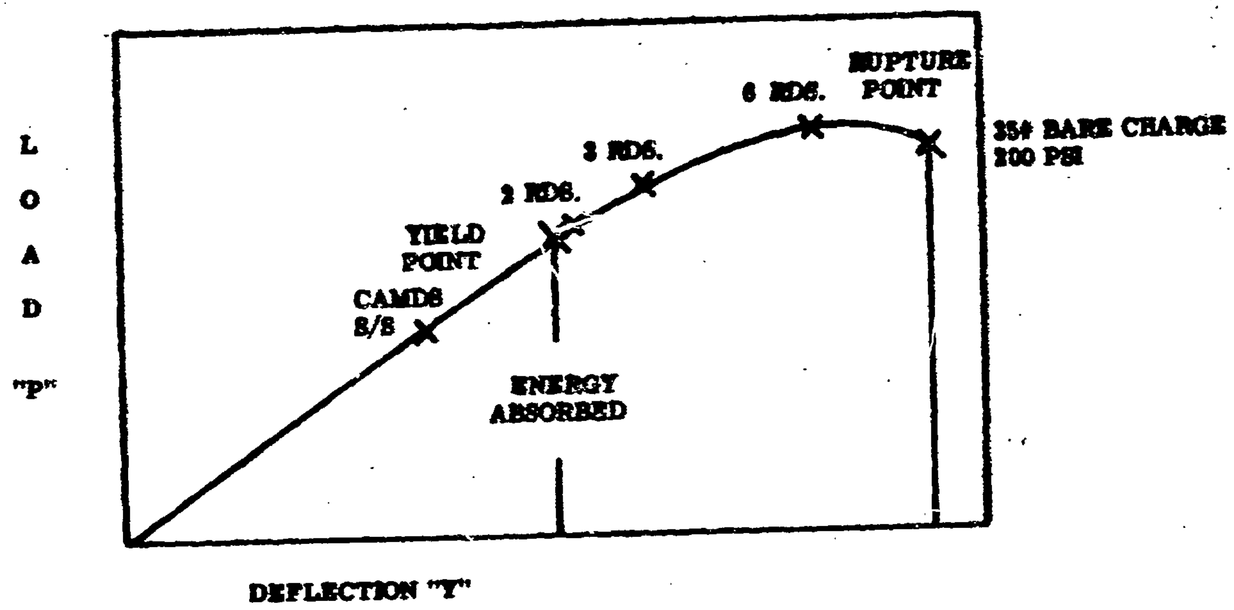


81MM

CAPACITY - (6) 81MM PROJECTILES
CHARGE SIZE - 15# HE
DESIGN/TEST CYCLE - 4 MONTHS



SUPPRESSIVE SHIELD LIMIT DESIGN CONCEPTS



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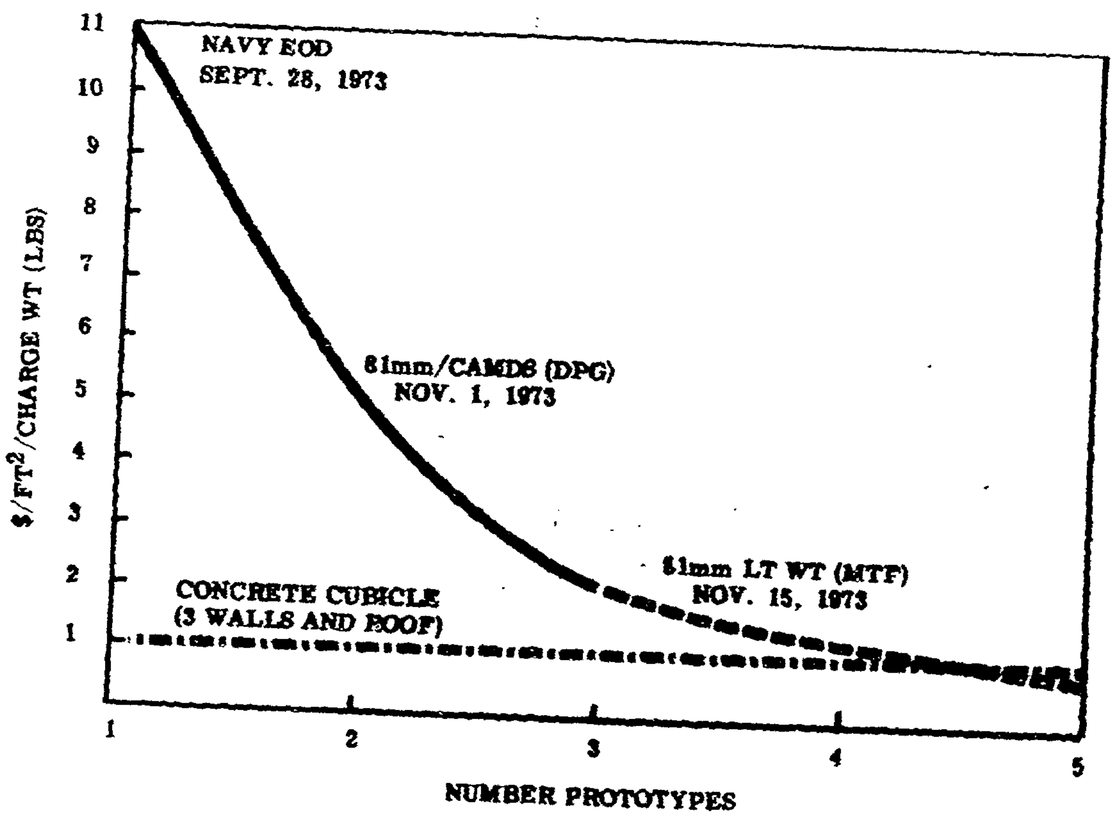
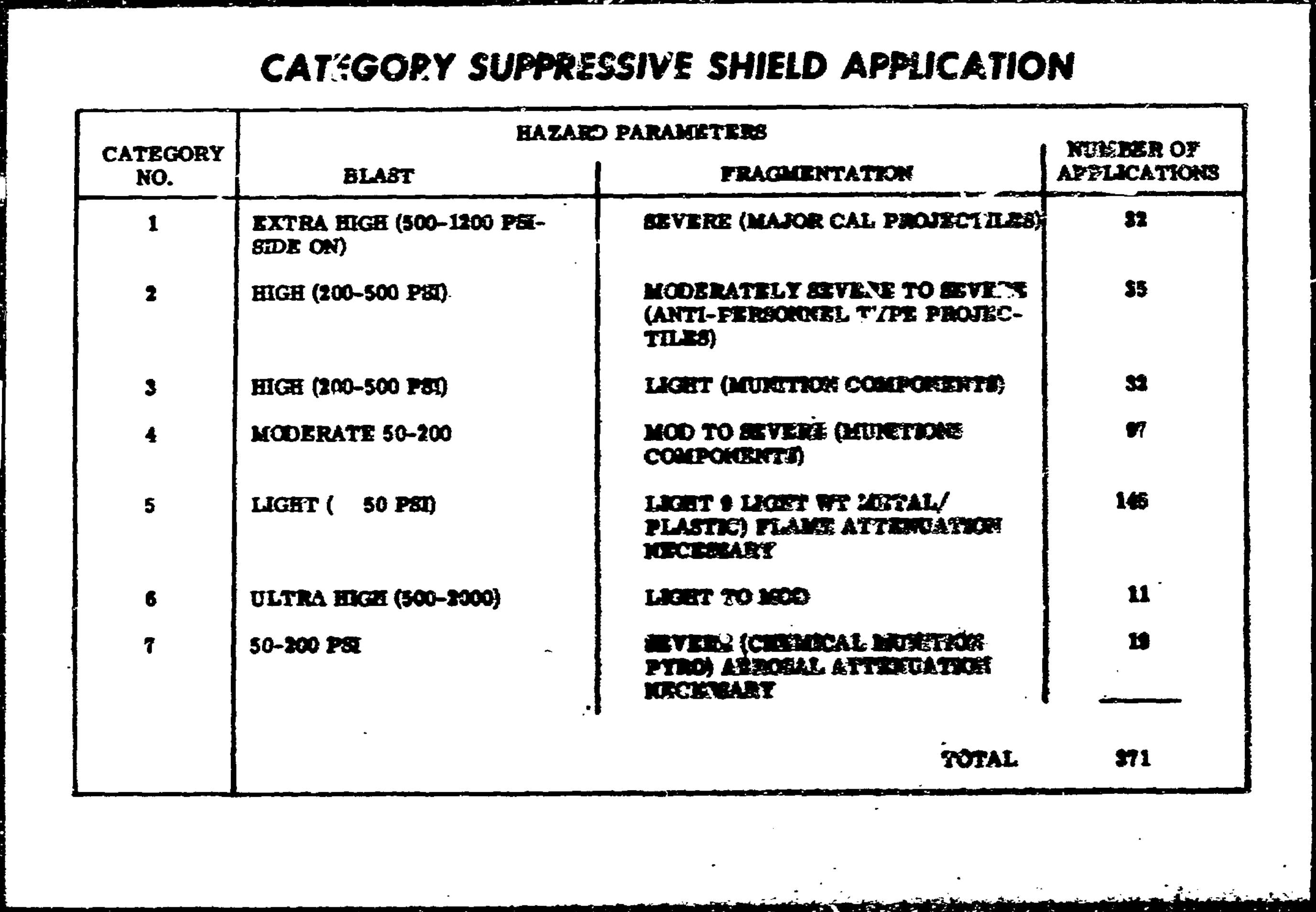
ENERGY ABSORBED - AREA UNDER CURVE

LEARNING CURVE
DESIGN EFFICIENCY VS NO. PROTOTYPE SHIELDS

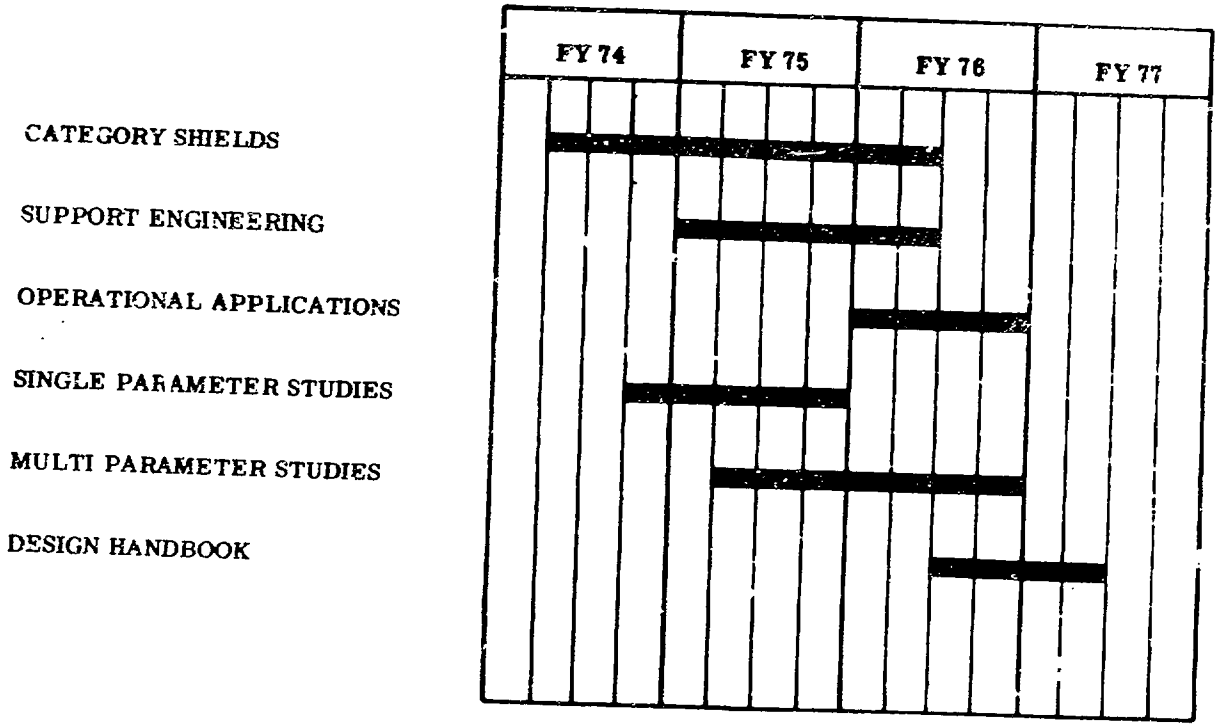




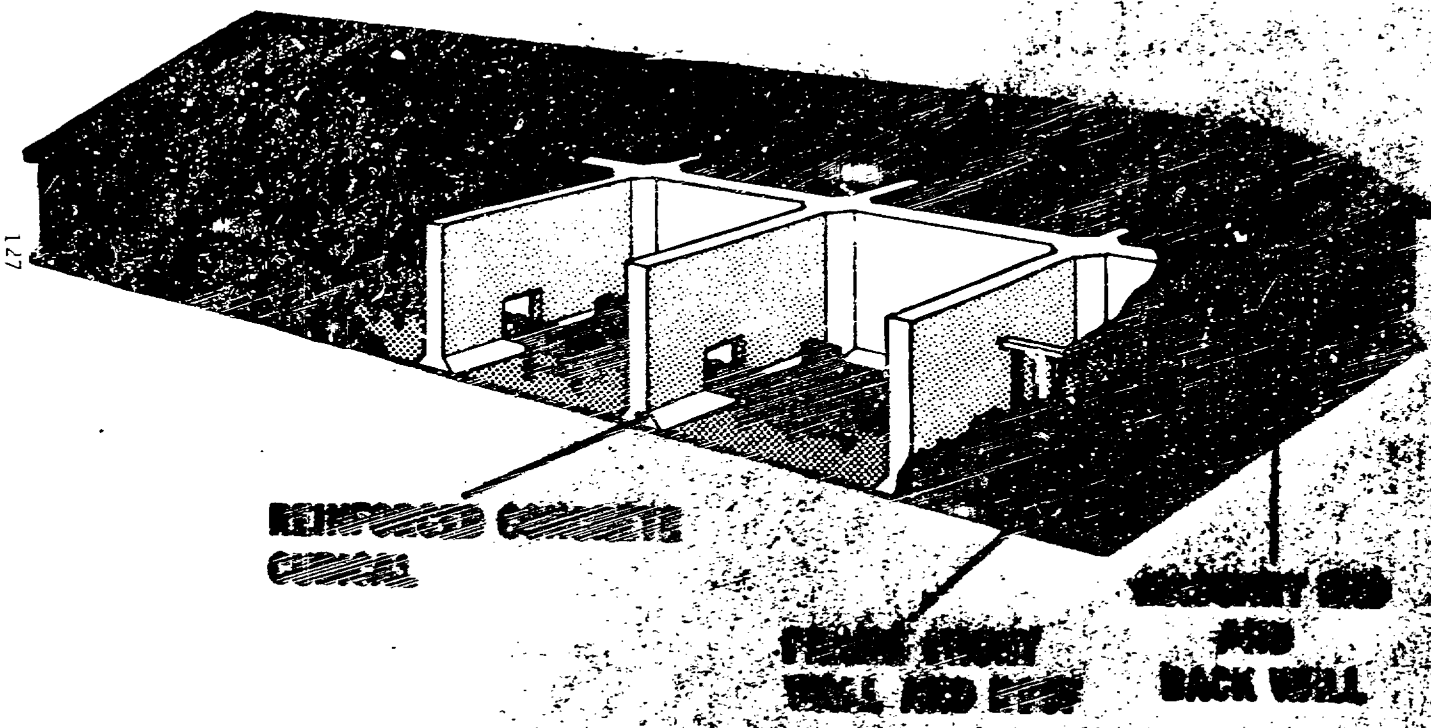
CATEGORY SUPPRESSIVE SHIELD APPLICATION

CATEGORY NO.	HAZARD PARAMETERS		NUMBER OF APPLICATIONS
	BLAST	FRAGMENTATION	
1	EXTRA HIGH (500-1200 PSI-SIDE ON)	SEVERE (MAJOR CAL PROJECTILES)	32
2	HIGH (200-500 PSI)	MODERATELY SEVERE TO SEVERE (ANTI-PERSONNEL TYPE PROJECTILES)	35
3	HIGH (200-500 PSI)	LIGHT (MUNITION COMPONENTS)	32
4	MODERATE 50-200	MOD TO SEVERE (MUNITIONS COMPONENTS)	97
5	LIGHT (50 PSI)	LIGHT (LIGHT WT METAL/ PLASTIC) FLAME ATTENUATION NECESSARY	145
6	ULTRA HIGH (500-2000)	LIGHT TO MOD	11
7	50-200 PSI	SEVERE (CHEMICAL MUNITION PYRO) AEROSAL ATTENUATION NECESSARY	19
		TOTAL	371

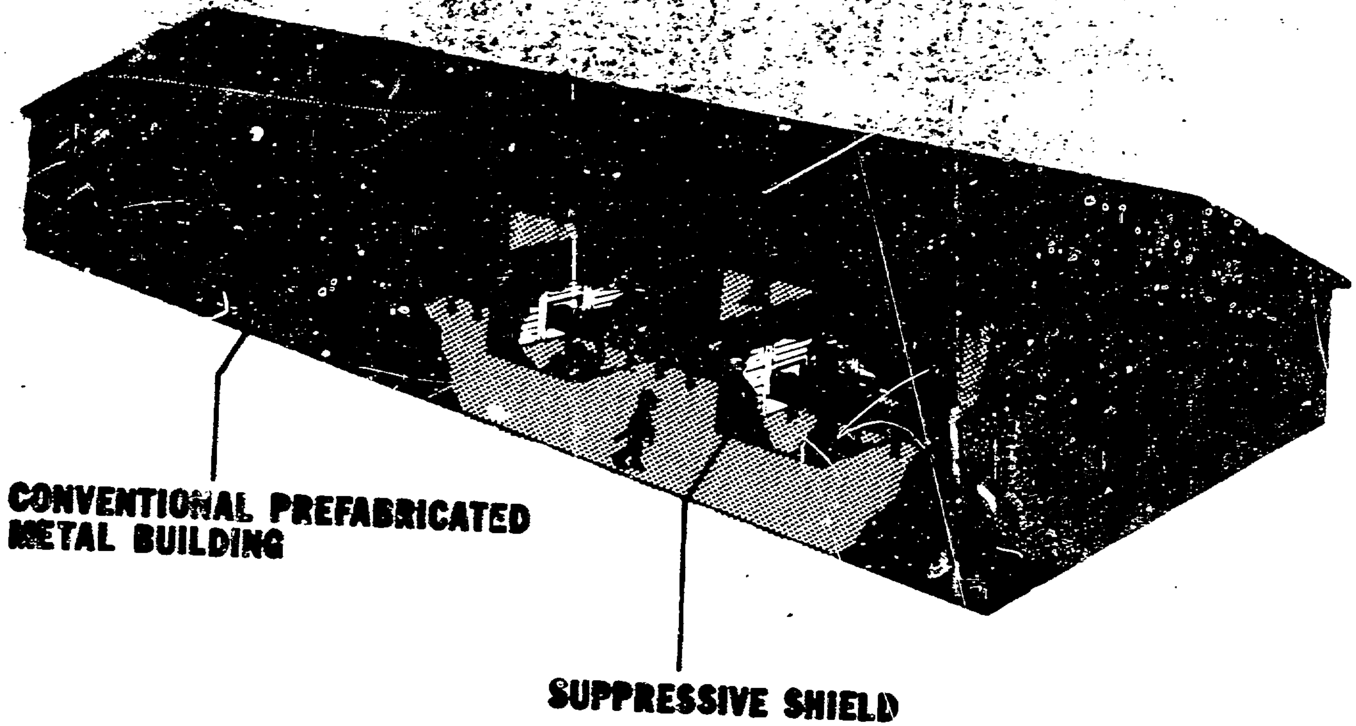
SUPPRESSIVE SHIELD PROGRAM



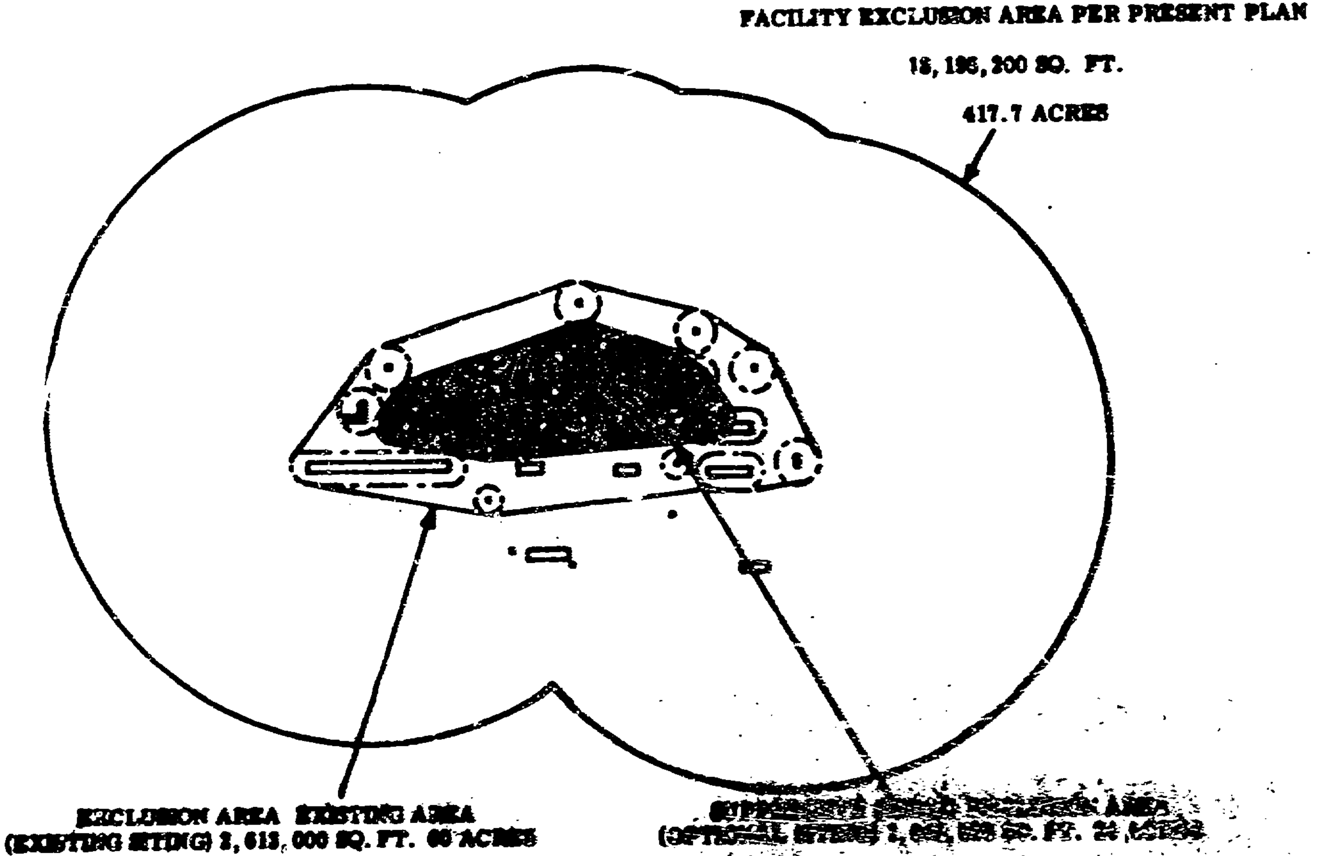
CONVENTIONAL STRUCTURE



SUPPRESSIVE SHIELD STRUCTURE



SUPPRESSIVE SHIELD BENEFITS
EXAMPLE 1 MELT-POUR MODERNIZATION
FY77-LINE C (MILAN AAP)

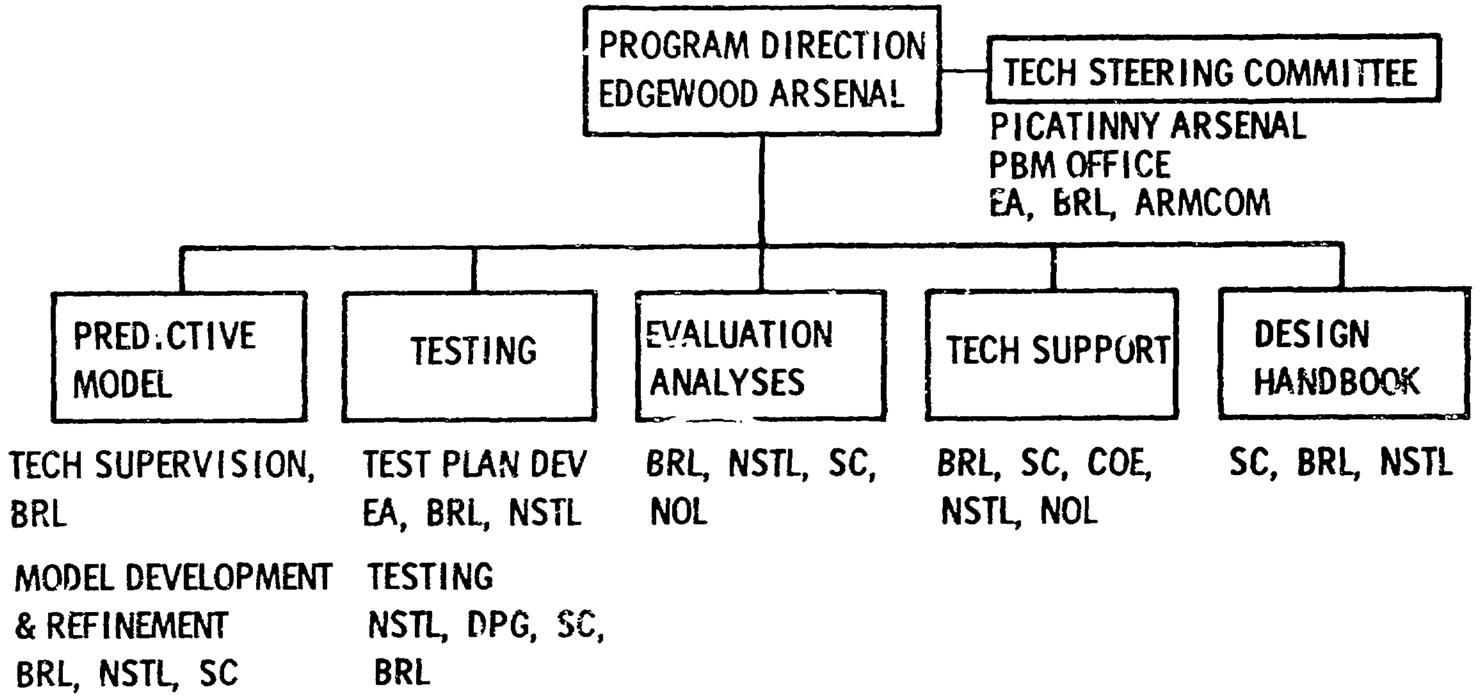


SUPPRESSIVE SHIELDING PROGRAM
SUPPORT ENGINEERING STUDIES

- DEVELOPMENT OF MAINTENANCE TECHNIQUES
- DEVELOPMENT OF DECONTAMINATION TECHNIQUES
- DEVELOPMENT OF REPAIR TECHNIQUES
- VALUE ENGINEERING
- SYSTEMS SAFETY ANALYSIS

MMT PROJECT 1264
SUPPRESSIVE SHIELDING PROGRAM

APPLIED TECHNOLOGY FUNCTIONAL MANAGEMENT



PROGRAM DIRECTION
EDGEWOOD ARSENAL

TECH STEERING COMMITTEE
PICATINNY ARSENAL
PBM OFFICE
EA, BRL, ARMCOM

PREDICTIVE MODEL

TECH SUPERVISION, BRL

MODEL DEVELOPMENT & REFINEMENT
BRL, NSTL, SC

TESTING

TEST PLAN DEV
EA, BRL, NSTL

TESTING
NSTL, DPG, SC, BRL

EVALUATION ANALYSES

BRL, NSTL, SC, NOL

TECH SUPPORT

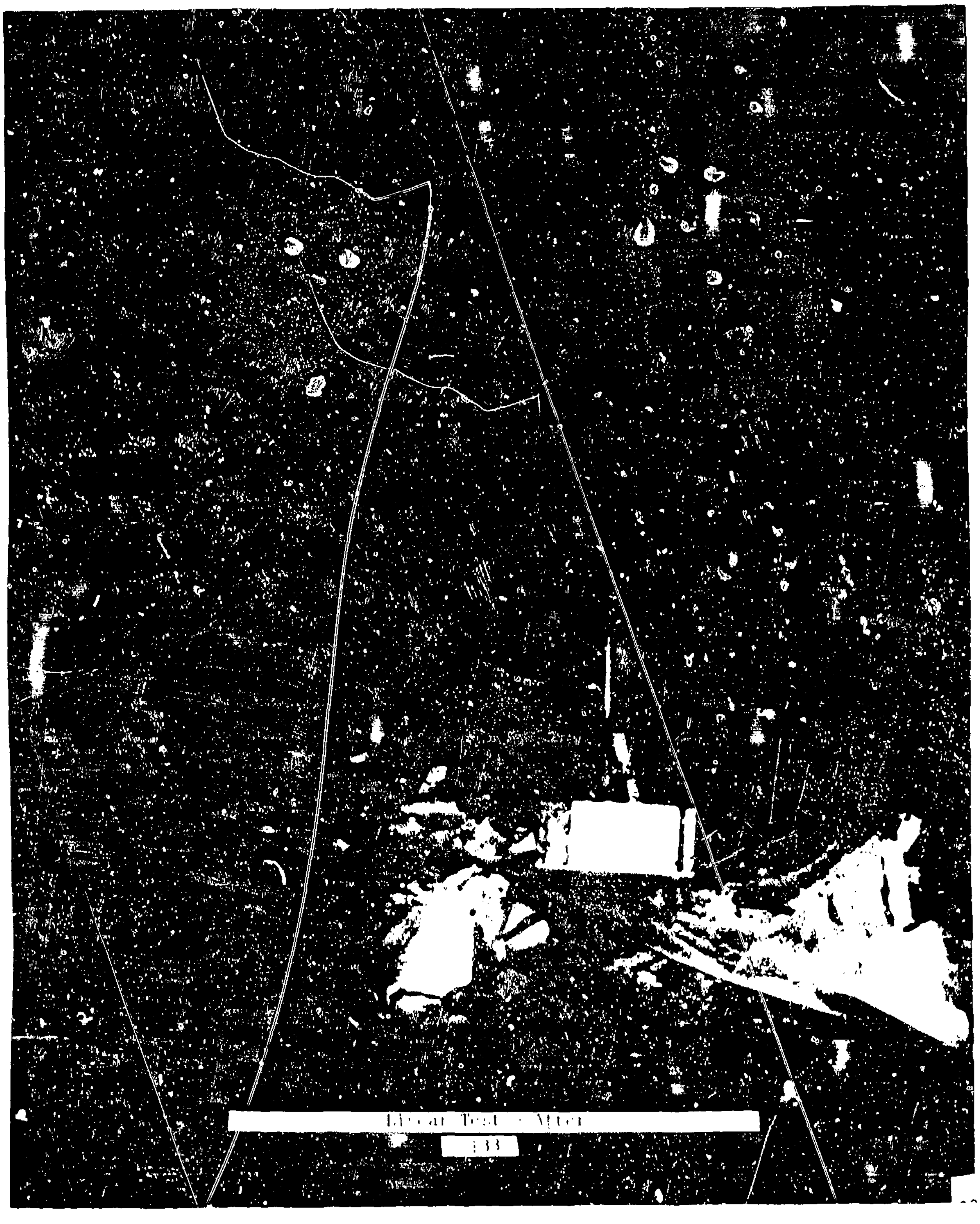
BRL, SC, COE, NSTL, NOL

DESIGN HANDBOOK

SC, BRL, NSTL

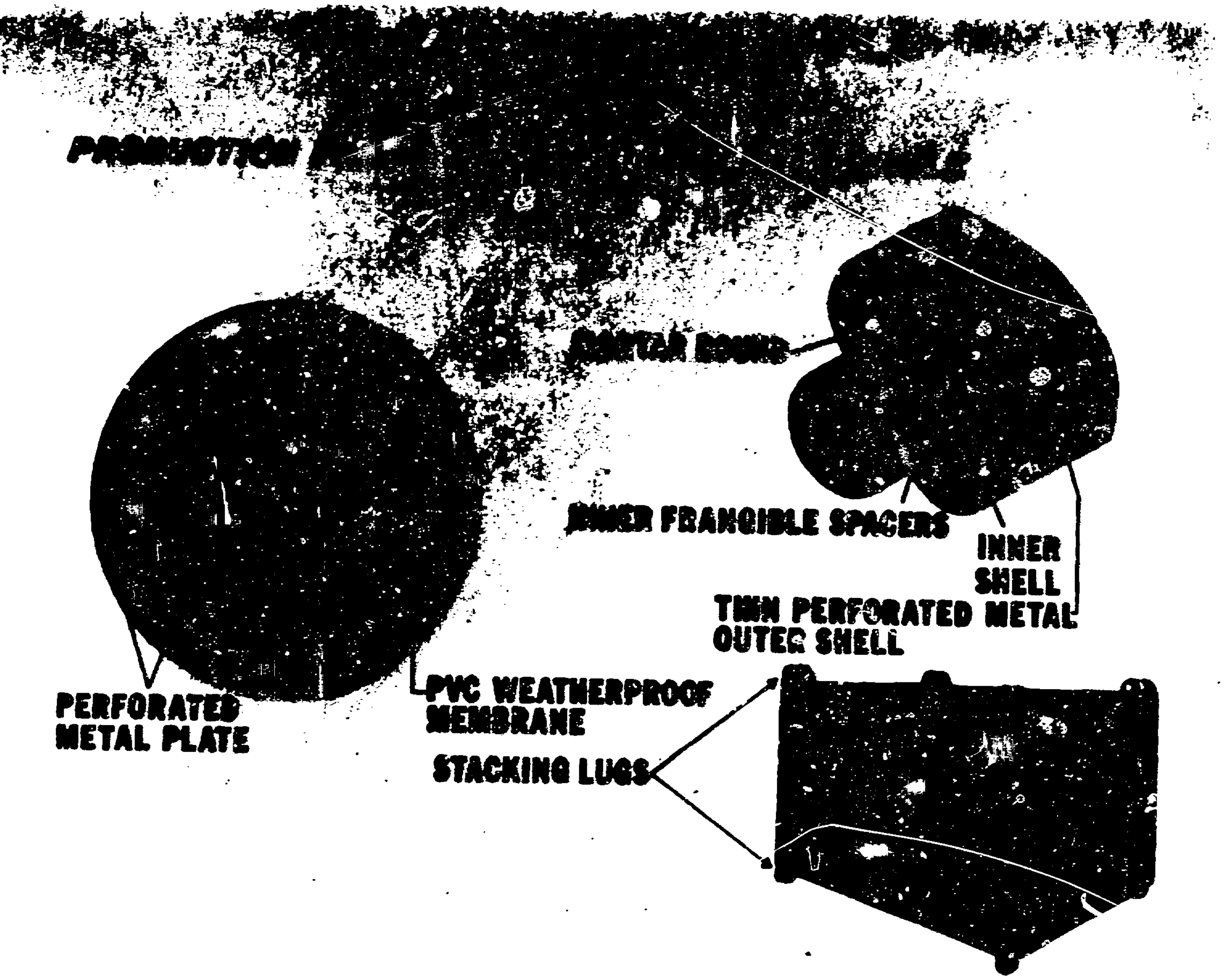
LEGEND:
COE: CORPS OF ENGINEERS
BRL: BALLISTICS RESEARCH LABORATORY
DPG: DUGWAY PROVING GROUND
NOL: NAVAL ORDNANCE LABORATORY
NASA-NSTL: NASA-NATIONAL SPACE TECHNOLOGY LABORATORIES
EA: EDGEWOOD ARSENAL
SC: SUB CONTRACTOR

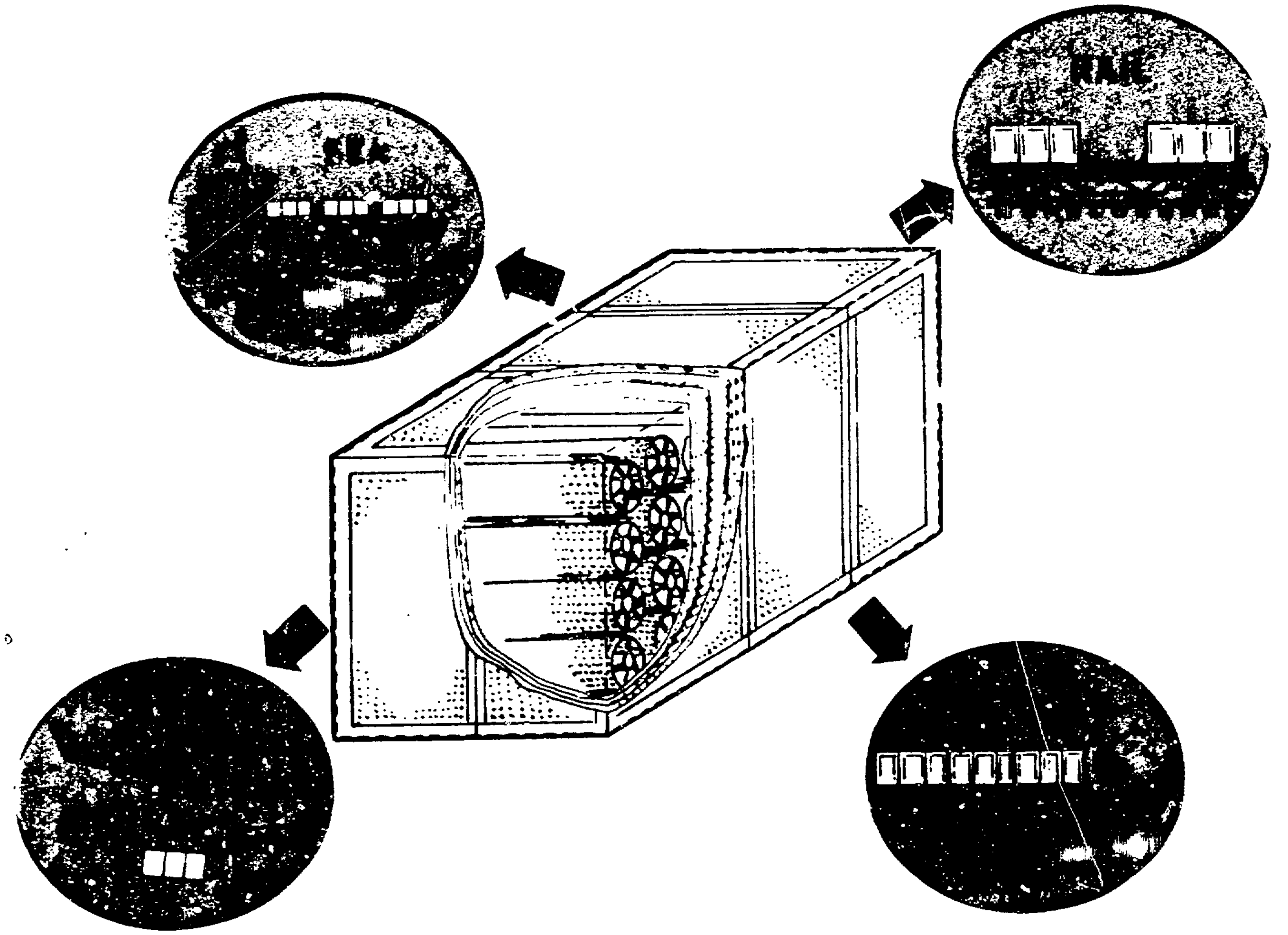
1 NOV. 1974



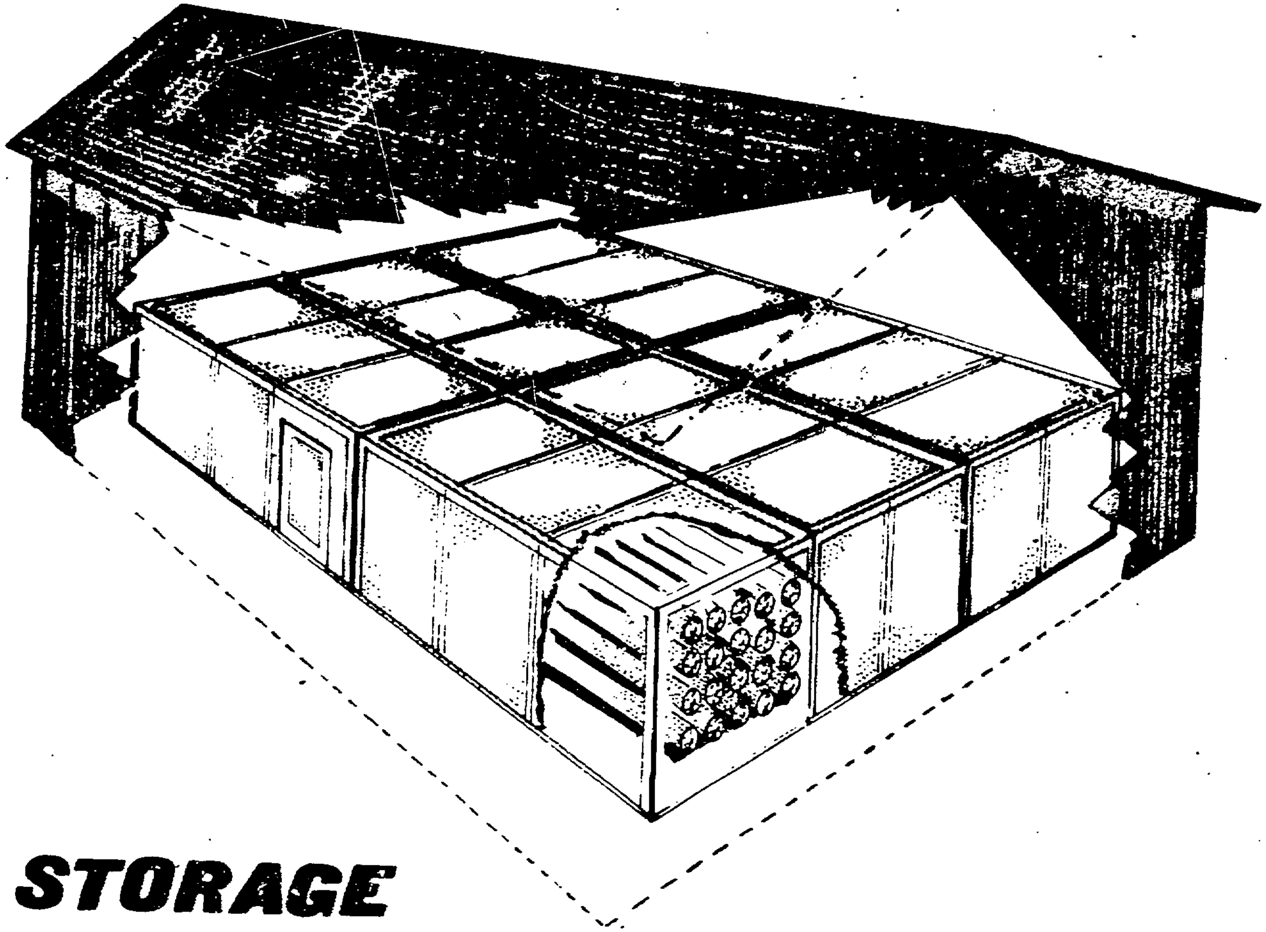
Lifecar Test - After

133


PRODUCTION
MORTAR ROUND
INNER FRANGIBLE SPACERS
INNER SHELL
THIN PERFORATED METAL OUTER SHELL
PERFORATED METAL PLATE
PVC WEATHERPROOF MEMBRANE
STACKING LUGS



TRANSPORTATION



STORAGE

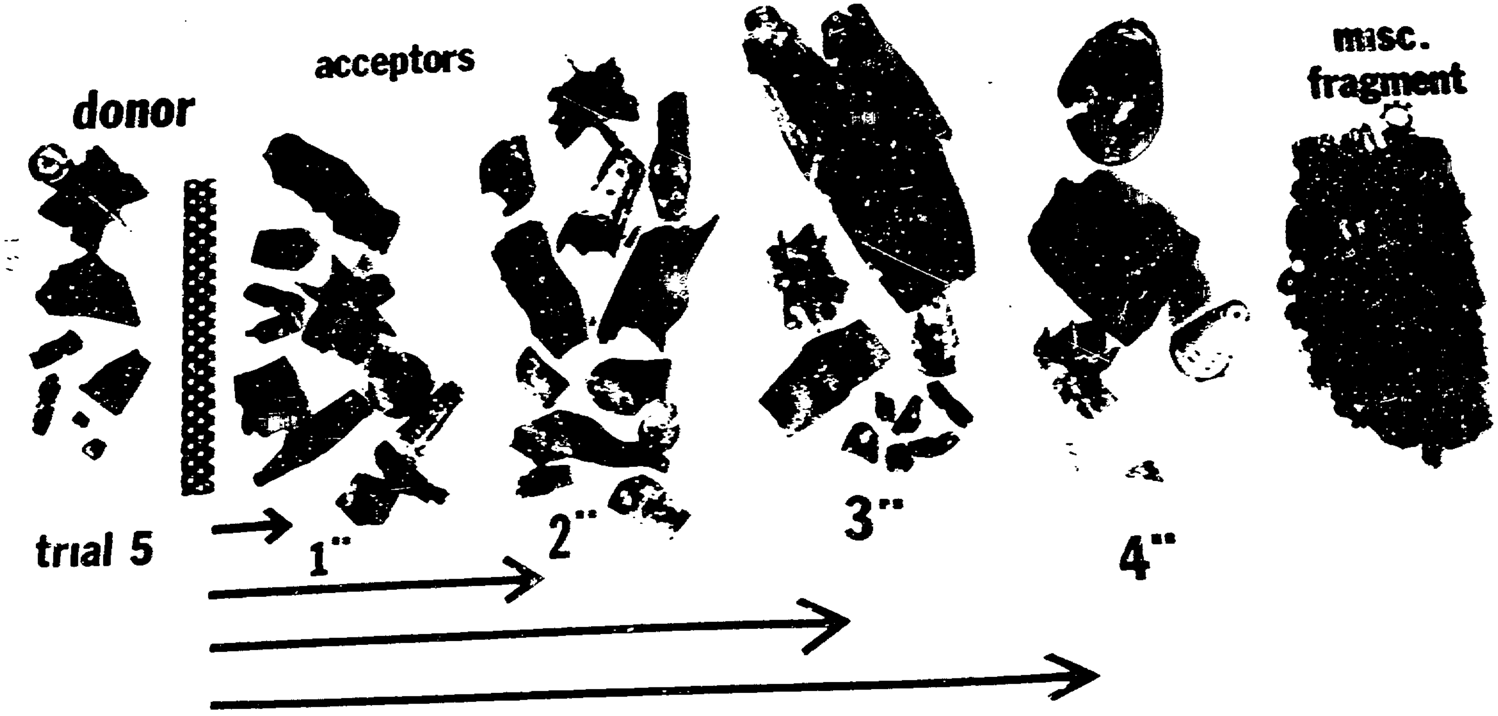


Figure 2-27
Recovered Fragments from Trial No. 5.

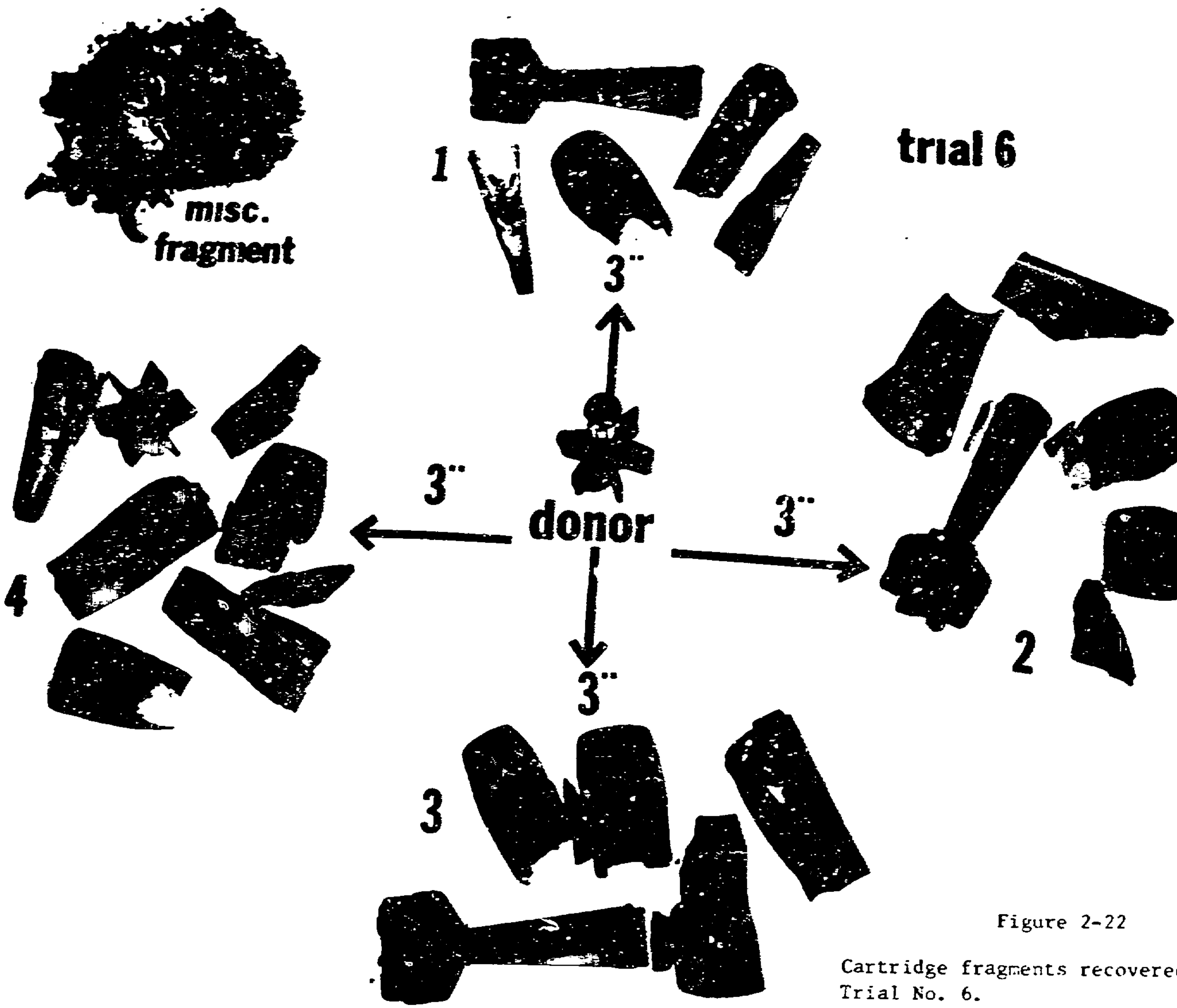


Figure 2-22

Cartridge fragments recovered from Trial No. 6.

COMPARISON OF STANDARD PALLET AND TRANSPORTABLE SHIELD

81MM MORTAR CARTRIDGE M374

	36 BOX PALLET	30 BOX PALLET	SUPPRESSIVE SHIELD PALLET
PROJECTILE WEIGHT (LBS)	9.34	9.34	9.34
PROJECTILES/PALLET (EACH)	108	90	96
PALLET WEIGHT (LBS)	2,008	1,690	2,140
PALLETS/MILVAN (EACH)	8	16	16
PROJECTILES PER MILVAN (ROUNDS)	864	1,440	1,536
LOADED MILVAN WEIGHT (LBS)	21,903	33,000	40,000

SEP 74

BENSON, ARIZONA RAILROAD EXPLOSIVES ACCIDENT

Mr. H. H. Wakeland
Bureau of Surface Transportation Safety
Department of Transportation
Washington, D. C.

Mr. Henry H. Wakeland, Director, Bureau of Surface Transportation Safety, National Transportation Safety Board, presented a summary of the investigation made by NTSB into the cause and effects of the rail accident that occurred at Benson, Arizona, 24 May 1973. The complete report on the DOT investigation is in the process of being published and a copy will be sent to the attendees of the seminar.

NONLINEAR DYNAMIC RESPONSE OF MAGAZINE HEADWALLS

Damoder P. Reddy
Hsueh-Sheng Ts'ao
Ross W. Dowdy

Agbabian Associates
El Segundo, California

INTRODUCTION

The Department of Defense Explosives Safety Board (DDESB) has been conducting a general program to determine safe intermagazine separation distances for various orientations of magazines storing chemical explosives. The main objective of the program is to recommend minimum intermagazine separation distances so that an explosion in one magazine (donor) will not cause an explosion in an adjacent magazine (acceptor).

Preliminary tests had indicated that specifications for minimum separation distances between magazines were excessively conservative for some orientations. Increasing land costs and siting problems made it desirable to justify reducing the front-to-rear separation distance. Earlier tests had indicated that earth-covered, steel-arch igloo magazines can be safely spaced side-to-side at a distance in feet of $1.25W^{1/3}$, in which W is the weight in pounds of the high explosives in storage. On the other hand, very little test data had been developed for determining the minimum safe distances for other magazine orientations.

In 1971, the DDESB sponsored a large-scale magazine explosion experiment called Eskimo I for the purpose of establishing minimum separation distances for face-on exposures of earth-covered, steel-arch magazines (Reference 1). Results of Eskimo I indicated that significant reduction of the formerly applicable face-to-rear and face-to-side intermagazine separation distances would be permissible.

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BRIEF DESCRIPTION OF ESKIMO I TEST

The Eskimo I test was conducted on December 8, 1971, at the Randsburg Wash Test Range of the Naval Weapons Center, China Lake, California. Four earth-covered, steel-arch magazines were exposed in the test to the explosion of the contents of a similar magazine. The donor magazine contained 200,000 pounds of high explosives. The four acceptor igloos faced the donor and were located at various distances ranging from 73 ft and 161 ft, as shown in Figure 1. The distances 73 ft and 161 ft correspond to $1.25W^{1/3}$ and $2.75\ W^{1/3}$, respectively, where W is the weight in pounds of the explosive in the donor magazine. Two concrete block structures simulating one particular type of Air Force aboveground magazine were also placed in the area at distances of 117 ft ($2\ W^{1/3}$) from the donor igloo as shown in Figure 1.

Each of the four acceptor igloos was 25 ft wide by 14 ft high, with their length limited to 20 ft. Steel wing walls were used in the test in lieu of concrete. The igloos were covered by a 90 percent compacted earth surcharge to a depth of 2 ft at the top of the steel-arch, as shown in Figure 2.

The damage to structures varied from minor headwall damage at the south igloo to complete destruction of the concrete block structures. The status of the acceptor charges after the test indicated a range from no explosion or burning in the south igloo to complete explosion or detonation of all charges in the east igloo.

Permanent deflections of the order of several inches, accompanied by yield-line formation, were noted in some of the surviving headwalls. On the other hand, photographic evidence indicated that the steel plate doors in two igloos were driven in with considerable velocity before coming to rest, while remaining partially attached to frames. In the forward exposure, complete failure of the hinges occurred, and the doors were driven violently against the rear wall of that magazine.

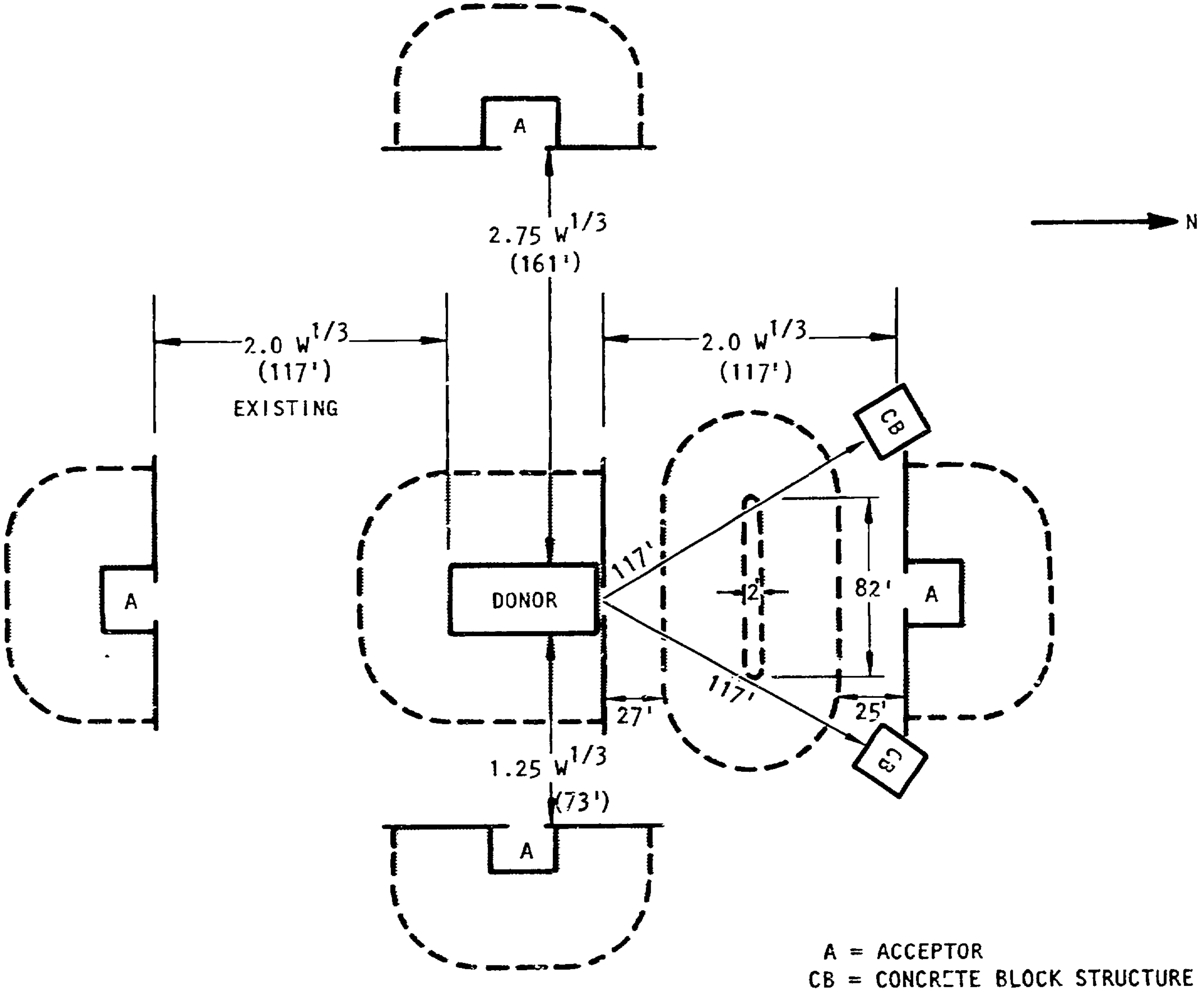


FIGURE 1. LAYOUT OF TEST STRUCTURES FOR ESKIMO I

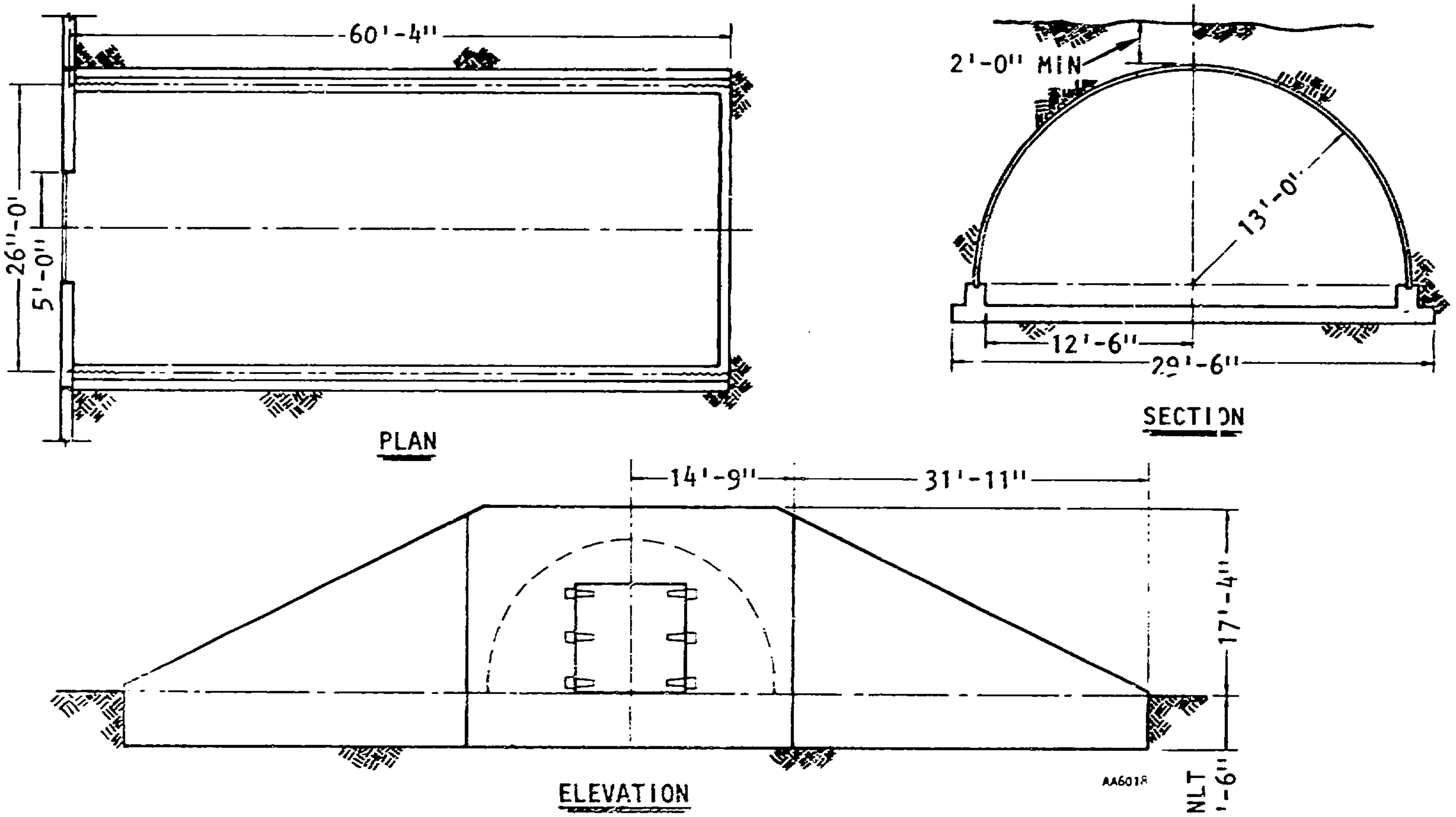


FIGURE 2. ACCEPTOR IGLOOS IN ESKIMO I TEST

FINITE ELEMENT ANALYSIS OF HEADWALL

The finite element method is an established structural analysis technique that is well documented (e.g., Reference 2). Basic to the method is the preparation of a mathematical model of the structure to be analyzed. The mathematical model is constructed by an assembly of individual elements such as beams, plates and membranes. The dynamic properties (such as the mass and stiffness) of the individual elements can be obtained easily. The mass and stiffness properties of the individual finite elements are appropriately added together to obtain the total mass and stiffness characteristics of the complex structure to be analyzed. The individual finite elements interconnect at the joints or nodes.

MATHEMATICAL MODEL OF HEADWALL

Although the magazine is supported in front by a headwall and two wingwalls, the wingwalls are not considered in the analysis. The effect is to neglect shear transfer from the wingwalls to the headwall. The transverse shear can be estimated by considering a strip of wingwall and headwall resting on the elastic foundation represented by the soil. The order of magnitude of this transverse shear is found to be very small in comparison to the expected maximum shear in the headwall (Reference 3) and therefore justifies the exclusion of the wingwalls from the model.

Ideally, the dimensions of individual elements should be made as small as possible so that the resulting finite element model accurately represents the headwall. The selection of small size elements results in a model with a large number of elements. The computational effort increases with the increasing number of elements. Thus to keep the cost of computations to a minimum the total number of elements in a model must be limited. The pressure loading on the headwalls measured during the test indicated significant frequency content up to about 1000Hz. Therefore, the mathematical model of the headwall is designed to respond to all significant frequencies in the pressure loading. The final mathematical model of the headwall is shown in Figure 3. Only one-half of the headwall is modeled since the headwall and the pressure loading are symmetrical about the centerline. The finite element mesh consists of 66 nodes and 51 plate elements.

The steel door consists of a 3/8 in. plate supported by channels and stiffeners. The door is represented in the model by plates of uniform thickness possessing the same stiffness as the door.

The soil covering the arch provides significant resistance to the headwall when the wall is subjected to normal loads. This resistance is normally taken into account in the calculations by representing the soil either by equivalent spring-mass or dashpot (damping) elements. On the basis of the results from auxiliary analyses using simpler models (Reference 3), it is decided to represent the soil by a series of dashpots with their coefficients equal to ρc, where ρ and c are the mass density and the pressure wave velocity of the soil medium, respectively.

Each steel door is connected to the concrete headwall by three hinges. The hinges permit the transfer of transverse shear forces but no bending moments between the door and headwall. The static condensation technique (Reference 3) is employed to introduce these hinges into the model.

BLAST PRESSURE LOADING ON MAGAZINE HEADWALLS AND DOORS

Air-blast overpressure data from the Eskimo I (Reference 1) and UK 71 Magazine Separation Tests (References 4-7) were reviewed to establish blast pressure loading histories for the use in the dynamic analysis of the headwall and door. Because of the very brief presentation of Kistler gage blast pressure data from Eskimo I (Reference 1), consideration was also given to theoretical and empirical estimates of peak blast overpressure and reflected overpressure pulse shapes (References 8 and 9).

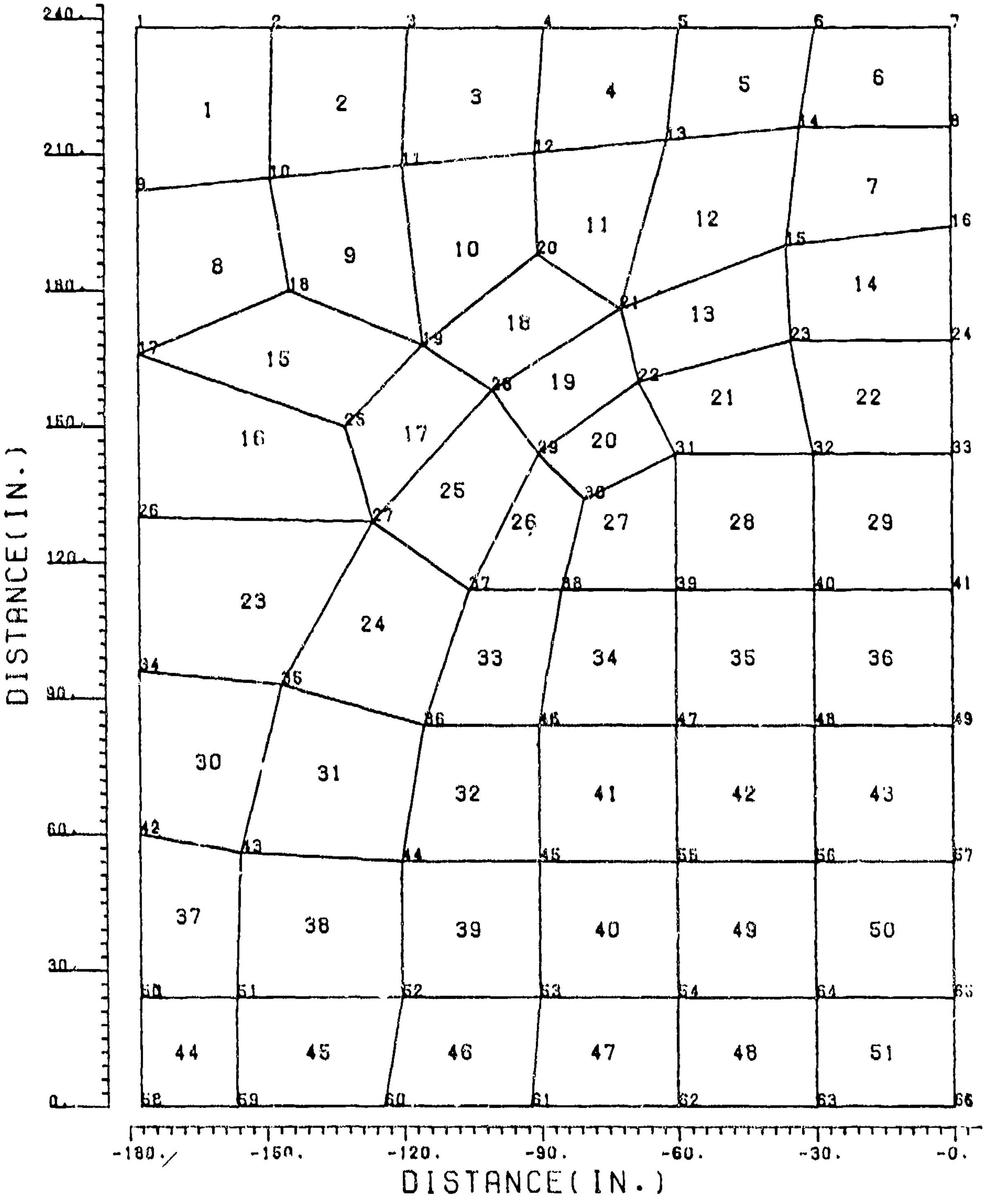


FIGURE 3. FINITE ELEMENT MODEL OF THE MAGAZINE HEADWALL

Since the pressure histories developed are to be used in computational simulations of the Eskimo I event, primary reliance for peak reflected pressure amplitudes, durations, and impulse values was placed on the Eskimo I test data. Corrections were introduced, however, to account for differences between head-on pressures measured at the headwall and side-on reflected pressures measured in front of the headwall.

The blast loading pressure histories adopted for use in the finite element calculations are shown in Figures 4, 5, and 6. Since the experimentally measured blast loading conditions at the south and west igloos are nearly equal, a single loading pulse has been adopted for these two cases. Three loading pressure histories are indicated in each figure. They represent loading histories for the three headwall zones indicated in Figure 7 and differ only during the unloading phase of the pressure history. The differences reflect the influence of unloading signals propagating downward from the top of the headwall. All of the pressure histories incorporate a 1-msec rise-time ramp front for compatibility with the integration time step.

A summary comparison of the measured data and the proposed loading pulses is given in Table 1. It is seen that the peak pressures proposed are consistently greater than the measured values.

ANALYSIS TECHNIQUES

The dynamic analyses using the finite element model of the headwall are performed using the INSLAB program (Reference 3). INSLAB is a dynamic, nonlinear finite element program in which the force equilibrium equations at any time are expressed as:

$$[M]\{\ddot{X}_t\} + [C]\{\dot{X}_t\} + [K]\{X_t\} = \{P_t\}$$

TABLE 1. COMPARISON OF HEADWALL BLAST PRESSURES FOR ESKIMO I

Igloo	Measured Data			Actually Used In Analyses		
	Peak Pressure psi	Duration msec	Impulse psi-msec	Peak Pressure psi	Duration msec	Impulse(b) psi-msec
South (Rear)	61 61 76[a] 72[a]	26.7 28.0 29.7 27.1	545 693 705 641	75	29	690 530 435
West	68 64	31.5 40.2	585	75	29	690 530 435
North (Front)	238	12.5	768	300	13.5	975 870 635
East	250		1010	525	11.0	1010 906 708

(a) Head-on measurement on wing wall. All other values are side-on measurements from stations 2 ft in front of the headwall.

(b) The three impulse values shown are for the base-, mid-, and upper-zones of the headwall.

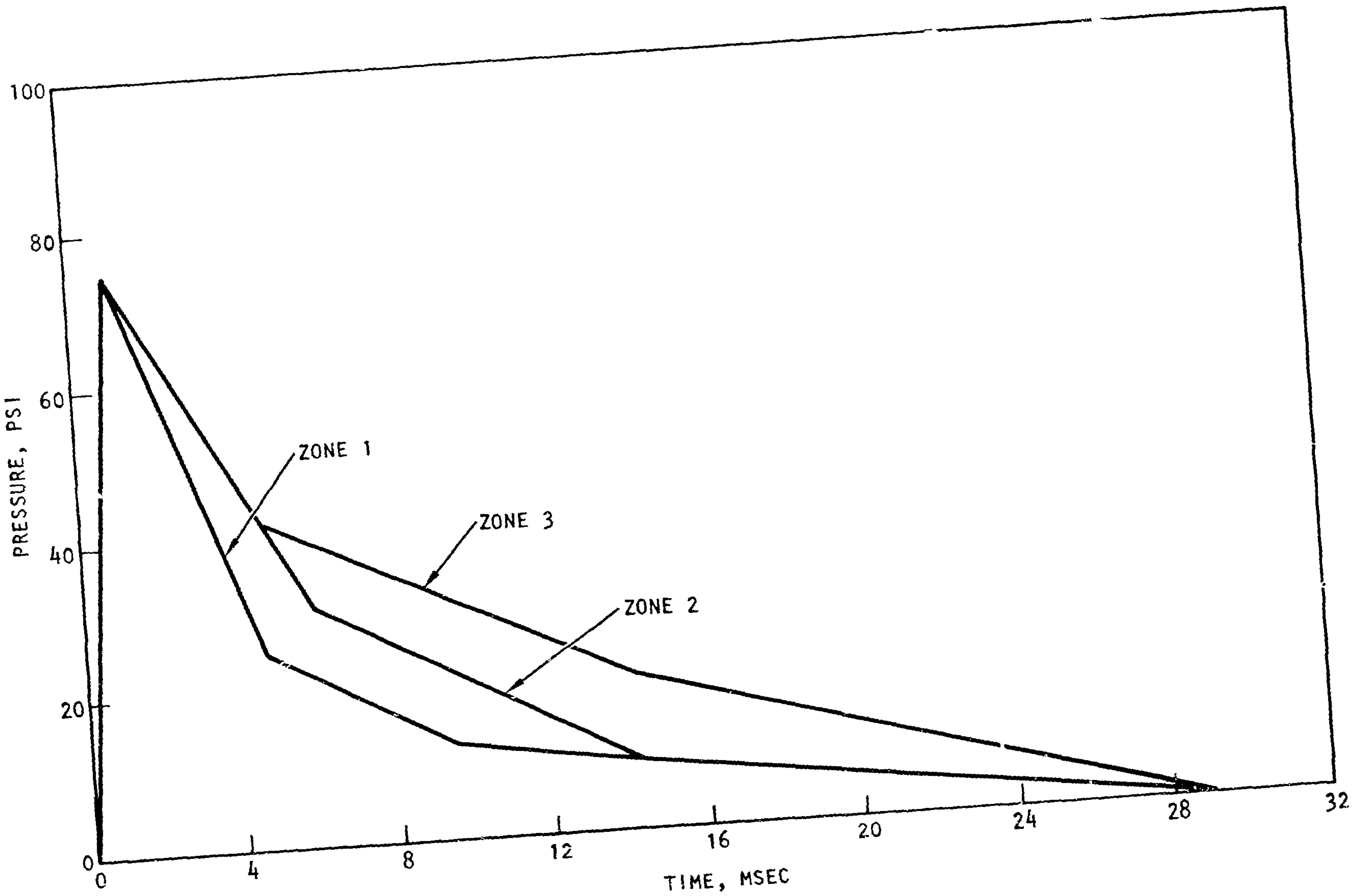


FIGURE 4. PRESSURE TIME-HISTORY FOR SOUTH AND WEST IGLOOS

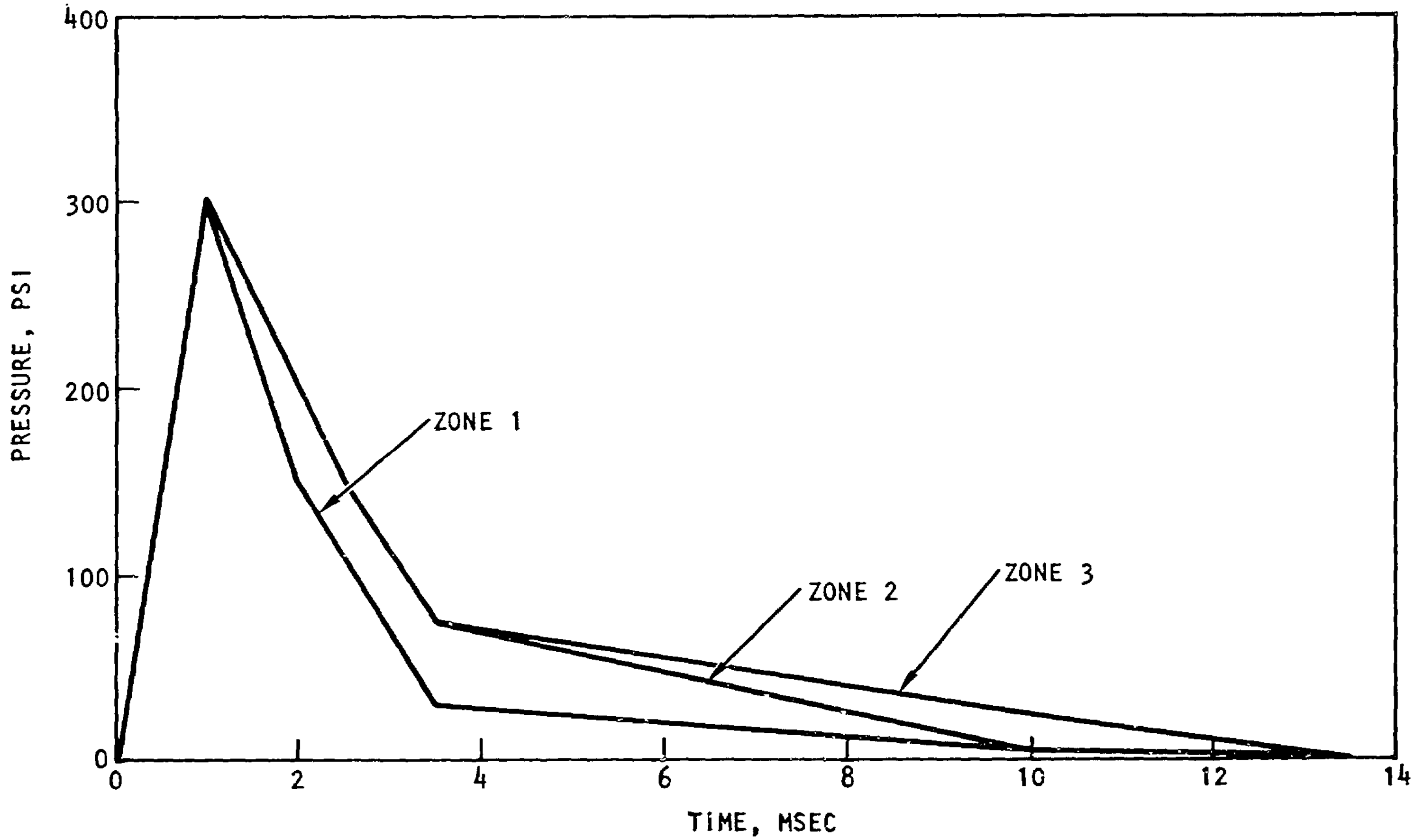


FIGURE 5. PRESSURE TIME-HISTORY FOR NORTH IGLOO

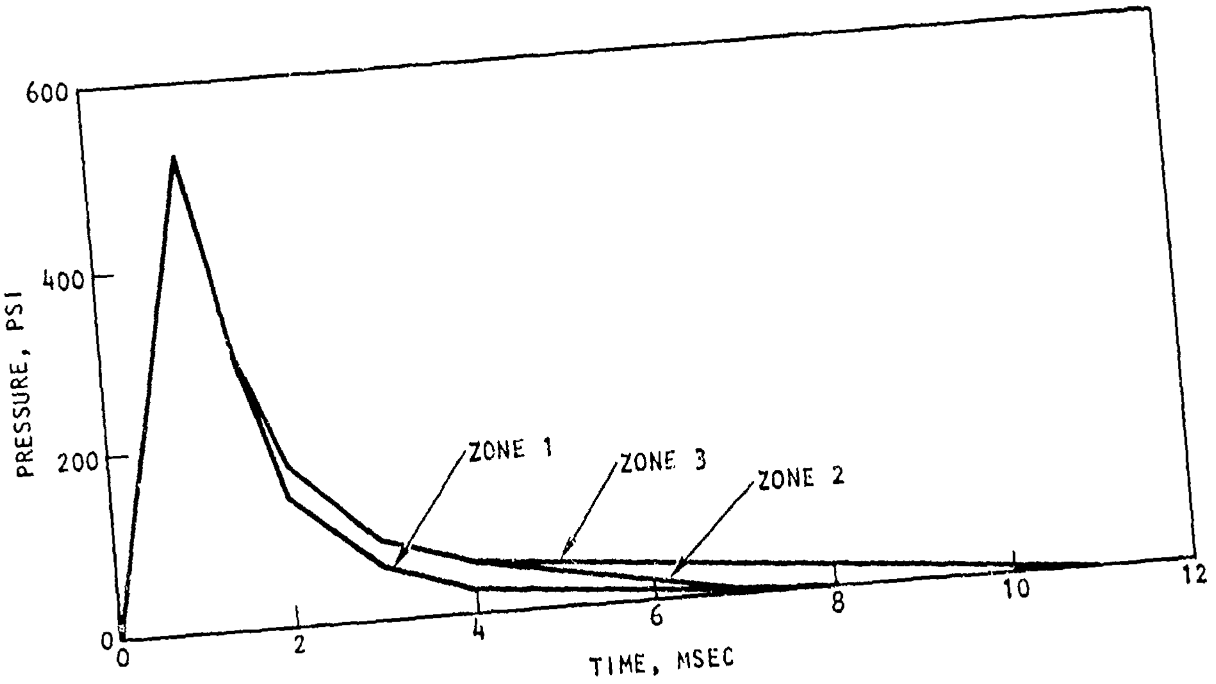


FIGURE 6. PRESSURE TIME-HISTORY FOR EAST IGLOO

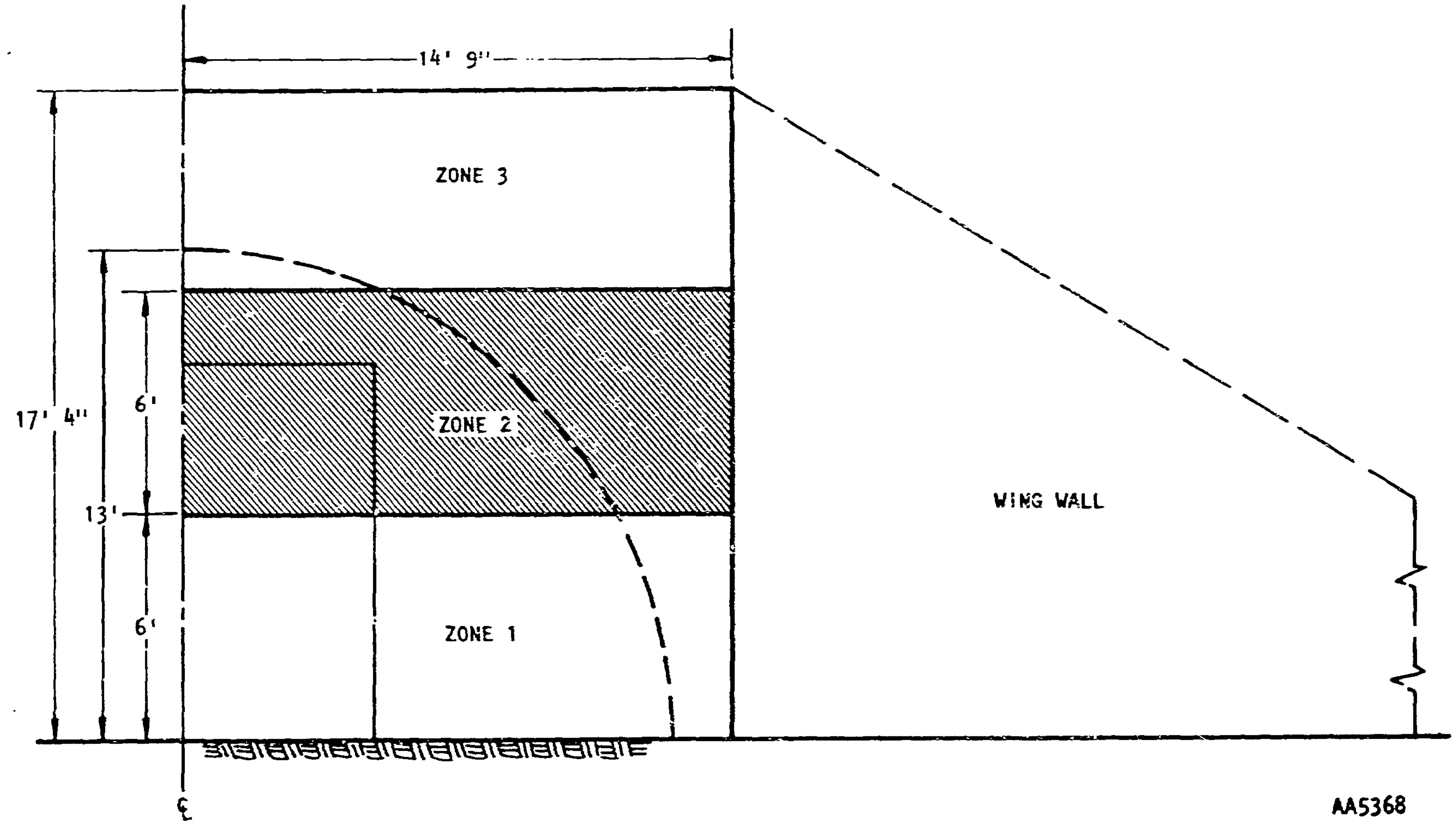


FIGURE 7. HEADWALL BLAST PRESSURE LOADING ZONES

in which $\{\ddot{X}_t\}$, $\{\dot{X}_t\}$, $\{X_t\}$ are the nodal displacement, velocity and acceleration vectors at time t; [M], [C], [K] are the mass, damping and stiffness matrices; and $\{P_t\}$ is the nodal point force vector at time t. For linearly elastic problems the mass, damping and stiffness matrices in Equation (1) remain constant so that they are evaluated only once.

The Eskimo I test data showed that all headwalls and doors in the test experienced large permanent deflections. This suggests that the analysis must consider the yielding of the headwall and door. To accomplish this, a bilinear moment - curvature relationship (Fig. 8) is assumed for the headwall and door.

The INSLAB Code solves the nonlinear equations of motion (Eq. 1) by a step-by-step numerical integration procedure that assumes a constant acceleration between successive time increments (Fig. 9). Further details on the numerical integration procedure may be found in Reference 3.

ANALYSIS RESULTS

Three different analyses representing the donor magazines in the Eskimo I test are performed. Since the south and west igloos were exposed to the same blast pressure, only one analysis is necessary for these two igloos. The same finite element mesh of Figure 3 is used in all three analyses.

RESPONSE OF SOUTH AND WEST IGLOOS

As mentioned above, one analysis represents the south and west igloos. The assumed pressure loading for this case is shown in Figure 4. The displacement, velocity and acceleration time histories are computed at several nodes of the model. Figure 10 shows motions at node 31 that corresponds to the top corner of the door. The displacement time histories for nodes 7, 16, 33, 47, 49 and 54 are shown in Figure 11. The displacements at these

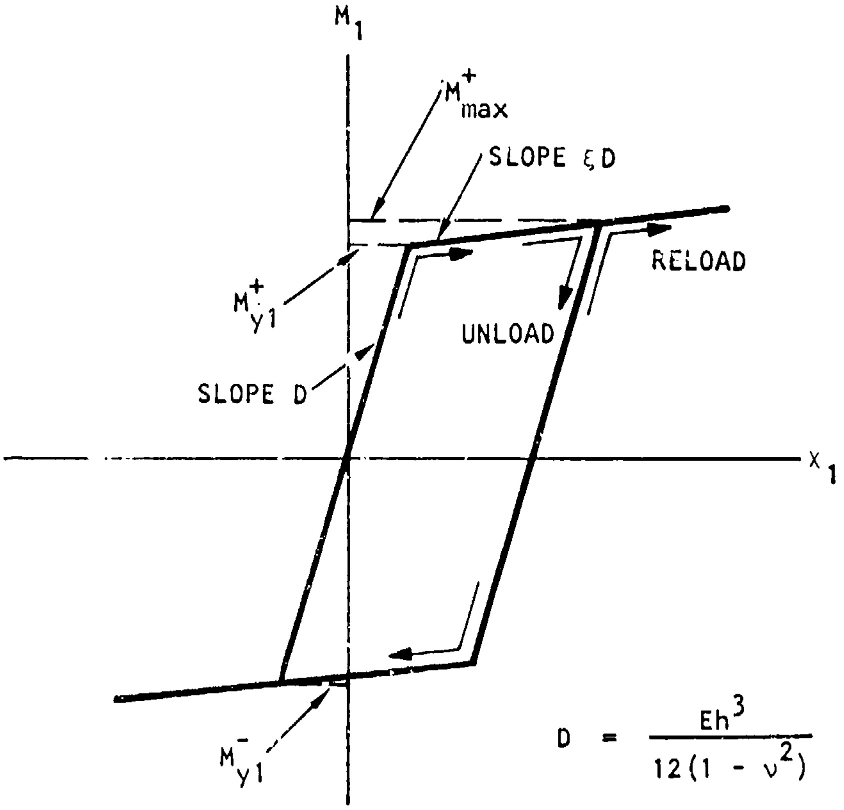
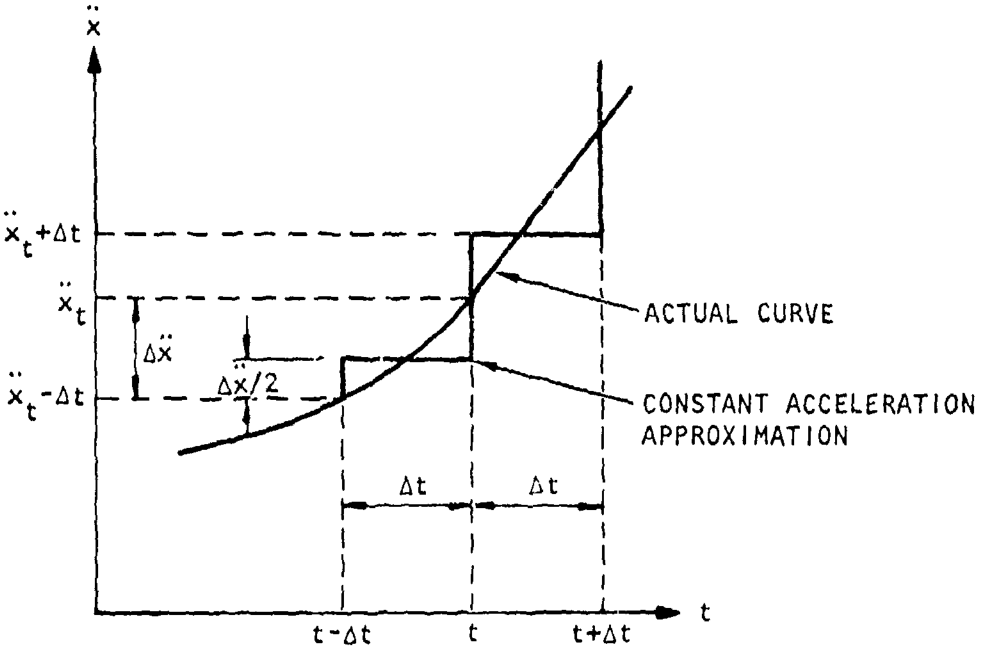


FIGURE 8. BILINEAR MOMENT-CURVATURE RELATIONS IN INSLAB



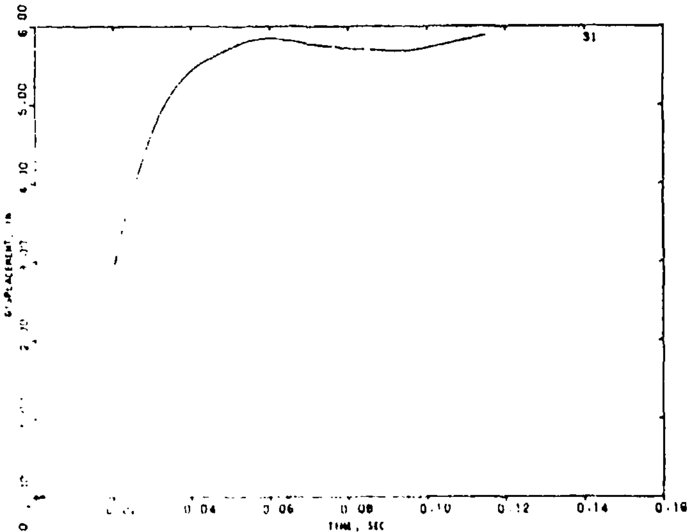
NOTE: FOR CONSTANT ACCELERATION METHOD:

$$\ddot{x}(t) = \ddot{x}_{t-\Delta t} + \Delta\ddot{x}$$

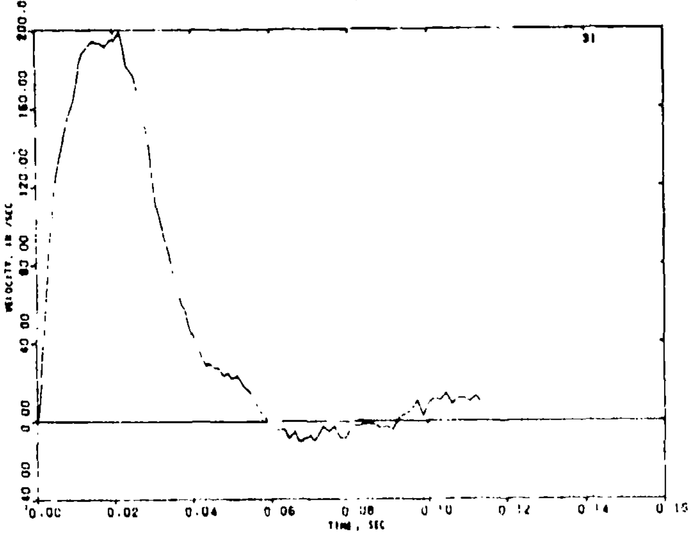
$$\dot{x}(t) = \dot{x}_{t-\Delta t} + \frac{1}{2}\left(\ddot{x}_{t-\Delta t} + \ddot{x}_t\right)\Delta t$$

$$x(t) = x_{t-\Delta t} + \dot{x}_{t-\Delta t}\,\Delta t + \frac{\Delta t^2}{4}\left(\ddot{x}_t + \ddot{x}_{t-\Delta t}\right)$$

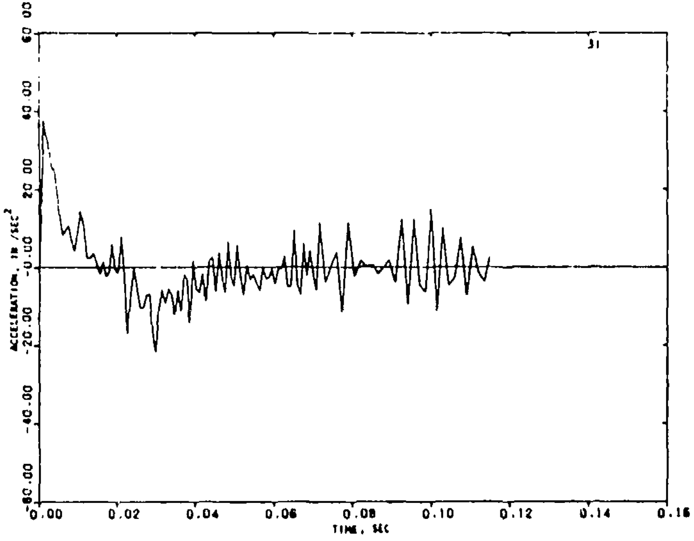
FIGURE 9. CONSTANT ACCELERATION METHOD



(a) DISPLACEMENT

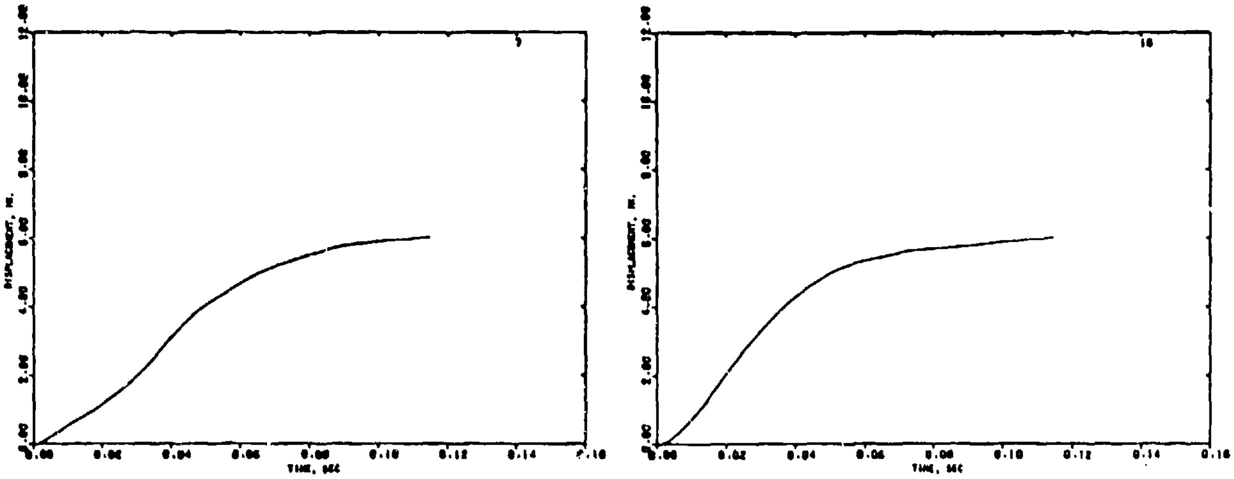


(b) VELOCITY

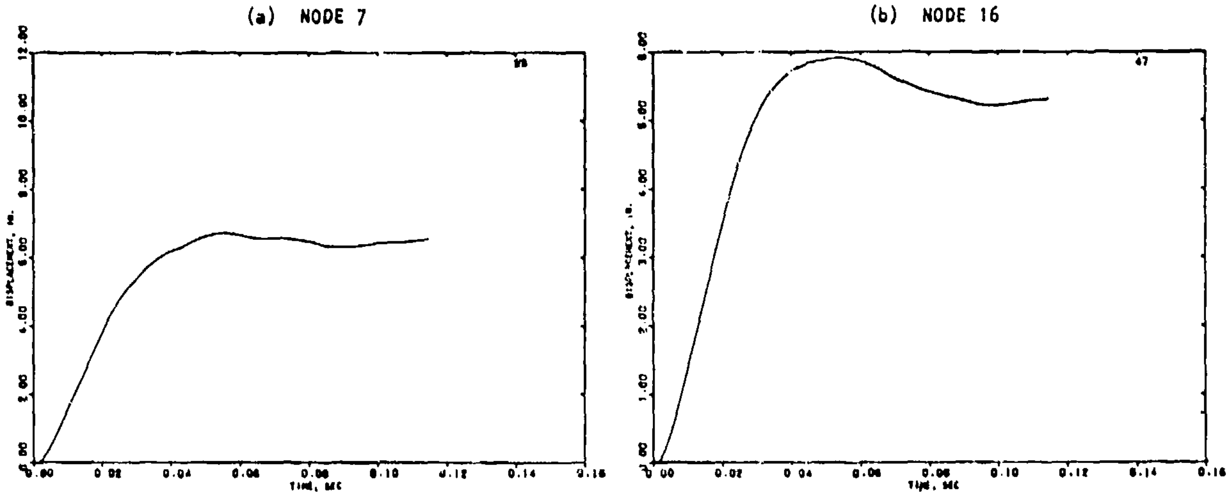


(c) ACCELERATION

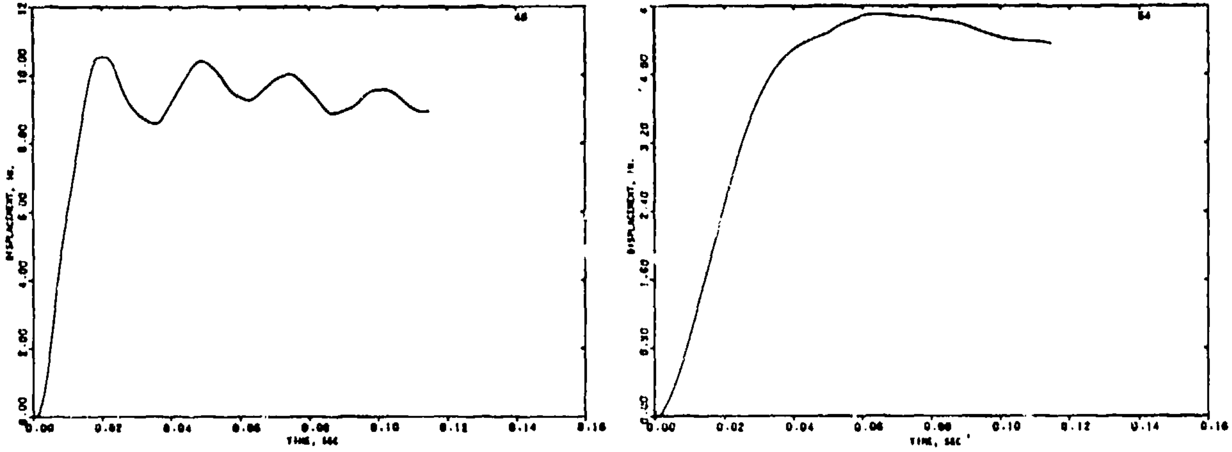
FIGURE 10. MOTION TIME HISTORIES OF THE SOUTH IGLOO (NODE 31)



(a) NODE 7 (b) NODE 16



(c) NODE 33 (d) NODE 47



(e) NODE 49 (f) NODE 54

FIGURE 11. DISPLACEMENT TIME HISTORIES OF THE SOUTH IGLOO

nodes are seen to be building up rapidly initially and then leveling off at late times at values ranging from about 5 in. to 10 in. The displacements at late times represent permanent displacements. In addition to the motion time histories at each node the INSLAB Code also provides contour plots of responses at selected intervals of time. Figure 12 shows the displacement contour plot of South headwall at 47.4 msec.

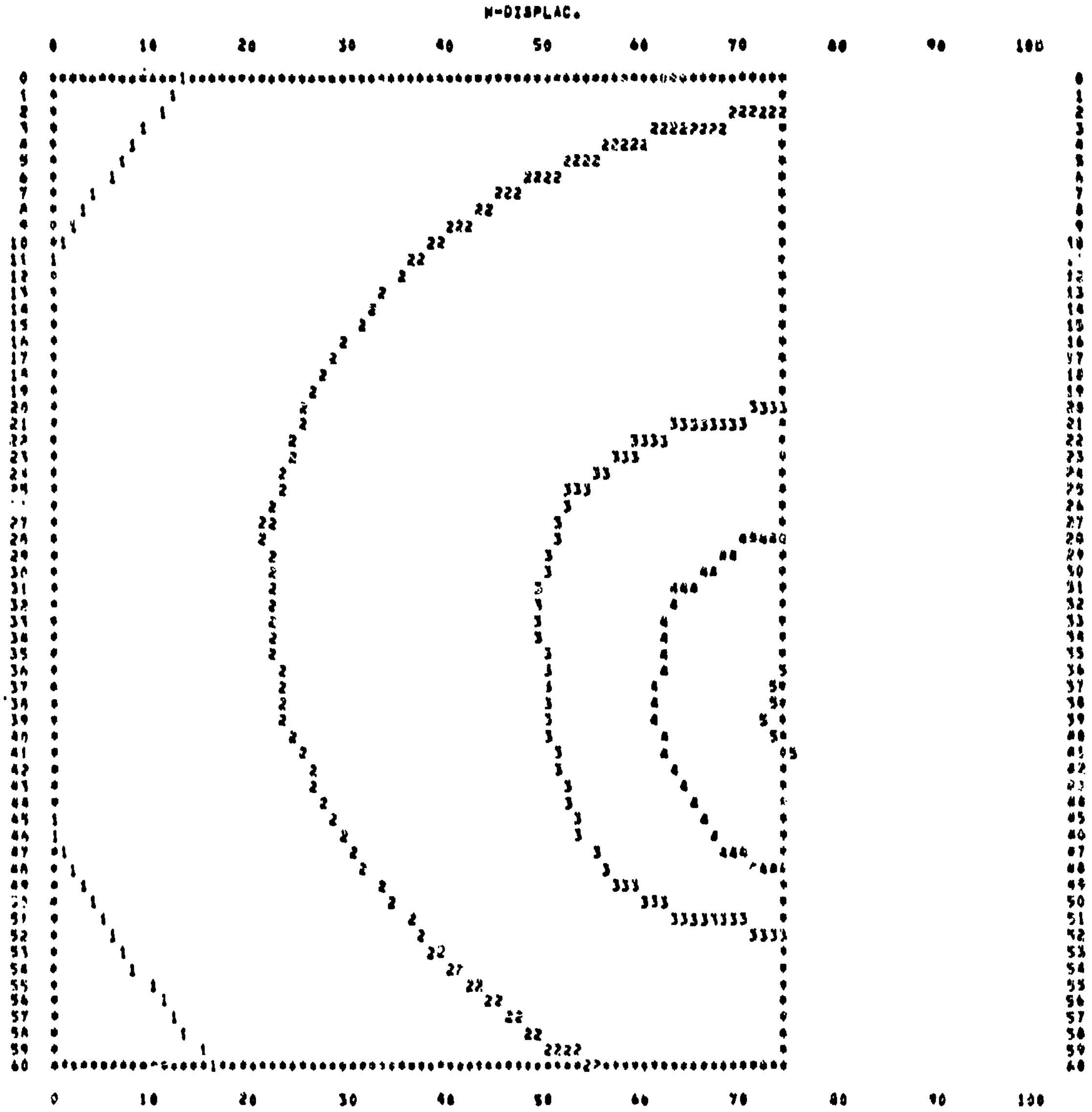
RESPONSE OF NORTH IGLOO

The displacement time histories at nodes 7, 16, 33, 47, 49 and 54 for the north igloo are shown in Figure 13. Since the input blast pressures in this case are more severe than those of the south igloo, the responses are, in general, greater in magnitude. The displacement at the center of the door rises to 26 in., then drops off rapidly, and finally oscillates at around the 10-in. level.

RESPONSE OF EAST IGLOO

The displacement time histories at nodes 7, 16, 33, 47, 49 and 54 for the east igloo, shown in Figure 14, indicate that the east igloo in general experiences larger magnitudes of displacements than the north igloo. Although the peak pressure is almost two times greater (525 vs. 300), the duration of the high pressure pulse for the east igloo is only about half as long as that for the north igloo. Thus the impulses, defined as the areas under the input pressure time histories, on the north and east igloos are about the same. Figure 15 shows the displacement, velocity and acceleration time histories at node 28, which corresponds to a location along the arch line.

All the time history plots shown were terminated at about 40 msec, although the calculations were performed up to about 100 msec. After about 35 msec, all the time histories exhibited (Fig. 15) unstable oscillations not experienced in the previous calculations for the north and south igloos.



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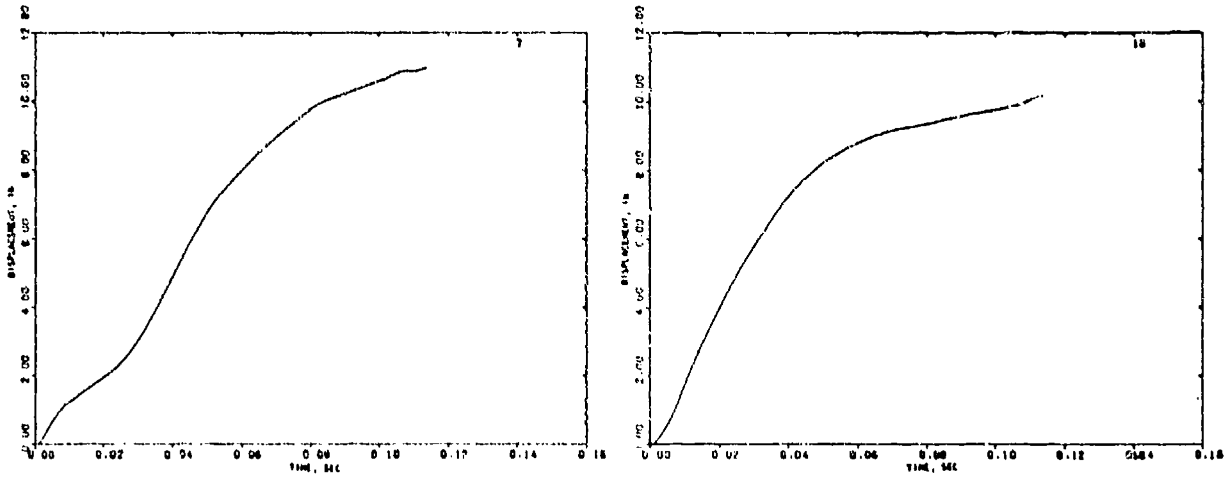
REFERENCES

LINE SYMBOL          VALUES

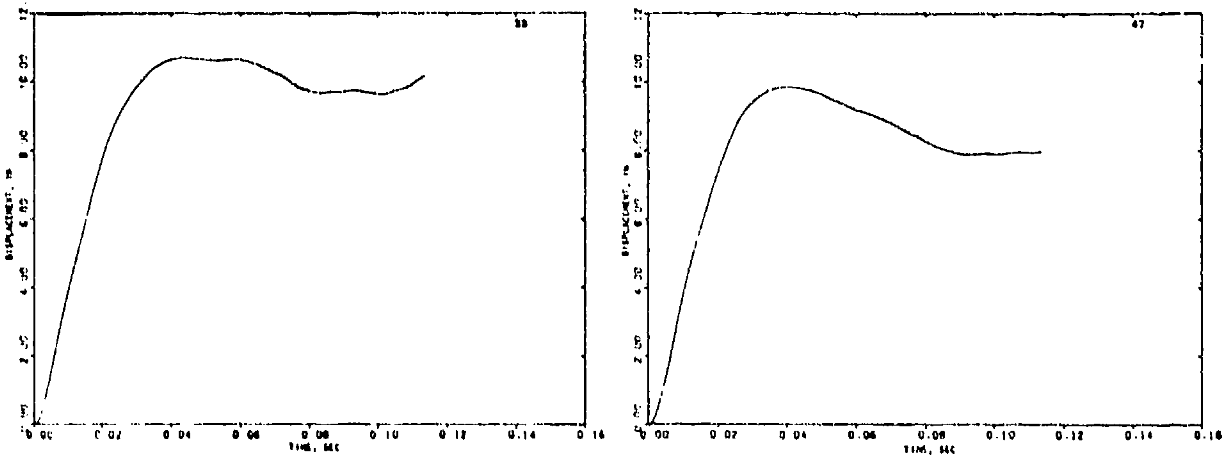
     0           .000000        .000000
     1          2.000000      -2.000000
     2          4.000000      -4.000000
     3          6.000000      -6.000000
     4          8.000000      -8.000000
     5         10.000000     -10.000000
     6         12.000000     -12.000000
     7         14.000000     -14.000000
     8         16.000000     -16.000000
     9         18.000000     -18.000000
     0         20.000000     -20.000000
     *             BOUNDARY POINTS
```

FIGURE 12. DISPLACEMENT CONTOUR PLOT OF SOUTH IGLOO
AT t = 47.4 MSEC



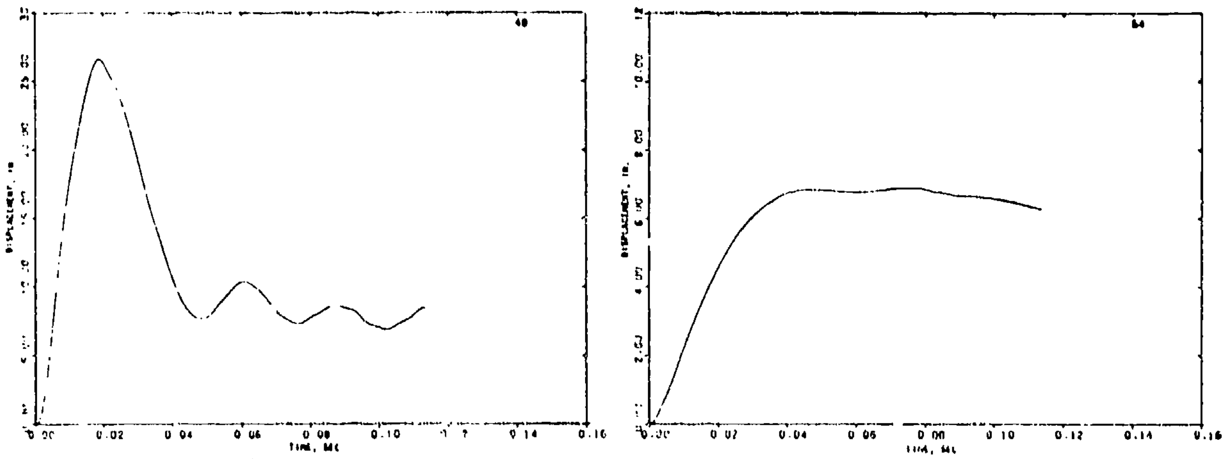
(a) NODE 7

(b) NODE 16



(c) NODE 33

(d) NODE 47

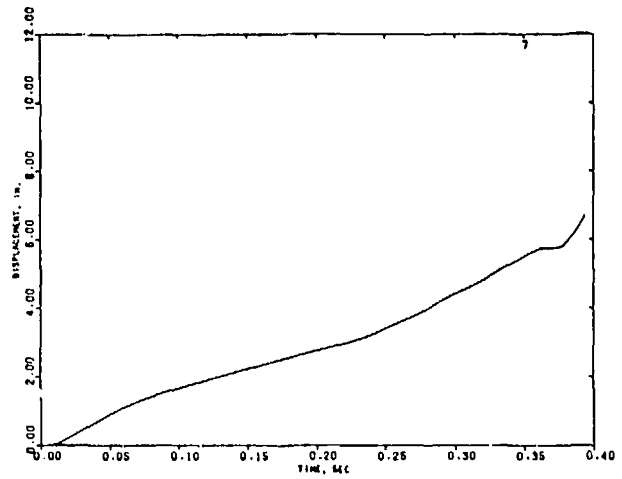


(e) NODE 49

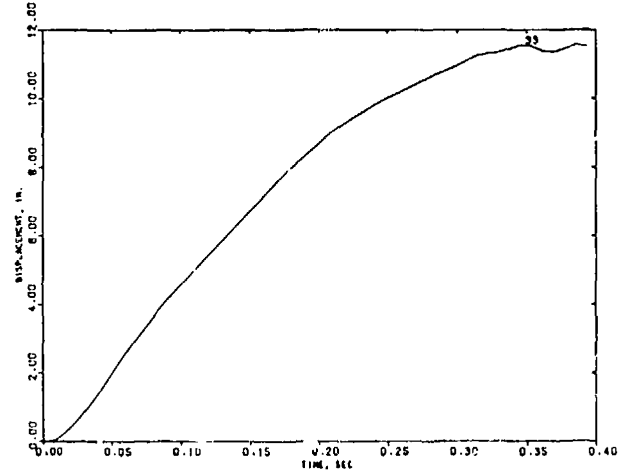
(f) NODE 54

FIGURE 13. DISPLACEMENT TIME HISTORIES OF THE NORTH IGLOO

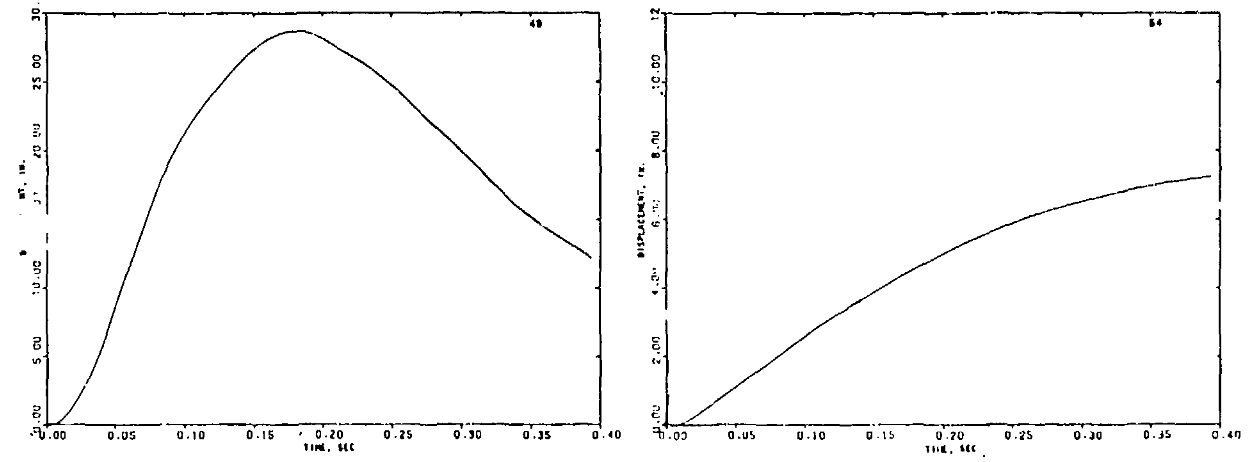
The displacements of the doorways are observed to be as high as 28 in. (Fig. 14e), which indicates that the doors have been already blown open. Furthermore, the extent of damage caused by the blast was masked by the subsequent detonation of the acceptor charges within the igloo in the actual test, so the comparisons of the field data with the computed response of the headwall will not be meaningful.



(a) NODE 7 (b) NODE 16

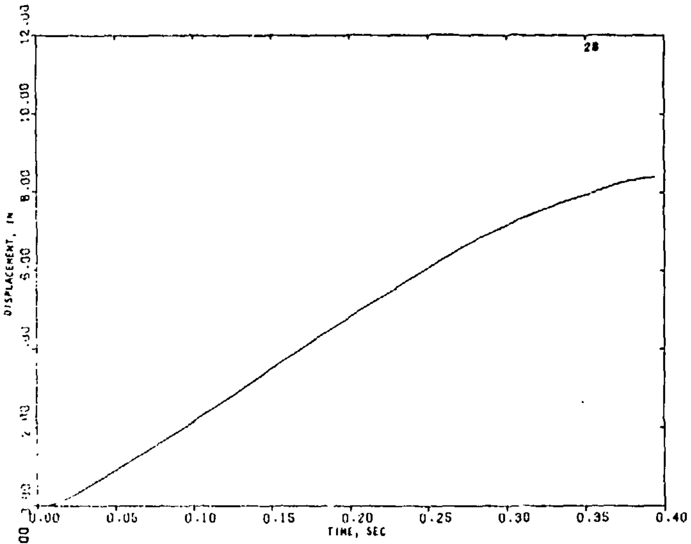


(c) NODE 33 (d) NODE 47

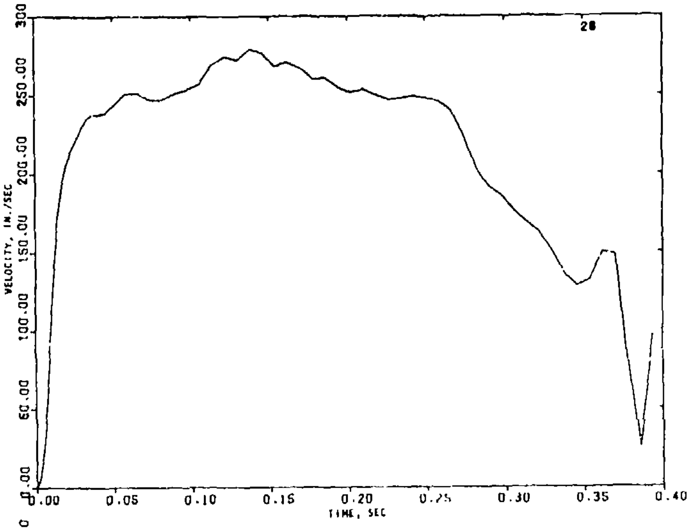


(e) NODE 49 (f) NODE 54

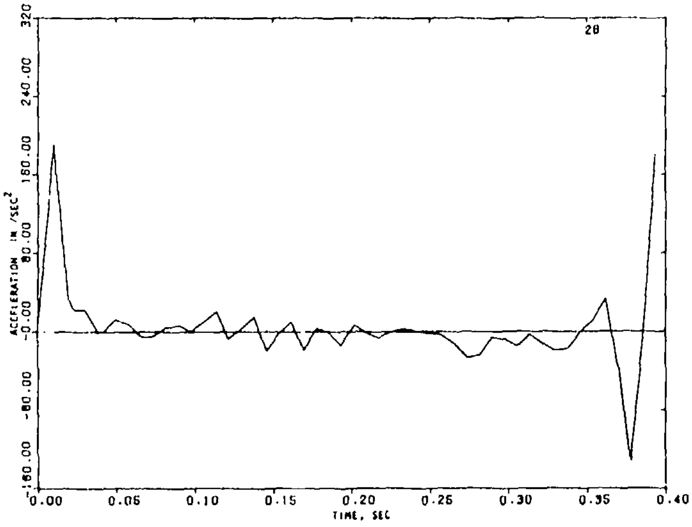
FIGURE 14. DISPLACEMENT TIME HISTORIES OF THE EAST IGLOO



(a) DISPLACEMENT



(b) VELOCITY



(c) ACCELERATION

FIGURE 15. MOTION TIME HISTORIES OF THE EAST IGLOO (NODE 28)

COMPARISON OF ANALYTICAL RESULTS AND FIELD MEASUREMENTS

Three types of field measurements were made in the Eskimo I test. These include, linear motion transducer data, accelerometer data, and static headwall measurements.

LINEAR MOTION TRANSDUCER DATA

The linear motion transducers are positioned above the center of the igloo doorways to measure movement of the concrete headwalls of the north, east, and south igloos. The maximum values listed in Table 2 were derived from the recorded data. Listed in Table 3 are the corresponding values obtained from the finite element calculations. These values were taken at node 33 (Fig. 3), which corresponds to the actual point on the headwall where measurements were recorded.

TABLE 2. SUMMARY OF LINEAR MOTION TRANSDUCER DATA

Location of Headwall Transducer	Max. Velocity, ft/sec	Av. Velocity from Initial Motion to Peak Excursion, ft/sec	Time from Initial Motion to Max. Velocity, ms	Av. Acceleration from Initial Motion to Max. Velocity, g
North Igloo	29.8	20.0	8.1	114
East Igloo	29.5	18.5	8.0	114
South Igloo	27.9	13.3	14.4	60

TABLE 3. MOTIONS FROM THE MATHEMATICAL MODEL

Headwall	Max. Velocity, ft/sec	Av. Velocity from Initial Motion to Peak Excursion, ft/sec	Time from Initial Motion to Max. Velocity, ms	Av. Acceleration from Initial Motion to Max. Velocity, g
North Igloo	42,2	28,3	6.8	259
East Igloo	49.1	36.5	5.8	285
South Igloo	20	11.7	11,2	64.8

A direct comparison of Tables 2 and 3 shows that the average accelerations of the south igloo give the best correlation. The ratios of the computed to the measured results are summarized in Table 4. The table also provides the ratios of the measured peak pressures and those used in the analysis.

TABLE 4. RATIOS OF THE ANALYTICAL AND THE MEASURED RESULTS

Headwall	Peak Pressure	Average Acceleration	Average Velocity	Maximum Velocity
North Igloo	1.26	2.27	1,41	1,41
East Igloo	2,10	2.50	1,98	1,66
South Igloo	0.99	1,08	0.88	0,72

STATIC HEADWALL MEASUREMENT

Static measurements were made in the Eskimo I test by setting up survey monuments 3 ft in front of the igloo headwalls. The distances from the monuments to the headwalls were measured at selected points before the test. These distances were again measured after the test. The net changes in displacements represented the permanent displacements of the headwalls. A gap of approximately 0.2 ft was found between the back of the south headwall and the earth cover at the top left corner, and a similar space of 0.1 ft wide was found at the top right corner. This demonstrates that the static measurements are not the maximum displacements but are the permanent movements of the headwall. These permanent displacements of the headwalls are shown in Figures 16 through 18 (Reference 1). All the measurements are subject to ±0.05 ft of error because pretest measurements showed that the walls deviated from a true vertical plane by that amount. The measured displacement patterns indicate that the different headwalls appear to have responded in different ways. More pronounced yielding of the steel arch was found in the south igloo. In the west igloo, there was clear indication that the steel arch acted as a reaction line resisting headwall movement. The difference in the observed data, therefore, implies that material properties in the two igloos are not the same. As mentioned before, the same finite element model is used to predict the responses of the south and west igloos. The assumed material properties of the model would therefore seem to represent characteristics that are a compromise between the actual properties of the south igloo and those of the west igloo.

The predicted permanent displacement contours from the INSLAB calculations for the south igloo were selected at the end of the numerical computation (t = 116.4 msec) and are shown in Figure 19. The general patterns are similar to measurements of the south igloo. However, computed contour lines indicate that all the points on the south and west headwalls move away from the donor magazine, and thus no lines of zero displacement exist. This appears to be consistent with actual measurements found for the west igloo.

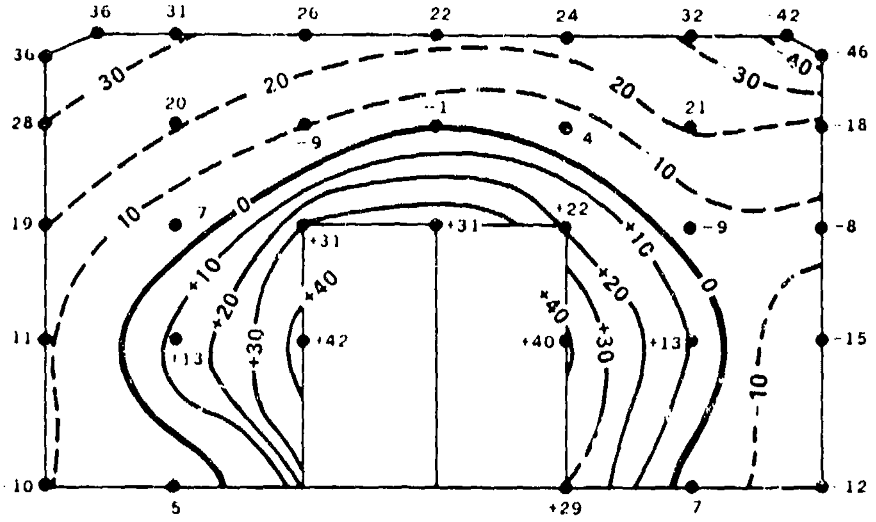


FIGURE 16. MOVEMENT OF HEADWALL OF NORTH ACCEPTOR IGLOO
A plus value shows movement away from the donor magazine; a minus value shows movement toward. The units are in hundredths of feet.

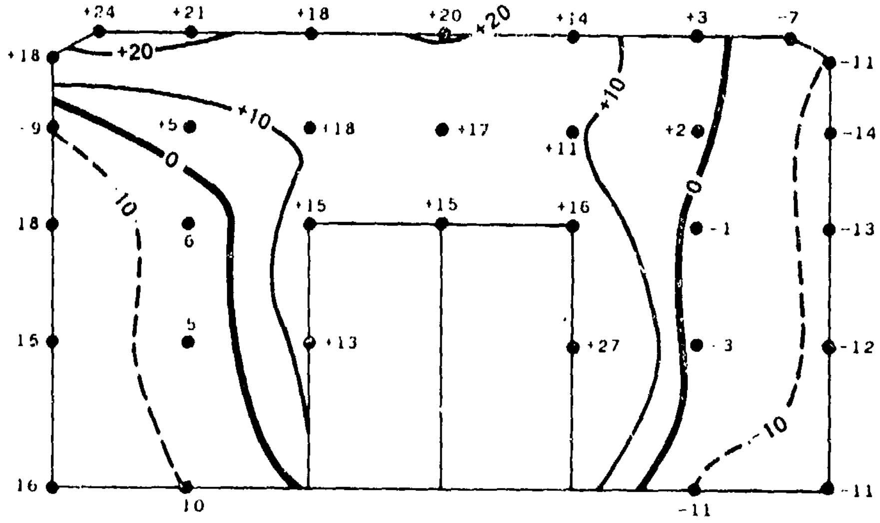


FIGURE 17. MOVEMENT OF HEADWALL OF SOUTH ACCEPTOR IGLOO
A plus value shows movement away from the donor magazine; a minus value shows movement toward. The units are in hundredths of feet.

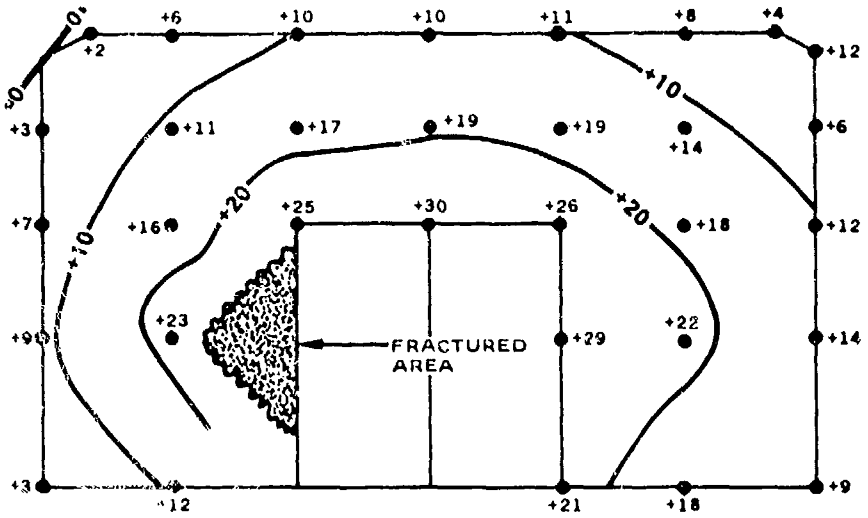


FIGURE 18. MOVEMENT OF HEADWALL OF WEST ACCEPTOR IGLOO
Plus values show movement away from donor magazine; one point (upper left) showed no movement. The units are in hundredths of feet.

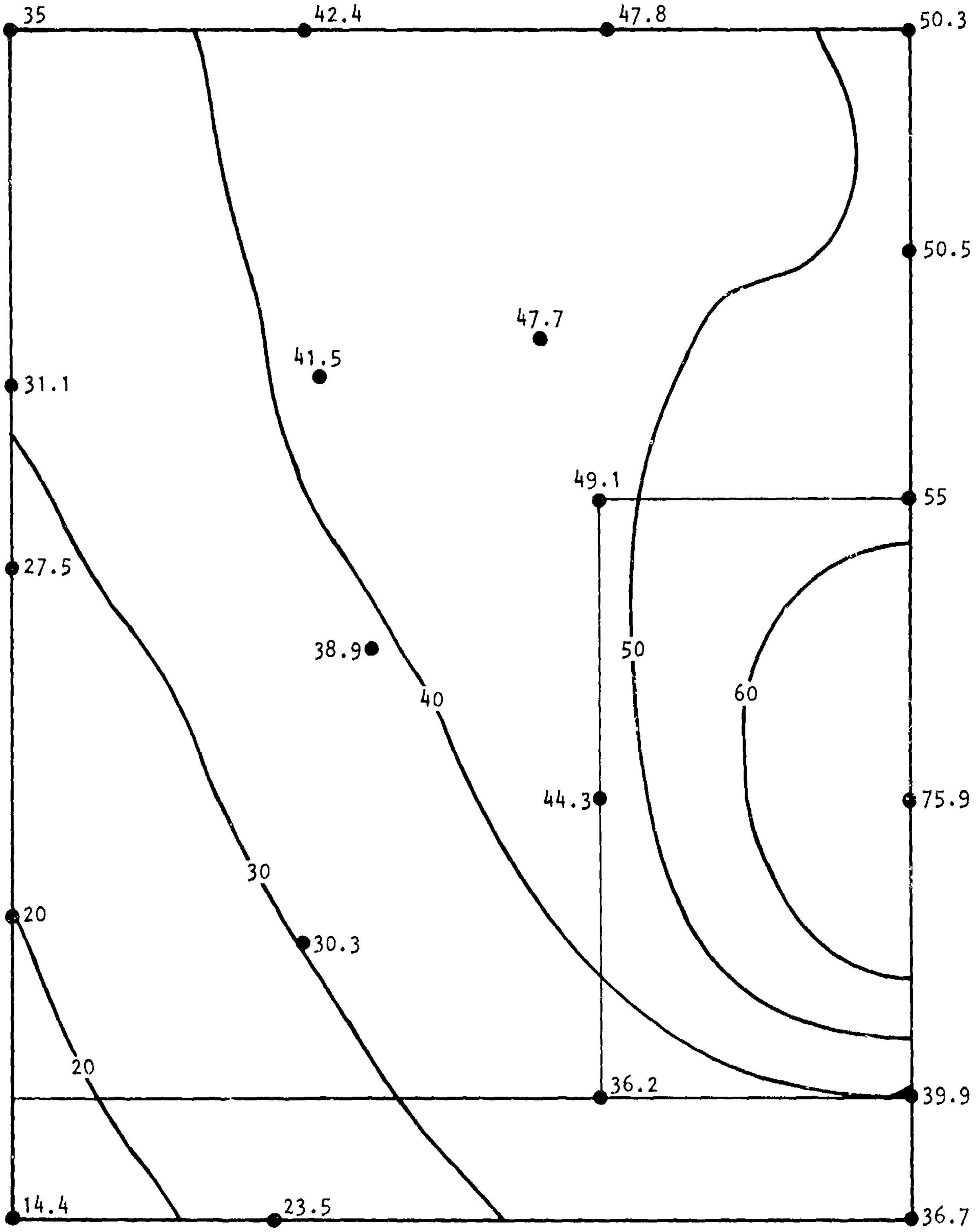


FIGURE 19. COMPUTED MOVEMENT OF HEADWALL OF SOUTH ACCEPTOR IGLOO (Units in hundredths of feet)

in both igloos, the measured displacements are smaller than the computed displacement values.

The computed permanent displacements of the headwall of the north igloo, shown in Figure 20, produce contour patterns quite different from the measured displacements (Fig. 16).

The qualitative similarities between Figures 17 and 19 suggest that the rigid body rotation about the floor level is about the same in both cases. Therefore, a more favorable comparison will result in this case if the rigid body translations (normal to the headwall) are neglected in each. The elimination of the rigid body components, in any case, does not influence computed stresses in the headwall.

ACCELEROMETER DATA

The accelerometers were installed on the center lines of the igloo floors near the front. Both vertical and horizontal motions were recorded. Only the horizontal component is listed here (Table 5) for comparison. The corresponding accelerations computed at node 65 of the mathematical model are shown in Table 6.

TABLE 5. HORIZONTAL COMPONENTS OF ACCELEROMETER DATA

Location of Accelerometer	Maximum Acceleration g	Approximate Frequency of Accelerations Hz
North Igloo	10.3	490
East Igloo	33.0	545
South Igloo	6.3	500
West Igloo	5.5	533

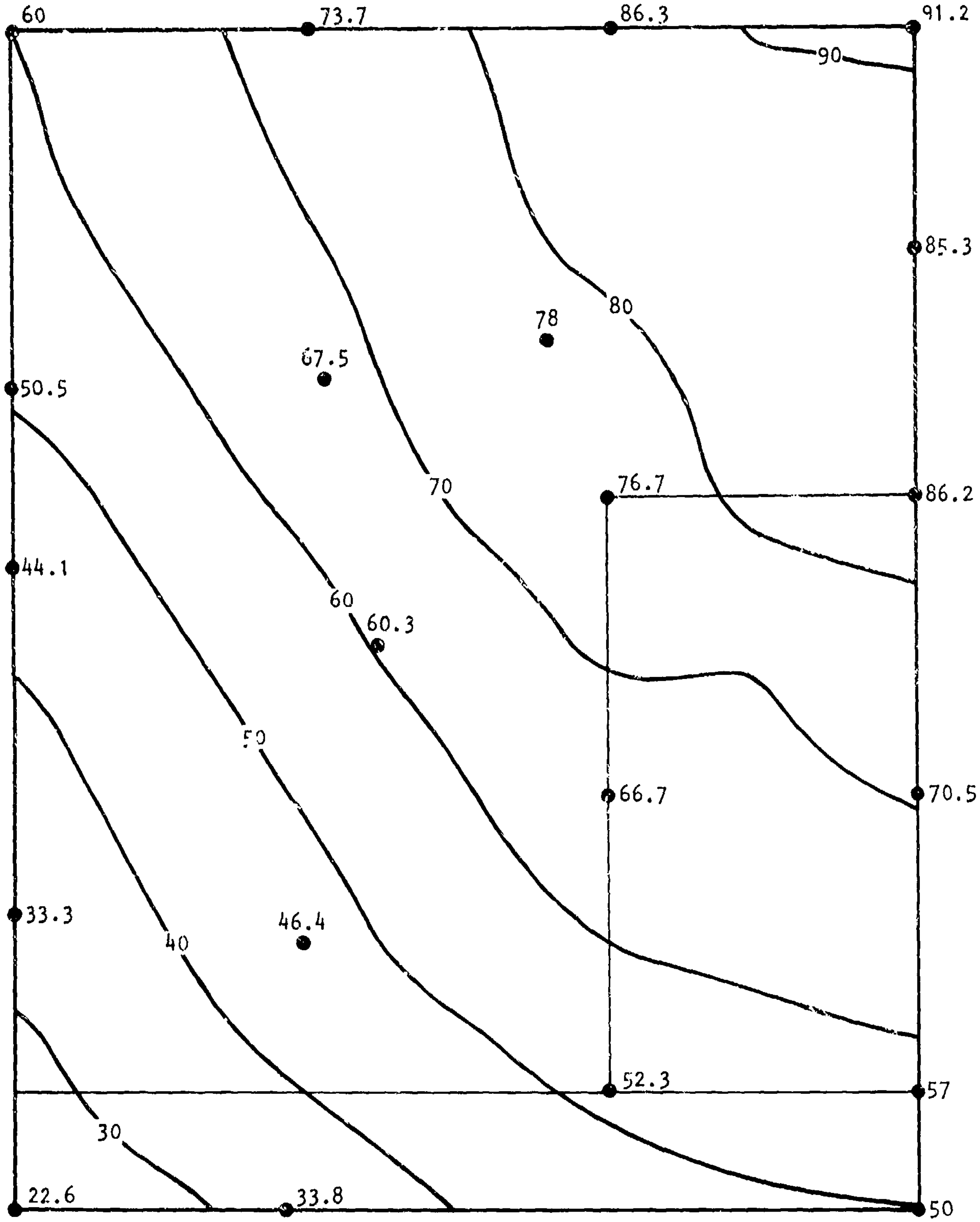


FIGURE 20. COMPUTED MOVEMENT OF HEADWALL OF NORTH ACCEPTOR IGLOO
(Units in hundredths of feet)

TABLE 6. MAXIMUM ACCELERATIONS OF THE MATHEMATICAL MODEL (NODE 65)

Headwall	Maximum Acceleration g	Approximate Frequency of Accelerations Hz
North Igloo	488	500
East Igloo	846	500
South & West Igloos	121	500

The maximum accelerations between the computed and the measured data are quite different. These differences indicate that the stiffness of the floor slab used in the finite element analysis is much smaller than its actual value.

MOTION PICTURE PHOTOGRAPHY

In the Eskimo I Magazine Separation Test, motion picture cameras were installed in the south and west igloos to capture the motion of the doors on film. Since the camera setup was not designed for measuring the door response, the estimates derived for the door motions are considered to be very crude. Two types of data were extracted from the movie film: one was the angular change of the door of the south igloo; the other was the movement of the two top corner points on the doorways of the south and west igloos.

The maximum angular change was observed to be 30°, using the line of the door hinges as reference. If a linear relationship is assumed, the maximum displacement at the center of one door panel is calculated to be

$$d_{max} = 60 \times \sin 30^{\circ} = 30 \text{ in.}$$

where the width of the door panel is taken as 60 in. This value appears to be high in comparison to either the calculations or the measured permanent deflections.

The maximum displacements on the corner points of doorways were measured to be 4.8 in. ±1.2 in. for the south igloo, and 3.36 ±1.2 in. for the west igloo. The order of magnitude of these values is in the same order as those from the calculations (Table 7) or those of the measured permanent deflections (Figs. 17 and 18).

The maximum velocities measured at the same locations as the displacements are 32.5 ft/sec for the south igloo and 20 ft/sec for the west igloo. These two values are higher than the computer result of 16.5 ft/sec, as shown in Table 7.

TABLE 7. COMPARISON OF ANALYTICAL RESULTS WITH THE MOTION PICTURE DATA

Igloo Location	Maximum Center displacement of door (inch)		Maximum Corner displacement of door (inch)		Maximum Corner velocity of door (ft/sec)	
	Experiment	Calculations	Experiment	Calculations	Experiment	Calculations
South	30 in.	10.6 in.	4.8±1.2	5.8	32.5	16.5
West	--	10.6 in.	3.4±1.2	5.8	20.0	16.5

CONCLUSIONS

In this study, the dynamic analyses of a headwall subjected to different explosive loadings are performed using the finite element method. The computed results are compared with the available data from the Eskimo I test. The following is a summary of the important conclusions of the study:

a. As part of a general program sponsored by the Department of Defense Explosives Safety Board, the present study is a relatively successful attempt to predict the response of magazine headwalls using INSLAB, a nonlinear, dynamic finite element computer program.

b. The measured values of the maximum velocities and accelerations in the south igloo are in good agreement with the calculated results.

c. The computed values of the maximum velocities and accelerations in the east and north igloos are found to be consistently greater than the measured values. The distribution of the permanent displacements as computed are also significantly different from those measured.

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ESKIMO III

Magazine Structure Damage Observations

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ESKIMO III, the third in a series of full-scale tests of earth-covered magazines sponsored by the Department of Defense Explosives Safety Board, was conducted at the Naval Weapons Center, China Lake, California, on 12 June 1974. Its main objective was to expose a new earth-covered, non-circular corrugated steel arch magazine to explosion of an adjacent magazine at the minimum side-to-side spacing now permitted by standards. In addition, magazine headwall and door structures were tested at several other distances and orientations of interest.

Target Magazines

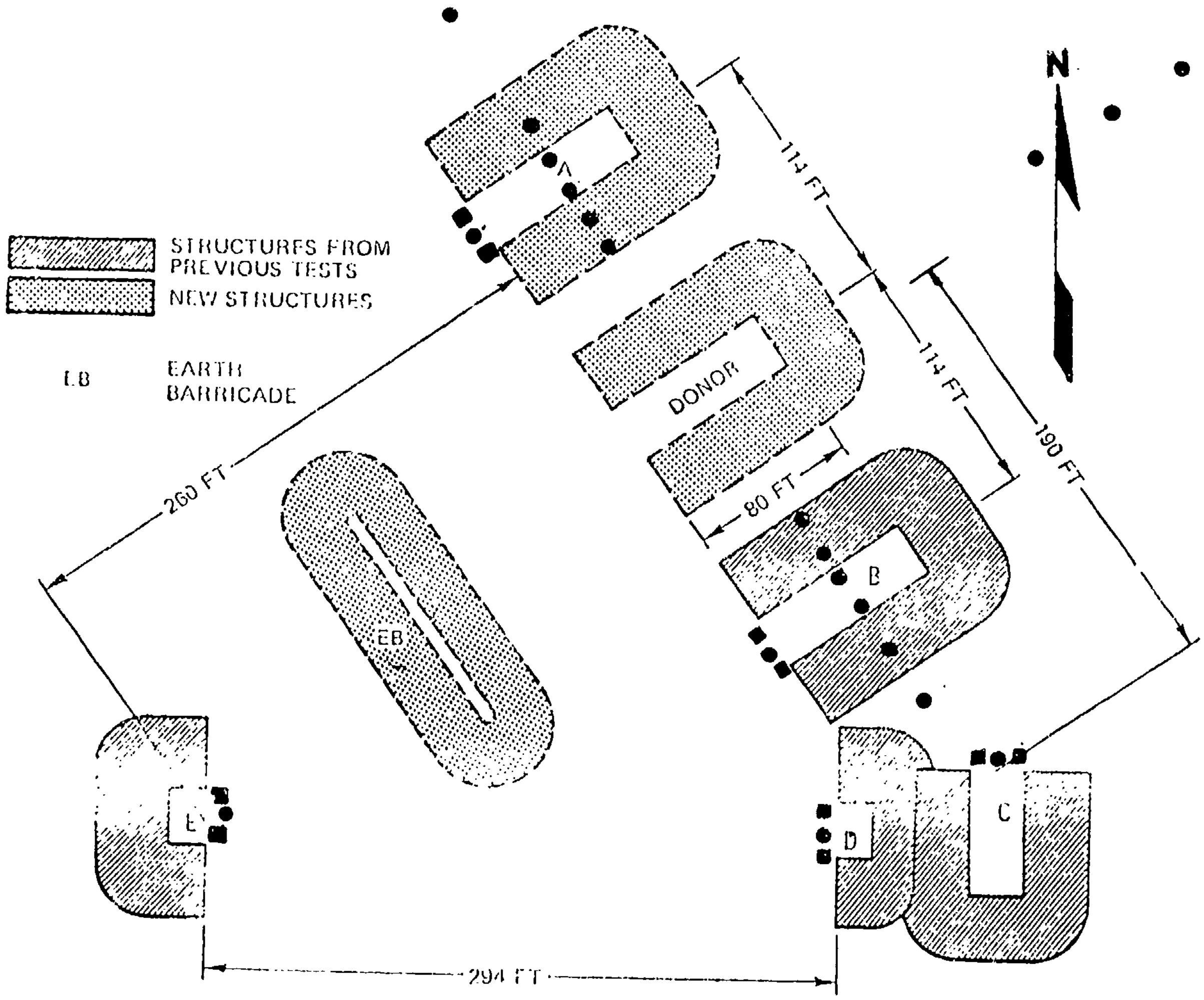
The explosion source consisted of 350,000 lb of tritonal in 750-lb bombs, in a light-gage, deep-corrugated steel arch magazine built to the same specifications as Acceptor A described below. The layout of acceptor magazines is shown in Figure 1. Several structures remained from ESKIMO II, the previous test in the series, and were rebuilt as necessary.

Acceptor A. This earth-covered structure was built with a light-gage, deep-corrugated arch rather than structural plate, but was otherwise identical to the standard steel arch igloo. In addition to constituting a full-scale qualification test of the lightweight arch at the side-to-side spacing of 1.25 $\mathrm{ft/lb}^{1/3}$ permitted by standards for earth-covered magazines, it furnished a test of the opinion that the earth cover is the most important factor in preventing explosion communication.

Acceptor B. The main objective of ESKIMO III was to qualify the oval steel arch igloo at the distance of 1.25 $\mathrm{ft/lb}^{1/3}$. Some authorities have felt that, because of the shallow crown of this arch, there is greater risk of catastrophic collapse under severe shock loading.

Acceptor C. The separation distance applicable to this exposure is 2.75 $\mathrm{ft/lb}^{1/3}$, and the location of this igloo meets that requirement almost exactly for an 80-ft donor igloo filled to capacity with bombs on pallets in a standard storage arrangement. Thus it afforded the opportunity for a direct test using an improved single-leaf sliding door on a sound, existing specimen of the standard headwall for the steel arch magazine.

Acceptor D. Despite some degree of unobstructed line-of-sight exposure between donor and acceptor headwalls, standards permit application



LEGEND

- ● Gage Mounted Flush with Ground
- ■ Gage Mounted on Concrete Headwall

Figure 1 ESKIMO III Near Field Layout

of the side-to-side distance in this case. Remaining from previous tests, this acceptor is at 2.55 ft/lb$^{1/3}$, about twice the required distance.

Acceptor E. This is a front-to-front exposure at 3.7 ft/lb$^{1/3}$ for the size of igloo donor in ESKIMO III. Standards require 6 ft/lb$^{1/3}$ with an earth barricade between. The orientation was tested in ESKIMO I with failure at 2 ft/lb$^{1/3}$; the standard distance is untested. The exposure might be considered equivalent to that between barricaded, substantial aboveground magazines or between strengthened operating buildings as well.

Incident peak pressure was measured at the ground surface in front of each acceptor igloo. Reflected peak pressure and impulse were obtained directly from blast gages set in each headwall. Rows of surface gages were positioned to measure the incident peak pressure on the earth over the oval arch and the light-gage circular arch, and to the rear of the donor. Acceleration and displacement measurements were made on the arches of the closest acceptors.

Damage Observations

Acceptor A. The deep-corrugated arch was deformed nonuniformly, the deformation being most pronounced along the side of the arch nearer the donor, about 7 ft above the floor line. The arch did not collapse, and the velocity of its inward movement would not have represented a hazard to explosives stored within.

Acceptor B. The noncircular steel arch magazine experienced only minor structural damage. The sides of the arch were pushed inward slightly, the maximum deformation occurring at a height of 4.5 to 5 ft above the floor level on the side nearer the donor. The floor bowed upward, the maximum displacement occurring along the centerline, where it was typically 0.3 ft. The central flat crown of the noncircular steel arch moved upward slightly with respect to the floor about 0.38 ft at the midsection of the arch.

Acceptor C. The horizontal-span, single-leaf sliding door withstood the blast with little apparent damage or deformation. It remained lodged in place at the door opening and could not be opened manually. The concrete headwall, which had remained from a 1963 test, experienced some cracking, inward displacements up to 0.4 ft, and interior concrete spallation near the door opening.

Acceptor D. This igloo experienced inward door movement with complete separation of one leaf through hinge failure. Inward rotation of the other leaf caused severe twisting of the steel door frame. Except for local damage near one edge of the opening, headwall damage was generally slight. Limited door deformation suggests that the leaves did not attain high velocities.

Acceptor E. The most severe door and headwall damage was experienced by this igloo. Here the door damage and deformation indicate that the leaves were driven inward with significant velocity. In addition, much of the steel channel door frame was separated from the concrete headwall opening. The maximum inward movement of the headwall was approximately 1.5 ft where the lower end of the door frame at one side separated from the floor.

Near Field Blast

Measurements made at the surface of the earth fill over the midsections of the igloos flanking the donor show that peak blast pressure and impulse are reduced far below their values at the same distances from an aboveground hemisphere of the same weight of explosive. The comparison of peak pressures is illustrated graphically in Figure 2. Similar reductions occur in blast impulse. The resulting arch velocities, derived from accelerometer records and dynamic displacement measurements, were found to range from about 7.5 to 9 fps.

Measurements to the rear of the donor magazine indicate that the free-field pressure and impulse observed there are the same as would be produced by a 37,000-lb TNT hemisphere about 150 ft away. Thus the near-field blast from ESKIMO III can apparently be simulated by an aboveground charge of little more than one-tenth the explosive quantity.

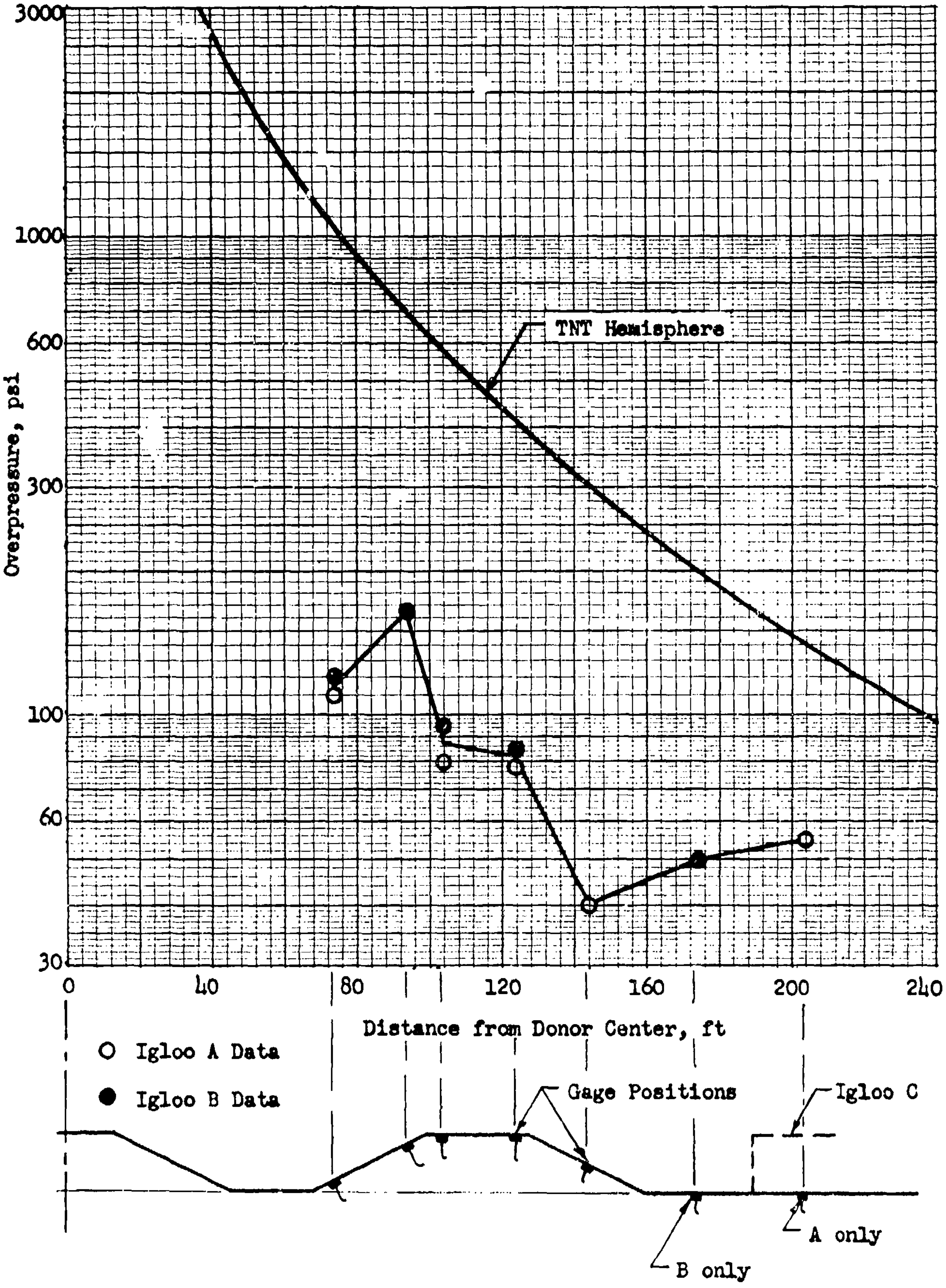


Figure 2 Blast Pressures on Side-to-Side Igloos

AIRBLAST EFFECTS ON WINDOWS IN
BUILDINGS AND AUTOMOBILES
ON THE ESKIMO III EVENT

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INTRODUCTION

Objectives

The objectives of this project were:

1. to determine the velocities, masses, and spatial densities of the fragments from three types of standard plate-glass windows mounted in closed, cubical structures at three ranges from ground zero;
2. to determine the same quantities for window fragments inside three automobiles, one oriented side-on and two oriented head-on to ground zero;
3. to document the window damage in ten automobiles located at three ground ranges;
4. to study the response of a clothed anthropomorphic dummy (a) standing behind one of the plate-glass windows and (b) sitting in an automobile; and

5. to estimate the hazards to occupants of buildings and automobiles exposed to similar levels of airblast.

Background

In order to access the flying-glass hazard to occupants of buildings, houses, and automobiles in the vicinity of an explosion, it is necessary to have information concerning the characteristics of fragments from windows broken by airblast. Reference 1 describes several experiments, conducted over the past 20 years, which provide data for a limited number of window types and conditions of exposure. More recently, a study was undertaken during the Eskimo II test in which 13.9 tons of explosive material was detonated at the Naval Weapons Center, China Lake, California in May of 1973 (Reference 2). Plate-glass windows of three designs were placed in cubical structures at overpressure levels between 0.2 and 0.5 psi, and conventional automobiles were positioned from 0.4 to 1.2 psi. The Eskimo III test provided an opportunity to evaluate the effects of yield by exposing similar plate-glass windows and automobiles to approximately the same overpressures in the vicinity of a much larger explosion (175 tons).

PROCEDURE

Modules

Ten 9-foot cubical boxes called modules (used previously on the Eskimo II test) were positioned along the northwest radial by China Lake personnel. Three modules abutted one another at the 5920-foot range, three at 3950 feet, and four at 3525 feet (see Figure 1). The only openings into each module were a hole where a window was mounted and an access door which was closed during the blast. All of the windows faced ground zero.

Windows

The three types of windows used on the Eskimo II and III tests are shown at the bottom of Table I. Types W1 and W2, designated as projected and horizontal-sliding, respectively, are commercial-type windows used extensively in government buildings and comply with, but do not exceed, the Architectural Aluminum Manufacturers Association (AAMA) specifications. The Type W3 window-walls were mounted in a neoprene structural gasket system used in Federal office buildings but no AAMA specifications are available. Three Type W1, four Type W2, and three Type W3 windows were mounted one each in the ten modules. One window of each type was tested at three ranges. The additional Type W2 window was located at the 3525-foot

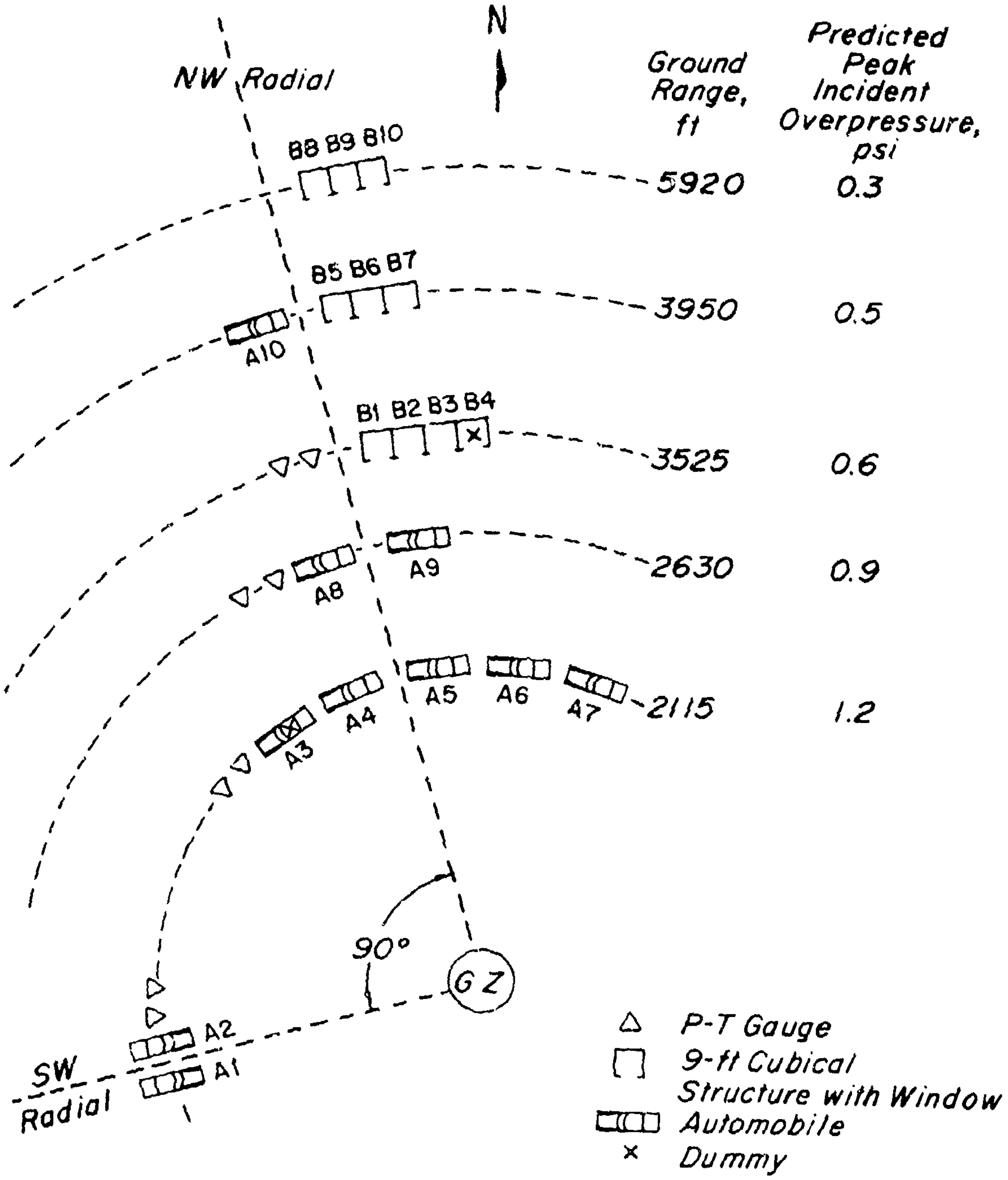


Figure 1. Far Field Layout for the Eskimo III Test.

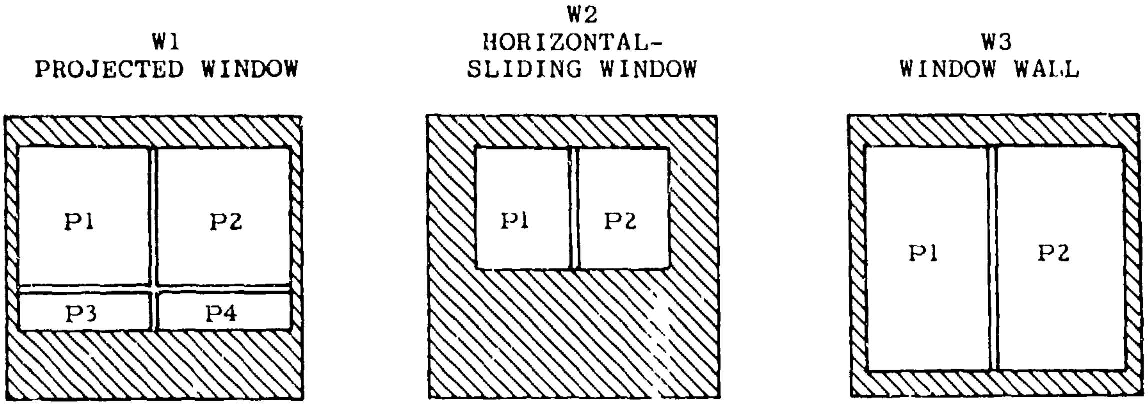
TABLE I

DESCRIPTION OF THE WINDOWS IN THE MODULES

Window Type	Parameters for Individual Panes					
	Number	Color*	Width, in.	Height, in.	Type of Glass	Frame Type
W1	P1	Copper	45	45	Plate	Fixed
	P2	Green	45	45	Plate	Fixed
	P3	Silver	42	20	Sheet	Top Opening
	P4	Black	42	20	Sheet	Top Opening
W2	P1	Copper	34	48	Sheet	Horizontal Sliding
	P2	Green	34	48	Plate	Fixed
W3	P1	Copper	48	90	Plate	Fixed
	P2	Green	48	90	Plate	Fixed

* A thin coat of paint was sprayed on both sides of each pane.

FRONT VIEW OF THREE MODULES INDICATING
WINDOW TYPE AND PANE NUMBERS


W1
PROJECTED WINDOW

W2
HORIZONTAL-
SLIDING WINDOW

W3
WINDOW WALL

range. The panes were spray painted different colors to aid in identifying the sources of the trapped fragments (see Table I).

Automobiles

Eight automobiles were exposed side-on to the blast, five at a range of 2115 feet, two at 2630 feet, and one at 3950 feet (see Figure 1). Two additional automobiles were exposed head-on at a range of 2115 feet.

Styrofoam

A Styrofoam witness plate was mounted on the inside back wall of nine of the modules in an attempt to trap glass fragments if the window was broken by the blast wave. The witness plates were fabricated at the Lovelace Foundation using low-density Styrofoam (Type II, described in Reference 3) glued to 1/2-inch plywood. Each witness plate included two pieces of Styrofoam each 90 inches high, 32.5 inches wide, and 6 inches thick. In each module the distance from the window to the surface of the Styrofoam was approximately 84 inches. Similar but smaller witness plates, each containing one piece of Styrofoam 32 inches high, 43 inches wide, and 6 inches thick, were mounted in the automobiles. One witness plate was installed in automobile A1, one in A2, and two in A4 such that Styrofoam was located approximately 32 inches behind each of the windows which faced ground zero in these three vehicles. Calibration techniques described in Reference 3 were used to develop a formula for determining the velocity of a fragment from its mass and the volume of the impression it made in the Styrofoam.

Dummies

Two anthropomorphic dummies attired in summer civilian clothing were supplied by the Lovelace Foundation for this test. One of the dummies was standing 35 inches behind pane P2 in the B4 module at 3525 feet. This module did not contain any Styrofoam witness plates. The dummy faced the window with his chest resting lightly against a narrow metal rod intended to stabilize his position prior to shock arrival while not interfering with subsequent possible blast displacement. The other dummy was secured by means of a lap seat belt in the driver's seat of a left-side-on station wagon, A3, located at 2115 feet on the northwest radial.

Cameras

Two high-speed (400 frames per second) motion-picture cameras were used by China Lake personnel to record the responses of the two dummies. A reference grid was painted on the portion of the module wall in the field of view of the camera in order to facilitate velocity determinations for the glass fragments and the dummy.

Overpressure Gauges

Eight self-recording BRL mechanical gauges, supplied by China Lake, were positioned, two each, at the 3525-, 2630-, and 2115-foot ranges on the northwest radial and at the 2115-foot range on the southwest radial. Additional gauges were located at closer ranges.

RESULTS AND DISCUSSION

General

All of the modules remained structurally intact and none of the Styrofoam witness plates were damaged or displaced by the blast experience. A total of 296 fragments were trapped from the 18 of 26 exposed panes which broke. Window damage was noted in four of the ten automobiles on the layout, but none of the windows broke in front of the witness plates. Dummy and glass responses were satisfactorily documented with both motion-picture cameras. Good pressure-time records were obtained from most of the gauges. In general, the average measured peak incident overpressures were close to the predicted values as given in Figure 1 for the five ranges of interest. The average measured overpressure was 0.60 psi at 3525 feet (0.6 predicted), 0.97 psi at 2630 feet (0.9 predicted), and 1.38 psi at 2115 feet (1.2 predicted).

Windows in Modules

The 26 panes of glass exposed in the modules are listed in Table II along with such information as glass thickness, whether or not the pane broke, and the number of fragments trapped. Eight of the ten panes at 3525 feet, seven of the eight panes at 3950 feet, and three of the eight panes at 5920 feet broke. As expected, only a portion of the glass from the broken panes was actually trapped. This is indicated by the amount of glass left in the frames and the number of fragments on the floor below the Styrofoam as shown in Figure 2, a postshot view of the modules at 3950 feet. Table II also contains the predicted peak incident overpressure, P_i, the calculated (using P_i) peak overpressure in the reflected wave at the front of the modules, P_r, and the predicted duration of the positive phase of the incident overpressure, t_p.

Masses and Velocities of Fragments

The masses and velocities were determined by procedures described in Reference 3 for all but 29 fragments

TABLE II

FRAGMENT DATA FOR THE WINDOWS IN THE MODULES

Ground Range, ft	P_i, psi	P_r, psi	t_p, msec	Module Number	Window Type	Pane Number	Glass Thickness, in.	Number of Trapped Fragments	V_{50}, ft/sec	M_{50}, gm	A_{50}, in.^{2}	E_{gm} or E_{ga}	b	E_b	E_{gv}	ρ_d, frags. per ft^2	ρ_w, frags. per ft^2
3525	0.6	1.2	250	B1	W2	P1* P2	0.236 0.239	0 19	- 37.6	- 16.6	- 1.71	- 3.54	- -0.321	- 0.0650	- 1.42	0 2.07	1.11
				B2	W3	P1 P2	0.239 0.239	25 21	60.8 40.3	10.8 22.0	1.12 2.27	4.98 4.37	-0.290 -0.192	0.0413 0.0765	1.38 1.66	2.84 1.77	2.31
				B3	W1	P1 P2 P3 P4	0.235 0.232 0.125 0.125	20 5 52 35	40.1 51.1 76.0 68.6	11.6 10.5 0.877 1.40	1.22 1.12 0.173 0.277	5.57 5.01 4.11 4.86	-0.222 -0.218 -0.232 -0.282	0.0557 0.138 0.0392 0.0315	1.52 1.56 1.49 1.34	2.81 0.443 5.87 4.21	5.76
				B4	W2	P1 P2*	0.236 0.236	** **	29† -	- -	- -	- -	- -	- -	- -	- 0	-
				Data from B1, B2, and B3 combined			0.125 0.238	87 90	74.1 45.1	1.06 14.2	0.209 1.47	4.45 4.61	-0.255 -0.257	0.0257 0.0294	1.43 1.53	5.10 1.68	
3950	0.5	1.0	260	B5	W3	P1 P2	0.232 0.232	4 12	21.7 53.6	61.3 12.1	6.52 1.28	1.51 4.66	-0.269 -0.230	0.225 0.0736	1.17 1.46	0.591 1.62	1.11
				B6	W1	P1 P2 P3* P4	0.239 0.236 0.124 0.122	13 0 0 46	25.4 - - 47.1	24.9 - - 2.91	2.57 - - 0.589	2.61 - - 3.24	-0.064 - - -0.194	0.126 - - 0.0401	1.59 - - 1.37	1.44 0 0 5.21	2.36
				B7	W2	P1 P2	0.236 0.234	0 8	- 39.5	- 10.6	- 1.12	- 12.9	- -0.173	- 0.0388	- 1.30	0 1.03	0.517
				Data from B5, B6, and B7 combined			0.122 0.235	46 37	47.1 35.0	2.91 18.0	0.589 1.89	3.24 5.19	-0.194 -0.218	0.0401 0.0454	1.37 1.57	2.60 0.775	
5920	0.3	0.6	290	B8	W3	P1* P2*	0.236 0.236	0 0	- -	- -	- -	- -	- -	- -	- -	0 0	0
				B9	W1	P1 P2 P3* P4*	0.239 0.236 0.124 0.124	1 0 0 0	16.7 - - -	21.5 - - -	2.22 - - -	- - - -	- - - -	- - - -	- - - -	0.222 0 0 0	0.111
				B10	W2	P1 P2*	0.203 0.236	6 0	22.6 -	35.5 -	4.32 -	3.93 -	-0.110 -	0.107 -	1.39 -	0.886 0	0.443
				Data from B8, B9, and B10 combined			0.124 0.208	0 7	- 21.6	- 33.0	- 3.92	- 3.54	- -0.094	- 0.105	- 1.39	0 0.148	
				Total Number of Trapped Fragments				267‡									

* This pane did not break.

** There was no Styrofoam in the module containing this pane.

† Velocity estimated from the motion-picture record (413 frames per second).

‡ Overall, an additional 29 fragments were trapped for which M and V were not calculated (see text) bringing the total number of fragments trapped to 296.

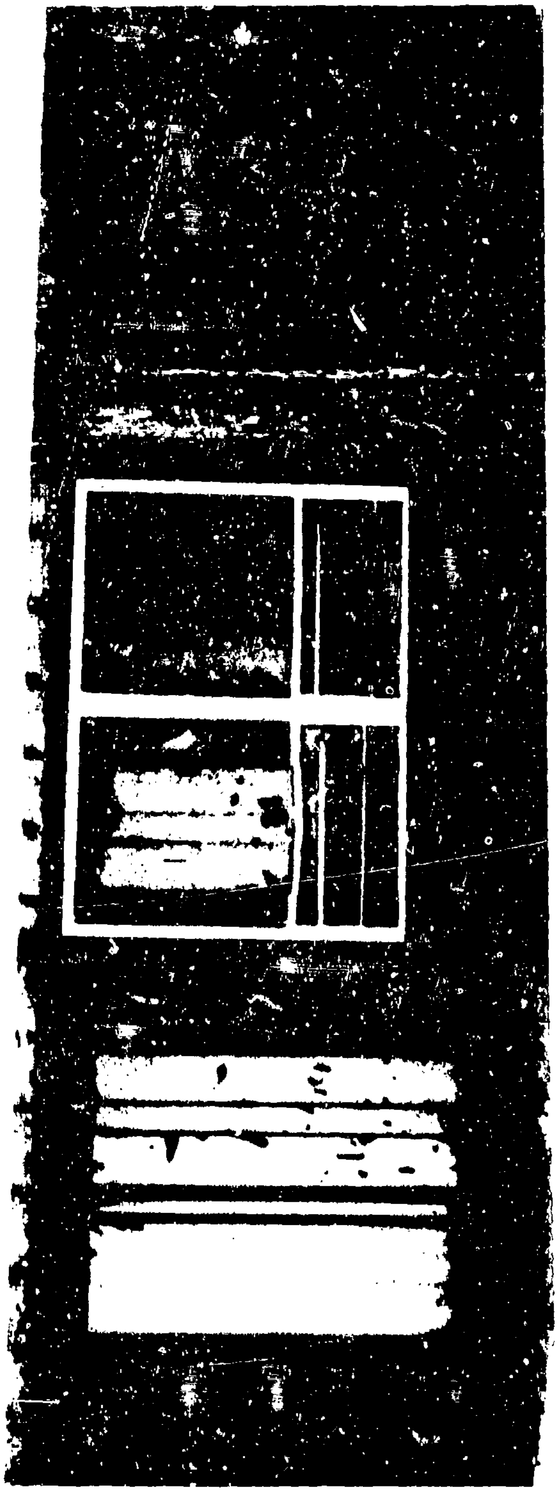


Figure 2. Postshot View of (from Left to Right) Modules B5, B6, and B7.

which struck so close to other fragments that the measured volumes of the impressions in the Styrofoam were suspect. As in the past, it was noted that for each pane an approximately linear relationship existed between the logarithms of the velocities and the logarithms of the masses of the fragments. A least-squares linear-regression analysis was performed for each pane and the results appear in Table II where V_{50} and M_{50} are the geometric mean fragment velocity and mass, respectively; b and E_b are the slope and the standard error in the slope of the regression line, respectively; and E_{gv} is the geometric standard error of estimate of fragment velocity. In addition, A_{50} is the geometric mean frontal area of the fragments (calculated from the density and thickness of the glass and M_{50}), and E_{gm} and E_{ga} are the geometric standard deviation of the fragment masses and frontal areas, respectively.

It was noted that the masses and velocities of fragments from panes of approximately the same thickness and located at the same ground range tended to be very similar. Therefore the data were combined into five groups (no 1/8-inch-thick fragments were trapped at 5920 feet) representing panes approximately 1/4- or 1/8-inch-thick located at the 3525-, 3950-, or 5920-foot ground range. These groups are shown in Figures 3 through 7 which contain regression lines as well as lines drawn one standard error of estimate on either side of the regression lines. The results of the regression analysis for each of the five groups are given in Table II where it can be noted that the mean fragment velocity estimated from the motion-picture record obtained at 3525 feet was 29 ft/sec compared to 37.6 ft/sec measured from the witness plate behind a similar pane in module B1 at the same range.

Spatial Densities of Fragments

All 296 fragments were used in computing the spatial densities of trapped fragments which, for each pane, tended to be constant over an area of Styrofoam equal to the size of the pane. This area was, in general, centered somewhat below the center of the pane as a result of the fragments' having fallen (due to gravity) in traversing the distance from the pane to the Styrofoam. Likewise, the density of trapped fragments for an entire window (i.e., counting the fragments from all of the panes) tended to be approximately constant over an area of Styrofoam equal in size to the window but displaced downward. The computed average densities (designated as ρ_d and ρ_w for the individual panes and entire windows, respectively) over these areas of approximately constant density are listed in Table II.

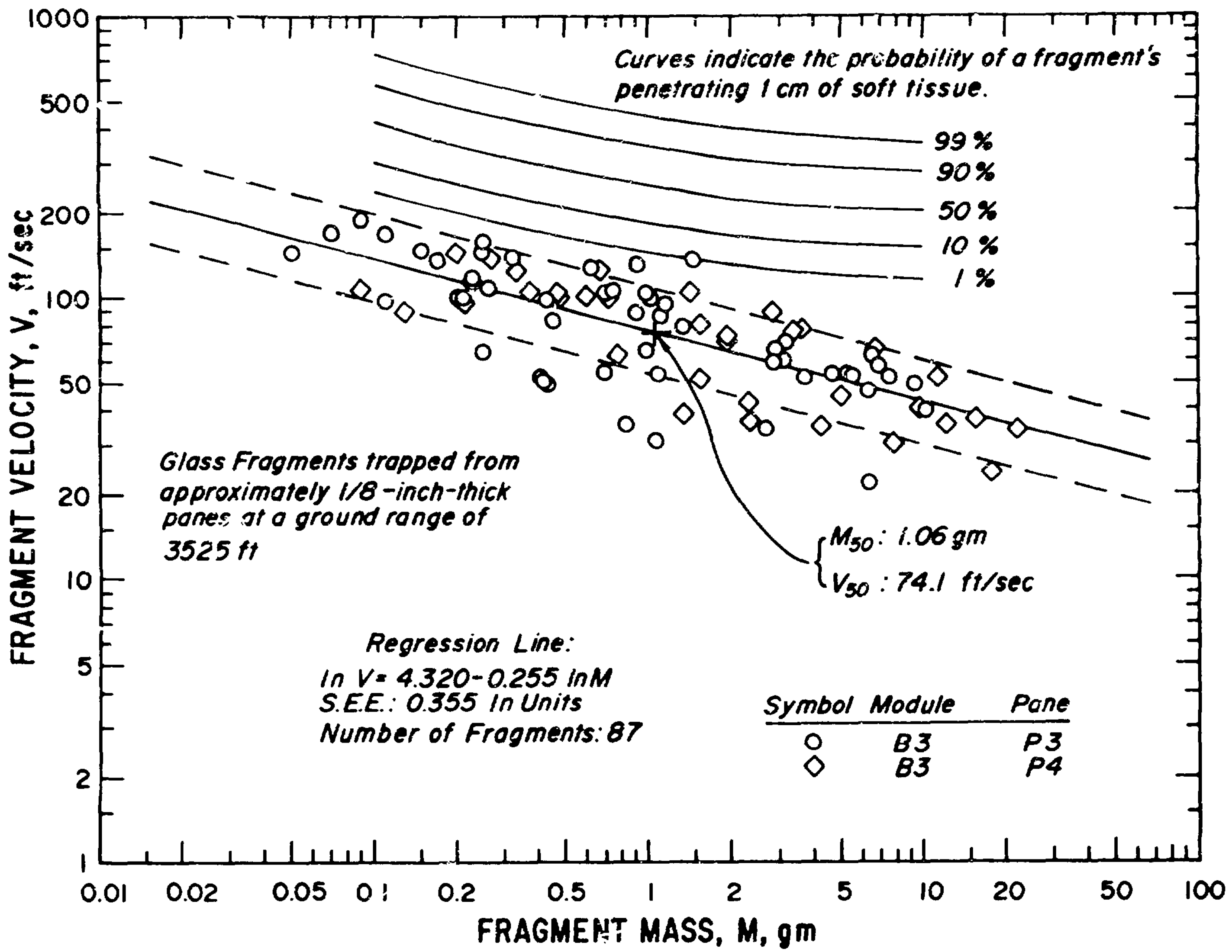


Figure 3. Glass Fragments Trapped from Approximately 1/8-Inch-Thick Panes at a Ground Range of 3525 Feet.

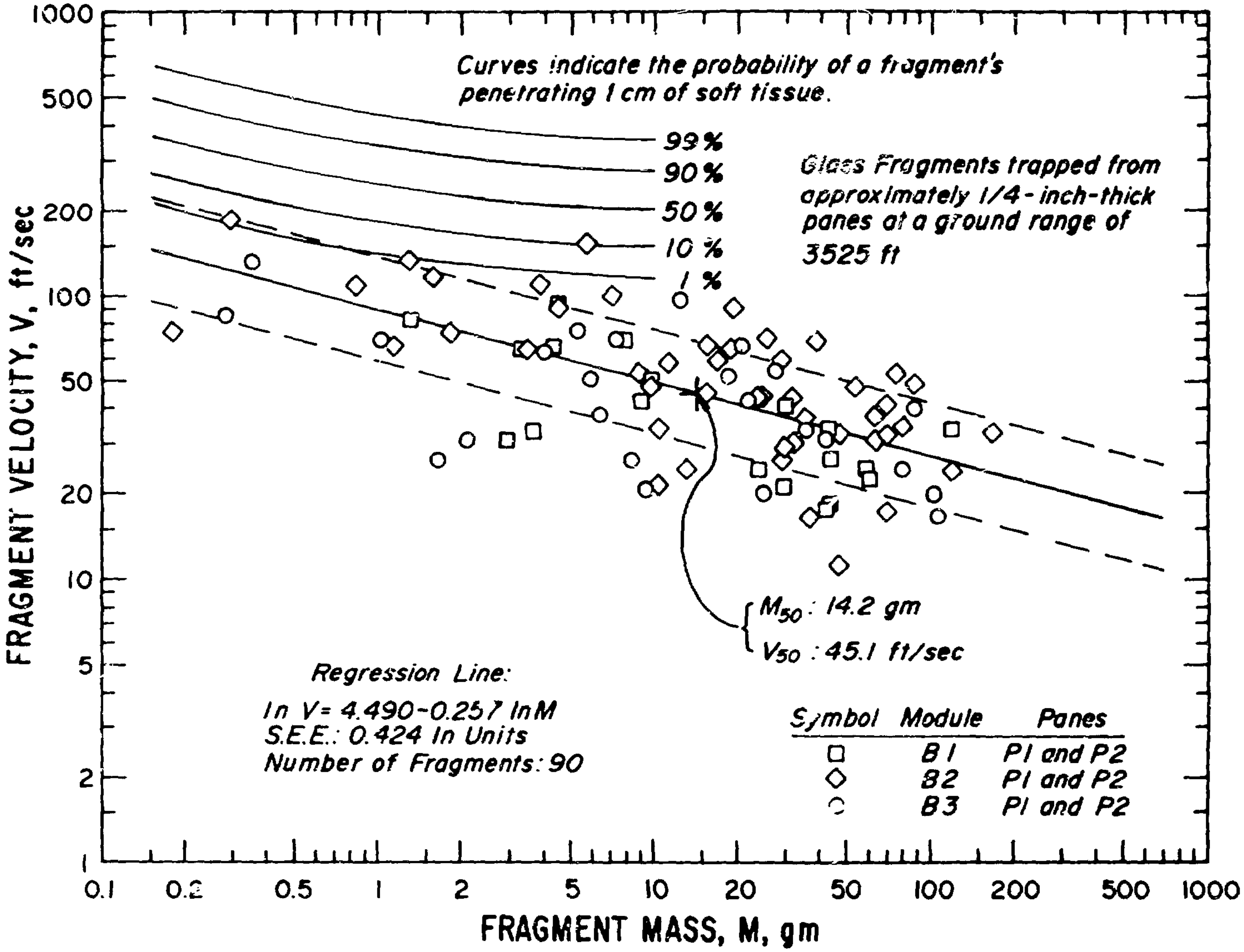


Figure 4. Glass Fragments Trapped from Approximately 1/4-Inch-Thick Panes at a Ground Range of 3525 Feet.

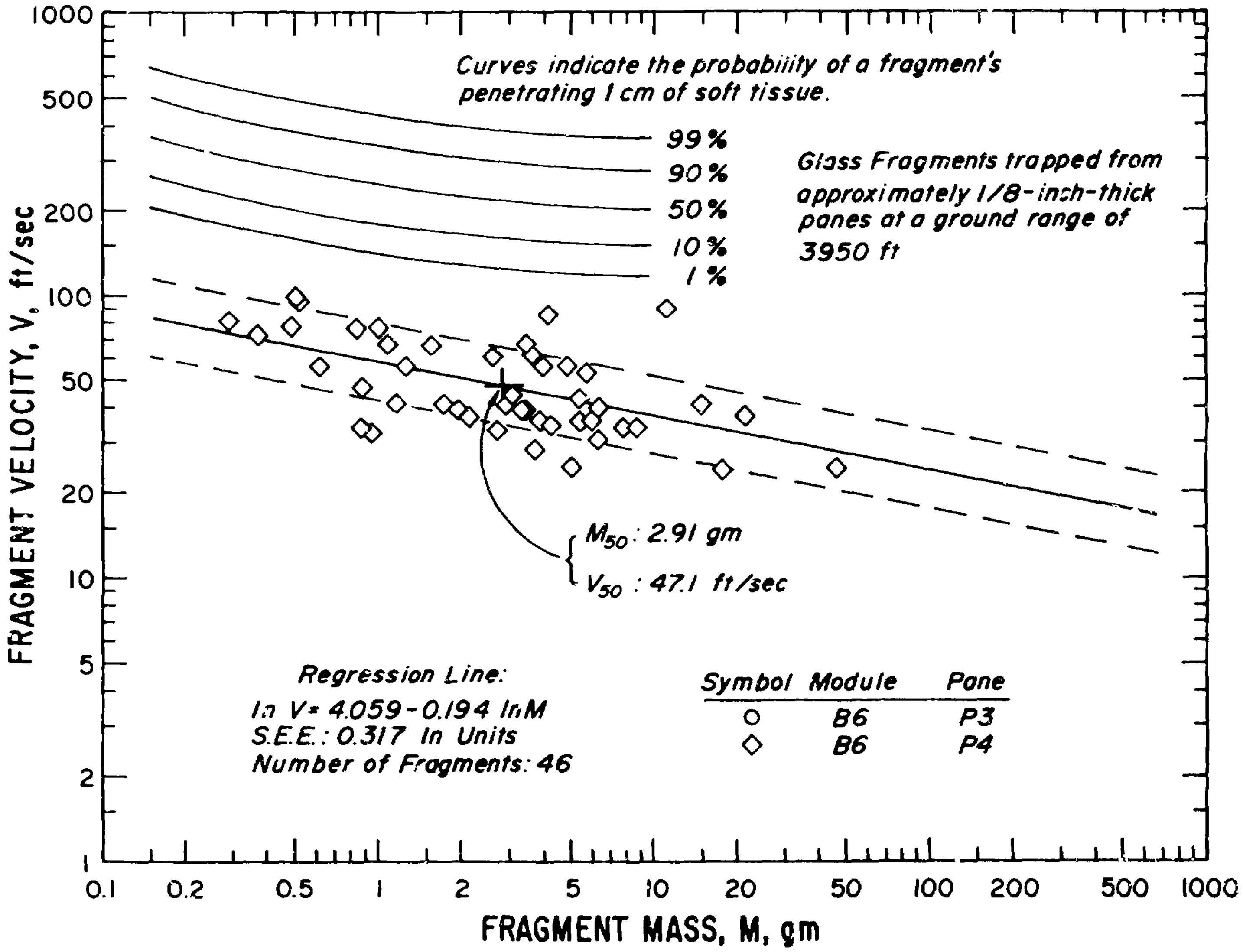


Figure 5. Glass Fragments Trapped from Approximately 1/8-Inch-Thick Panes at a Ground Range of 3950 Feet.

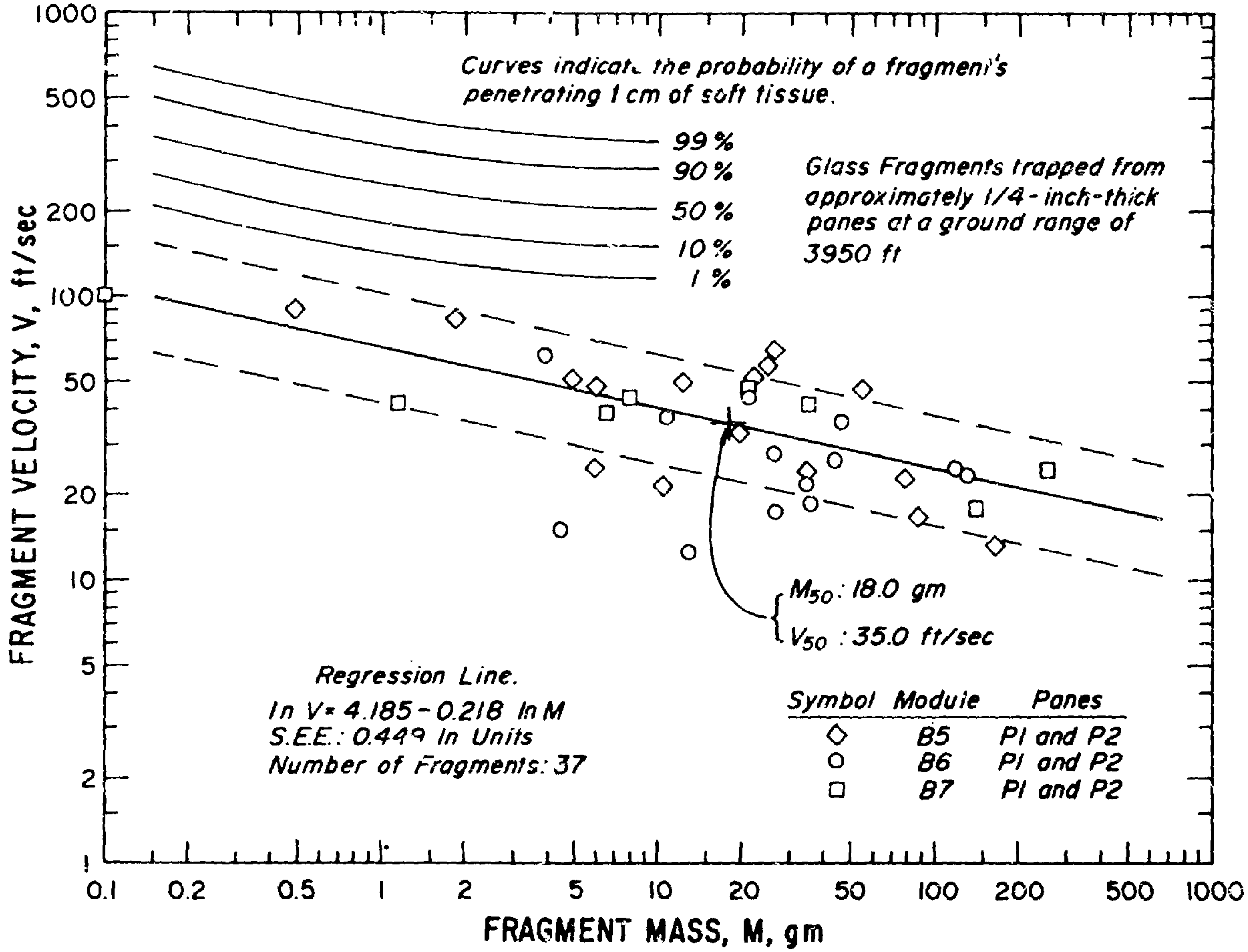


Figure 6. Glass Fragments Trapped from Approximately 1/4-Inch-Thick Panes at a Ground Range of 3950 Feet.

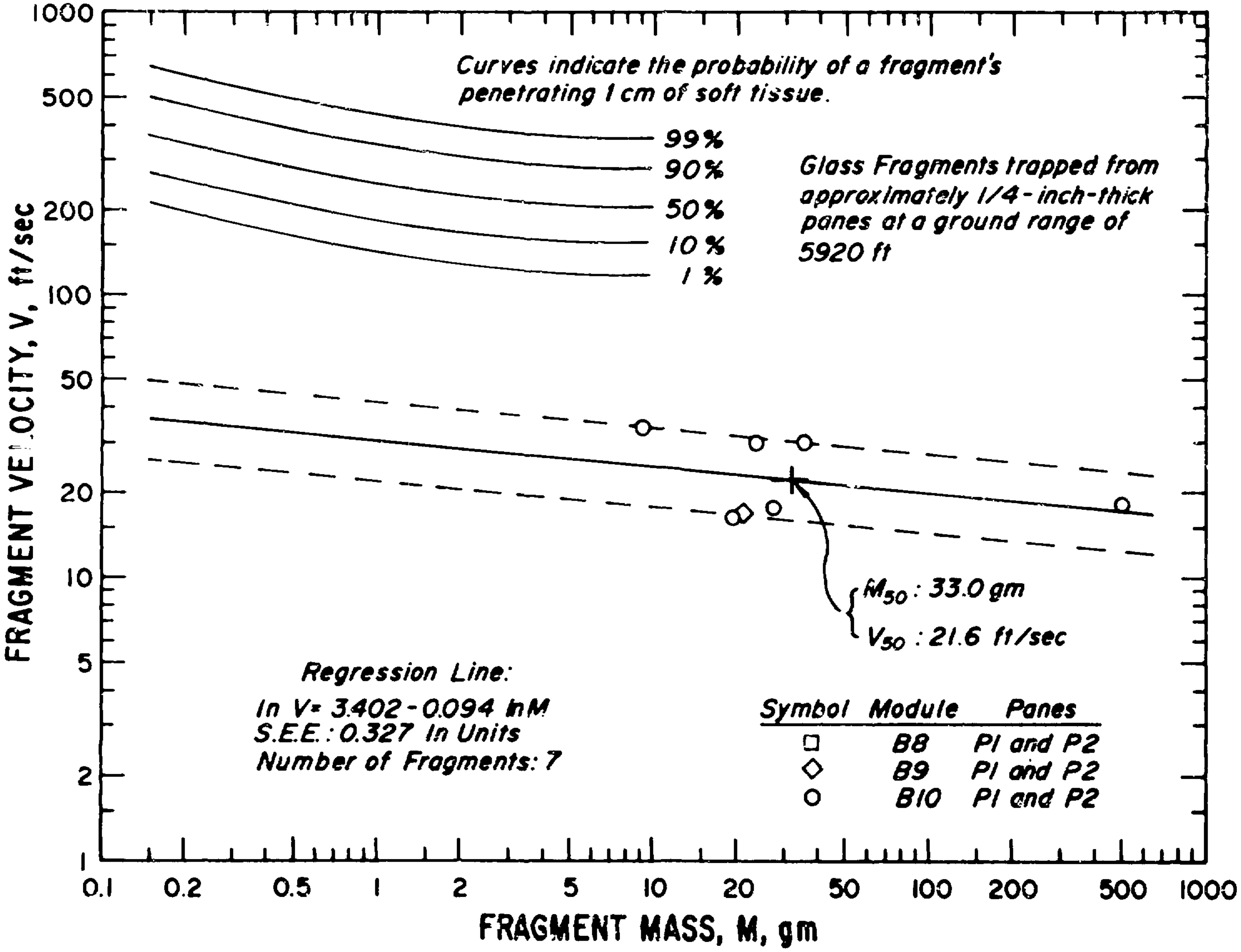


Figure 7. Glass Fragments Trapped from Approximately 1/4-Inch-Thick Panes at a Ground Range of 5920 Feet.

Comparisons with Prior Data

In order to make comparisons between the Eskimo II and III tests and prior experiments, all of the data were plotted in Figures 8 through 10 which were modified from Reference 1. In these figures, it can be seen that the fragment velocities, frontal areas, and densities for the two Eskimo tests were fairly consistent, indicating that these quantities were not greatly dependent on the yield. Further, the Eskimo test data line up reasonably well with the corresponding values for the prior data when plotted against the effective peak overpressure, i.e., the peak overpressure on the window. This overpressure was assumed to be P_r for the Eskimo tests since all of the windows faced the advancing blast wave. However, on all three figures the Eskimo test data tend to fall above the regression curve based on the prior data only. Thus, the Eskimo test data suggest that in each case the shape of the regression curve may need to be modified for the lower overpressures. In the case of the mean fragment velocity, this is probably because the fragments with sufficiently low velocities are not likely to be trapped in the Styrofoam.

Biological Hazards

Figures 3 through 7 contain curves indicating

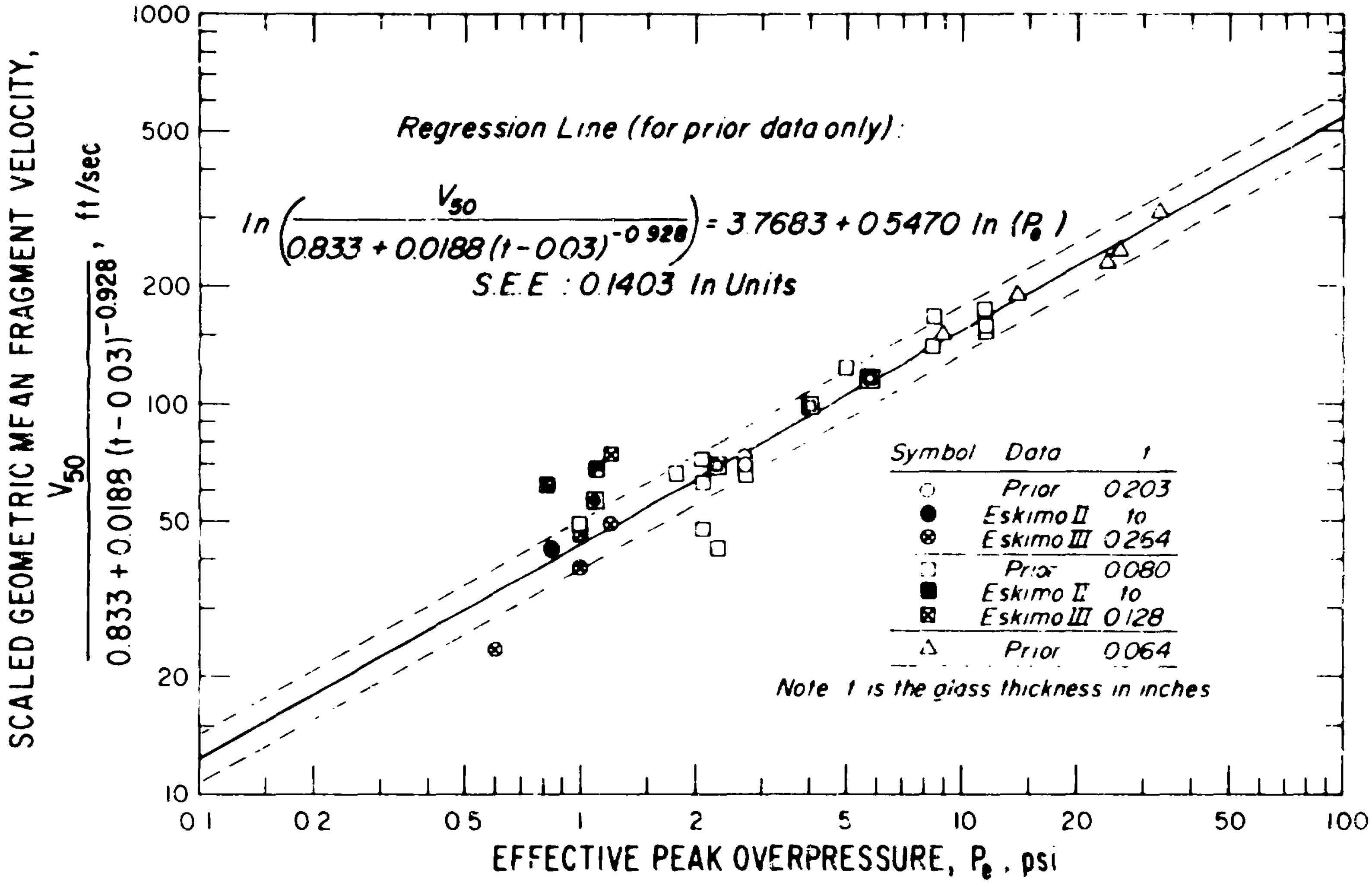


Figure 8. Scaled Geometric-Mean Fragment Velocity vs Effective Peak Overpressure.

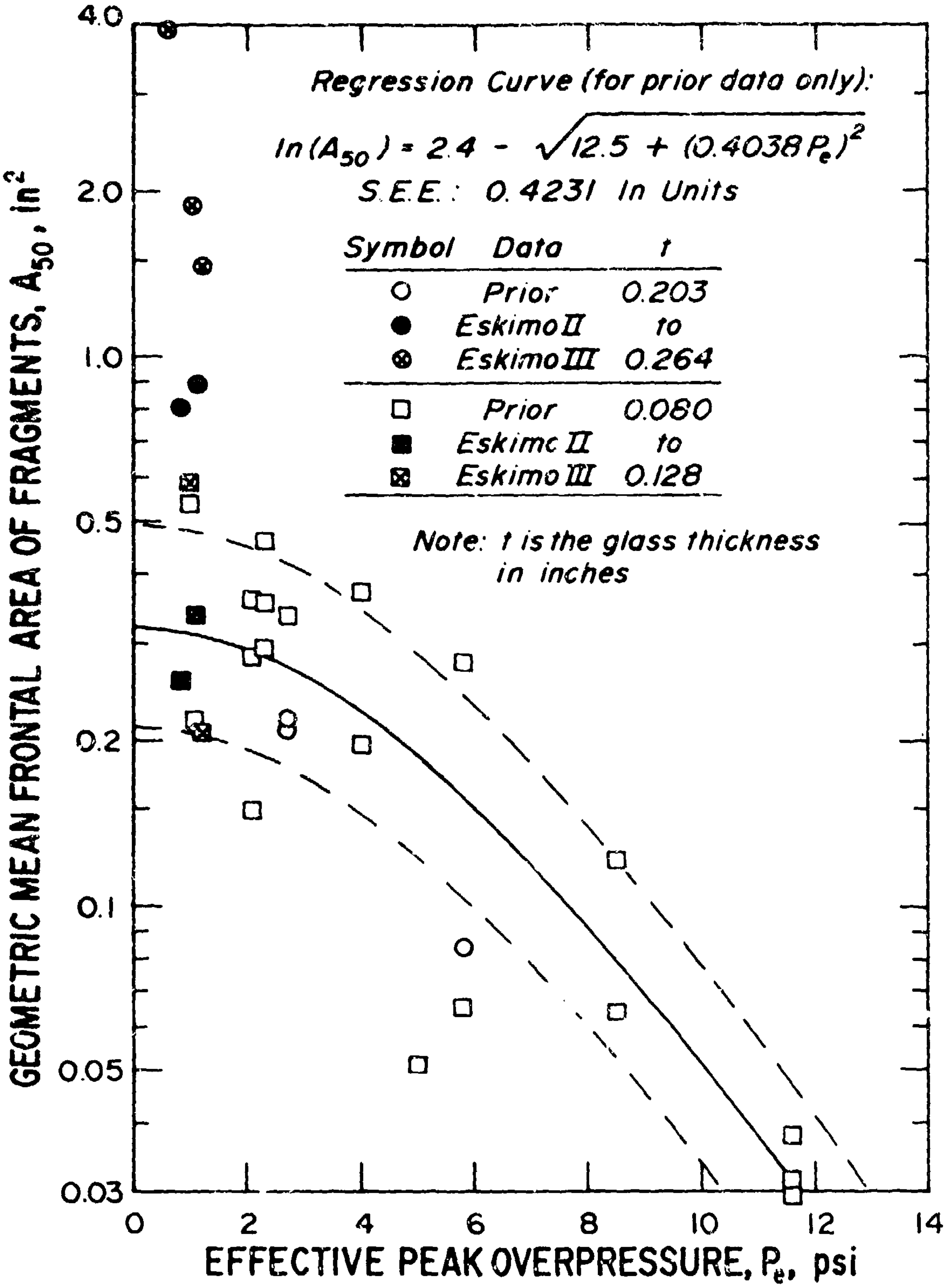


Figure 9. Geometric-Mean Frontal Area of Fragments vs Effective Peak Overpressure.

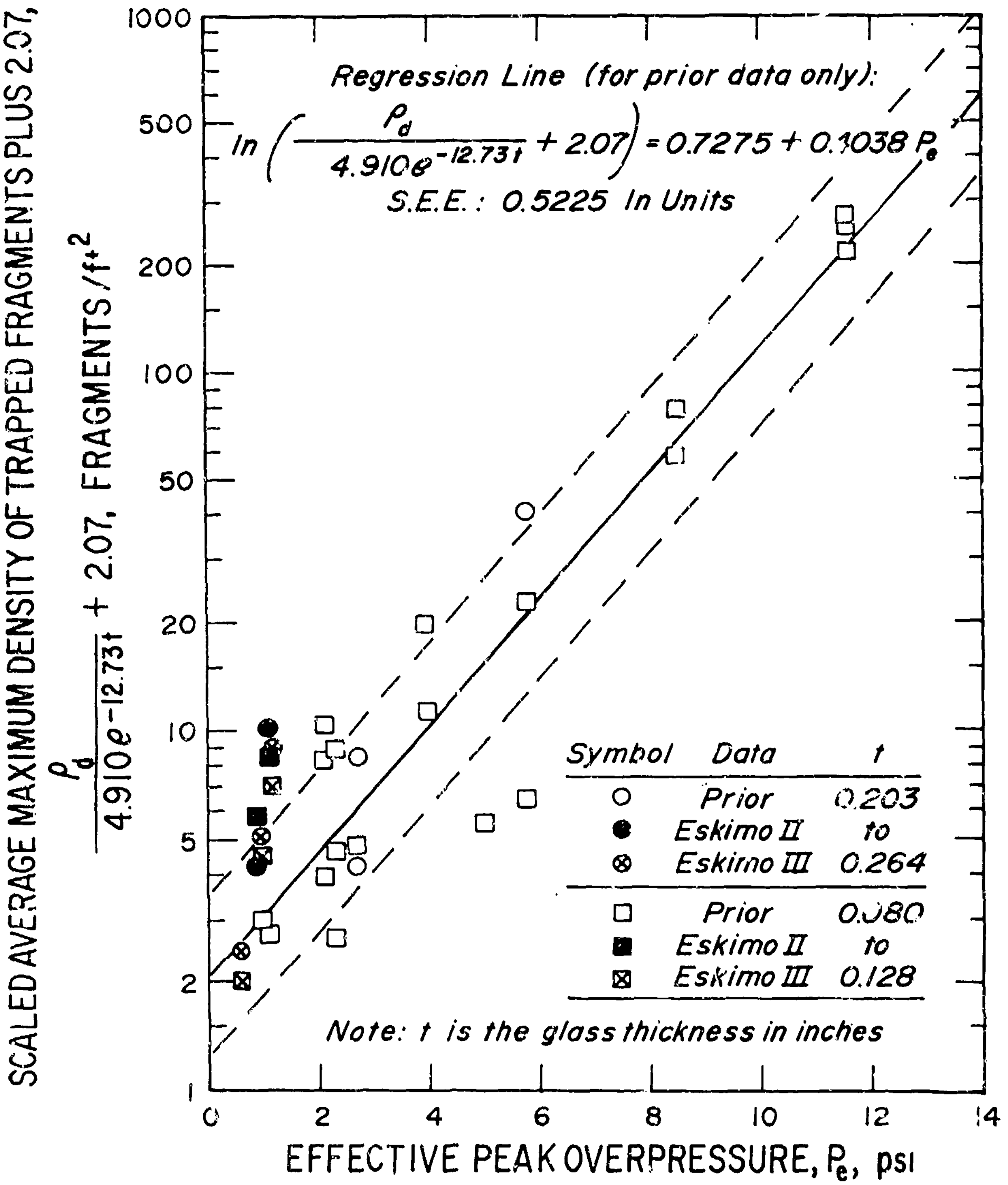


Figure 10. Scaled Average Maximum Density of Trapped Fragments Plus 2.07 vs Effective Peak Overpressure.

the probability of a fragment's penetrating 1 cm of soft tissue as given in Reference 4. It can be seen that, of the 267 trapped fragments for which masses and velocities are available, only three had at least a 1.0-percent probability of penetrating 1 cm of soft tissue. All three occurred at the 3525-foot range where fragments were trapped behind eight panes, giving an average of about one fragment for each two panes with a significant (at least 1.0 percent) probability of penetrating 1 cm of soft tissue. The highest probability computed at this range was 11 percent. No fragments with a significant probability of penetrating 1 cm of soft tissue were caught behind the sixteen panes at the 3950- and 5920-foot ranges.

Data from two biological studies were used to estimate the probability of skin penetrations by fragments trapped from the windows in the modules. In the first study (Reference 5) glass fragments (0.054 to 1.9 gm) were impacted in random orientations, and in the second study (Reference 6) plexiglas fragments (1.0 to 100 gm) were impacted point-on. The velocity for a 50-percent probability of bare-skin penetration varied from 480 ft/sec for a 0.054-gm fragment to 33 ft/sec for a 100-gm fragment. The velocity for a 1.0-percent probability of bare-skin penetration varied from 200 ft/sec for a 0.054-gm fragment to 22 ft/sec for a 100-gm fragment. Limited data from Reference 6 indicated that the above velocities should be increased by 65 ±15 percent for skin covered with two layers of light clothing. Using the above values, the numbers of fragments with greater than a 1.0- and 50-percent probability of penetrating bare skin and skin covered with two layers of light clothing were counted in Figures 3 through 7, and the results appear in Table III. Although some of the assumptions needed to derive Table III might be questioned, the values strongly suggest that a significant number of skin penetrations might have occurred had people been located behind the windows in the modules during the Eskimo III event.

Dummy in Module

The window pane (P2) 35 inches in front of the dummy was not broken by the blast wave. From the motion-picture record it was determined that no fragment from pane P1, which did break, struck the dummy and that the dummy suffered no displacement during the blast experience. At postshot examination, the dummy and clothing were found to be intact.

Windows in Automobiles

The locations of the automobiles on the layout are

TABLE III

PREDICTED SKIN PENETRATIONS BY FRAGMENTS FROM THE WINDOWS IN THE MODULES

Ground Range, ft	Predicted Peak Overpressure, psi		Average Glass Thickness, Inches	Percent of Trapped Fragments With Greater Than A (1%/50%) Probability of Penetrating	
	Incident	Reflected		Bare Skin	Skin and Two Layers of Light Clothing
3525	0.6	1.2	0.125	67/10	7/0
			0.238	71/36	29/6
3950	0.5	1.0	0.122	37/4	4/0
			0.235	54/16	11/0
5920	0.3	0.6	0.208	14/0	0/0

indicated in Figure 1, and the observed window damage is given in Table IV. At 2115 feet (1.2 psi) the most common damage was to the larger windows such as the windshield. On the average, about one window per automobile was damaged, of which approximately one half broke out and one half sustained multiple cracks but remained in place. The only window damage sustained by the two automobiles at 2630 feet (0.9 psi) consisted of multiple fractures of one windshield. None of the windows in the automobile at 3950 feet (0.5 psi) were damaged. There was evidence that four automobile windows were broken by bomb fragments or crater ejecta rather than by the airblast itself. This damage was not included in Table IV.

The window which dislodged from the frame in automobile A3 traveled across the field of view of the motion-picture camera. From analyzing the record, it was determined that the peak velocity of the center of mass of the pane was about 12 ft/sec. Because of the low velocity and the fact that the glass did not break and produce sharp edges, it is estimated that the pane would have a very small probability of penetrating 1 cm of soft tissue. Although the pane was quite massive, it would probably not be very hazardous from the point of view of blunt-body trauma because of the low velocity.

TABLE IV

AUTOMOBILE WINDOW DAMAGE

Ground Range, ft	P_i, psi	Automobile			Windows Damaged	Extent of Window Damage
		Orientation	Number	Description		
2115	1.2	Face-On	A1‡	Peugeot Station Wagon	None	None
			A2‡	Chevrolet Pickup	None	None
		Left Side-On	A3	Buick* Station Wagon	Windshield Left Rearward** Rear	Multiple fractures Intact but dislodged Partly broken out
			A4‡	Dodge Station Wagon	Windshield† Right Rear-Door Rear	Completely broken out Multiple fractures Completely broken out
			A5	Dodge Fuel Truck	Right Door	Multiple fractures
			A6	VW	None	None
			A7	Rambler Station Wagon	None	None
2630	0.9	Left Side-On	A8	VW Square Back	Windshield	Multiple fractures
			A9	Chevrolet Station Wagon	None	None
3950	0.5	Left Side-On	A10	Ford Station Wagon	None	None

* An anthropomorphic dummy was secured in the driver's seat of this station wagon by means of a lap seat belt.

** Analysis of the film record from the camera (392 frames per second) indicated that the window achieved a peak velocity of 12 ft/sec.

† The windshield had multiple fractures prior to the test.

‡ No missile impacts were noted on the Styrofoam witness plate which faced ground zero in this vehicle.

Note:
Window damage due to bomb fragments or crater ejecta has not been included in the table.

Dummy in Automobile

No damage was observed to the dummy secured by means of a lap seat belt in the driver's seat of the left-side-on station wagon (A3) at 2115 feet (1.2 psi). The window behind the left rear door was blown into the vehicle, but it did not strike the dummy. From the motion-picture record it was determined that the dummy suffered no significant displacement during the blast experience.

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THE NATIONAL EXPLOSIVES TAGGING PROGRAM

R. F. Dexter
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Bureau of Alcohol, Tobacco and Firearms
Washington, D. C.

The Bureau of Alcohol, Tobacco and Firearms has a regulatory and criminal enforcement responsibility in the control of explosive materials. Inherent in this control is the responsibility to reduce the hazards to persons and property caused by the criminal use of explosives in bombs and destructive devices.

The Explosives Tagging Program is a means to influence the reduction in the number of domestic bomb incidents. However, the ultimate success of this endeavor hinges on continued multiagency cooperation and support of the committees activities. Without your participation this report would not have been possible. For this I would like to thank all agencies and persons for your interest and invaluable support of the Bureau in this program.

Rex D. Davis

Rex D. Davis
Director

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EXPLOSIVES TAGGING PLAN

SUMMARY

There is a compelling need for a coordinated National Program to control the illegal use of explosives.

Statistics compiled by ATF and FBI covering the period from January through March, 1974, indicates that, in the United States there was one reported bombing every 5-1/2 hours which involved death, serious injury or property damage. Because of the reporting method used, it is believed that bombing incidents are actually more frequent than reflected by these figures.

The unlawful use of explosives in the United States has resulted in very high material cost to the government, industry and the public. In addition to the many deaths, critical injuries, and the crippling and maiming of innocent bystanders resulting from the illegal use of explosives, there is a staggering cost incurred from property damage, lost man-hours and indirect expenses.

Since the end of 1971 to present there have been 146 deaths, 238 injured, over $100 millions of dollars in property damage, and an incalculable cost loss in production time and manpower to government and industry. In the last 18 months there have been 124 evacuations from Federal buildings alone, resulting in an estimated $590,000 cost loss in man-hours.

1,386 bomb threats were received by the civilian airline industry, requiring 109 diversions to alternate airports. Each diversion cost $10,000 - $200,00 per incident.

Initial studies, technological assessment and preliminary investigations have established the current technical feasibility of detecting and identifying the source of most illegally used explosives. This presentation will describe the costs and methods implementing a viable program to detect and identify explosives through tagging. Also, this program includes a companion effort which is necessary to ensure the development of a National capability for detecting untagged explosives.

WHY THE TAGGING PROGRAM

The Explosives Tagging Program was conceived to substantially reduce the bombing threat and to coordinate those feasibility efforts already initiated. Various government agencies had begun unilateral efforts to solve their own particular problems, but no coordinated approach to the overall solution was in existence. As a result, there was much duplication of effort with its attending inefficiency and waste of public funds.

This problem was recognized by some ten Federal agencies and a series of ad hoc meetings were held in late 1972. At the last meeting conducted in early 1973, an agreement was reached that the Bureau of Alcohol, Tobacco and Firearms be given the role of lead agency for the total program. Federal Charters were subsequently issued to evaluate and recommend specific courses of action for the development of a program to control the illegal use of explosives.

PROGRAM MANAGEMENT

The Bureau of Alcohol, Tobacco and Firearms has primary responsibility for the regulatory control over the manufacture, importation, distribution and use of explosives. In addition, ATF is responsible for the investigations of bomb threats to Treasury facilities, bomb incidents affecting interstate commerce, and accidental explosions where explosives are believed to be involved under the provisions of the Organized Crime Control Act of 1970 and the 1968 Gun Control Act. In short, ATF's responsibilities concerning explosives are quite broad and are established by law.

Since ATF has been acting in the role of lead agency, the explosives industry, as represented by the Institute of Makers of Explosives (IME), pledged complete cooperation in this tagging effort. Massachusetts has enacted legislation and several states have legislation pending which would require explosives to be identified through the incorporation of additives. For economic reasons, the explosives industry is justifiable concerned that a single uniform identification system be developed by all states.

Under the provisions of the interagency Committee Charters, the ATF Advisory Committee on Explosives Tagging recommends an overall course of action to the Director of ATF. The Technical Subcommittee of the Advisory Committee evaluates existing and proposed systems for the explosives detection and identification. To date, numerous technical proposals have been reviewed by the Subcommittee and an evaluation of these technical concepts and existing instruments have been prepared as fact sheets and are enclosed in this report.

PROGRAM PARTICIPATION

In addition to the public sector, the Federal agencies represented on the two committees are the Bureau of Alcohol, Tobacco and Firearms; Law Enforcement Assistance Administration; The Federal Bureau of Investigation; Secret Service; Bureau of Mines; Federal Aviation Administration; Department of Defense; Internal Revenue Service; Atomic Energy Commission; Environmental Protection Agency and The Postal Service. Although not formerly represented, some Foreign governments have expressed considerable interest in the program.

PROGRAM THRUST

The thrust of the Explosives Tagging Program is two fold.

Preventive detection and investigative identification, with and without tagging. The short range objective of the program is to tag within an 18 month period, all dynamite produced in this country so that it can be easily detected or identified after use. The long range objective of the program is to develop the capability for detecting or identifying those explosives which cannot be tagged.

MAJOR PROBLEMS

The single major problem encountered by the Explosives Tagging Program is funding. During FY 74, administrative costs were nominally met by ATF, but during FY 75, administrative support will either be extremely marginal or non-existent. The U.S. Treasury Department, as proponent agency for the program, was unable to allocate any funding in FY 74, and the supplemental requests for FY 75 and FY 76 have been disapproved. The only funding specifically obligated thus far for program coordinated effort has been $470,000 from LEAA for technological assessment, feasibility studies and demonstrations. Efforts are now being pursued to obtain funds to continue on-going and new program objectives.

SIGNIFICANT MILESTONES

Eventhough no funding is presently available, a significant effort has been channeled into this project with much of the preliminary work necessary to continue this program being accomplished. The results of the technology assessment, feasibility analyses and laboratory tests support the concept that specialized taggants may safely and reliably be added to dynamite and blasting caps. There is a high confidence that cost effective explosive detectors can be developed and deployed within 18 months. In addition, manufacturing methods, operational procedures and controls must be developed and implemented within this same time period. There is likewise high confidence that these additional functions can also be developed and implemented within the same 18 month period.

To adequately meet the bomb threat problem and because of the anticipated countermeasures that will be taken by some criminals when it becomes known that commercial explosives are tagged, a companion research and development program is required. Results of feasibility studies show promising solutions for the detection of untagged explosives and for the tracing of explosive residues.

KEY OBJECTIVES

The key objectives of the program are summarized.

Add taggants to dynamites produced by all manufacturers. This will permit the detection and tracing of the explosive used in the criminal bombing to the ultimate purchaser. Add taggants to blasting caps. This will permit the detection of explosives which use blasting caps. Approximately 95% of all illegal explosions use blasting caps. Design and test taggant sensors. This will permit the detection of tagged explosives. Finally, develop operational procedures and controls for the short range goals; namely, detection and identification of tagged explosives.

The initial feasibility phase for project requirements and results of the research and development efforts needed for untagged explosive detection and identification is 18 months to completion of the R&D tests and 24 to 36 months for operational deployment. The first project requires the development of detectors for untagged explosives. This permits detection of explosives for which tagging is not feasible. Secondly, develop the methods and procedures for identifying untagged explosive residues and thus linking the explosives to the purchaser. Finally, develop prototype detectors, methods and procedures which would provide assurance that both devices and methods meet the program requirements.

DESCRIPTION OF SUBPROGRAMS AND CANDIDATE SYSTEMS

The two main areas of the Explosives Tagging Program are Detection and Identification. In each case there is the option of achieving these objectives with or without tagging.

In the short term 18 month goal, the fastest and cheapest solution to meet the programs objectives is through the use of taggants. Explosive tagging is the addition of small amounts of an easily detectable or identifiable material to the explosives compounds.

SUBPROGRAMS

The total Explosives Tagging Plan is conveniently divided into four subprograms.

(1) Identification with tagging; (2) detection with tagging; (3) identification without tagging; and (4) detection without tagging.

A brief description and status of each subprogram is as follows:

IDENTIFICATION WITH TAGGING (TABLE 1)

Coded Microspheres. Tiny glass beads manufactured with a chemical code, and coated with a phosphor to permit their location in the bomb debris using a hand held ultraviolet light, are mixed with the explosive during production. After the glass bead is recovered by the investigator, the code is deciphered by the laboratory and the ultimate purchaser is ascertained by record search. Three systems have been proposed for the identification tagging of explosives.

The sensitization study is near completion. Limited testing has been performed by Lawrence Livermore Laboratories to evaluate the three candidate systems and their report is now completed and will be available. This testing will be the basis for the selection of the candidate system.

This is a short range program effort.

DETECTION WITH TAGGING (TABLE 2)

Sulfur hexafluoride as a taggant. A nontoxic, easily detected gas called sulfur hexafluoride is infused into small plastic chips which are then mixed with the explosive during production. As the gas slowly leaks from the explosive into the surrounding air, it is easily detected with low cost portable equipment. Studies of barrier effects, manufacturing compatibility, and investigation of other vapor taggants are on-going at Brookhaven National Laboratory. The final feasibility report is due in February, 1975.

Other studies (Table 3) funded by the Federal Aviation Administration on the detection of detonator caps by the x-ray fluorescence of lead which is used in many blasting caps have shown the feasibility of the heavy metal tag concept.

This is a short range program effort.

IDENTIFICATION WITHOUT TAGGING (TABLE 4)

Only the most limited feasibility work has been performed, most of which involves characterization of the explosive through measurement of its trace impurities. Techniques that have been used in this analysis are gas chromatography and mass spectrometry.

This is a long range program effort.

DETECTION WITHOUT TAGGING (TABLE 5)

Many solutions to this problem have been proposed. Techniques and devices which have been investigated or proposed include bioluminescence, mass spectroscopy, gass chromatography, electron capture detectors, fluorescence, chemiluminescence, x-ray fluorescence, and neutron activation analysis. Basically, all of these systems sensitively detect explosives vapors or some unique property of the bulk explosive in its container.

A feasibility study has been initiated on a laser opto-acoustic method for explosives detection.

Additional studies are underway to characterize vapors emanating from explosives. This is a long range program. About 1 year would be needed for feasibility studies and 16 to 24 months for product development and testing.

USER AGENCIES (TABLE 1)

Every state, county, city agency responsible for investigating criminal bombings or for public protection is a potential user. The Federal agencies who will use these explosive detection and identifications systems are depicted on (Table 1).

NEED FOR A COHERENT PROGRAM

The unlawful use of explosives in the United States has reached a level that has caused public concern and has resulted in a very high cost to the government, state, industry and the public. The statistics have been presented. Loss of human life, property damage, injury and maiming of innocent bystanders. The cost in life cannot be measured. One out of every nine bomb threats involves the Federal, State or local government. Recent bombings include the tragedies at the Pan Am airlines facility, and attempted bombings at the French, Iranian and English Embassies, and the United Nations.

A direct result of this program will be the reduction of incidents involving the criminal and terrorists use of explosives with the saving of lives and property and the prevention of injury. It is difficult to estimate the cost versus benefit of this program. However, the program can effectively reduce the percent of bomb incidents, to property, loss due to injury and maiming, and the cost of lost man-hours. It must be recognized that this program will not stop all bomb incidents. The bomber is categorized into three types: (1) the professional;(2) the subprofessional; and (3) the amatuer. This program may or may not effect the professional bomber activities. However, the subprofessional and certainly the amatuer bomber incidents will be reduced. Even if it is a 10% incident reduction the program will have earned its way.

In the past ten years, Federal agencies have spent over $15,000,000 dollars on explosive detection and identification projects with much duplication of effort and tax dollar loss. The Explosives Tagging program provides the effort and orderly development needed to produce a system that will detect and identify select explosives within 18 months through tagging. The same program encompasses the long term effort needed to detect and identify those explosives that cannot be tagged.

SYSTEMS APPLICATION

The main FAA requirement is the interrogation of luggage and freight. The prime Post Office and Internal Revenue Service requirement is to address the letter bomb threat. The major requirement of the law enforcement community is investigative information. This program meets all of these requirements.

There is no single solution to the total problem of explosives detection and identification. The most effective and cost efficient means of accomplishing the necessary development efforts is to have a single agency coordinate them, a fact that was recognized when ATF was selected and approved by Treasury as proponent agency for this purpose.

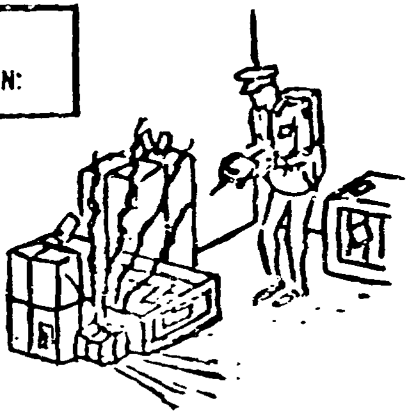
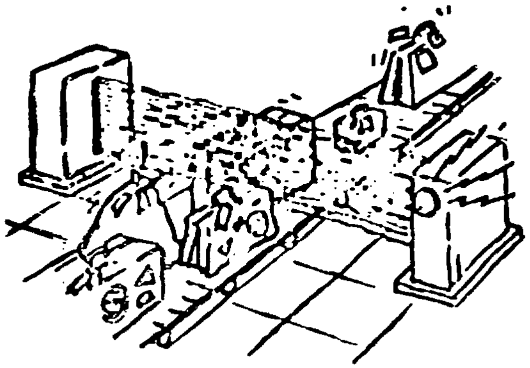
	VOLUMETRIC DETECTION	COOPERATIVE SEARCH	POST-DETONATION IDENTIFICATION
SYSTEM APPLICATION:			
PROBLEM EXAMPLE:	• AIRLINES RECEIVE 2000 TELEPHONE THREATS/yr • LOS ANGELES POLICE DEPARTMENT HAD 740 BOMB THREAT CALLOUTS IN 1972	• AIRLINES SEARCH 170 MILLION PIECES OF LUGGAGE PER YEAR • 87 BILLION LETTERS AND PARCELS (50:1) THROUGH POST OFFICE IN 1972	• BOMBING INCIDENTS IN FY 71 897 EXPLOSIVE (non-military) 56 MILITARY ORDNANCE 59 OTHER
PRIORITY SOLUTIONS: (interagency defined)	• LASER OPTOACOUSTIC VAPOR DETECTION • SF_6 TAGGANT	• X-RAY FLUORESCENCE TAGS	• CODED TAGGANTS MICROSPHERES PHOSPHOR GRAINS RARE EARTHS

Figure 1. Explosives Detection and Identification

CONCLUSIONS

The conclusions drawn are:

- There is an urgent need for the development of procedures for preventing explosions and for identifying the bomber in those situations where the explosion cannot be prevented.
- The tagging for identification subprogram meets the explosives industries' needs for a coding method upon which uniform State legislation can be based.
- Tighter user controls will be established if explosives can be traced. This will reduce the presently high theft rate.
- A unified approach to the overall explosives problem prevents duplication of effort and reduces expenses to the Federal government.
- The Explosives Tagging Program provides a much needed tool for investigative and public safety officers.
- A first step will be made toward the international control of explosives.

RECOMMENDATIONS

Members of the Advisory Committee, the full Technical Subcommittee, and invited representatives from the explosives industries have met on three occasions during the past year to review existing technology as it applies to the Explosives Tagging Program. From these meetings, the following recommendations have emerged.

o Because of its broad involvement with the regulatory and criminal investigation aspects of the explosives problem, ATF should continue its leadership in the Explosives Tagging Program.

o The short range objectives of the tagging program should be implemented since these objectives can be quickly accomplished.

o A level of effort on all fronts is necessary.

(TABLE 1)

EXPLOSIVES TAGGING PLAN

USER AGENCIES

AGENCY	DETECTION	IDENTIFICATION	USEAGE
ATF	X	X	BOMB INVESTIGATION, VIP PROTECTION, ACCIDENTAL EXPLOSIONS
FBI	X	X	BOMB INVESTIGATION, INTERNAL SECURITY
SS	X		VIP PROTECTION, SECURITY
FAA	X		SECURITY, PUBLIC SAFETY
BOM		X	REGULATORY INVESTIGATION
DOD (MILITARY SERVICES)	X	X	MILITARY APPLICATIONS, DEMILITARIZED EXPLOSIVES, SECURITY
IRS	X		MAIL INTERROGATION
PO	X		MAIL INTERROGATION
LAW ENFORCEMENT (STATE & LOCAL)	X	X	INVESTIGATION, PUBLIC SAFETY

Identification with Tagging

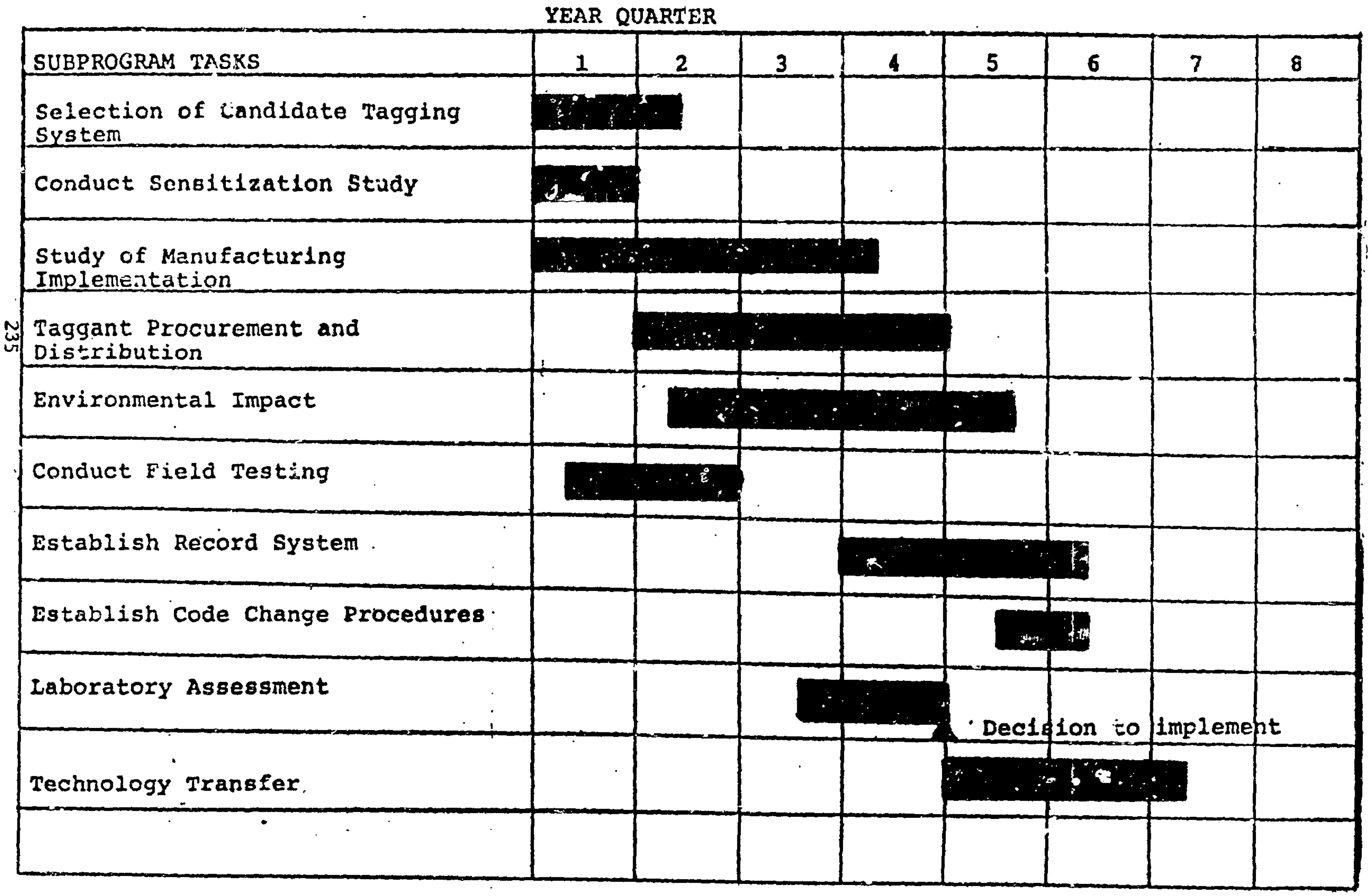


TABLE 3

Detection with Tagging - Vapor Tag

SUBPROGRAM TASK	YEAR QUARTER	1	2	3	4	5	6	7	8
Environmental Impact		■	■	■	■				
Development of SF$_6$ Loading Technique				■	■	■			
SF$_6$ Background and Barrier Effect Study		■	■	■					
Investigation of Other Gaseous Taggants			■	■					
Optimization of SF$_6$ Detector						■	■		
Field Testing System				■	■	■			
Technology Transfer						■	■	■	
Study of Alternate Detection Systems		■	■	■	■	■	■	■	■

TABLE 4

Detection with Tagging - Heavy Metal Tag

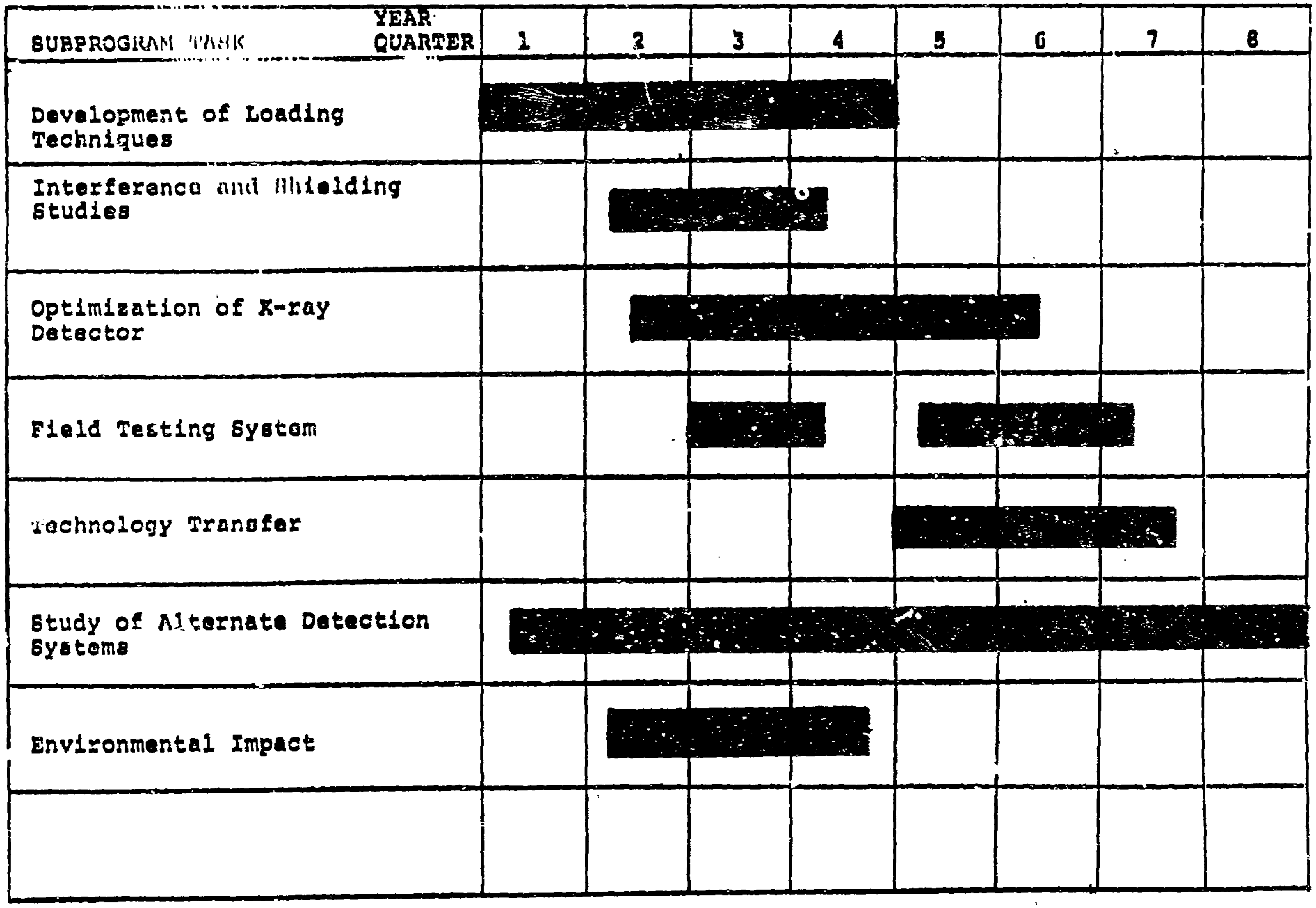


TABLE 5

Identification without Tagging

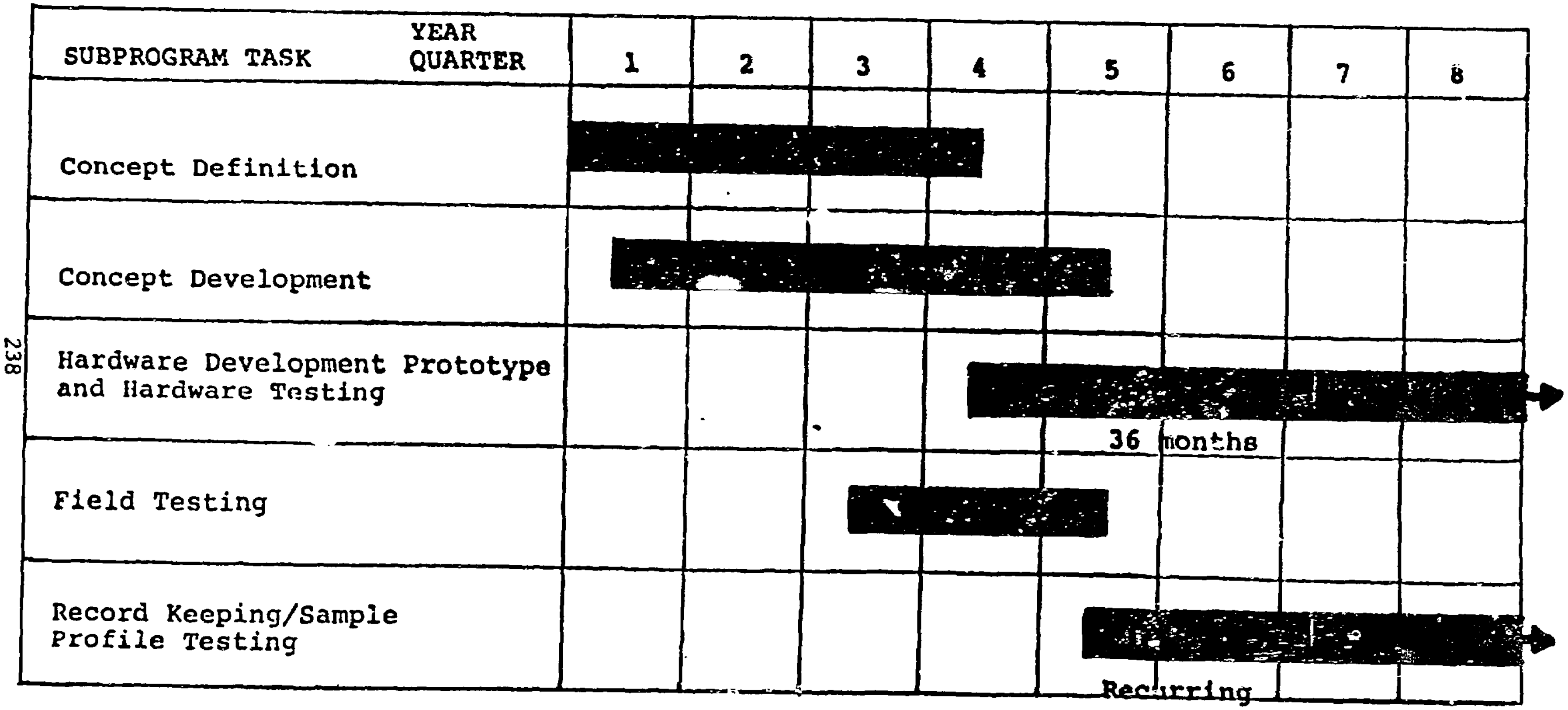
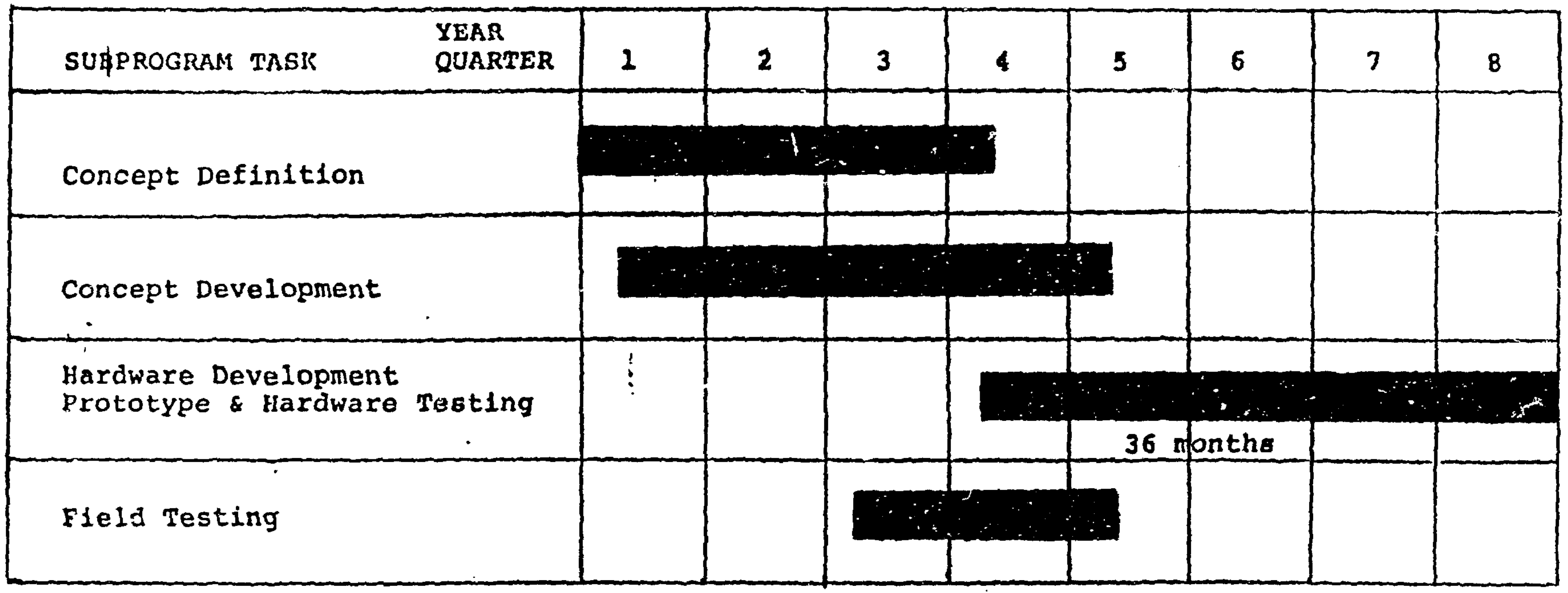


TABLE 6

Detection without Tagging



SUBPROGRAM TASK / YEAR QUARTER	1	2	3	4	5	6	7	8
Concept Definition	■	■	■	■				
Concept Development	■	■	■	■	■			
Hardware Development Prototype & Hardware Testing				■	■	■ 36 months	■	■
Field Testing			■	■	■			

HAZARD CLASSIFICATION TESTS (TB-700-2)
OF XM188E1 PROPELLING CHARGE

EDMUND DEMBERG

PICATINNY ARSENAL, DOVER, NJ

Last year at the 15th Annual DoD Explosives Safety Seminar, I was in attendance when one of the eminent speakers gave a presentation on the shortcomings of the Explosive Hazard Classification Procedures of TB 700-2. He appealed, not for just a paste and patch job but, for the complete transformation of TB 700-2. His speech was met with overwhelming approval. In concluding, he asked if any member of the audience wished to defend TB 700-2. He found no such champion. Well, it took me a year to gain the courage to speak on behalf of TB 700-2.

Army Technical Bulletin TB 700-2 has served us well and deserves a better fate than we plan for it. Modification, emendation, revision, updating -- YES! Extirpation -- NO! TB 700-2 is a valuable safety tool. It provides a means of obtaining data on a developed item to enable the assigning of the appropriate Quantity-Distance Class, Storage Compatibility Group, DOT Bill of Lading Class and DOT Container Marking. The data obtained and the resulting hazard classification are for the packaged item; the configuration of the item in storage and shipping.

Every researcher seems to have a procedure he would like to nominate for inclusion in TB 700-2. Drop, Bullet Impact, SUSAN Sensitivity, Set Back, Vibration, Temperature Cycling, Gun Firing, Closed Pipe, Flying Plate, etc. are all touted as necessary for hazard classification. Well, they are not! Don't be stampeded by the quest for more and more data.

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Only data pertinent to hazard classification of the packaged item in storage and shipping belongs in TB 700-2.

TB 700-2 is not designed to replace the safety and performance tests conducted during the development stage to qualify an item for military use. Nor is it used to qualify an explosive, propellant, or pyrotechnic for use in an end item. TB 700-2 is also not designed to determine the in-process hazards involved in the assembly or manufacture of an item or material. These are all dynamic situations where the item may be exposed to a variety of stimuli and energy levels. They are primarily concerned with finding if the item is safe to handle, transport, arm disarm, or function and the potential causes of accidental initiation. The situation in shipping and storage is more static. We are trying to determine the effects of an accidental initiation and set parameters to protect personnel and property against them. We want to know if the item will detonate or burn and if propagation can be obtained between adjacent items or packages. We are interested in overpressure and fragments.

Is it necessary to subject items to all sorts of stimuli to determine their hazard classification? Each test expends funds and manpower. If the packaged item is a static situation, where there is no change in configuration, contents, distances between items, etc., why not take a worst case situation and observe the results? An overtest perhaps, but one that would provide the margin of safety we can live with. From the results of this accidental initiation couldn't we determine the safety requirements to protect personnel and property? Well that is exactly what is done in TB 700-2?

In performing TB 700-2 tests, items are subjected to accidental initiation, explosive shock, and high heat of fire. The centrally located item of a package is primed and initiated. In some cases, normal initiation is used while in others an explosive cap and booster are employed. The packaged items are also burned in a fire. Visual observations and auditory responses are made of the resulting reaction. Gauges measure over pressures. Any fragments produced are measured for size, configuration and distribution. We determine if the items detonate or burn and if there is propagation to adjacent items and from package to package. The data is utilized to ascertain the hazard classification and provide the required measure of protection for personnel and property.

There are areas of TB 700-2 that require modification. The priming of the central test item requires exacting definition to insure methods are standardized and results meaningful. It is of the utmost importance to prime an item so the main charge is subjected to the initiating stimuli and/or explosive shock. Priming that foils this could result in an underclassification that does not indicate the hazards in shipping or storage of the test items. Oneexample to illustrate the point is the TB 700-2 tests of a round containing explosive sub-missile. Priming of the round results in the almost harmless discharge of the contents. However, priming of one sub-missile results in most cases in a high order detonation of the main charge; the complete cargo of sub-missiles.

A second area requiring revision or rather addition is interpretation of results. There is no criteria for establishing hazard classification based on test results obtained on end items of ammunition and explosive, rocket motors or devices containing solid propellants. It is in this area that measurements of overpressures, fragmentation and TNT equivalency are essential for hazard classification. These measurements would enable quantitative values to be established for quantity - distances and compatibility grouping. To accomplish their measurements, instrumentation is needed. Relying on human sensors proves to varied and uncertain to establish accurate values. The instrumentation and procedures deemed necessary must be fully described in TB 700-2 to make sure sufficient data is obtained.

The minimum test criteria for bulk compositions in chapter 3 requires reevaluation and revision. For one thing, it does not include pyrotechnics. Nor are tests applicable to gels or slurrys. And most important, the tests are conducted on small samples of material and not on the size or configuration of the material in shipping or storage.

But rather than delve on the shortcomings of TB 700-2, let us again reiterate that there is a need for revision. This does not, however, preclude the use of the procedures in TB 700-2 to obtain data to enable the hazard classification of Ordnance items and related materials in shipping and storage. With this objective in mind, I would like to relate our most recent hazard classification tests to illustrate how TB 700-2 works.

A series of tests were conducted with 8" XM188E1 Propelling Charges in M460 Containers at Yuma Proving Ground under the technical supervision of Picatinny Arsenal. The tests conducted were those prescribed in Army Technical Bulletin TB 700-2 and TNT equivalency tests. Tests were conducted as described in Table 4 of TB 700-2, "Minimum Test Criteria for Determining Hazard Classification of Gun Type Propellants for Cannon, Gun Tube, Mortar and Rocket Motors Up to 8 Inch Diameter"; Minimum Test Criteria - Finished Items. These consisted of single charge detonation (Test A), sympathetic detonation (Test B), and external heat test (Test C).

The 8-inch propelling charge, XM188E1 is of the separate-loading type. It is a two-increment "white bag" charge, 31 inches long by 8 inches in diameter. The charge consists of high-energy propellant, M30E1. The XM188E1 propelling charge is packed provisionally in metal container, M460. The final pack will be in metal container, PA 66. The containers differ only in size and did not influence tests results.

A total of five detonation tests (Test A) were conducted. Each XM188E1 Propelling Charge was primed with a 30 gram explosive booster (Composition C-4) and an engineering special blasting cap. The primed item was placed upright in the center of the test area. No explosions occurred in the five tests conducted when the primed items were fired. In each instance, the container ruptured and strew approximately a 120-foot diameter area with burning and unburned propellant. TNT equivalency was 0 to 1.5%. The container broke into mainly three fragments; the top, bottom and container tube. The bottom remained in the crater. The container tubes were ruptured in various jagged shapes and thrown from 6 to 54 feet. The tops were thrown up to 240 feet. A few large fragments were found thrown up to 100 feet. The craters produced were small and circular, approximately 4 inches in depth and 24 inches in diameter.

Although not required, based on results of Test A, two sympathetic detonation tests were conducted. In the initial test, the primed donor container was ruptured at the bottom. A large amount of propellant burned near the rupture - in excess of 10 minutes. The stack, including a top container was still intacted and held by the steel strapping. The acceptor was scorched and had slight dent. There was unburned propellant strewn out from the rupture up to 35 feet in one direction. There was 0% TNT equivalency. The second test the donor ruptured and dispersed the stack. There was a small fire near the stack and a lot of unburned propellant strewn around. The top of the donor was blown 18 feet away and the bottom remained in the crater produced. The container tube was ruptured in a jagged form and thrown 15 feet. The acceptor was intact except for a dented-in side and thrown 45 feet. The heavier sand filled containers were thrown from 2 to 21 feet in a circular pattern from the center of the target area. The TNT equivalency was 1.4%. Crater was 4-inches deep by 10 inches in diameter. No detonations of the donor or acceptor were obtained.

One external heat test was conducted. Seven M460 containers containing XM188E1 Propelling Charges were arranged on a wooden crib and bonded together with steel bonds. The containers and combustible materials were saturated with 107 gallons of diesel fuel. The assembly was initiated at two places with electric squibs and smokeless powder. An intense fire resulted rather quickly. First report was heard after one minute. Seven distinct reports were heard within a space of three minutes. Balls of fire and smoke followed each report as propellant was released into the fire from the ruptured containers. TNT equivalency was 0. All the cans ruptured and burned. Large fragments of the cans were thrown up to 270 feet. Top lids traveled up to 500 feet from the fire. No detonations were obtained during the external heat test.

TNT equivalencies were obtained with paper blastmeters. Calibration was conducted with 1/2, 1, and 5 pound TNT blocks at 15 and 30 feet from center of target.

Based on the results obtained, a recommendation was made for AMC and DOT hazard classification on the XM188E1; and by analogy, the XM123E2 and XM201 Propelling Charges in metal containers as follows:

AMC Hazard Class - 2

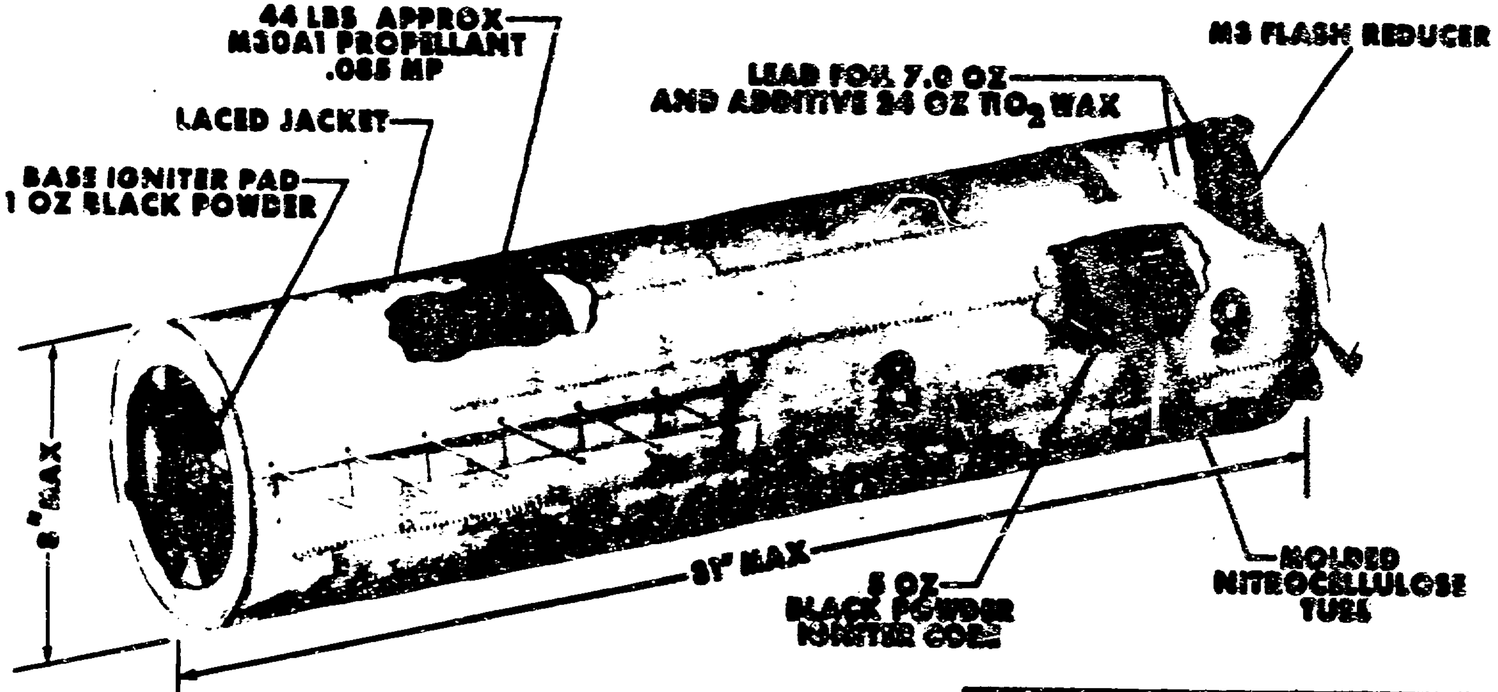
AMC Compatibility Group - J

DOT Bill of Lading Class - Explosives B

DOT Container Marking - Propellant, Explosive (Solid) Class B

In conclusion, tests run in accordance with procedures in TB 700-2 provide sufficient data for AMC and DOT hazard classification. That is what the Safety Engineer needs to insure protection of personnel and property. Indiscriminate selection of additional tests can only result in unnecessary expenditure of funds and manpower. Revision to TB 700-2 should be geared to provide procedures for every material/assembly/component and to yield more quantitative measurements to insure proper classification.

CHARGE, PROPELLING, 8 INCH, XM188E2
FINAL DESIGN

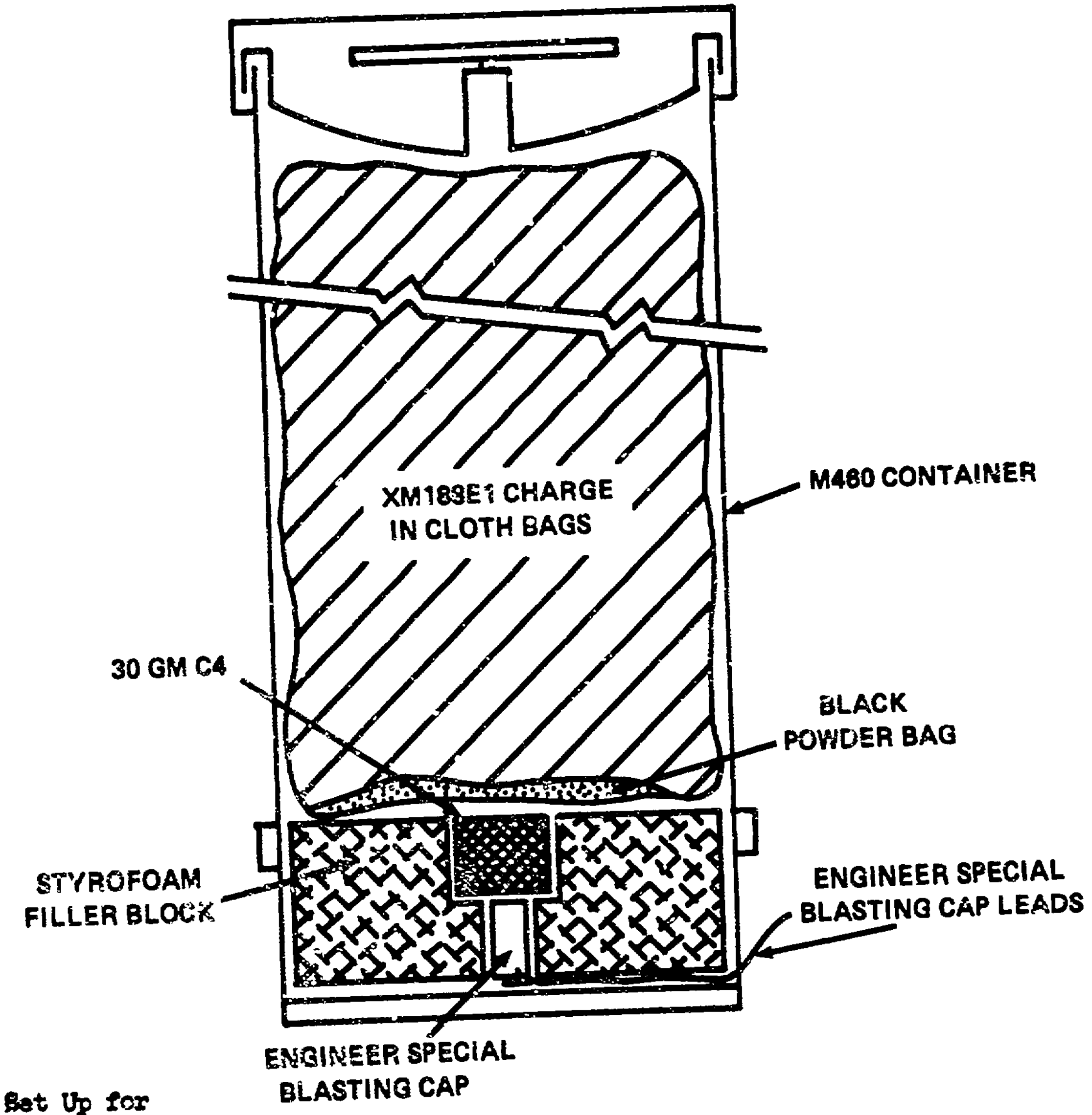


CHARGE:	XM188E2
TYPE:	SEPARATE LOADING
PROJECTILE:	M106, HE
CANNON:	XM201
WEAPONS:	M110E2, MSP

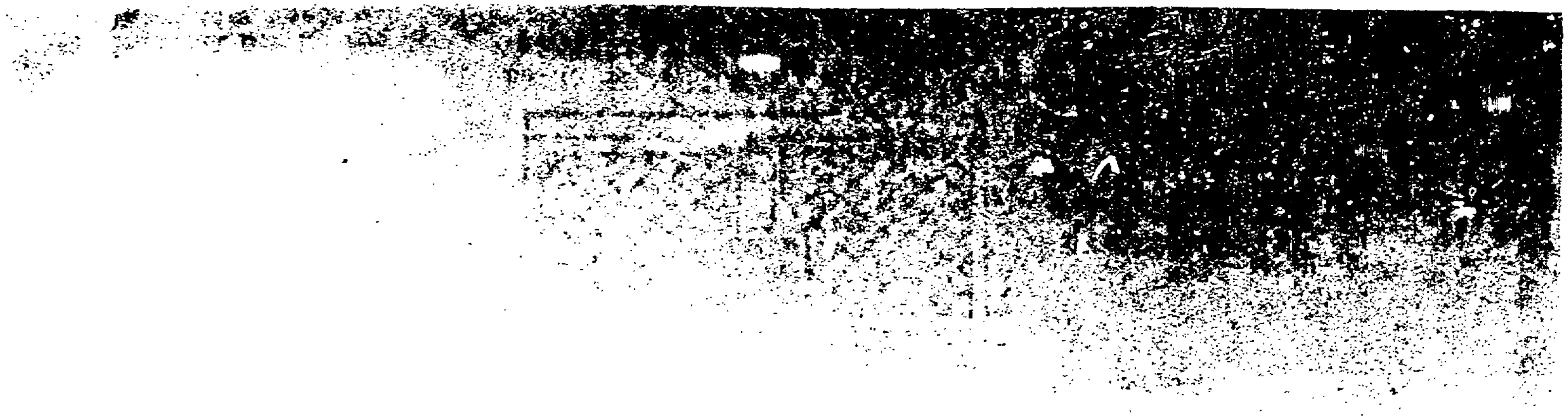
PICATINNY ARSENAL
DECEMBER 1972

#1 XM188E2 Propelling Charge

CONTAINER ASSEMBLY

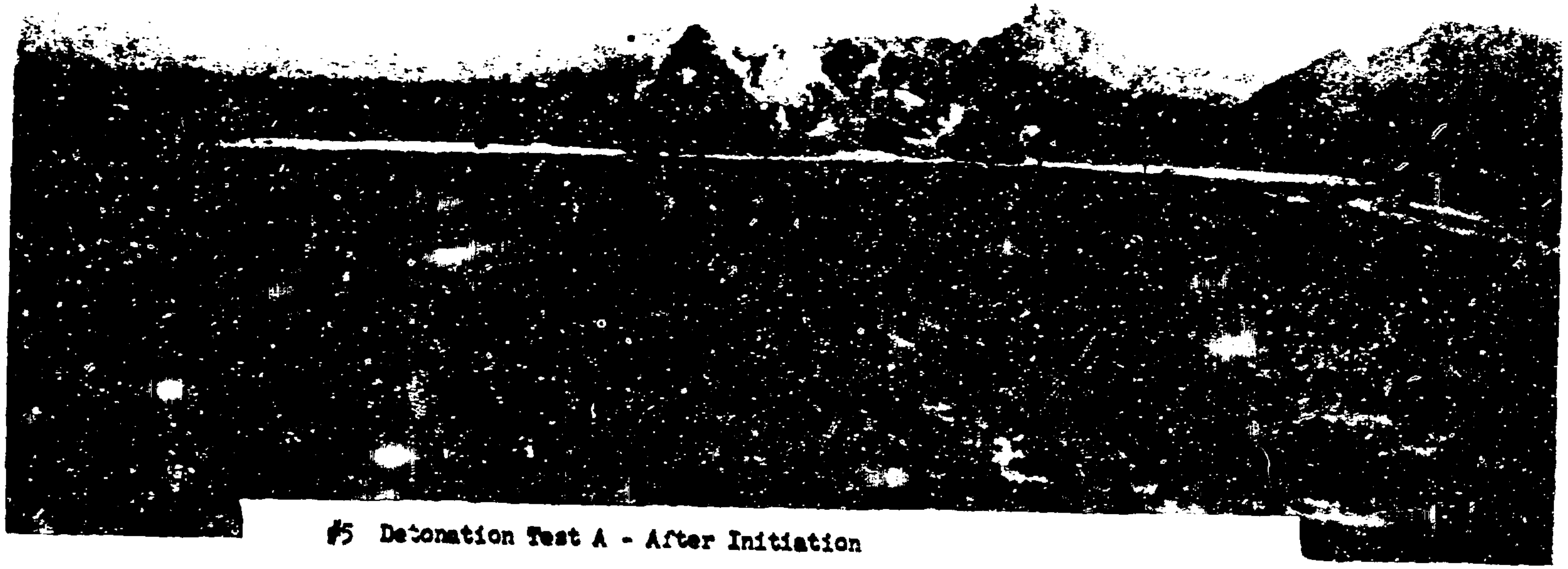


#2 Internal Set Up for
Detonation Tests



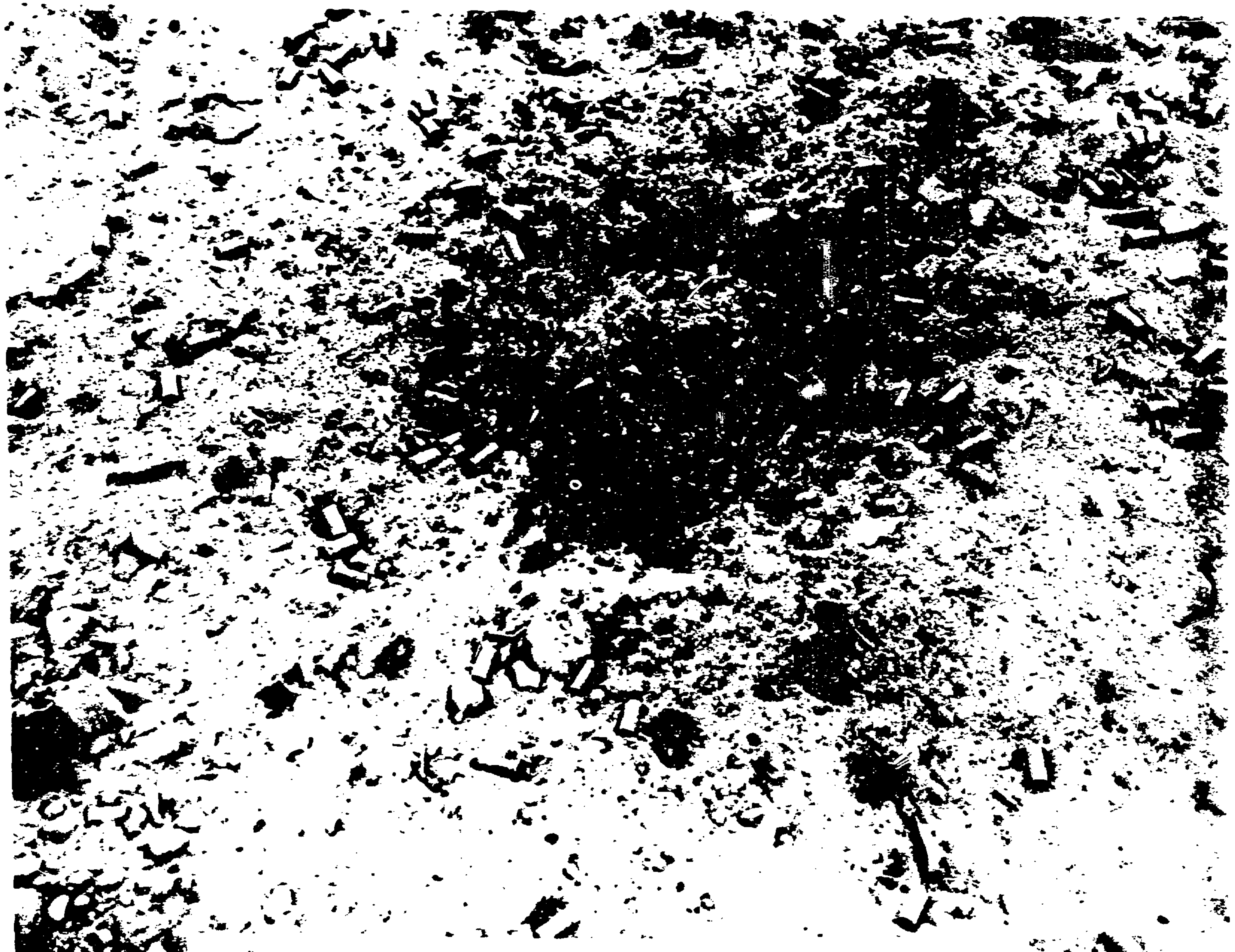
#3 Detonation Test A - Set Up

#4 Detonation Test A - Initiation

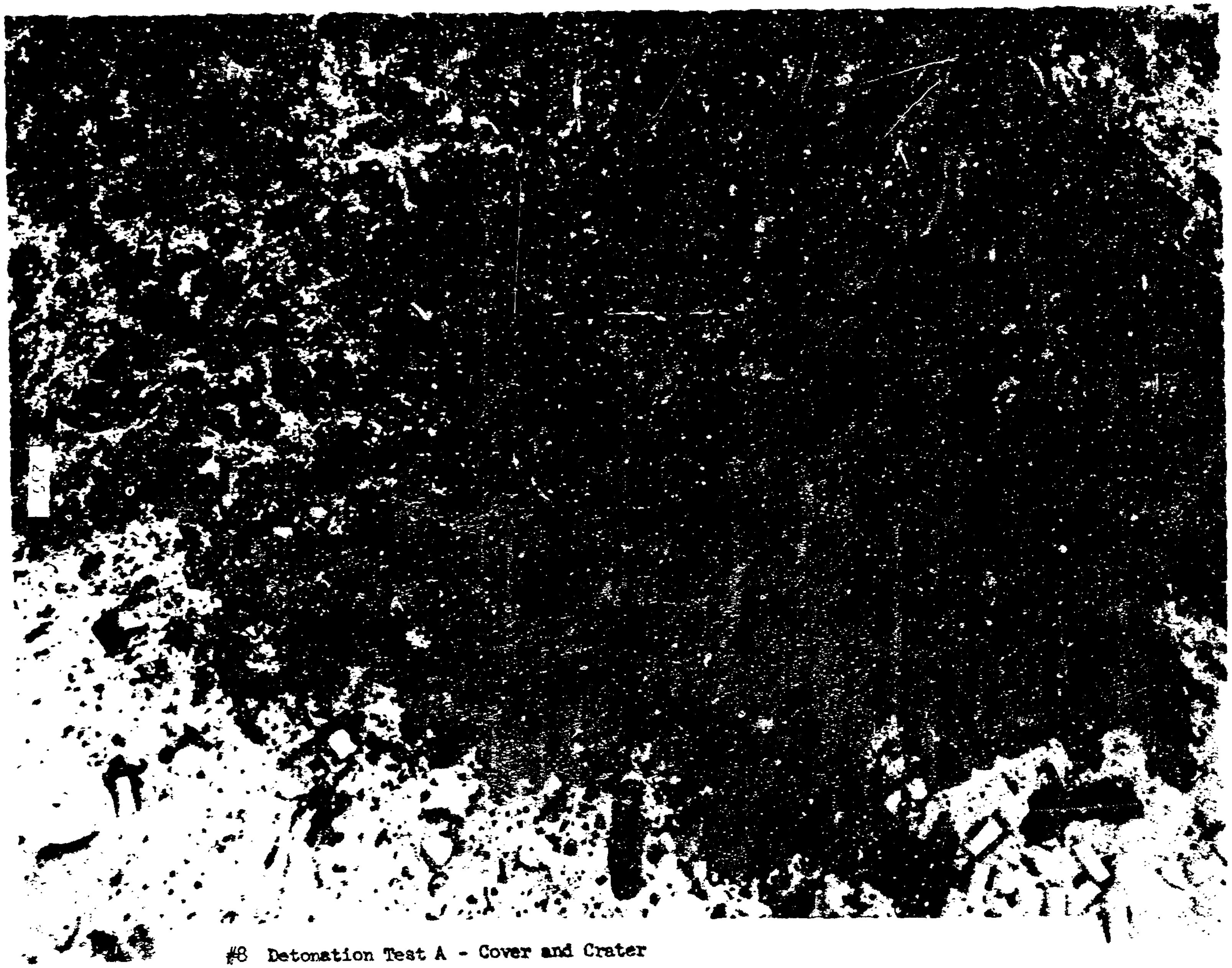


#5 Detonation Test A - After Initiation

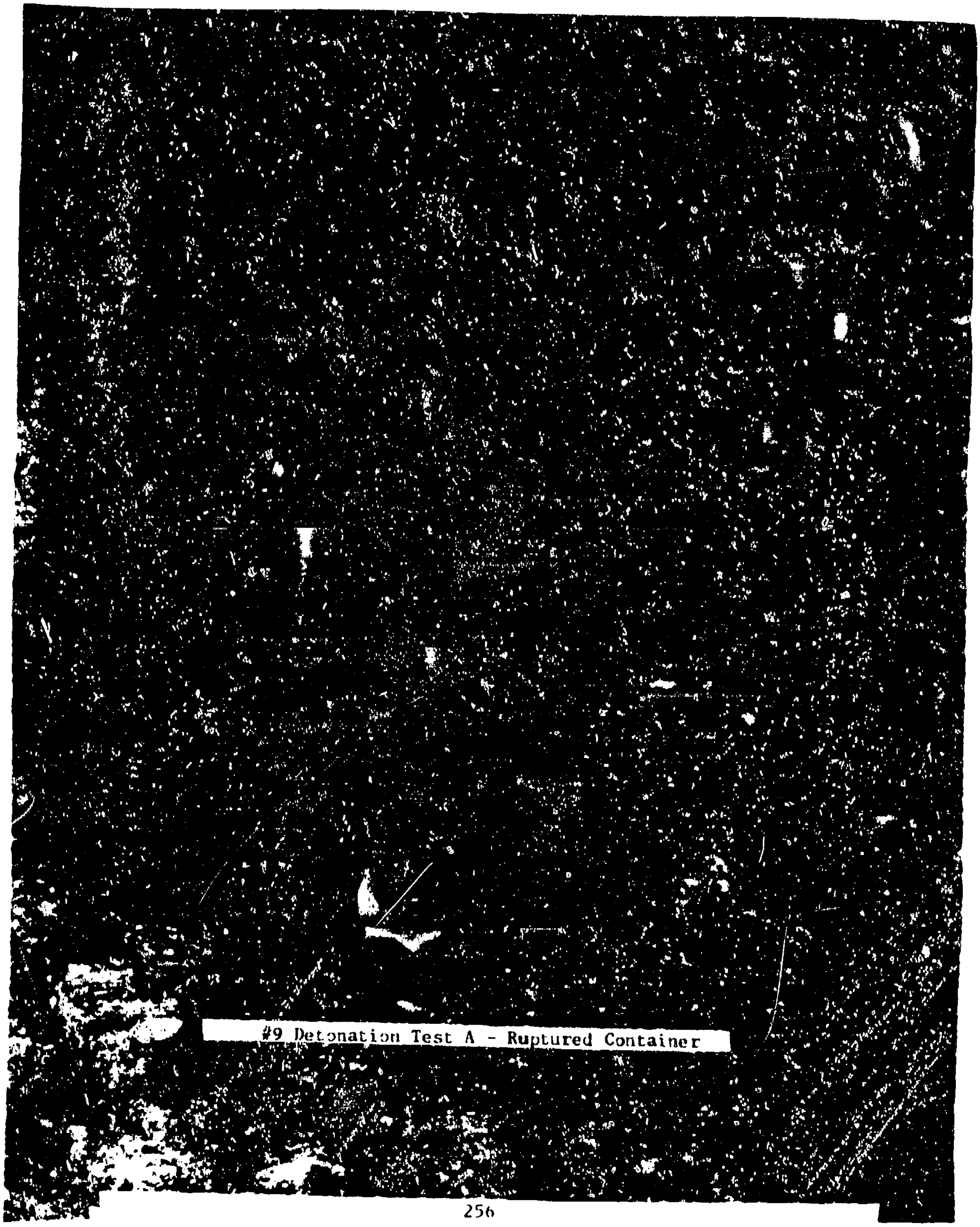
#6 Detonation Test A - Crater and Burned Out Container



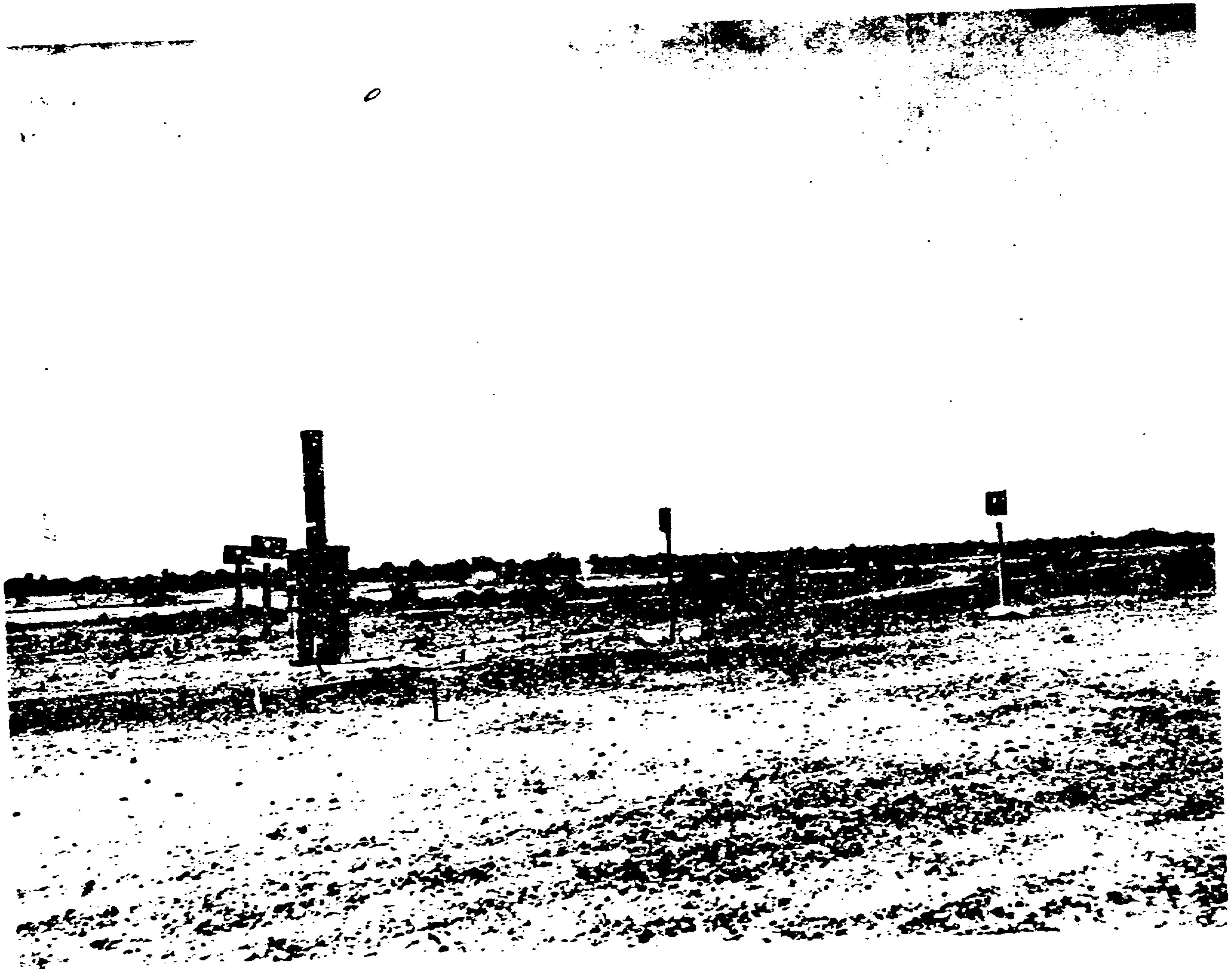
#7 Detonation Test A - Unburned Propellant



#8 Detonation Test A - Cover and Crater

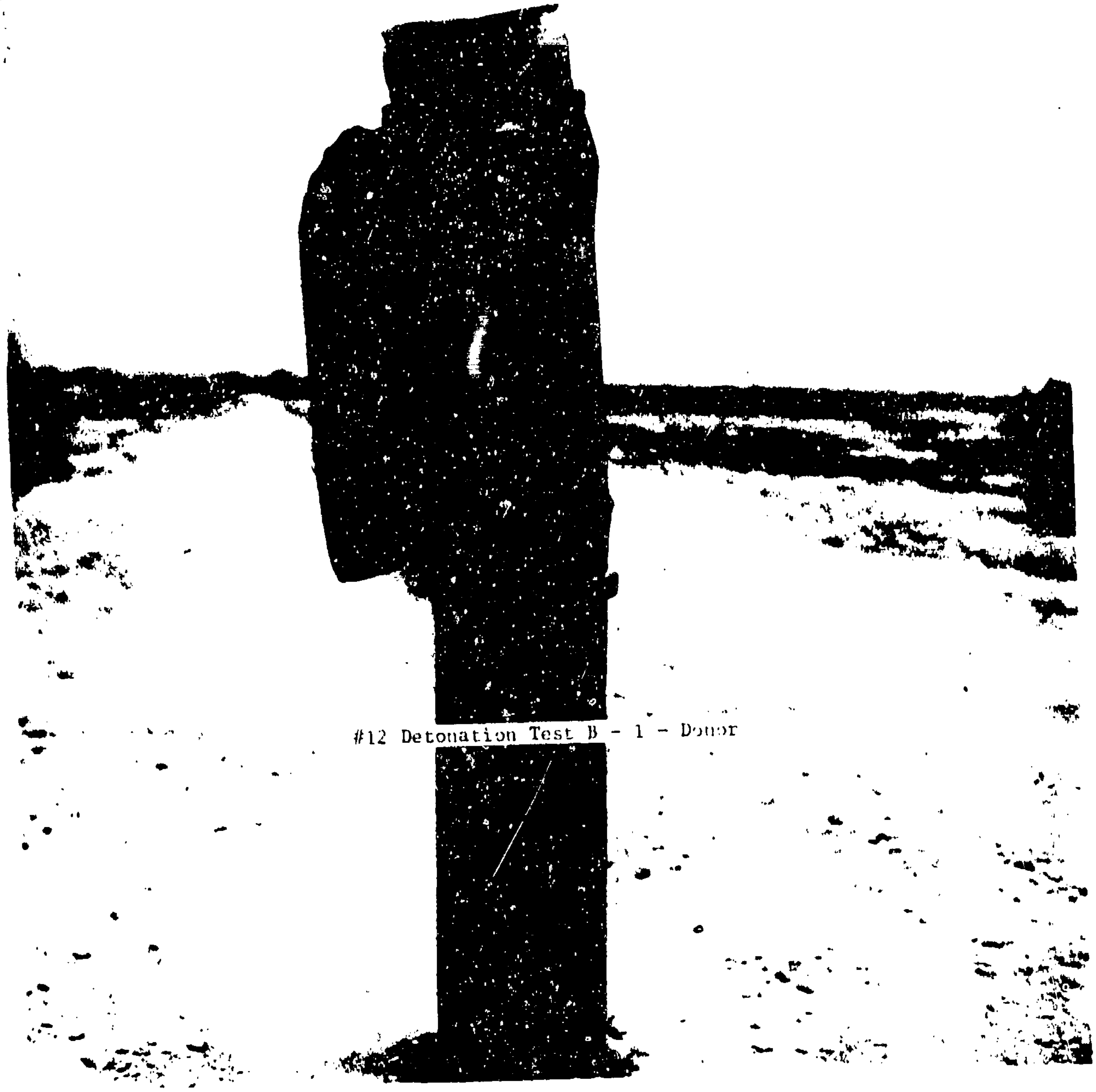


#9 Detonation Test A - Ruptured Container



#10 Detonation Test B - Set Up

#11 Detonation Test F - 1 - Initiation

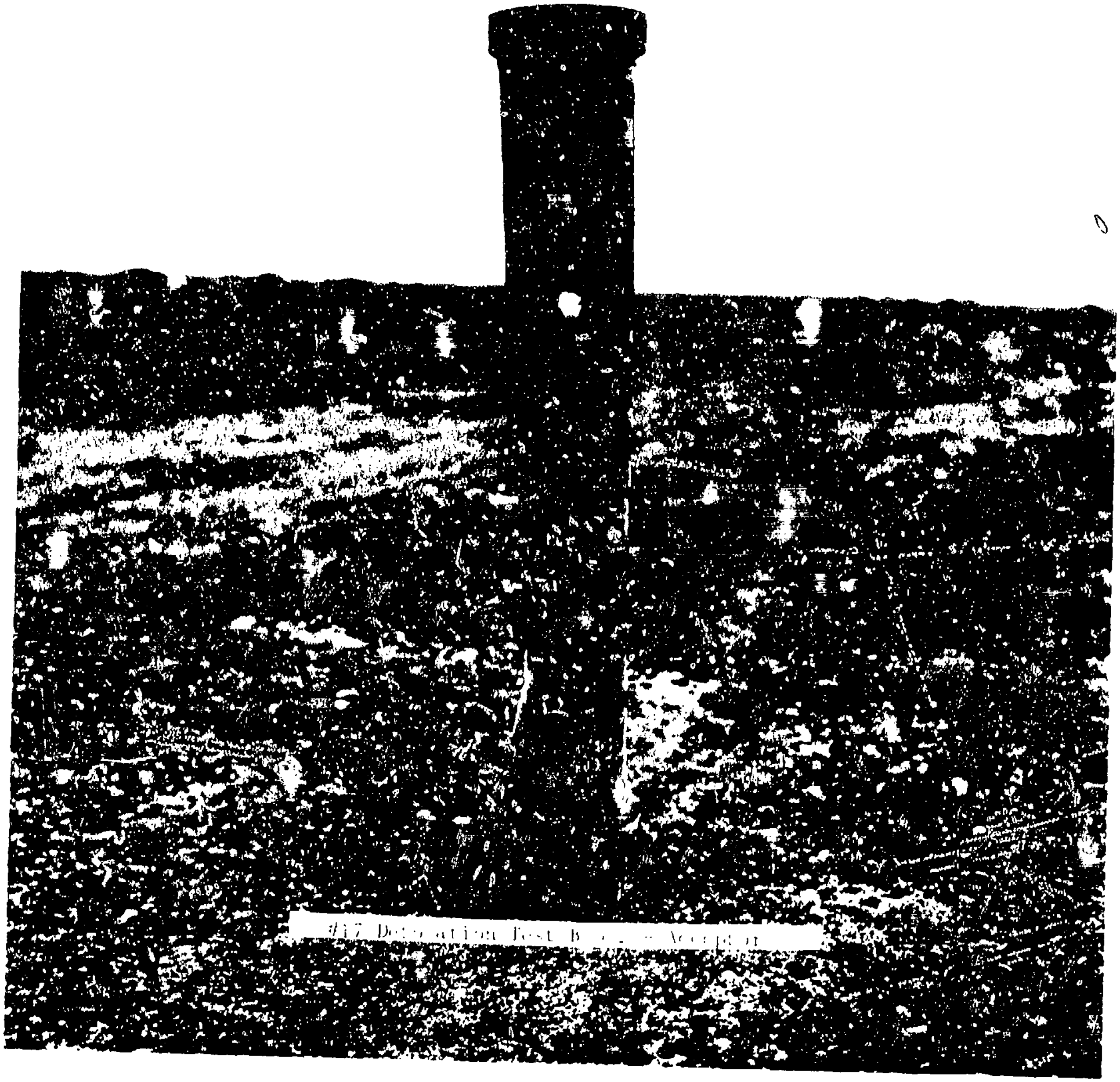


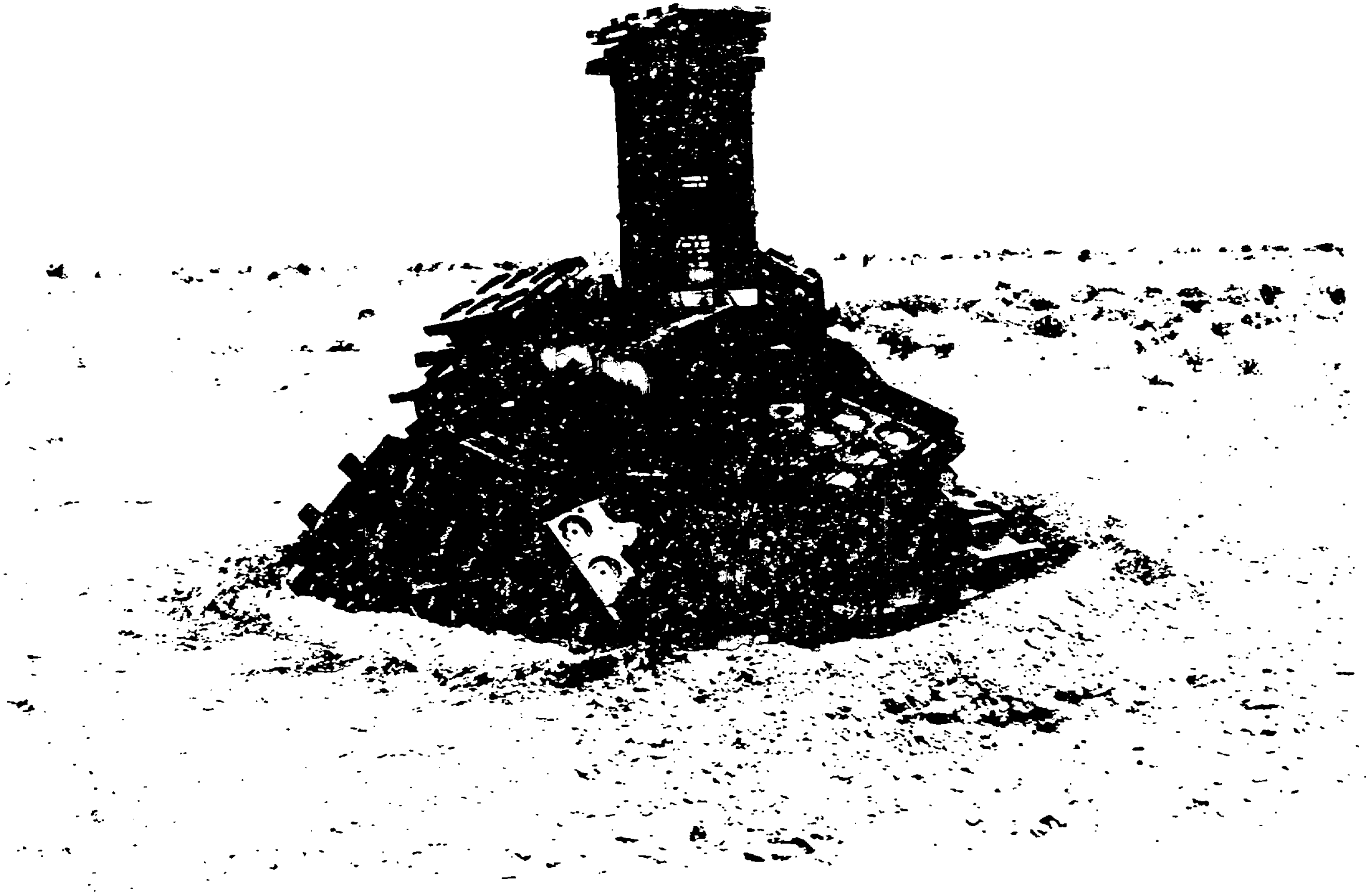
#12 Detonation Test B - 1 - Donor

#13 Detonation Test B - 1 - Stack after Initiation

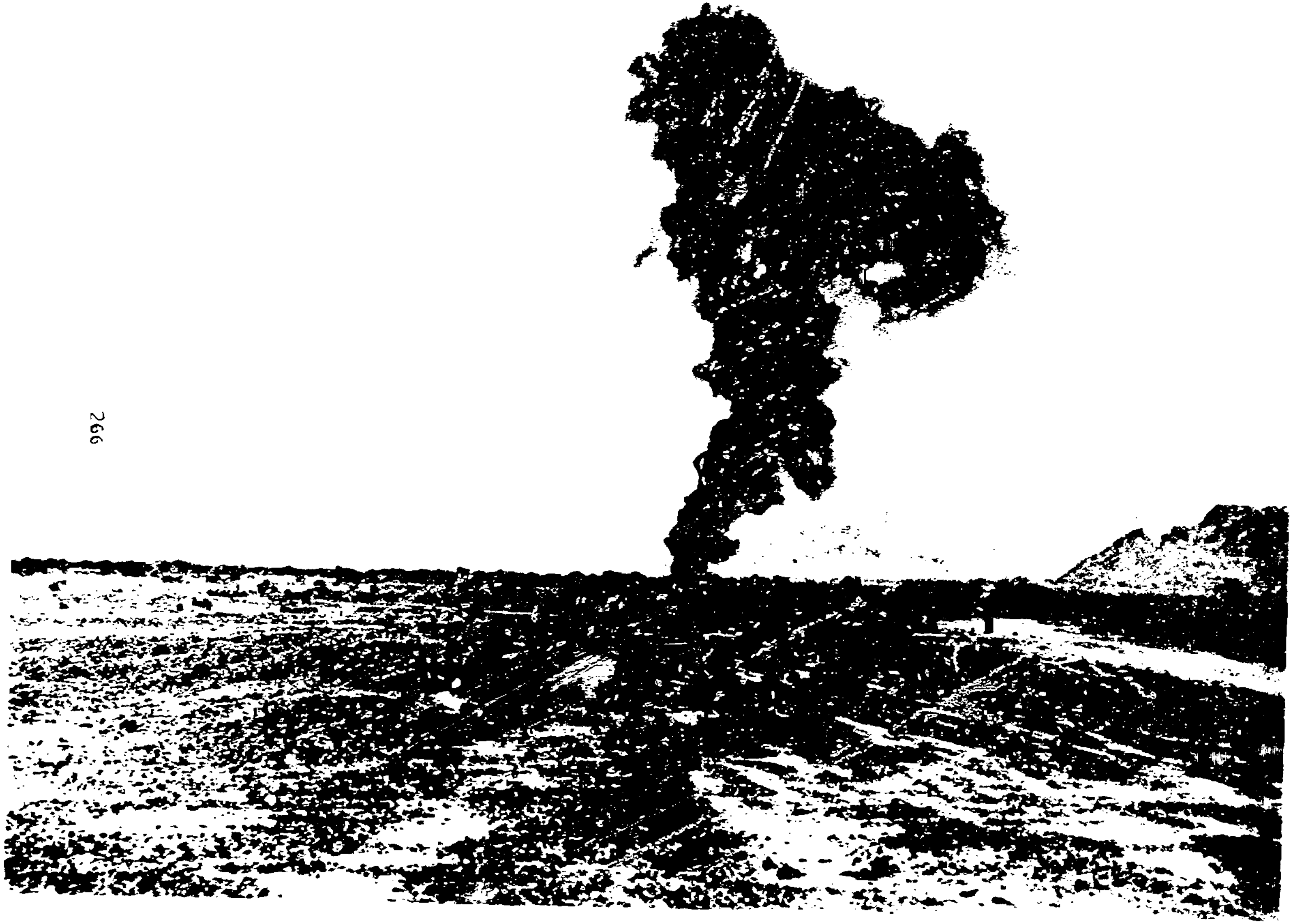
#15 Detonation Test B - 2 - Dispersed Stack (Test 2)

16 Detonation Test B - 2 - Donor


#17 Detonation Test B[illegible] - Acceptor



#15 External Heat Test C - Set Up



#19 External Heat Test C - Burning Stack

#20 External Heat Test C - Burned Out Area

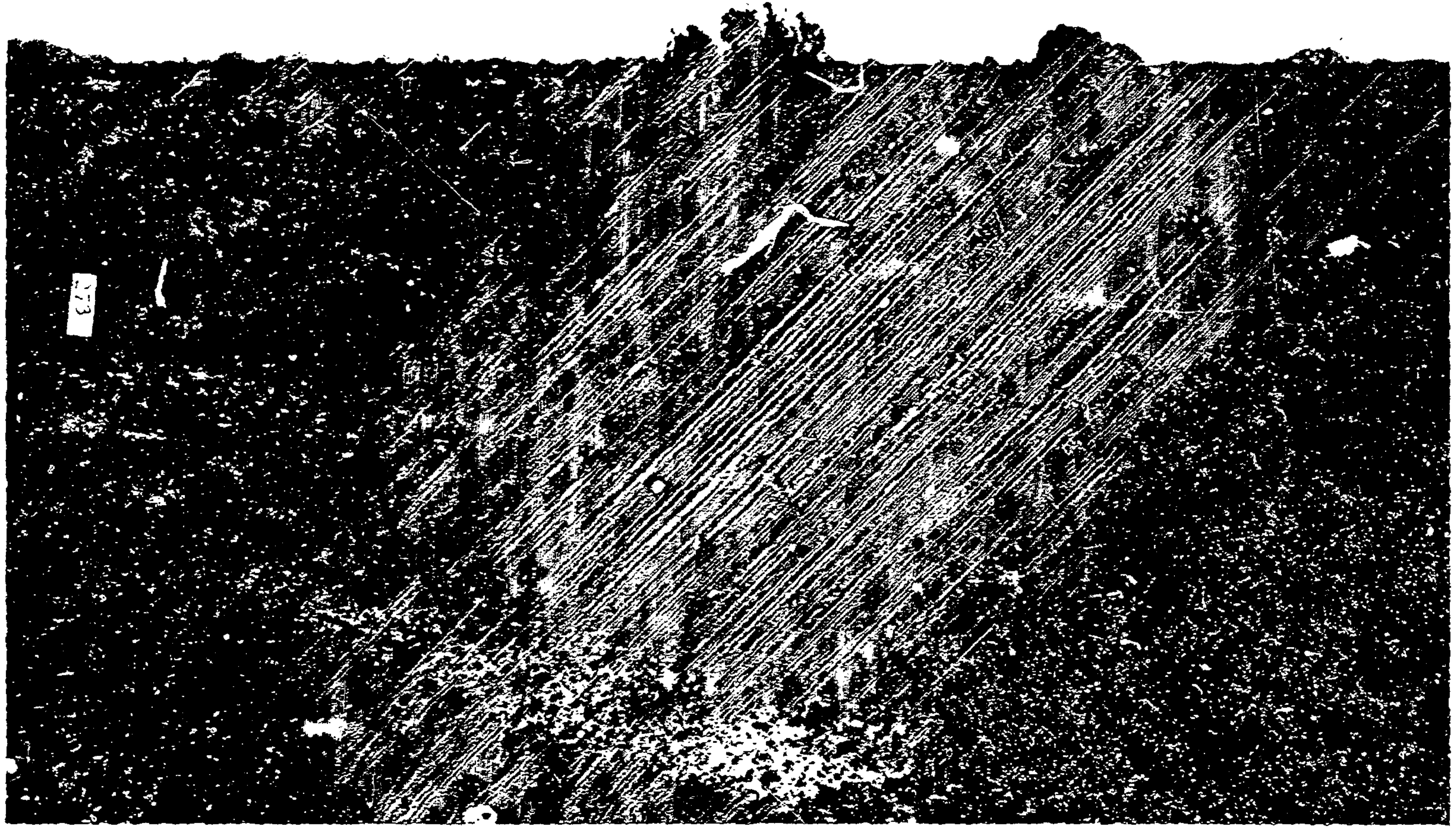
#[illegible] External Heat Test C - Burned Out Containers at 12'

#22 External Heat Test C - Lid at 3-'

#23 External Heat Test C - Fragment at 500'

#24 External Heat Test C - Burned Out Container at 60'

#25 External Heat Test C - Burned Out Container at 90'

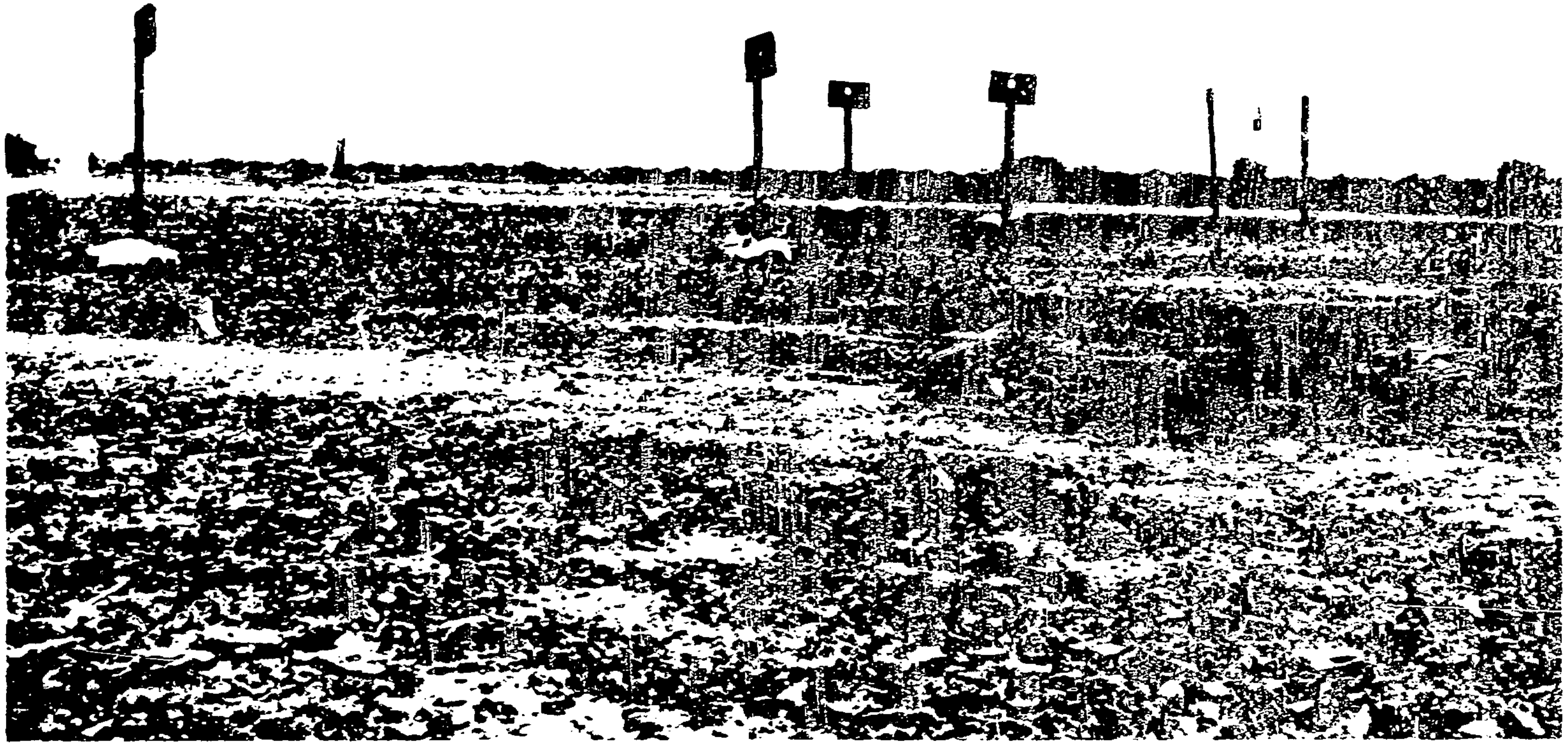


#26 External Heat Test C - Top Ring at 100'

#27 External Heat Test C - Bottom Ring and one side at 140'

#28 External Heat Test C - Fragment at 150'

#29 External Heat Test C - Burned Out Container at 270'



#3. Calibration - Set Up

TNT EQUIVALENCY INVESTIGATIONS

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ABSTRACT

As part of the Army's plant modernization program, an effort is currently under way to generate airblast data for explosives and propellants. The purpose is to provide realistic data in support of structural designs. In this work, peak pressure, impulse and other blast wave characteristics are compared to similar parameters obtained from a hemispherical surface burst of TNT. The results are reduced to a TNT equivalency value, which is defined as the weight ratio of TNT to test-material for given output conditions. Various factors influence the magnitude of TNT equivalency. These include. charge geometry, critical mass/dimensions, confinement, distance from charge burst, and method of initiation. This paper discusses the effects of the different variables from experimental and analytical viewpoints. It also introduces new inferences about high energy materials drawn from the shapes of TNT equivalency curves, and discusses initiation sources in terms of critical energy considerations.

1. INTRODUCTION

The airblast parameters such as peak overpressure, positive impulse, positive phase duration, etc. are being determined for explosives, propellants and pyrotechnics in their in-process and final product forms. The data obtained from these experimental investigations are being applied, by the Manufacturing Technology Directorate of Picatinny Arsenal, to designs of new manufacturing acilities as part of the Army's Ammunition Plant Modernization Program.

If building construction and quantity-distance siting are based on evaluations of the maximum airblast output that an energetic material is capable of achieving, then the cost of new manufacturing facilities may be reduced and/or safety can be improved. When building construction and siting are based on maximum output, changes in the manufacturing process can be implemented or new equipment may be used without concern that the facility would not survive an accidental explosion.

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The measured airblast parameters for a material of interest is often viewed on a relative basis, that is, it is compared with the airblast produced by a hemisphere or sphere of TNT. The convention that is most frequently used in defining TNT equivalency is that it is the ratio of the weight of a hemisphere of TNT to the weight of the test material that will give the same peak pressure, or impulse, at the same distance. The ratio is multiplied by 100 so that the TNT equivalency is expressed as a percentage.* The reason that TNT equivalency is most often defined with respect to a hemispherical surface burst, as the reference shape, is because the most extensively documented data on the blast wave parameters for TNT have been obtained for the hemispherical shape (Ref. 1).

It is well established for explosives that the values of the airblast parameters at a given distance will depend upon charge geometries. It is occasionally suggested that the TNT equivalency should be defined or referenced with respect to the same geometry as the test material (i.e. a propellant cylinder of L/D=1 should be compared with a TNT cylinder of L/D=1, etc.). However, this suggestion is not practical for investigations in support of facilities modernization because it would require that TNT be evaluated in geometric shapes that are the same as that of the test material (hoppers, pipes, etc) or that all tests be done on spheres or hemispheres of the test material. Either suggestion is impractical for at least two reasons: it would be too costly to evaluate both TNT and the test material in the various shapes in which in-process materials are found, and secondly, if only hemispheres were evaluated, it would not allow us to take into account the significant effect of charge geometry on the amplitude of the blast wave.

In order for meaningful comparisons to be made between the material being tested and TNT, the blast wave shapes must be similar, Figure 1. It is not necessary that rigorous requirements of similarity (dynamic and kinematic) be met; only that a sharp rise in pressure and exponential decay of the wave be obtained. Pressure-distance and impulse-distance curves for the test sample may or may not be parallel to the TNT curve. Whether or not it is parallel will depend on composition, which depends upon energy density, oxygen balance and other factors. In any event, much can be gleaned from the curve shapes derived from such studies, and these will be analyzed with respect to the TNT equivalency phenomenon.

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* For example, suppose a 1 lb TNT hemisphere gives the same peak pressure at a given distance as a 10 lb cylindrical propellant charge. The TNT equivalency of the propellant is considered to be 10 percent, 1/10 x 100, at that distance.

This paper is primarily concerned with a discussion of the factors that affect the blast output. Results of experiments on a variety of energetic materials will be used to illustrate how variables such as charge size, geometry, confinement, initiation method, etc., influence the blast wave and hence TNT equivalency. Based on the results of experiments we will also show that materials can be divided into two broad categories which we call high explosives and marginal explosives. The category into which a material is placed is determined by the shape of its TNT equivalency curve. In other words it depends upon the extent to which the pressure-distance and impulse-distance curves for the test material are parallel to or deviate from the TNT pressure and impulse curves. An understanding of the factors affecting airblast output is important in planning experiments, interpreting their results and in the intelligent use of experimental data.

2. FACTORS AFFECTING BLAST OUTPUT

For all materials the airblast output decreases with an increase in distance.* The degree or extent of that decrement depends primarily upon two factors. One has to do with kinetics of the reaction (a characteristic of the explosive or propellant composition), the other concerns charge geometry. These and other conditions which affect the decay of the blast wave with distance will be discussed in the following sections.

2.1 Properties of the Material

If the pressure vs scaled distance and scaled impulse vs scaled distance curves for TNT and the test material were parallel, then a single value for TNT pressure equivalency and a single value for TNT impulse equivalency would exist. However, the curves for the two materials would be parallel only if the blast waves were completely similar (i.e. met the rigorous definitions of kinematic and dynamic similarity). If TNT and the test material had the same geometry and approximately the same energy density (energy release per unit volume) and the same oxygen balance we would expect complete similarity of the blast wave and the curves would be parallel.

However, in the applications discussed in this paper, involving primary explosives, secondary explosives, propellants and pyrotechnics, the materials have widely different energy densities. The overpressures produced by materials of lower energy densities than TNT, are lower close to the source and higher at large distances. The opposite is true for the higher energy

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* There is evidence to the contrary, for impulses at scaled distances less than 2.5 (see Ref. 1).

density materials. They have higher initial overpressures, but lower overpressures at large distances from the charge. This is primarily because energy is dissipated at a much higher rate in shock fronts of higher overpressure.

The oxygen balance of the material being evaluated is also important. If a composition has a negative oxygen balance, i.e. deficient in oxygen, the detonation products can react with the oxygen in the air, in a process called afterburning which results in a greater blast effect.

These effects are illustrated in Figure 2, which shows the results of tests on nitroglycerin (Ref. 2) and N-5 paste propellant (Ref. 3) containing 10 percent process water. Both materials are in a cylindrical container, L/D=1. The energy density as measured by the heat of detonation is 1590 cal/gm for nitroglycerin and for N-5 propellant it is approximately 1200 cal/gm. Thus, in comparing nitroglycerin with N-5 propellant we see that close to the charge the pressure is much higher for the material with the higher heat of detonation, but as the distance from the charge increases the differences between the two materials decreases. At larger scaled distances than shown here we would expect the N-5 curve to approach and finally cross the nitroglycerin curve.

2.2 Geometric Effects

It is well established that for high explosives, (Refs. 4,5,6) the blast wave shape and the airblast parameters of nonspherical charges differ significantly from spherical charges. These differences are most pronounced close to the charge. As the distance from the charge increases the blast wave tends toward sphericity and the blast wave parameters approach that of a point source.

The geometric shapes evaluated in our investigations were shapes that simulated actual process or shipping container configurations. Hence, no spherical or hemispherical configurations were evaluated (with the exception of a single test on 4500 lb of black powder (Ref. 7) and the routine calibration tests on hemispheres of C4 explosive). The effect of charge geometry on the peak overpressure can be illustrated by considering test results for nitroglycerin, (tested in cylindrical containers of L/D=1), with the peak pressure distance curve for a hemisphere of TNT, Figure 3. The difference in the heat of detonation between TNT and nitroglycerin is about 13 percent (1400 and 1590 cal/gm, respectively). The differences in the two curves are attributable to geometry

Another comparison can be made between N-5 propellant and M-1 propellant, Figures 4 and 5. The M-1 propellant is packaged as the M-1 propelling charge (Ref. 8) in a cylindrical container, L/D=6, while the N-5 has an L/D=1. The heat of detonation of M-1 propellant is almost identical to that of N-5 propellant. Thus we should only expect to see the effects of geometry. Close to the explosions the pressures are higher for L/D=6 than the L/D=1 as expected. Other work done on the effect of geometry on blast output (Ref. 4) shows that close to the charge, an increase in L/D results in an increase in peak pressure. There is some evidence (Ref. 4) that this effect peaks at L/D=6.

2.3 Confinement Effects

The degree of confinement, as characterized by the weight ratio of the explosive to that of the confining material, is an important factor that can affect the blast output. For high explosives it has been shown that a very small amount of confinement results in a higher blast output over that of a bare high explosive charge (Ref. 9). This may be due to some spalling of the bare charge from the precursor shock wave. As the amount of confinement increases, the blast output decreases below that obtained with a bare charge. This effect of confinement is somewhat different for materials that are not high explosive. In particular, black powder showed that as confinement increased the blast output increased. Figure 6 shows qualitatively how the confinement affects the peak pressure. In all experiments, particular attention is paid to ensuring that the amount of confinement is properly scaled so that the experiment simulates the actual system that is modelled.

2.4 Effect of Mass and Critical Dimension

In order to determine maximum airblast output, the dimensions of the test material must be above some critical size. If the size is too small, a detonation will not propagate. The kinetics of the reaction is a dominant factor in establishing the critical size of an energetic material. Because kinetic data is not available for most of the materials of interest, experimental approaches must be used. For high explosives there is no problem in testing above its critical mass (and dimensions) since these values are quite small. That is, detonation of high explosives can occur in charges weighing grams or less, and sizes that are smaller than a centimeter. Propellants and pyrotechnics generally have large critical dimensions, from several inches in diameter to many feet.* Thus it is important to ensure that tests are

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* The critical diameter of a typical composite solid propellant is between 60 and 72 in. (Ref. 10).

carried out above the critical diameter, and/or mass. This is accomplished in our studies by testing at several different charge sizes to assess the dimensions above which the results are independent of charge size. In this way it is experimentally determined if the results on a small scale can be applied to full scale systems. An example of the dependence of TNT pressure and impulse equivalency on the weight of black powder is shown in Figure 7. Other materials also exhibit similar behavior. Thus, as a necessary part of TNT equivalency studies we must determine the critical diameter or mass of the material for the type of confinement that exists under the process conditions that are being simulated. To ascertain if the critical diameter and/or mass have been achieved, it is necessary to: (a) determine the size scaling relationships experimentally, i.e., to find the weight beyond which the curve for TNT equivalency versus weight (at selected distances) is flat, and (b) determine if the value of the experimentally determined equivalency is consistent with the order of magnitude that is expected based on the heat of detonation and oxygen balance of the material. The latter two parameters are only indicators of what the magnitude of blast output should be, i.e., "high" or "low". They are insufficient in themselves to be used reliably as a quantitive predictive tool.

Scaling techniques of the sort briefly described above must be used, since the cost of full scale testing for every material would be prohibitive. However, if scaled tests (weights of less than 100 lb) show low or no blast output, then, depending upon the physical variables, tests may have to be carried out for sizes that may approach full scale to insure that maximum output has been reached.

2.5 Initiation Method

Secondary high explosives are readily detonated with small booster explosives. Primary explosives, being more sensitive, can be detonated by means of a hot wire, a blasting cap, or a detonator. However, propellants and pyrotechnics are most readily or conveniently driven to a detonation by means of an explosive booster whose detonation pressure is higher than the detonation pressure of the test material. In this work, we do not attempt to determine the minimum stimulus required for detonation because this involves sensitivity investigation. We are only concerned with whether or not the initiator is adequate to cause the material to achieve its maximum possible energy release. Of course, the initiator must not be so large that is makes a significant contribution to the airblast output. The contribution of the booster is, nevertheless taken into account in the calculations of equivalency. For many materials an increase in airblast output may be achieved by increasing the booster size. Thus several size boosters are usually evaluated in a test program to ensure that maximum output is obtained. An example of this is shown in Figure 8, for M-1 propellant, which shows the effect of booster size on TNT equivalency.

Initiation methods other than using high explosive boosters can be used to initiate a detonation. This subject will be discussed in detail in Section 3.

3. INFLUENCES AND INTERPRETATIONS OF BLAST DATA

3.1 Initiation Method and Critical Initiation Energy

Under manufacturing plant, storage and transportation conditions, the most likely initial initiation stimulus is a heat source, causing burning of the material to occur. The fire or deflagration reaction may transit to a detonation. The conditions under which this can occur depends upon many factors including the mass of material, the amount of confinement, its initial temperature, the rate of temperature rise, the details of the ignition source and the way in which the deflagration spreads. It is much more expensive to carry out experiments where a transition to a detonation can be achieved, than it is to initiate a detonation by means of a shock wave from a booster explosive. Although a detonation that occurs as a result of the deflagration to detonation transition is a more realistic situation, the end result, when compared to a booster explosive initiation, is the same, i.e., detonation of the material.

The objective of TNT equivalency studies is to determine the maximum output; it is not essential to determine all the ways in which a detonation can occur. It is sufficient to show that a certain magnitude reaction can be achieved.

There are several factors that affect the initiation of an energetic material by a shock wave. They are: the peak pressure of the disturbance, its duration, and the surface area of the initiaton source that has a direct action of the test material. The shock wave can be produced by a high explosive booster, by impact of a foil or by a thick plate impact. If the foil and plate are of the same material and velocity then the pressure at the acceptor face is the same, but the duration is much smaller for the foil than it is for the thick plate. Similarly, we can increase the duration of the shock wave produced by an explosive booster, by increasing the weight of the booster, where the booster is in contact with the acceptor material. It has been shown for three different explosive materials, using test results of a number of investigations, that the shock sensitivity of an explosive can be characterized by a critical energy for initiation, i.e. peak pressure and duration of pulse (Ref. 11). Conceptually this relationship is seen in Figure 9. This curve has been well defined for the region between no reaction and ignition threshold, curve B. In Figure 9 we see that in the region between curves A and B there is a continuum of ever-increasing reaction intensity levels, as we increase the pulse width for a given pressure.

In our work the peak pressure of the donor charge was constant (C4 boosters were used in the majority of the tests). The duration, or pulse widths, were increased by using a range of booster weights. Figure 8 shows the TNT equivalency for a number of booster sizes. As booster size (pulse duration) increases, the TNT equivalency or reaction intensity level increases, until a large enough booster is used that no longer produces an increase in blast output in the test material.

The same results could have been obtained by using a booster with a lower peak pressure, but longer pulse duration. By using lower pressure boosters or impact of flyer plates, we would still be able to map out the possible reaction intensity levels that the test materials achieve. This would be the same as already achieved with C4 boosters.

In a study pyrotechnic materials (Ref. 12) we achieved a wide range of pressure and pulse widths (durations) by using the gaseous products of the detonation of an explosive booster to fill a large heavily confined air cavity, Figure 10, adjacent to the pyrotechnic mix (50 lb). Essentially, the sequence of events was as follows. The explosive is detonated in a few micro-seconds and the reaction products expand into the air cavity. The resulting transient pressure rapidly decay and a relatively quiescent state is achieved in the air cavity. The initial pressure within the cavity will depend upon the volume of the cavity and the quantity and type of explosive used. A series of gas dynamic calculations were performed to determine the test parameters that would produce pulse durations of the order of a millisecond using explosives weighing approximately one pound. The air cavity experiments gave at least as large an airblast output as experiments where the booster was placed inside the pyrotechnic charge. The same airblast output (TNT equivalency) was also achieved when the explosive booster was separated from the pyrotechnic charge by an air space, Figure 11. In these tests the booster explosive was supported by a heavy walled cardboard tube, which provided the stand-off distance, as well as a means for preventing the booster explosion's gaseous products from venting to the atmosphere at the time of detonation. Thus in the above mentioned air gap experiments the peak pressure was lower and duration of the shock wave was greater than if the booster explosive were inside the pyrotechnic material, yet the airblast output from pyrotechnics initiated by these two methods was the same.

3.2 Categorizing Energetic Materials

On the basis of experimental data on a variety of explosives, propellants, and pyrotechnics we have observed that these materials fall into two categories which can be described in terms of the shapes of their TNT equivalency curves. The two categories are characterized as marginal explosives and high explosives.

The shape of the equivalency-distance curves for materials that we call marginal explosives can be seen in Figure 12. The TNT equivalency increases with scaled distance and reaches a maximum at a scaled distance in the neighborhood of 10 ft/lb and then decreases. In these cases the maximum value of TNT equivalency is well below 100 percent. Materials that we have evaluated thus far that can be categorized as marginal explosives are: an in-process form of N-5 propellant containing 30 percent process water, black powder, guanidine nitrate (less than 150 lb charges), tetracene, lead azide and two illuminant pyrotechnic compositions.

This listing contains a diverse range of compositions and it is necessary to remember that energetic materials should be viewed in terms of both their sensitivity and explosive output. A material such as lead azide is very sensitive, but has a low explosive output. On the other hand, TNT is a relatively insensitive composition that has a relatively high explosive output.

Materials that we classify as high explosives have TNT equivalency vs distance curves that decrease with distance or are constant with distance (depending upon factors such as charge geometry). Materials that we have evaluated that fall into the category of materials that behave like high explosives, in addition to the secondary high explosives, are M-1 propellant, N-5 paste propellant with 10 percent process water, M-30 propellant, and lead styphnate. Typical equivalency curves are shown in Figure 5.

4. CONCLUSIONS

We have shown in this paper that the airblast output and the TNT equivalency of explosives, propellants and pyrotechnic materials depend upon many factors. In order to design meaningful experiments and for the resulting data to be intelligently applied, it is important that the many factors and parameters that affect the airblast be recognized, and that the data be used in the context in which they were derived. In line with this, it would seem reasonable to assign a more descriptive term for TNT equivalency which would more suitably reflect the influence of these variables and would be more useful to the engineer for structural design purposes. Such a term could be designated as "TNT Equivalency Profile" and would constitute a family of curves showing Impulse and Pressure Equivalency versus Scaled Distance, as well as Pressure versus Time and Distance for various systems.

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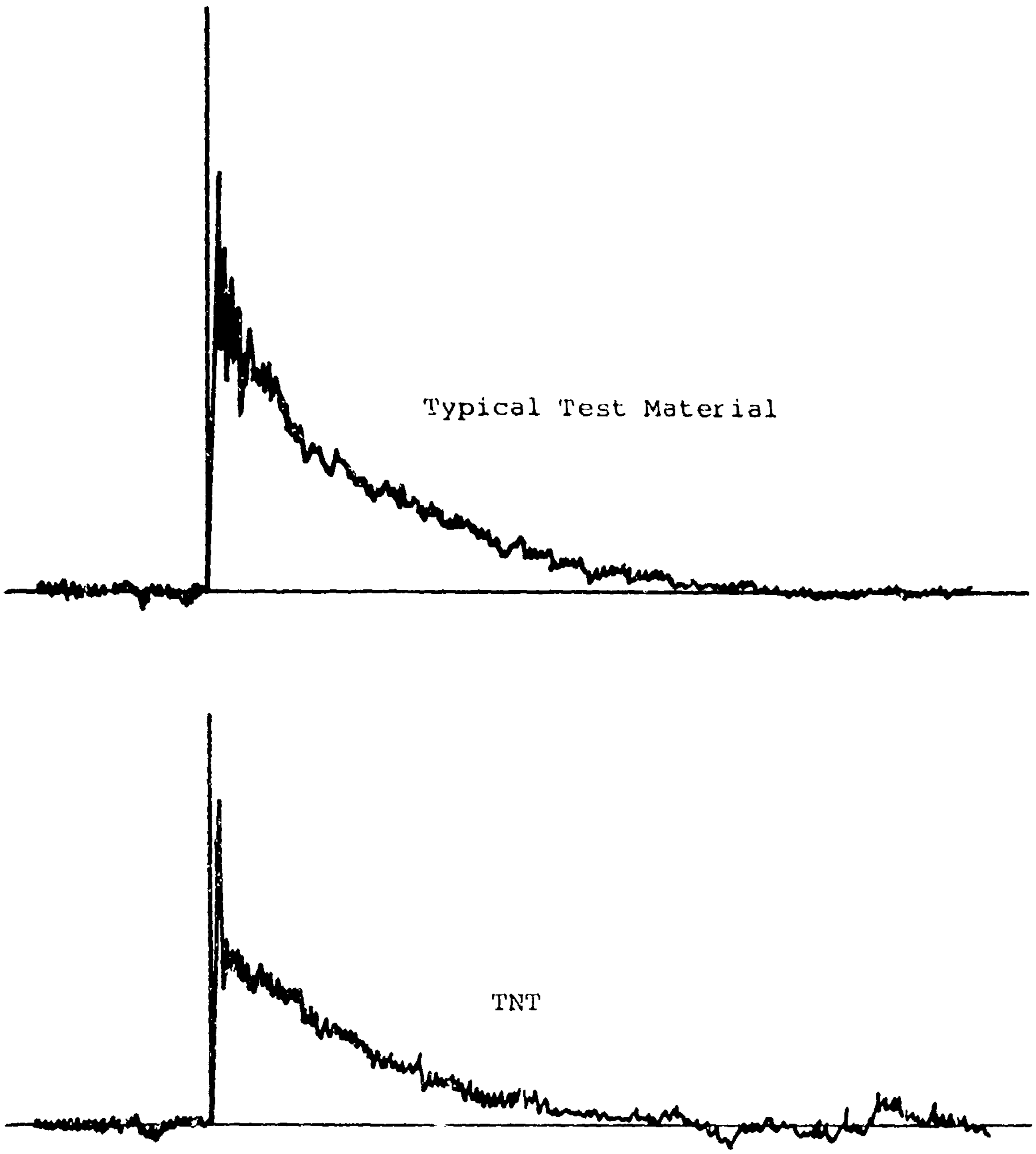

Fig. 1 PRESSURE-TIME RECORDS

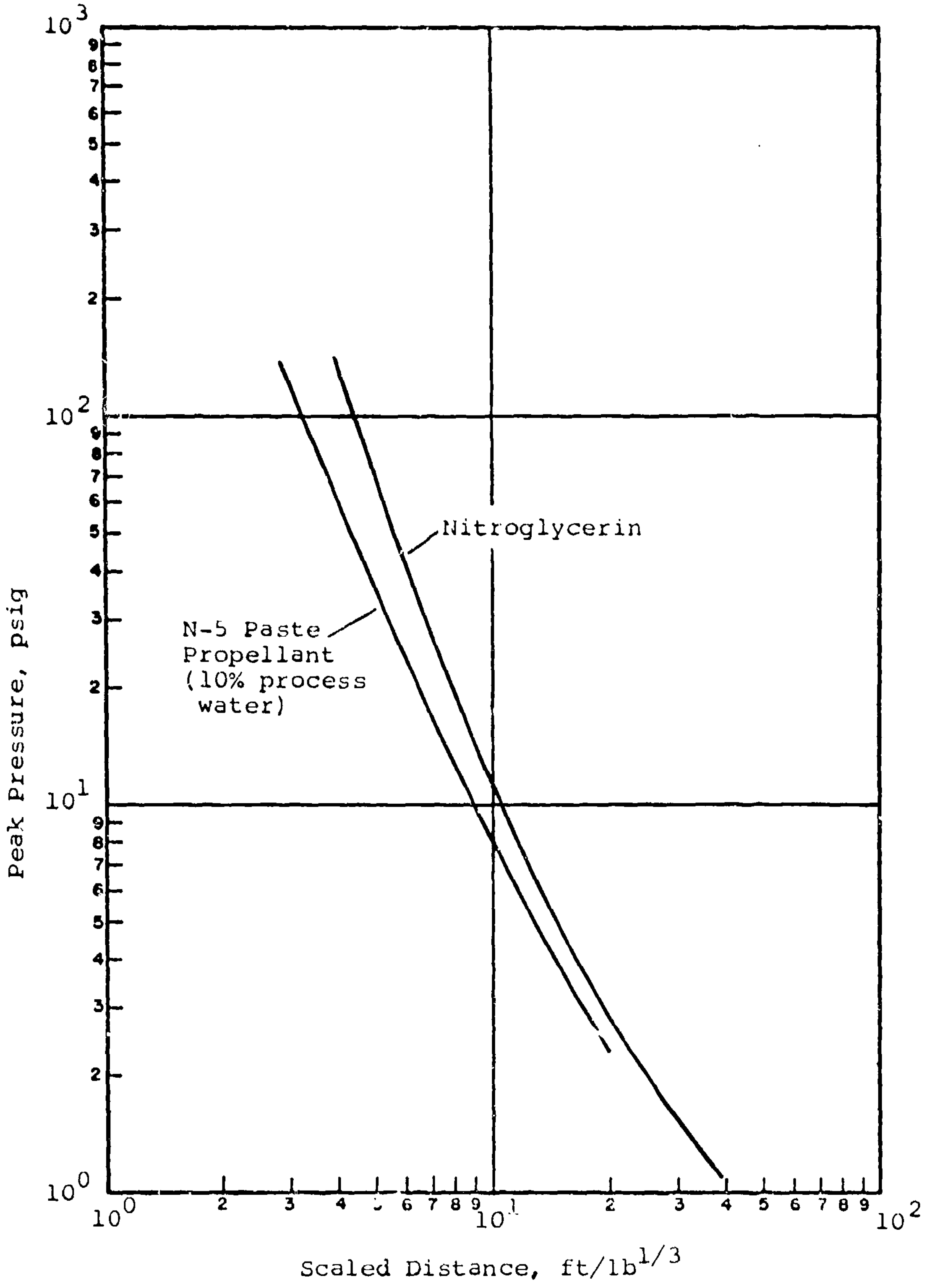

Fig. 2 BLAST OUTPUT COMPARISON, EFFECT OF ENERGY DENSITY

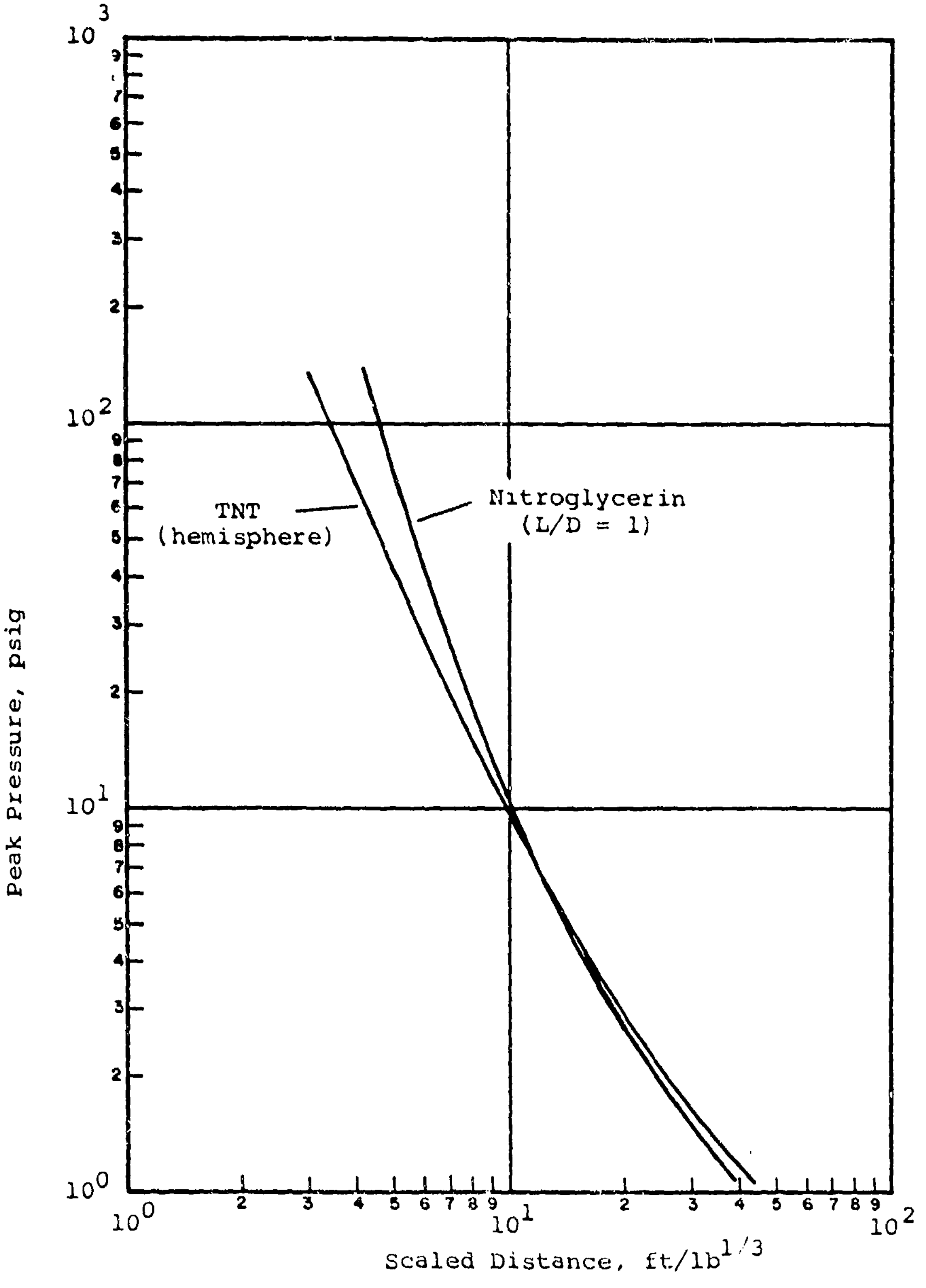

Fig. 3 BLAST OUTPUT COMPARISON, GEOMETRY EFFECTS

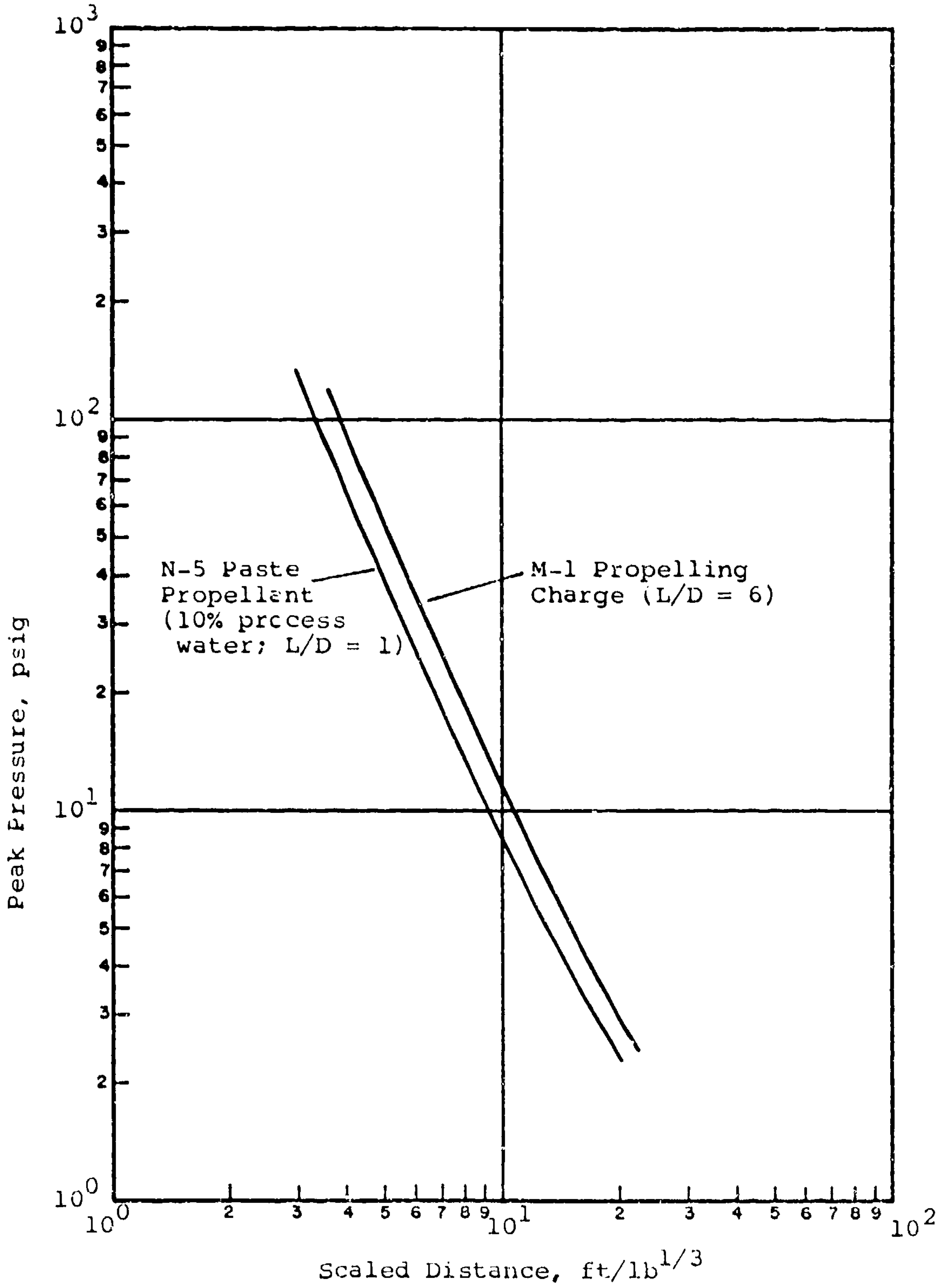

Fig. 4 BLAST OUTPUT COMPARISON, GEOMETRY EFFECTS

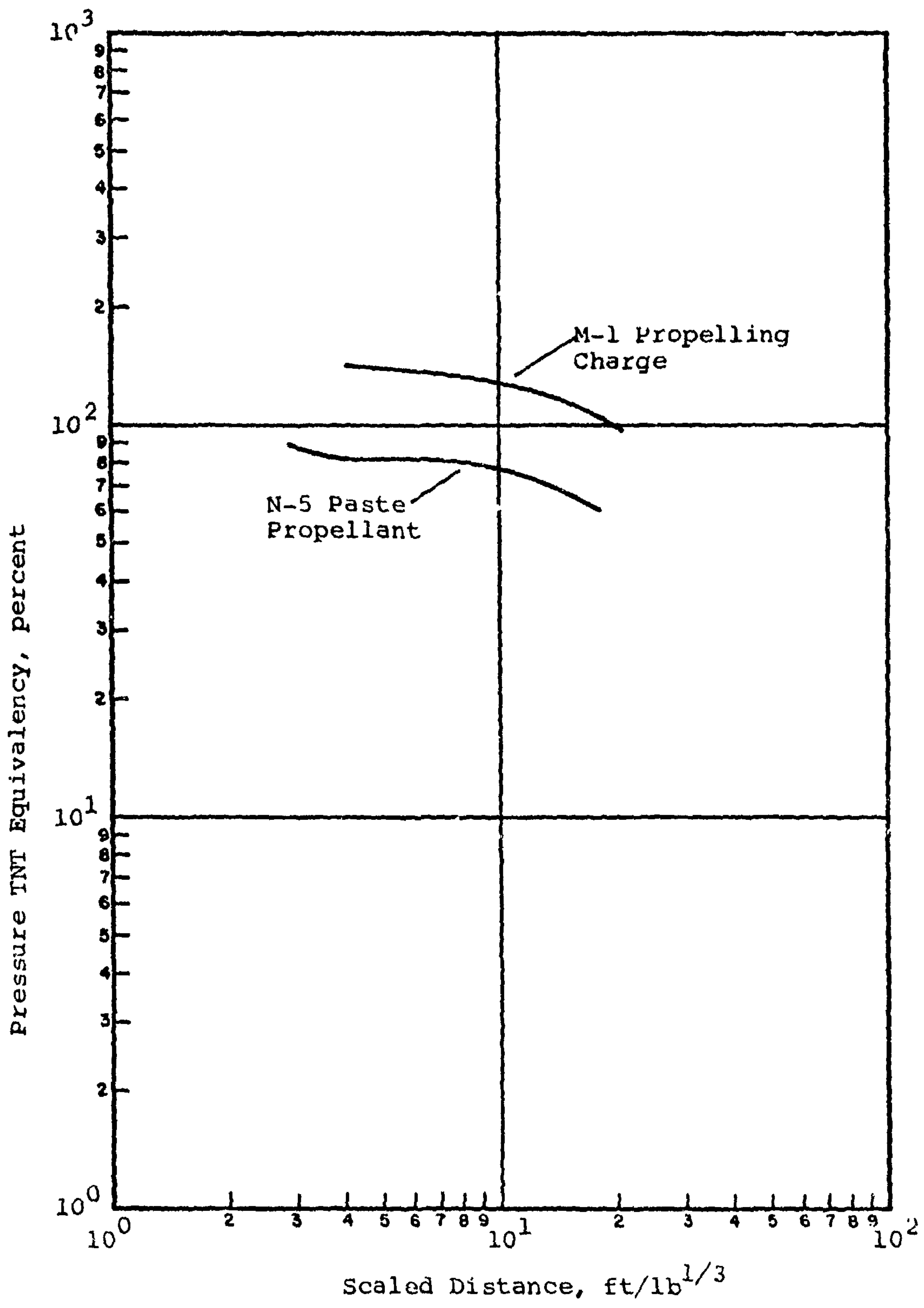

Fig. 5 EQUIVALENCY COMPARISON

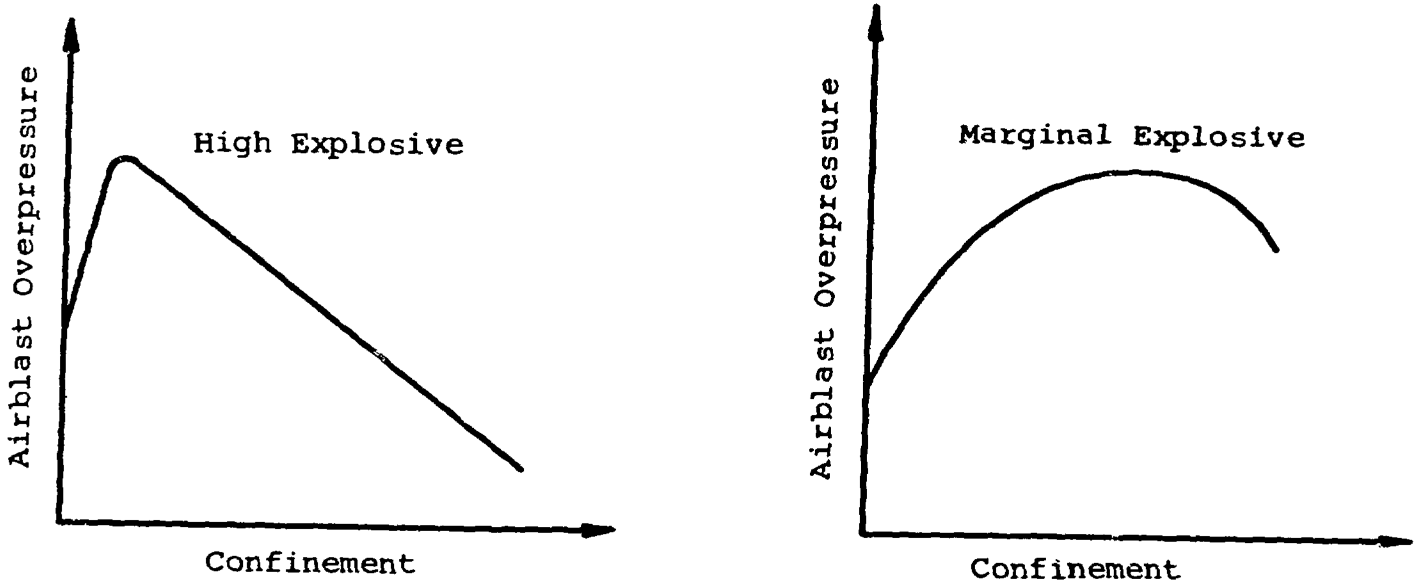

Fig. 6 EFFECT OF CONFINEMENT ON BLAST OUTPUT

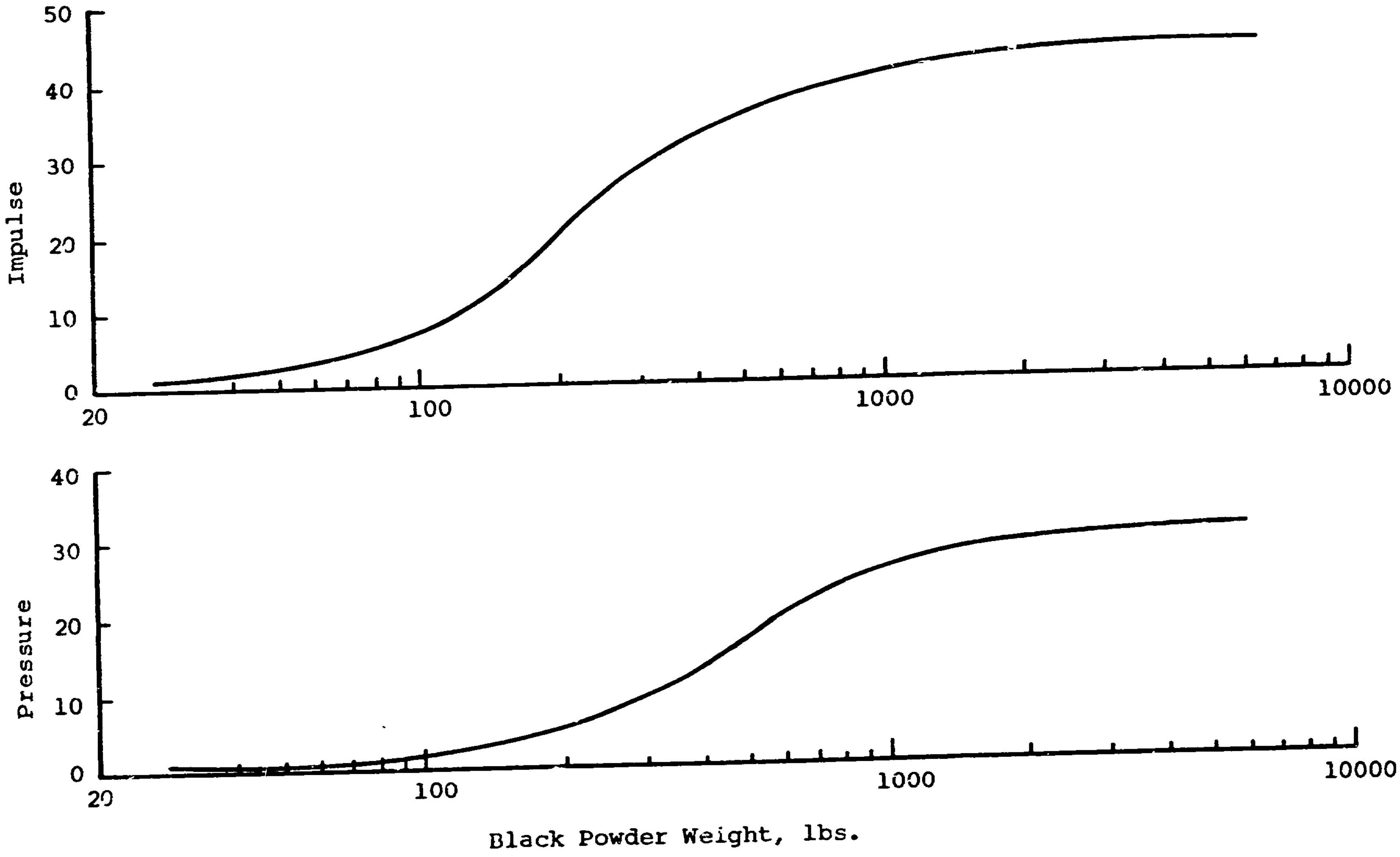

Fig. 7 EFFECT OF WEIGHT CHANGE ON EQUIVALENCY

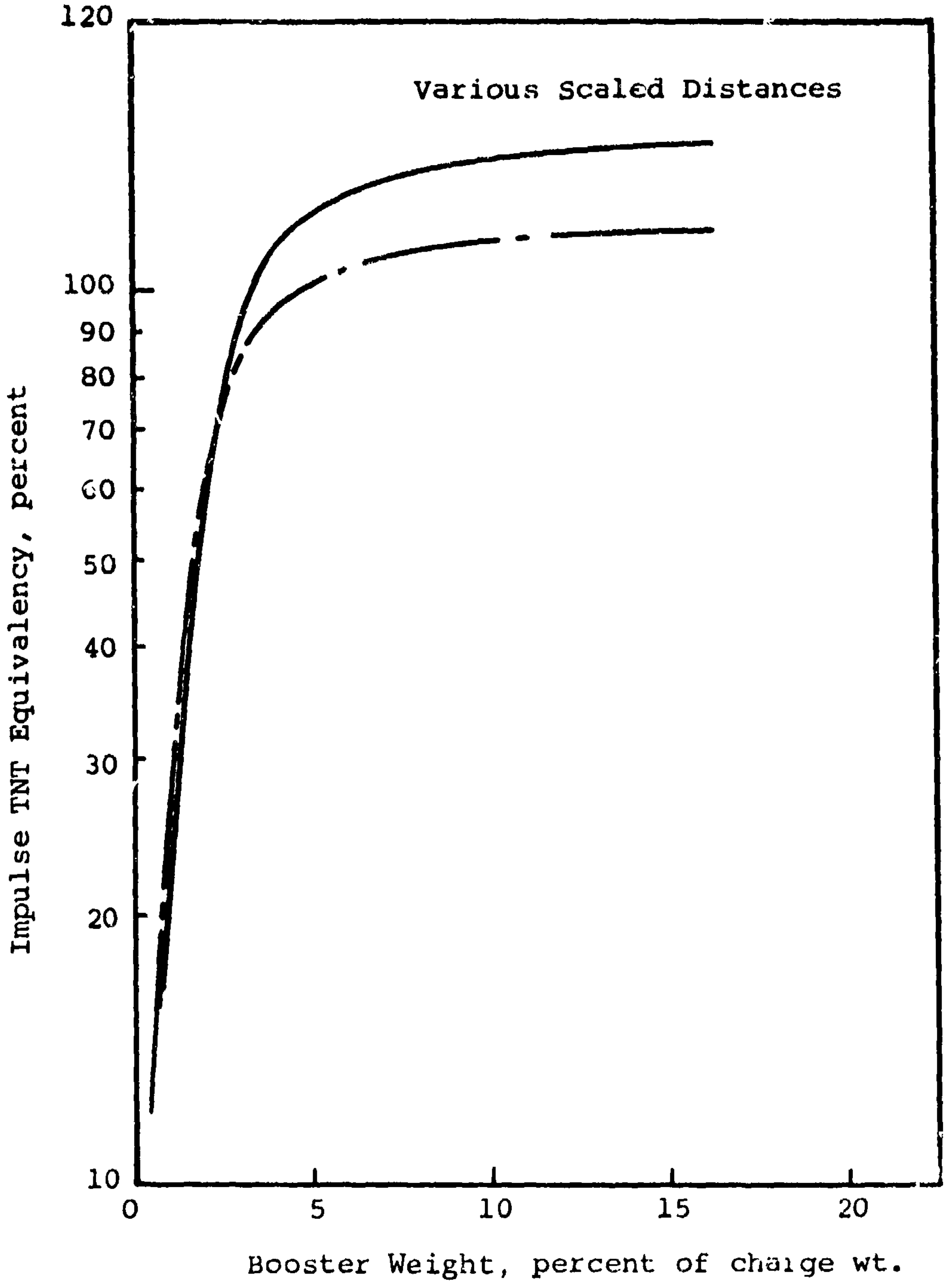

Fig. 8 EFFECT OF BOOSTER SIZE FOR
M-1 PROPELLING CHARGES

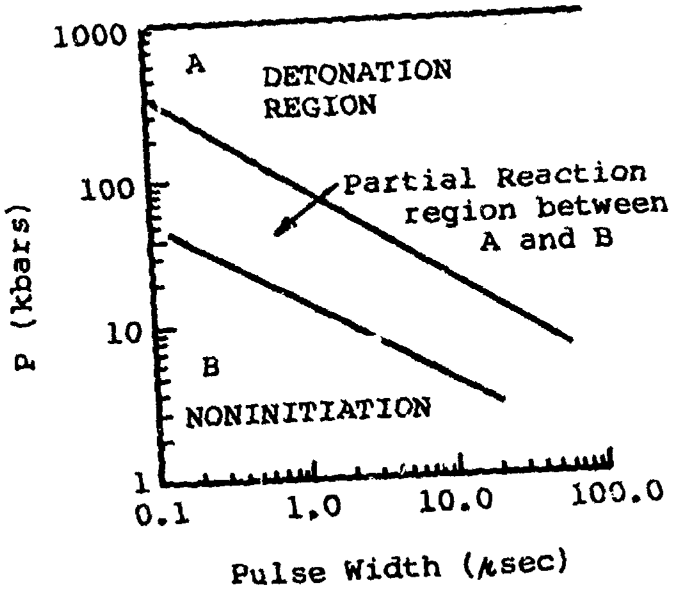

Fig. 9 BOUNDARY FOR SHOCK INITIATION OF REACTIVE MATERIALS (not to scale)

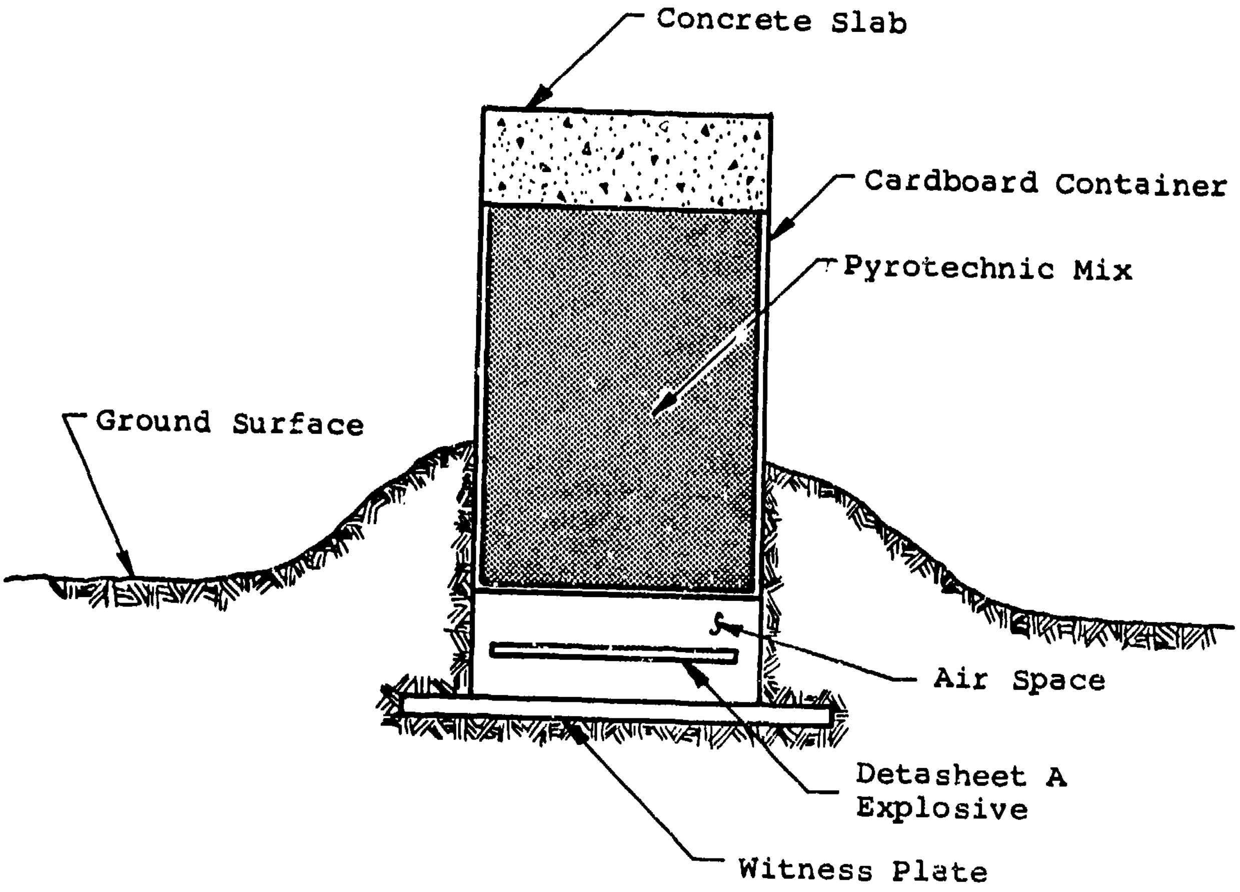

Fig. 10 AIR CAVITY CONFIGURATION

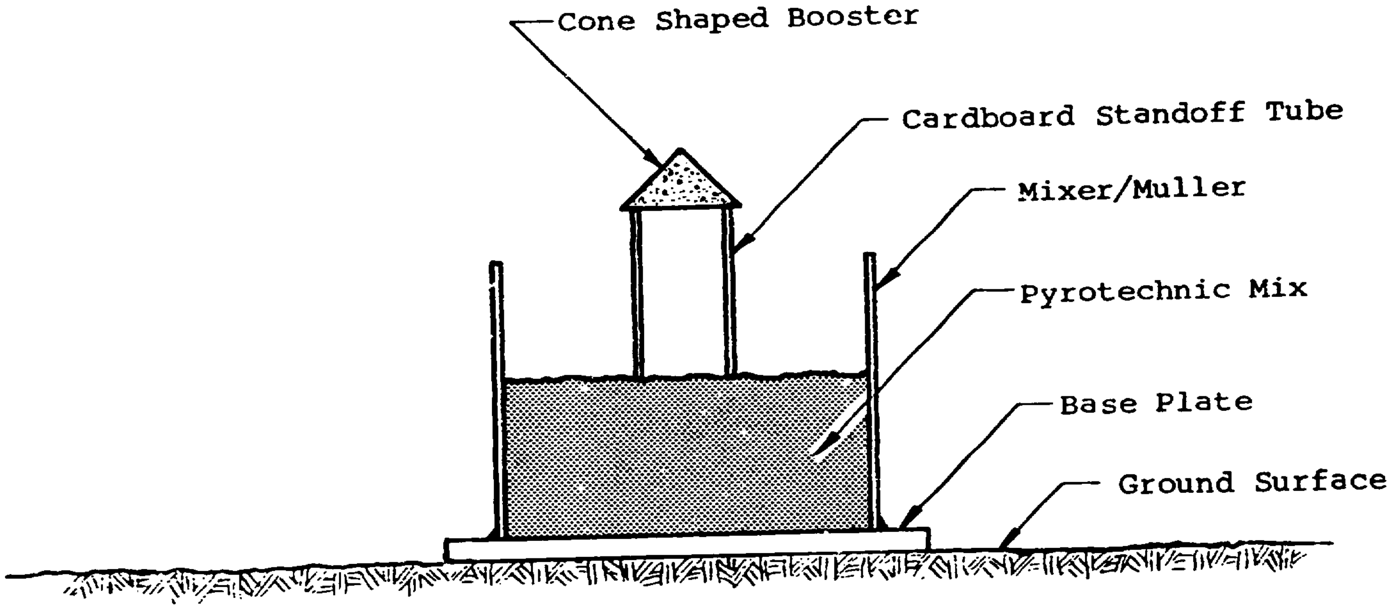

Fig. 11   MIXER/MULLER CONFIGURATION

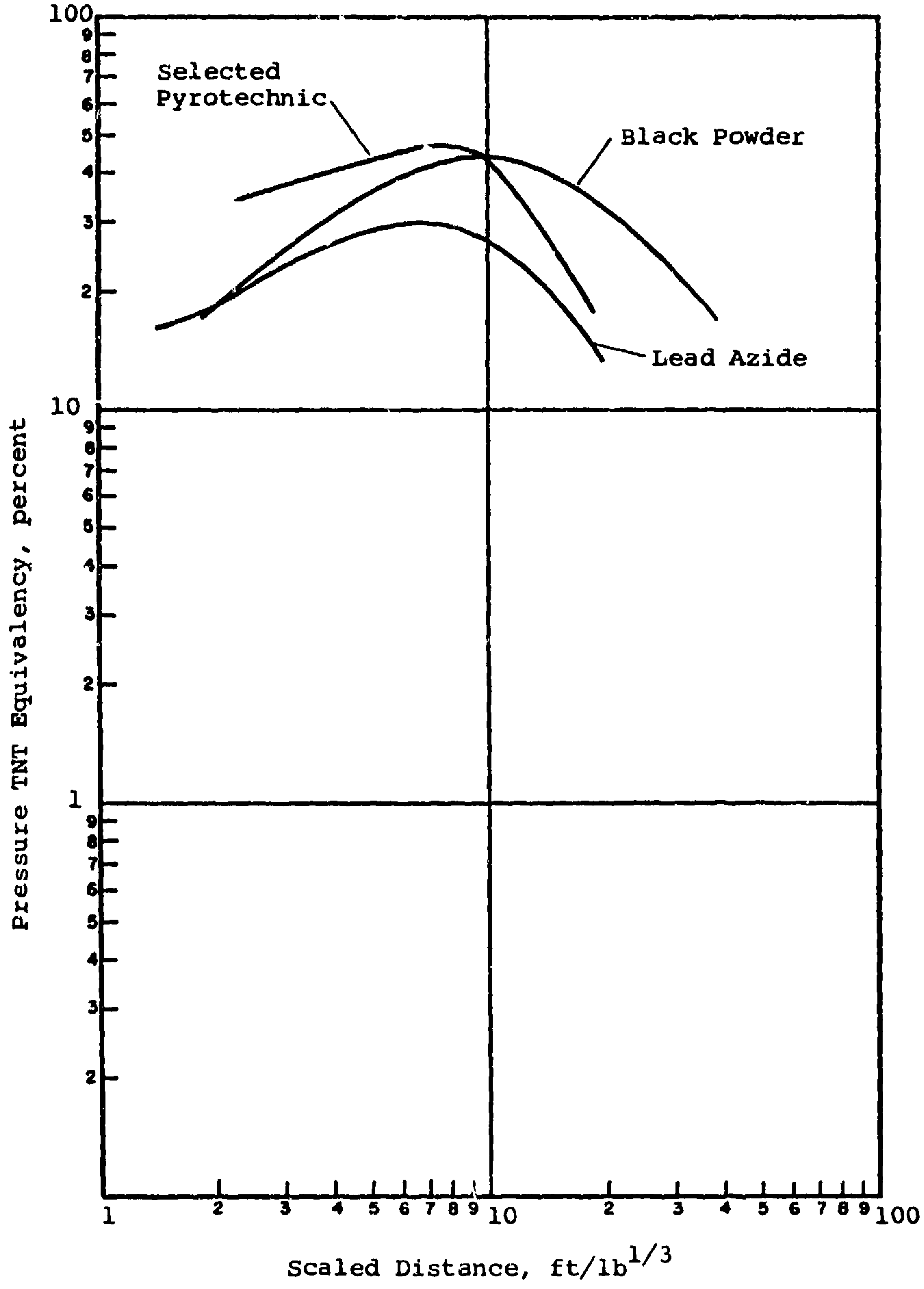

Fig. 12 PRESSURE EQUIVALENCY FOR SOME MARGINAL EXPLOSIVES

EFFECTS OF CHARGE SHAPE, CHARGE COMPOSITION AND SURFACE CONDITIONS ON BLAST ENVIRONMENT

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INTRODUCTION

The U. S. Army Armament Command (ARMCOM) is modernizing ammunition facilities used in the manufacturing, processing, and storage of conventional munitions. Consistent with new safety regulations, protective structures are being designed to comply with criteria and methods in the TM5-1300 Manual, *Structures to Resist the Effects of Accidental Explosions* [1]. A scale-model cubicle test program to supplement material in TM5-1300 was sponsored by Picatinny Arsenal (Manufacturing Technology Directorate) and conducted by CEL.

The testing descibed in this paper was conducted to determine the effects of charge shape and composition on the results of the scale model cubicle tests, which would use composition B cylinders. The test site was also utilized for determining the explosive yield of an RDX slurry of the type stored in tanks used in ammunition production facilities.

A more detailed description of the test program and results will be published in a CEL Technical Note [2].

OBJECTIVE

The primary test objectives were to determine the effects of charge shape and composition on the pressure-time-distance relationships for composition B, TNT, and RDX slurry surface bursts. Results should show the equivalencies of composition B and RDX slurry and the effects of using composition B cylinders in the cubicle test program.

Secondary objectives included a study of the effects of surface conditions and charge elevations on shock wave characteristics. A direct comparison of pressure-time data outside a cubicle from the detonation of cylinders and spheres centered in the cubicle was an additional objective to be accomplished during the cubicle test program.

TEST PROGRAM

Program Development

The original test plan specified a direct comparison of air-blast parameters from detonations of TNT spheres, composition B cylinders, and RDX slurry containers. All charges were slightly elevated over a stiffened 1-inch steel plate to eliminate cratering. Poor detonation of the center-initiated cast TNT spheres precluded use of the TNT test data. Similar problems with small TNT spherical charges have been reported by Fisher and Pitman of NOL [3].

The test program was then expanded to include surface bursts of composition B hemispheres, spheres, and cylinders. The spherical and hemispherical data would be compared with known TNT surface burst results for determination of TNT equivalency of composition B. Results would also be compared to determine the effect of charge shape.

The hemispherical composition B charges were detonated on sand and on a replaceable 4-inch steel plate to determine which condition produced the most consistent results for surface bursts. The test results indicated that the steel plate should be used for the subsequent surface burst tests of composition B spheres and cylinders.

Spherical composition B charges were also detonated from small elevations so that the effects of small heights of burst could be evaluated for both spheres and cylinders. This information was then used to evaluate the elevated RDX slurry tests. Table 1 summarizes the test program.

Explosives

Cast composition B hemispheres, spheres and cylinders (L/D = 1) and cylindrical rigid plastic containers of an RDX slurry were used. Physical characteristics of the explosives and detonation details are shown in Figure 1.

Test Site

Testing was conducted at the Pacific Missile Range, Point Mugu, California. Three gage lines, each originating at ground zero, were placed at 90 degrees to each other. The ground surface along each gage line was leveled and covered out to a range of 52 feet. Except for a 4 x 4-foot area centered on ground zero, the first 10 feet of the lines was covered with a steel plate 4 feet wide by 1/4 inch thick. From 10 to 52 feet, the lines were covered with 3/4-inch plywood. Surface conditions at ground zero are summarized in Table 1. Pressure transducers were located on each line at 2, 4, 8, 16, 32, and 50 feet from ground zero. Each transducer was mounted in a steel jacket encased in 1 cubic foot of concrete. The concrete block was buried so that the pressure gage was flush with the ground surface.

Instrumentation

Piezoresistive pressure transducers (HFG series by Tyco Instrument Division, Bytex, Inc.), designed to measure dynamic overpressures, were placed in accordance with the predicted pressure at each gage location.

The pressure-time data was recorded on magnetic tape and then digitized. The digitized data was integrated to obtain an impulse-time record, which was displayed on a hard copy plot with the pressure-time record.

Quick-look data was provided by an oscillograph plotter after each test.

Test Data

A typical computer printout of pressure-time and impulse-time data plots is displayed in Figure 2. Peak pressure and maximum impulse were taken directly from this plot of the digitized data. The end of the positive phase duration was taken at the point of maximum impulse.

Gages at ranges of 16, 32, and 50 feet generally exhibited overshoot due to ''ringing'' of the gage diaphragm whose natural frequency was nearly that of the peak pressure loading. The positive phase duration at these ranges was long enough so that an exponential curve could be fitted through the average of the data points to obtain the correct peak pressure. Since large segments of the exponentially decaying curve will plot as a straight line on a log pressure versus time plot [4], these curves were also generated to aid in curve fitting. The log pressure plot expanded, straightened and reduced the slope of the fitted curve and thus allowed for better and more consistent peak pressure analysis of ''ringing'' gages. Since the ''ringing'' was balanced around the average pressure-time plot, there was no need to correct the impulse data. Positive phase duration was unaffected.

Pressure and impulse measurements, from repeated tests and multiple gage lines, were averaged and plotted. Table 1 summarizes the number of measurements averaged per plotted value and the figure numbers where the average data points are plotted. Tables of individual measurements are presented in Reference 2. Positive phase durations, not presented here, are also included in Reference 2.

DATA ANALYSIS

The surface burst tests of the spherical and hemispherical composition B charges were conducted for comparison with TNT surface burst data from similarly shaped charges. These tests give the basis for evaluating the cylindrical composition B test data by determining the best surface to use for the test program, by providing a check on the instrumentation system, and by yielding the equivalency of composition B. The concept of charge weight equivalency is then used to describe the effect of charge shape on air blast parameters.

The surface burst and small height of burst data on cylinders and hemispheres are used to help evaluate the results of the elevated RDX slurry tests. The RDX slurry data is then compared to the hemispherical surface burst curves by using charge weight equivalency.

The effect of charge shape and charge weight on the environment outside a three-wall cubicle is shown by directly comparing peak pressures, scaled impulses, and scaled durations.

Effect of Surface Conditions

The two surface conditions considered to be the easiest to repeat with consistency throughout the test program were a dry sand surface that could be refilled after each test and a hard steel surface that could be replaced as required. The hemispherical surface bursts were conducted on both of these surfaces to determine the surface effect on pressure and impulse results. The results shown in Figures 3 and 4 from tests on the steel surface agree very well with TNT data while results from tests on the sand surface are significantly lower. Since composition B output is known to be at least equivalent to that of TNT, it was determined that the hard steel surface would best serve the purposes of the test program. As shown in Figures 3 and 4, an extreme difference in surface hardness has a significant effect on blast yield at scaled distances less than about 20 ft/lb$^{1/3}$.

TNT Equivalency of Composition B

The composition B hemispherical and spherical surface burst data are compared to data from similar tests [5,6,7,8] of larger quantities of TNT in Figures 3, 4, 5, and 6. Differences are small.

Peak pressure from the hemispherical composition B surface burst, detonated on a plate, is virtually the same as that from TNT (see Figure 3). Similar results were obtained with spheres. The spherical composition B peak pressure test values fall on one or the other of the TNT curves (see Figure 5).

Scaled impulses from composition B and TNT hemispherical and spherical surface bursts are compared in Figures 4 and 6. Agreement between the composition B data (on a steel plate) and TNT data is good.

It was anticipated that composition B and TNT charges of the same shape and under similar conditions would have almost identical blast yield. TM5-1300 gives the TNT equivalencies for composition B at pressures between 2 and 50 psi as 1.10 for peak pressure and 1.06 for impulse. In order to experimentally measure these equivalencies, one must be able to measure a ratio in the scaled distances, at the same pressure or impulse, of 1.03 ($1.10^{1/3}$) and 1.02 ($1.06^{1/3}$), respectively. Determining such a low equivalency was not possible because of (1) the magnitude of the standard deviation and (2) the relatively small number of data points. It is important to note that the standard deviation reflects natural differences between identical tests as well as experimental error. The difference between Distant Plain Event 6 [6] and Prairie Flat [7,8] (shown in Figure 5) is an example. At the lower pressure levels the two similar tests differ by more than 10%. This difference can be attributed to many factors including blast anomalies, test site differences, and experimental error.

Shape Equivalency

It is recognized that charge shape has a significant effect on airblast parameters. Results from charges of different shapes are compared in the literature. References 9 through 11 are examples of previous studies. In these references, peak pressure measurements were compared by taking their ratio at given scaled distances. An alternative method would be to show the ratio of equivalent weights that produce the same pressure (or impulse) at the same ground range.

Figures 7 and 8 present composition B cylindrical surface burst test results. These results can now be compared with the spherical and hemispherical results to determine shape equivalency.

Pressure Equivalency. Peak pressures from hemispherical, spherical, and cylindrical surface bursts are compared in Figure 9. The spherical and cylindrical curves are from composition B test results. The hemispherical relationship is taken from TM5-1300 for a TNT surface burst, though composition B results can be considered to be identical for our purpose. Equivalent weight ratios for pairs of charges of different shape are shown in Figure 10. As expected, equal weights of the sphere and cylinder produce higher pressures than a hemisphere at the smaller scaled distances and lower pressures at the greater scaled distances. The composition B test data was limited to a minimum scaled distance of 2.80 ft/lb$^{1/3}$. Data from Reisler [6] indicates that the equivalent weight of a hemisphere to that of a sphere has a maximum value of 3.25 lb/lb at a scaled distance of 2 ft/lb$^{1/3}$. Data is not available for cylinders at scaled distances less than about 3 ft/lb$^{1/3}$.

The high equivalency values are not unusual. The basic pressure curves for spheres and hemispheres are well documented but are not usually compared in this manner. Since pressure (and impulse) changes are relatively insensitive to weight changes ($z \propto 1/W^{1/3}$), equivalent weights amplify the pressure (or impulse) differences. Note that at a scaled distance of 2 ft/lb$^{1/3}$, the peak pressure of a sphere is about twice that of a hemisphere, but the equivalent weight of the hemisphere to produce that pressure is 3.25 times the weight of a sphere.

Impulse Equivalency. Scaled unit impulses from hemispherical, spherical, and cylindrical surface bursts are compared in Figure 11. The spherical and cylindrical curves are from the composition B test results. The hemispherical relationship is taken from Kingery's TNT data [5]. The hemispherical composition B results were in good agreement with the TNT results (Figure 4). The TNT data was used since it is a composite of many large scale tests and since the differences between TNT and composition B are not measurable within the accuracy of our recording system. Thus, the effect of charge shape on impulse is the result. Considering the scatter of impulse data, the only significant differences occur at scale distances less than about 6 ft/lb$^{1/3}$. The scaled impulses of the cylinder and sphere peak much higher than those of the hemisphere (42 versus 26 psi-msec/lb$^{1/3}$) and at a slightly larger scaled distance. The data also shows the usual trend of scaled impulse data to fall from the peak value (near 3 ft/lb$^{1/3}$) until it again increases with decreasing scaled distance.

Because of the slope reversal in the impulse data near a scaled distance of 3 ft/lb$^{1/3}$, there is a discontinuity in equivalent weights. (Equal impulse lines are at a 45-degree slope on the scaled impulse versus scaled distance plots. Pairs of scaled distance values that fall on these 45-degree lines describe the weight equivalency. A point-by-point analysis produces a discontinuity when the scaled impulse curve reverses slope to one greater than 45 degrees. This occurs at the peak of the lower curve when values are being calculated point by point at decreasing scaled distances.) For this reason the impulse equivalency curve in Figure 12 for W_{hem}/W_{cyl} is terminated at 3.2 ft/lb$^{1/3}$. Results for a sphere (W_{hem}/W_{sph}) would have been similar within the same range of scaled distances. (Figure 11 shows good agreement between the sphere and cylinder for scaled impulses at scaled distances greater than 3 ft/lb$^{1/3}$.)

Effect of Small Heights of Burst

The RDX slurry tests had originally been detonated at small elevations over a stiff steel plate to reduce cratering and to simplify the test setup. They were to be compared directly to TNT spheres at the same elevation, but improper detonation of the TNT charges made that impossible. Composition B cylinders and spheres were detonated at small heights of burst to see how the results differed from those of surface bursts. The cylinders were elevated 3 radii (ground surface to center of gravity of charge) and the spheres were elevated 3 radii of a cylinder of the same weight. Table 1 summarizes the heights of burst for the different charges.

Peak pressures and scaled unit impulses for the elevated spheres and cylinders are compared in Figure 13. Data points from the elevated tests are plotted with the best fit curves from the surface burst tests. Small differences in peak pressure occur at levels above 100 psi with the elevated results being slightly lower. Elevating the charges reduced the peak in the impulse curve near the scale distance of about 3 ft/lb$^{1/3}$.

Equivalency of RDX Slurry

The RDX slurry peak pressure and scaled impulse data are compared to TNT hemispherical results in Figures 14 and 15. The TNT pressure data was taken from TM5-1300 and the impulse data from Kingery [5]. The equivalent weight ratios (W_{TNT}/W_{slurry}) were calculated from these figures and are displayed in Figure 16. The pressure equivalency is highest (1.80 lb/lb) at a scaled distance of 5.2 ft/lb$^{1/3}$. The impulse equivalency peaks at 1.40 lb/lb at a scaled distance of 6 ft/lb$^{1/3}$. The small height of burst of the RDX slurry charges probably reduced the output at scaled distances less than about 4 $ft/lb^{1/3}$ (see previous section). To allow for this height of burst effect, it is recommended that the peak equivalency values be used for decreasing scaled distances as shown by the dashed lines in Figure 16.

Inspection of Figure 15 (with the knowledge that equal impulses occur on 45-degree lines) shows that at a scaled distance near 2.7 $ft/lb^{1/3}$ a discontinuity in impulse equivalency occurs. A dashed vertical line is shown at this scale distance in Figure 16. At scaled distances less than 2.6 $ft/lb^{1/3}$ the equivalency increases substantially to a value of around 5 lb/lb. This high equivalency occurs because the impulse curve for the RDX slurry does not exhibit the trend of other impulse data to turn down at a scale distance around 3 $ft/lb^{1/3}$ before again increasing with decreasing scaled distance.

Three-Wall Cubicle Effects

Peak pressure, scaled impulse, and scaled duration data around a three-wall cubicle were obtained from 1-pound spheres and cylinders and 2.65-pound spheres centered in the cubicle. Gage lines were located along the ground surface perpendicular to the front (open) wall, the sidewall and the backwall. The results from the two charge shapes along the three-gage lines are compared for 1-pound charges in Figures 17, 18, and 19. Figures 20, 21, and 22 compare results from spheres of different weight (1.0 and 2.65 pounds). Figure 23 compares results for different directions from 1-pound spherical charges.

Effect of Charge Shape on Leakage Environment. Results from pressure gages outside the open front wall of the cubicle are shown in Figure 17. Charge shape did not affect scaled durations at any scaled distance. At scaled distances greater than 4 $ft/lb^{1/3}$, scaled impulse and peak pressure data showed no charge shape effects. The average peak pressure of the cylinder at 4 $ft/lb^{1/3}$ was 15% higher than that of the sphere and the scaled impulse of the cylinder at 2 $ft/lb^{1/3}$ was 14% higher than that of a sphere.

Cylindrical charge data on a line perpendicular to the open wall of a cubicle produces results that can be used for spherical charges. At worst, the data will be slightly conservative at scaled distances less than 4 $ft/lb^{1/3}$.

Pressure gage measurements along a line perpendicular to the sidewall followed the same trend as found out the front. However, pressures and impulses were affected to a greater scaled distance (8 $ft/lb^{1/3}$). (Note that the cylindrical pressure at 4 $ft/lb^{1/3}$ is higher than the average of numerous tests run during the subsequent cubicle test program. The average from a larger sampling gives a pressure about 20% higher than that of a sphere. See Reference 12.)

Thus, if data from cylindrical charges is used to design for spherical charges, it would be conservative at scaled distances less than 8 $ft/lb^{1/3}$.

A somewhat different trend is found in comparing results from the sphere and cylinder opposite the backwall of the cubicle. Scaled durations are still the same. However, spherical pressure data is higher at scaled distances less than about 13 ft/lb$^{1/3}$ and cylindrical impulse data is higher over the entire range of measurements. Thus impulse data but not pressure data from cylindrical tests can conservatively be used for a spherical charge. However, more extensive testing from three different cylindrical charge weights (Reference 12) showed that the peak pressure versus scale distance curve of the cylinder has the same maximum pressure value as that of the sphere but at a closer scaled distance. Because the maximum pressure behind the backwall was the same for both shapes, the design method proposed in Reference 12 is applicable to both. That method uses two intersecting straight lines to describe the pressure environment. A horizontal line (dependent on charge density, W/V) limits the maximum pressure and intersects a diagonal line describing the lower pressures at larger scale distances.

<u>Effect of Charge Weight on Leakage Environment.</u> Two spherical charge weights were tested in the cubicle—1.07 pound and 2.65 pounds. Results, plotted in Figures 20, 21, and 22, show considerable differences in the blast environment parameters. This is expected since the size of the cubicle remained constant and was not scaled up for the increased charge weight. Correct scaling requires that the charge density, W/V, remain constant. Therefore, results from different charge weights within a single geometry cubicle are dependent on W/V.

CONCLUSIONS

1. The air-blast environment from composition B charges is essentially equivalent to that from TNT charges of the same shape. The TNT equivalencies in TM5-1300 (1.10 for peak pressure and 1.06 for impulse) should be used in design.

2. The contained RDX slurry is a high explosive with a TNT equivalency that varies with scaled distance and is more indicative of charge shape and containment than charge composition. Peak pressures and impulses for RDX slurry tanks should be obtained directly from the plots of these parameters versus scaled distances (Figures 14 and 15). Since TNT equivalency by weight is not constant, it offers no advantages in design applications.

3. Charge shape effects on the surface burst environment were substantial at scaled distances less than 20 ft/lb$^{1/3}$. Charge shape must therefore be considered at these scaled distances.* Use of data from cylindrical

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* The TM5-1300 Design Manual was developed from tests of TNT and composition B charges of both spherical and cylindrical (L/D = 1) configurations. The design data presented reflects this charge shape phenomenon. For charges with L/D greater than one, a procedure whereby the charge is assumed to consist of a series of spherical charges is used. This procedure has produced good agreement with available test data, and a supplement to TM5-1300 is being prepared.

charges at less than 20 $ft/lb^{1/3}$ would be conservative in most cases (i.e., charges approaching spherical, hemispherical, or cylindrical shapes).

4. Charge shape affects the blast environment outside a protective cubicle less than it does in the case of a surface burst. Use of cylindrical charges for the test program described in Reference 12 will produce design curves that will be applicable for most charge shapes.

5. An extreme difference in surface hardness has significant effect on the surface burst environment at scaled distances less than 20 $ft/lb^{1/3}$. A stiff steel plate on sand, for the scale model tests, gave the best agreement with large scale results.

6. Small heights of burst (0.40 $ft/lb^{1/3}$) measurably reduced side-on overpressure and impulse at scaled distances less than 5 $ft/lb^{1/3}$.

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Mr. Richard Rindner of Picatinny Arsenal conceived and administered the study. Mr. Norval Dobbs of Ammann and Whitney provided valuable technical guidance during the program. Testing was conducted at the Pacific Missile Range (PMR), Point Mugu, California. Personnel from the Launching Division at the Operations Department at PMR set up and detonated the explosives. The PMR Data Automation Division digitized and produced hard copy plots of the data.

The author gratefully acknowledges the contribution of these people to the study.

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Table 1. Summary of Test Program[a]

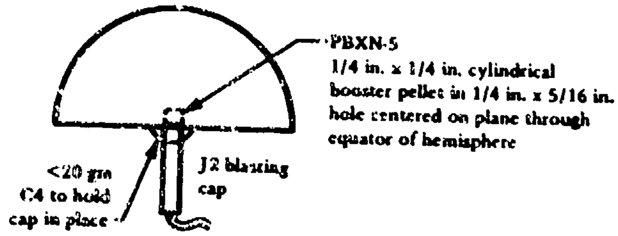
Explosive			Conditions		Number of Gage Measurements per Plotted Value	Figure Numbers
Composition	Shape	Weight (lb)	Elevation[b] (in.)	Surface		
Composition B	cylinders (L/D = 1)	0.5 1.00 1.49 2.01 3.03	3.3 4.0 4.8 5.2 6.0	stiffened steel plate	4 4 4 4 4	9
RDX slurry	encased disc	2.1[c] 3.7[c]	5.8 6.6	↓	18 20	10,11
Composition B	hemispheres	1.0 2.95	surface burst	4-in. steel plate and sand	6 6	3,4
Composition B	spheres	1.07 2.67	{surface burst} and 4.1 5.9	4-in. steel plate	6 6	5,6,9
Composition B	cylinders	1.49 3.03	{surface burst} and 4.8 6.0	4-in. steel plate	6 6	7,8,9
Composition B	spheres	1.07 2.67	1.83 1.83	three-wall cubicle without roof	3 2	17,18,19 20,21,22
Composition B	cylinders	1.00	1.83	↓	2	17,18,19

[a] Shown in sequence of testing.

[b] Elevations from ground to c.g. of charge except for slurry which was measured to bottom of container.

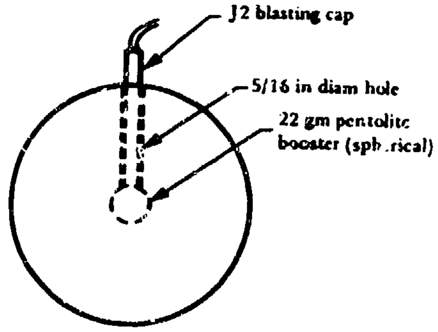
[c] Includes weight of 100-gram booster.

Hemispherical Charges – Composition B



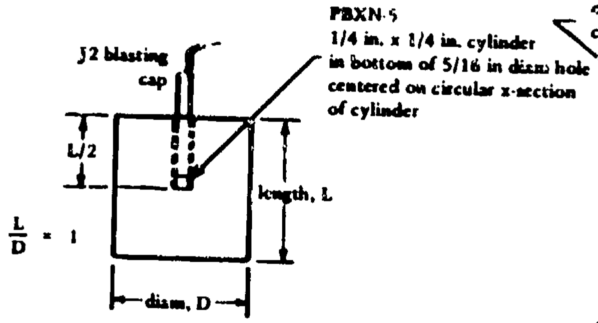
Avg. Charge Weight (lb)	Nominal Diameter (in.)
1.00	4.00
2.95	5.75

Spherical Charges – Composition B



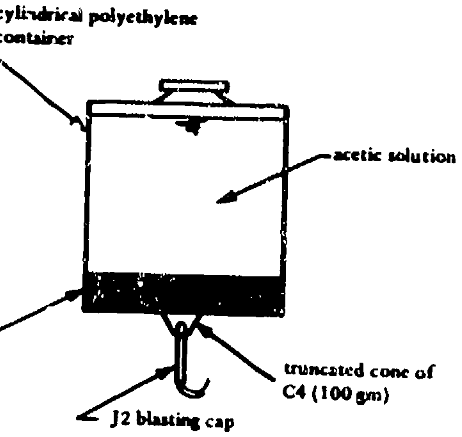
Avg. Charge Weight (lb)	Nominal Diameter (in.)
1.07	3.25
2.69	4.38

Cylindrical Charges – Composition B



Avg. Charge Weight (lb)	Avg. Diameter (in.)
0.49	2.2
1.00	2.7
1.49	3.2
2.01	3.5
3.03	4.0

Encased RDX Slurry Charges*



Avg. Charge Weight (lb)	Container Diameter (in.)
1.9	7
3.5	8.5

* See Table 1 for detailed listing of RDX slurry specimen dimensions

Figure 1. Charge dimensions.

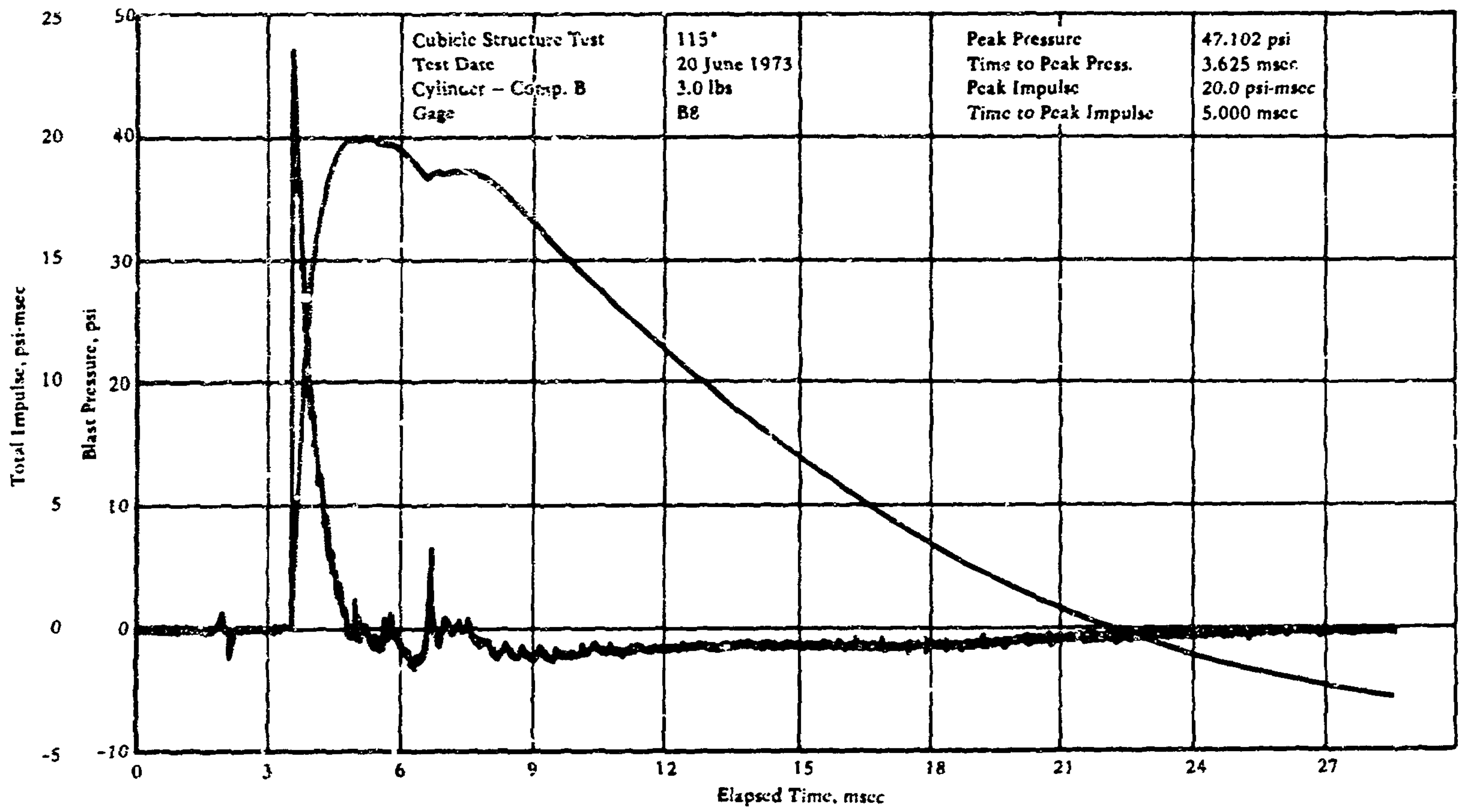


Figure 2. Typical plot of digitized pressure-time data.

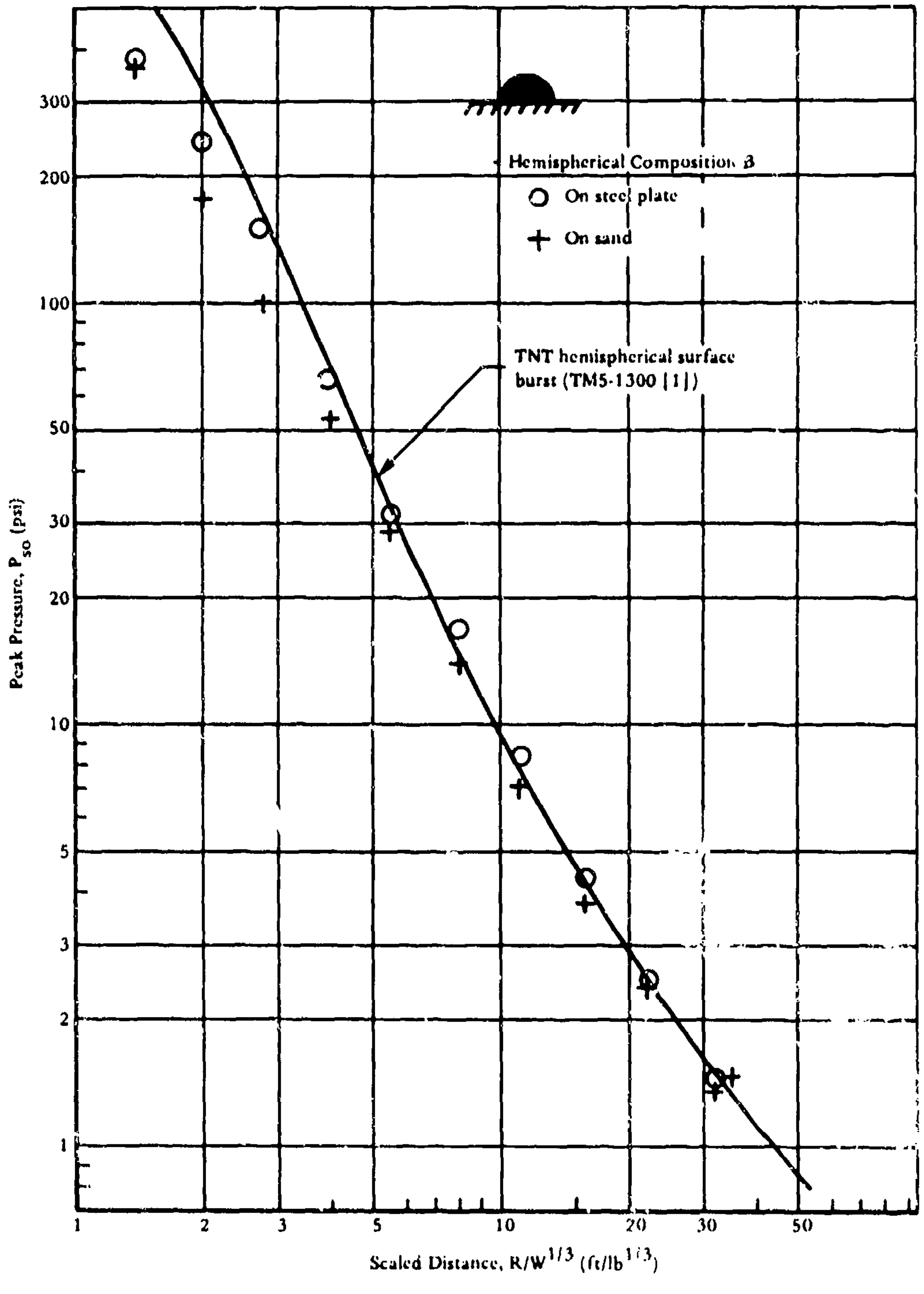


Figure 3. Peak pressure from hemispherical surface bursts on sand and on steel plate.

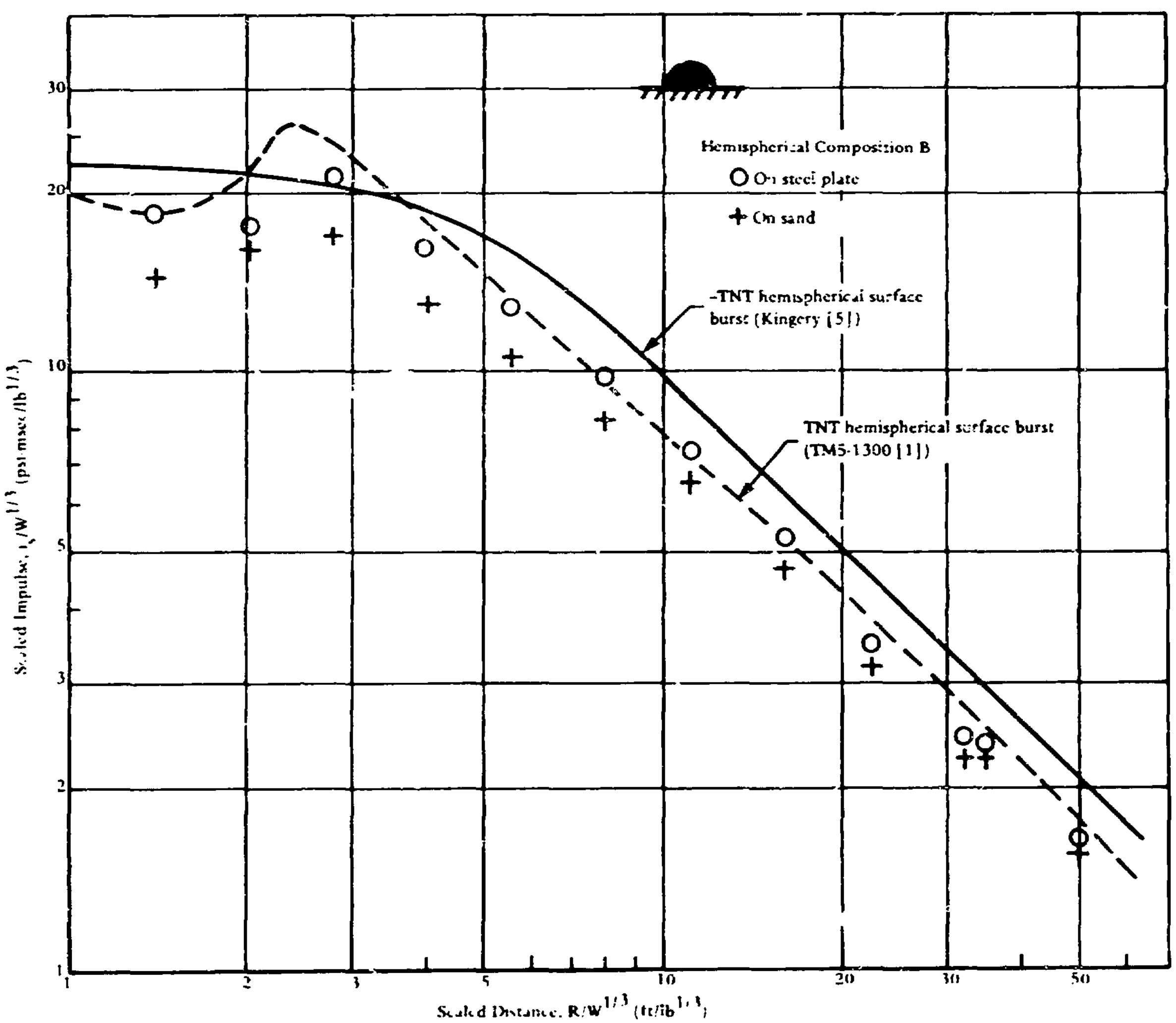


Figure 4. Scaled impulse from hemispherical surface bursts on sand and on steel plate.

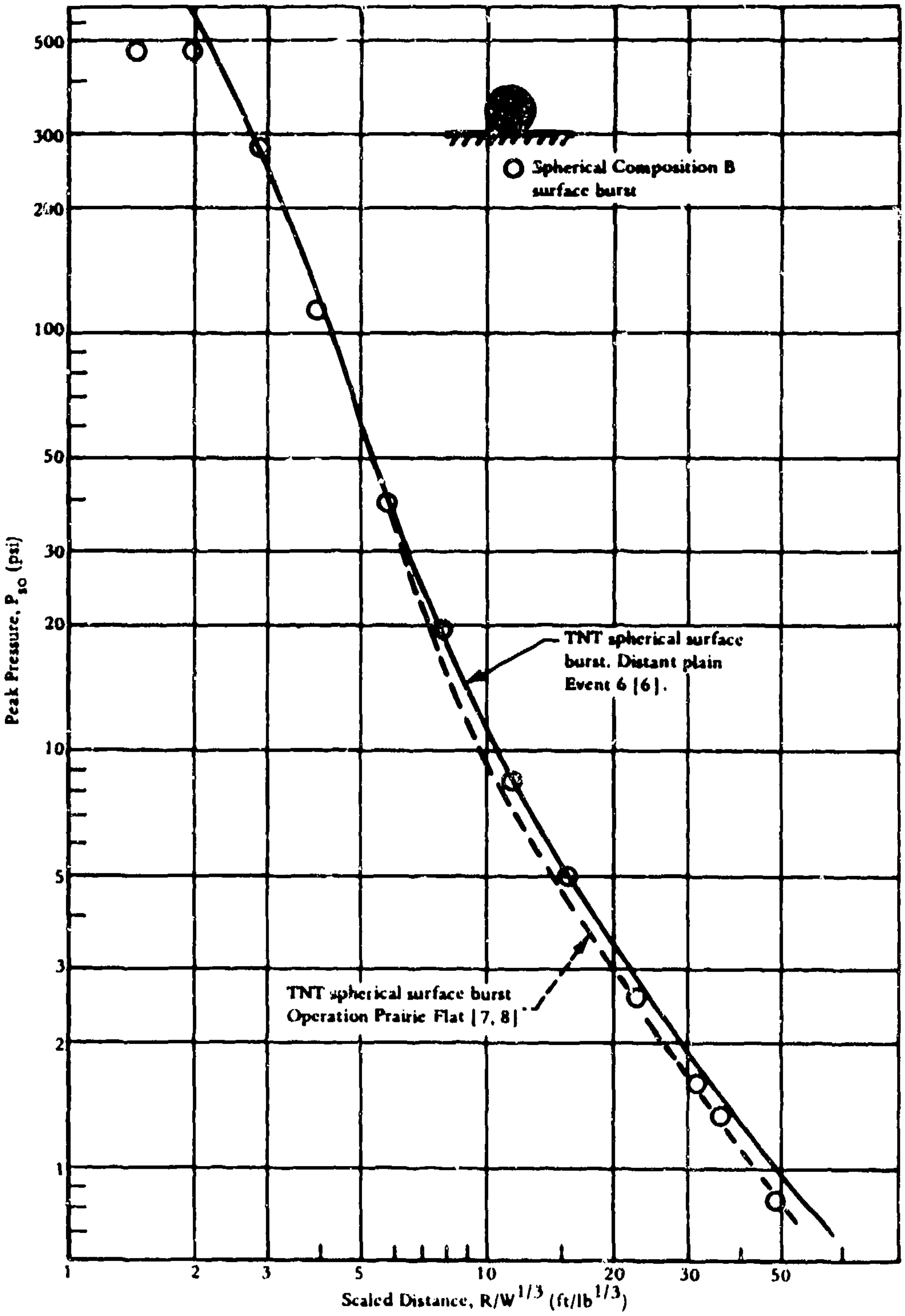


Figure 5. Peak pressure from spherical surface bursts.

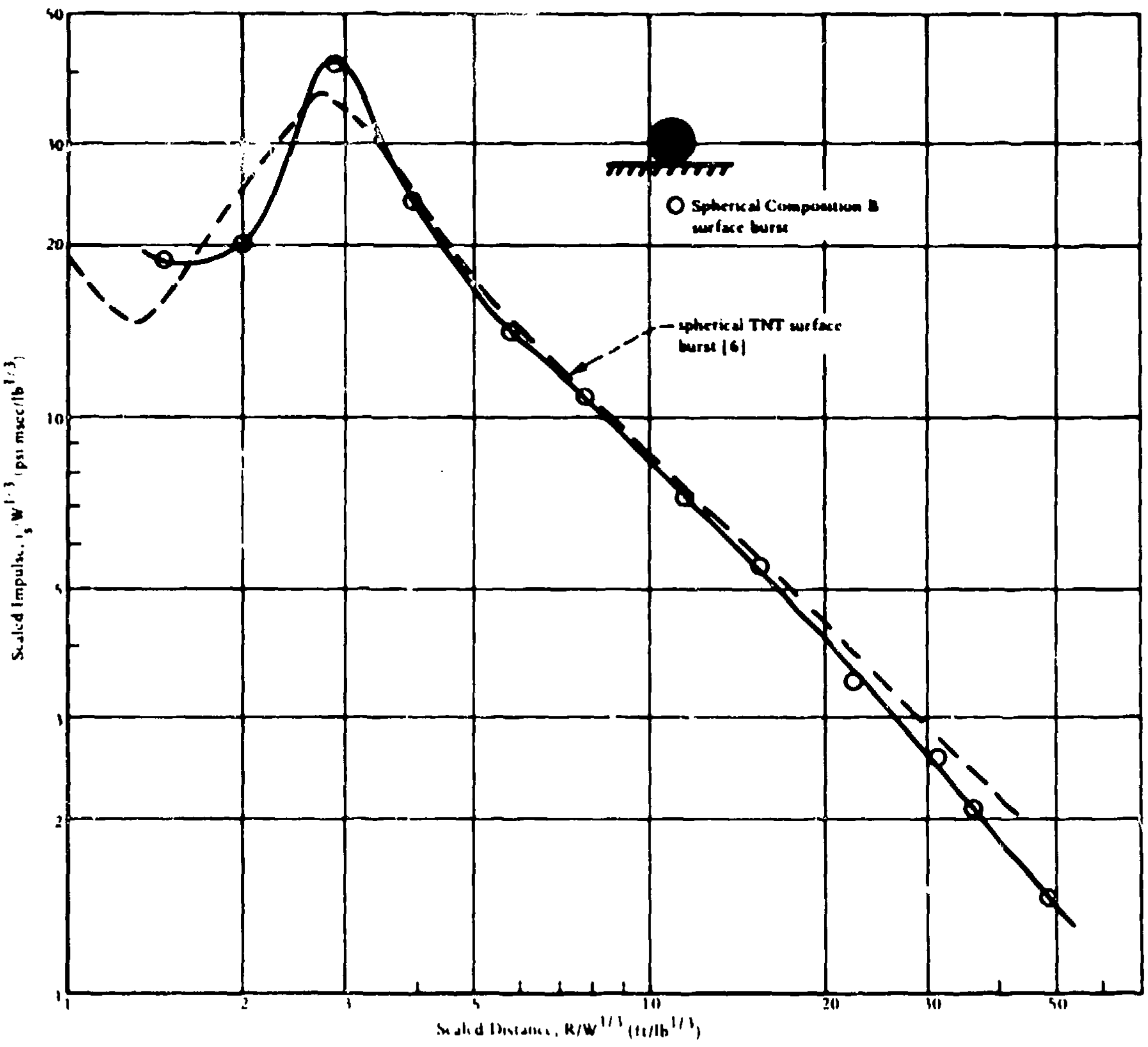


Figure 6. Scaled impulse from spherical surface bursts.

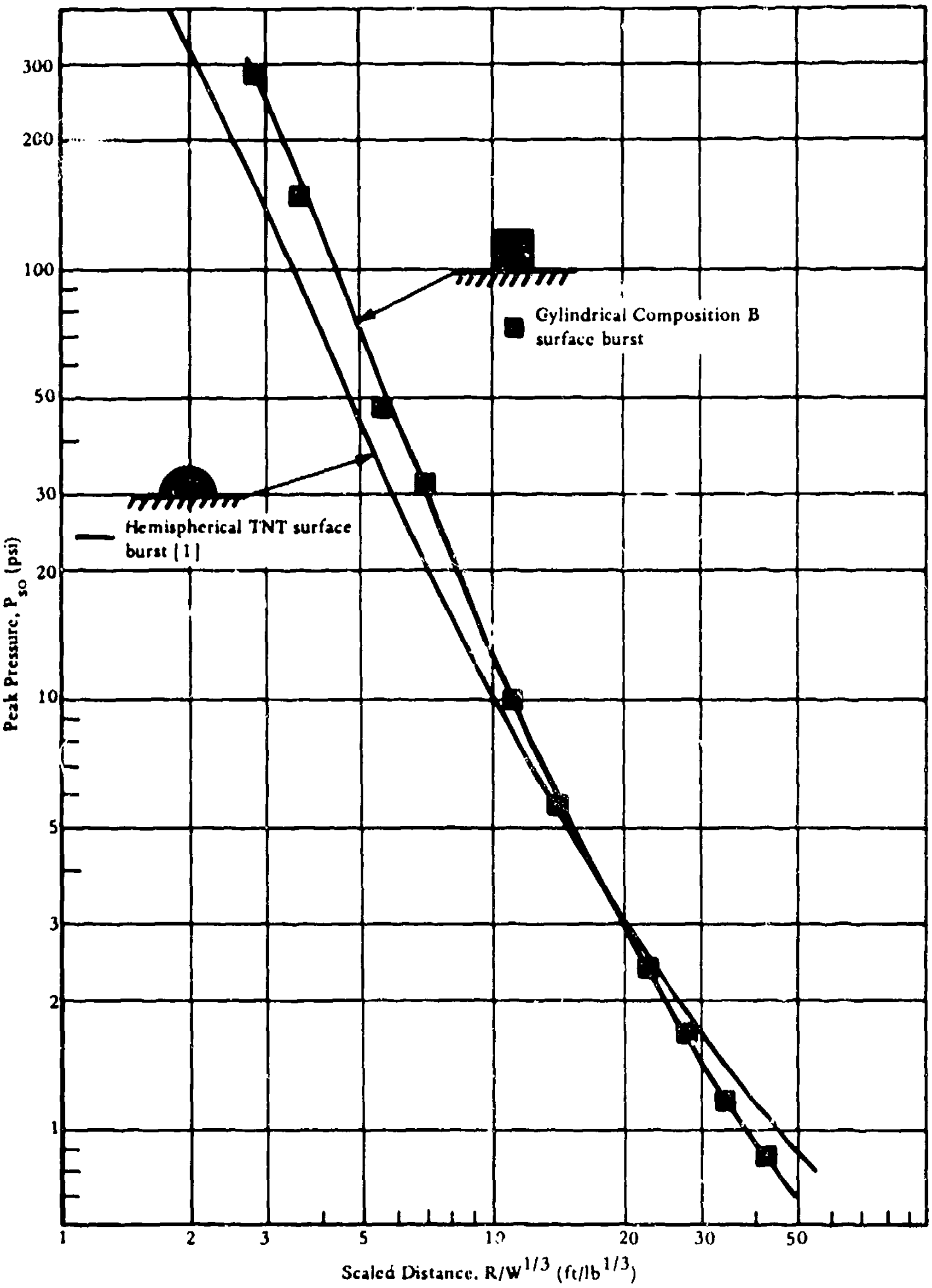


Figure 7. Peak pressure from cylindrical composition B and hemispherical TNT surface bursts.

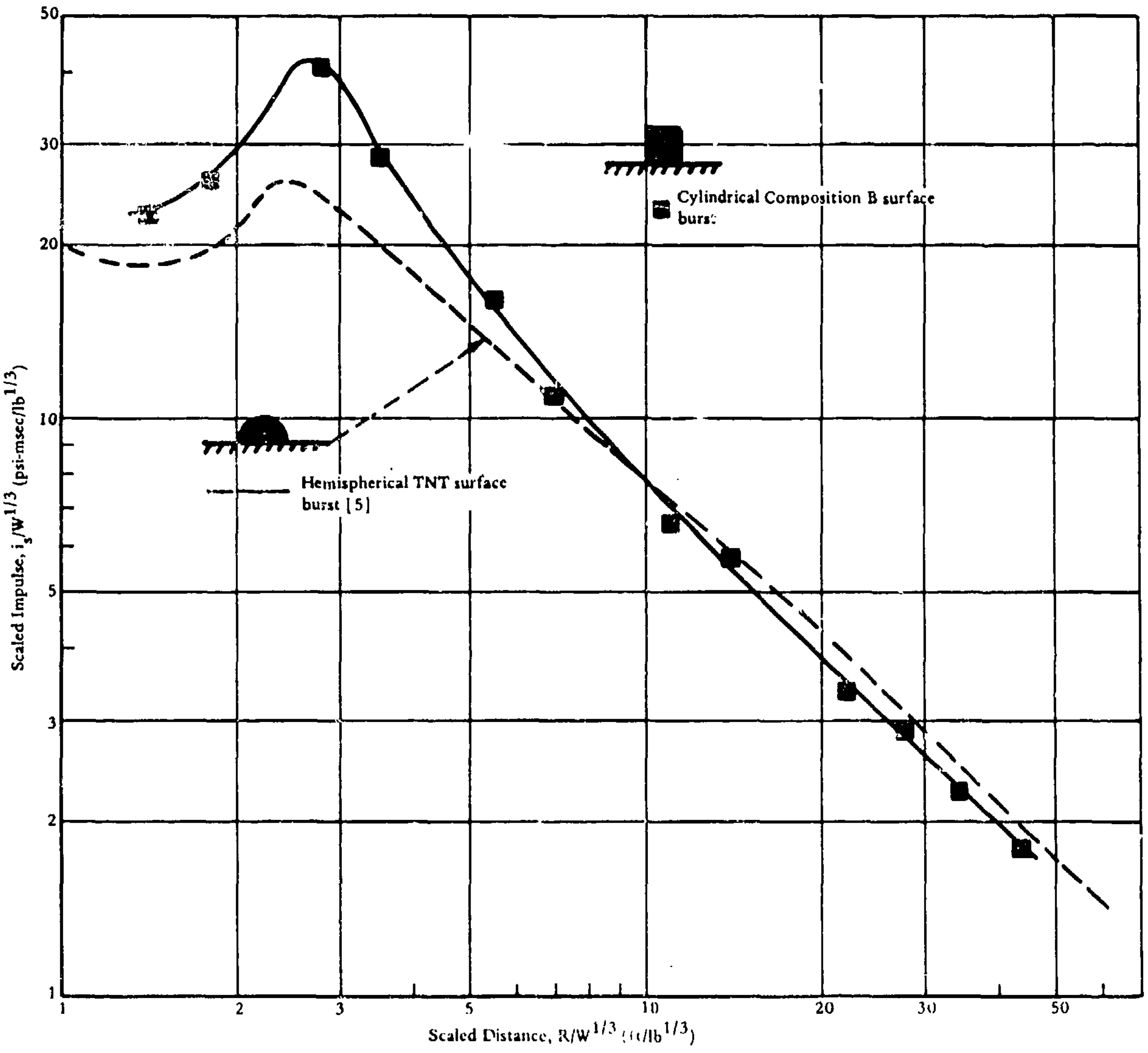


Figure 8. Scaled impulse from cylindrical composition B and hemispherical TNT surface bursts.

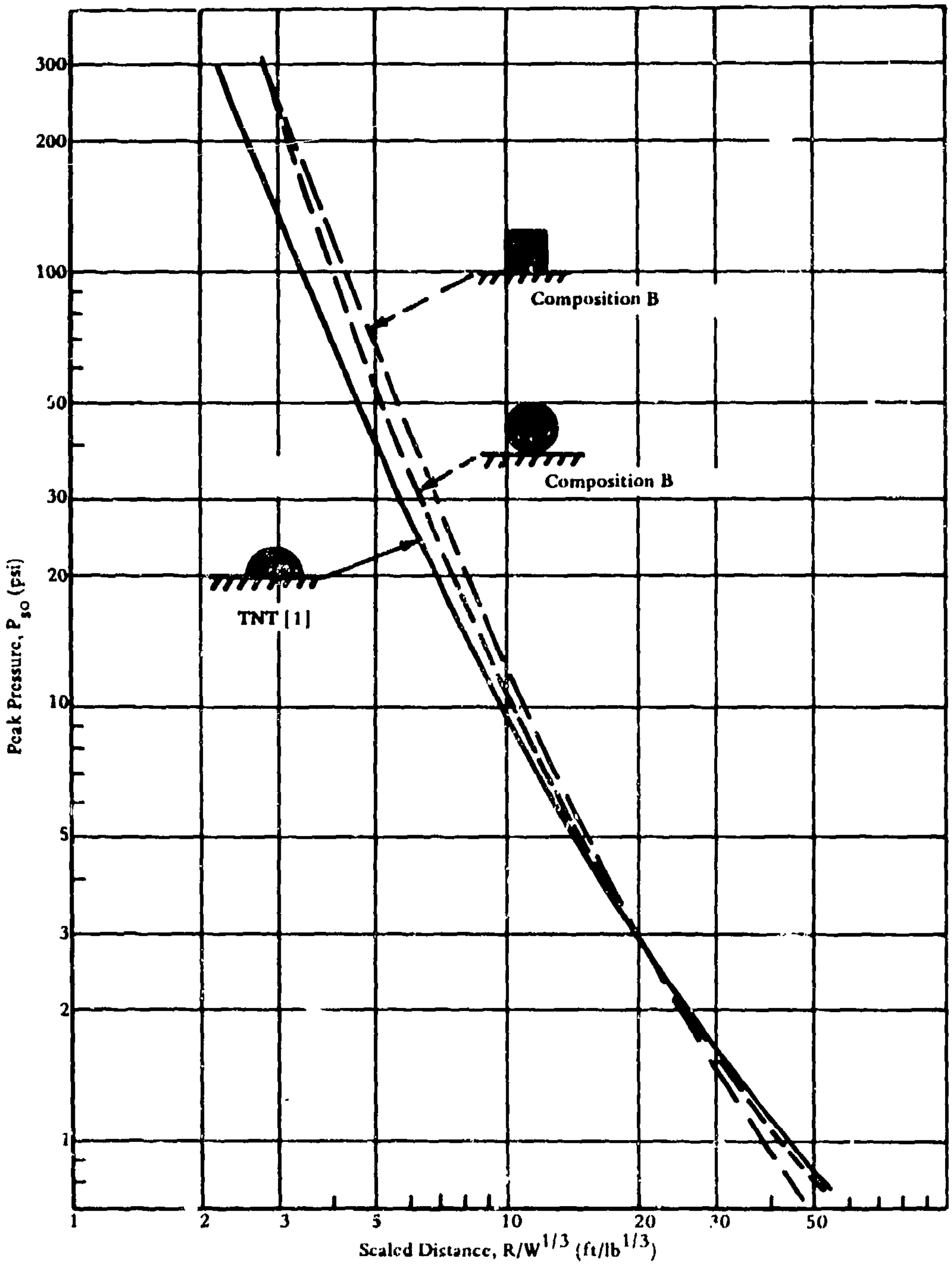


Figure 9. Peak pressure from spherical, hemispherical, and cylindrical surface bursts.

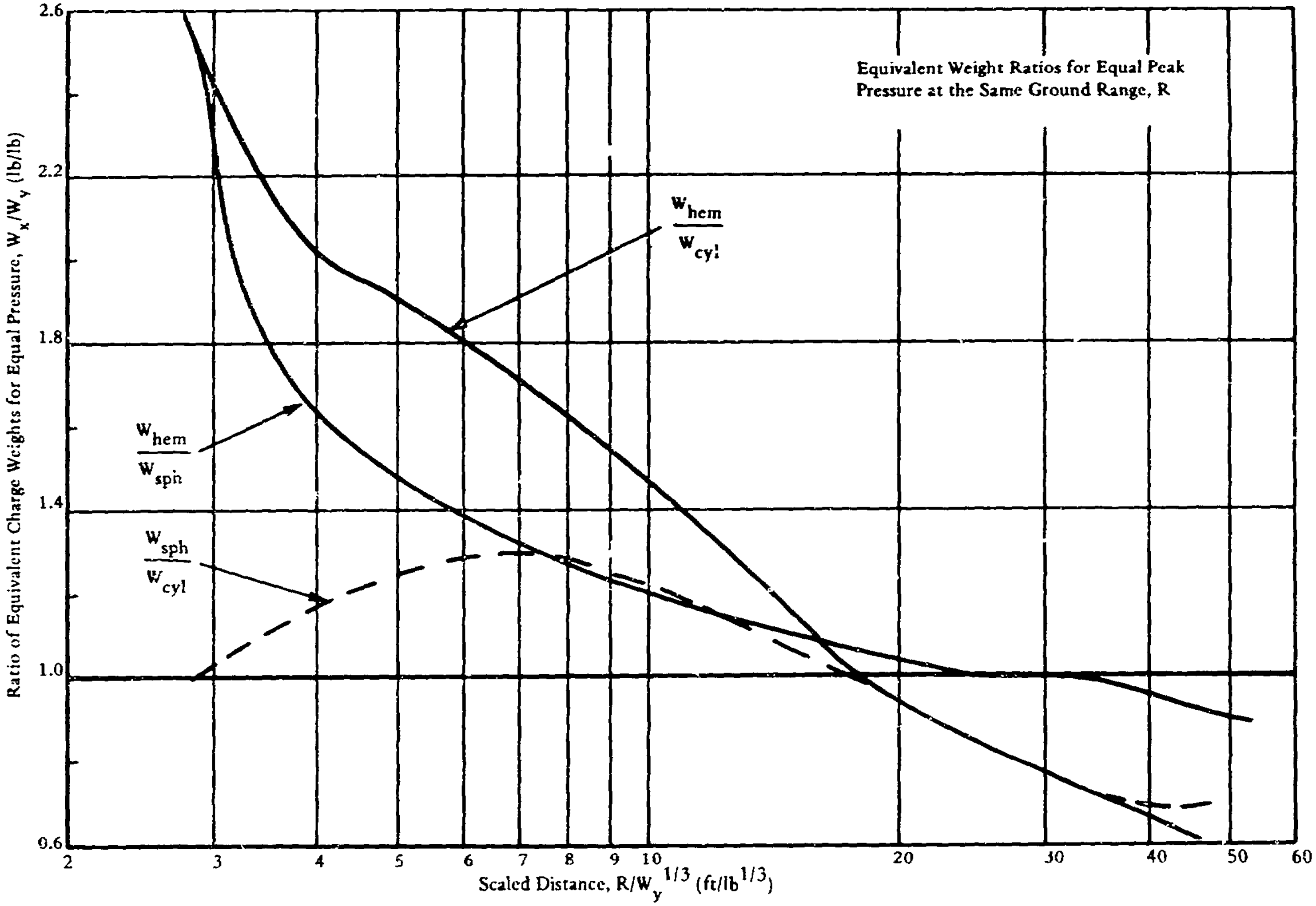


Figure 10. Equivalent weight ratios for equal pressures from charges of different shape.

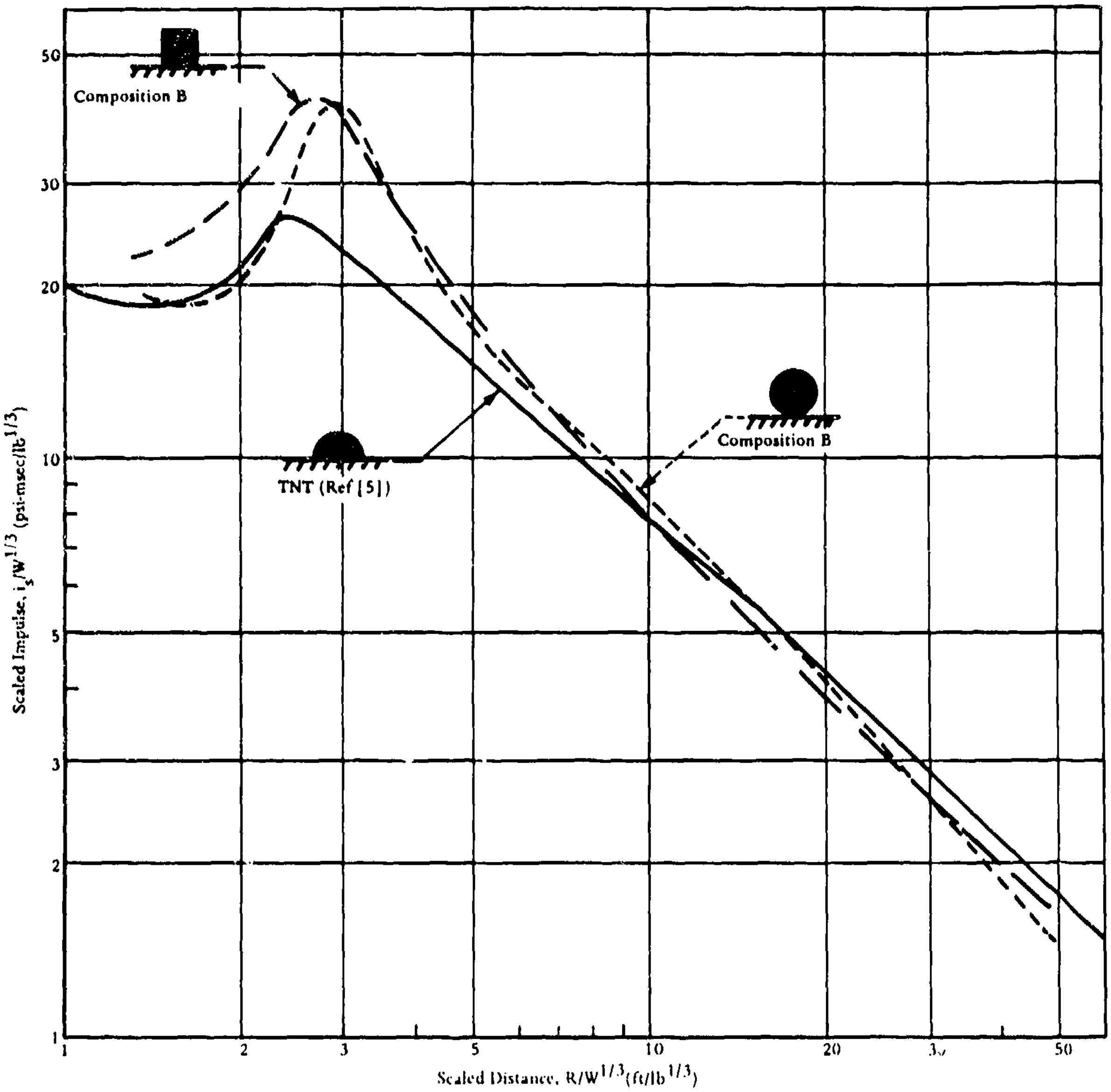


Figure 11. Scaled impulse from spherical hemispherical and cylindrical surface bursts.

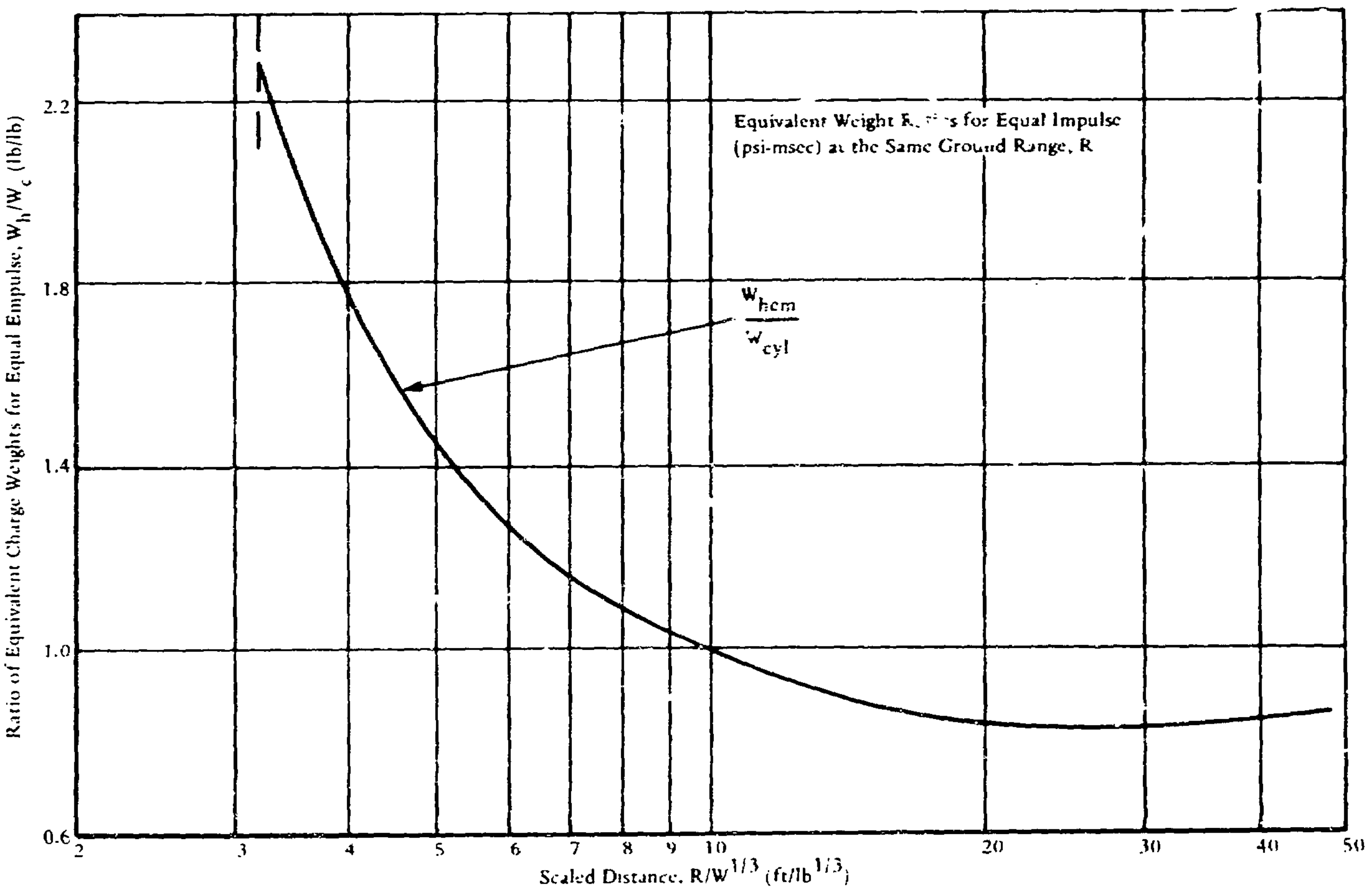


Figure 12. Equivalent weight ratios for equal impulse from hemispherical and cylindrical surface bursts.

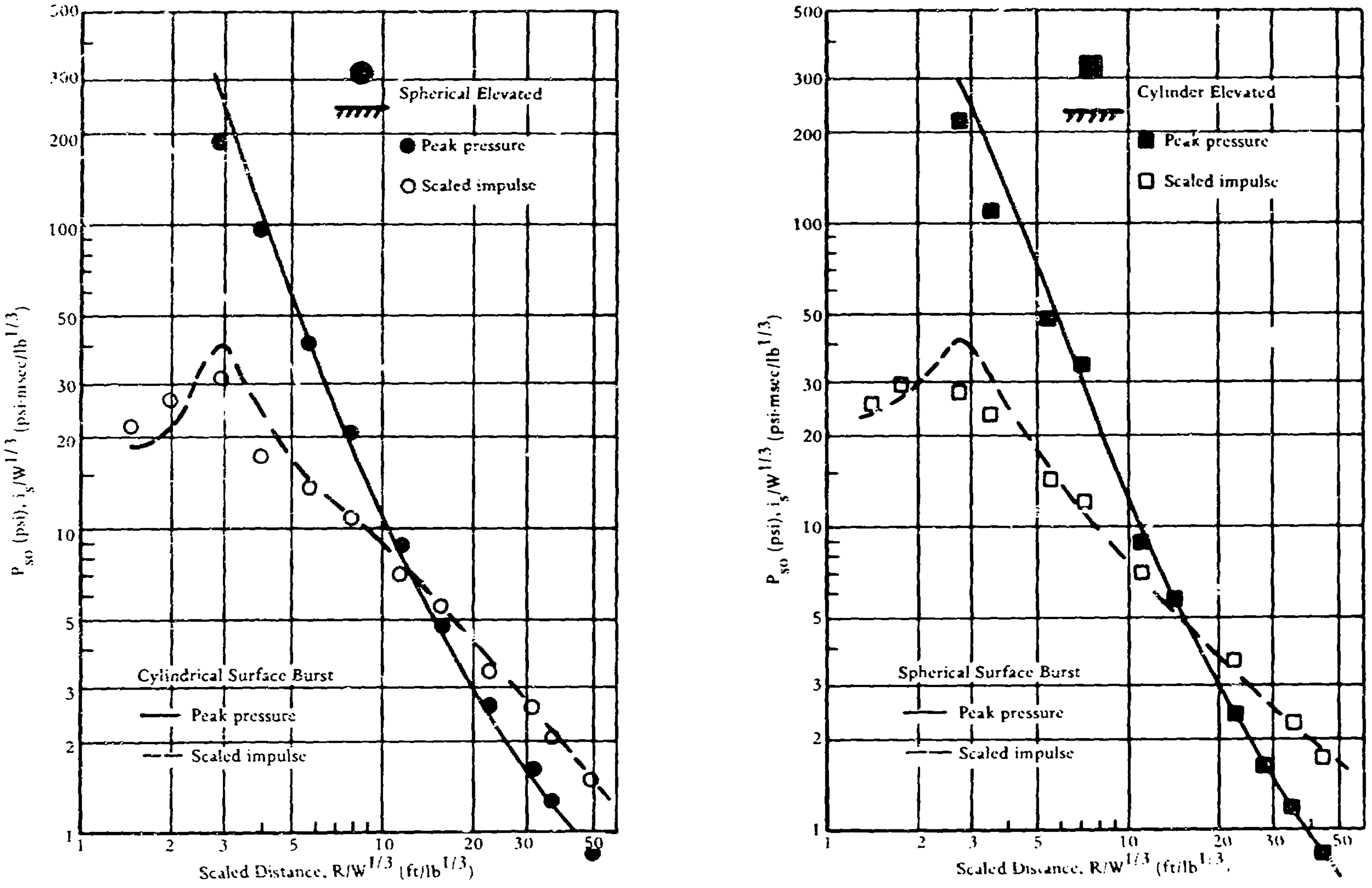


Figure 13. Peak pressures and scaled impulses for surface bursts and elevated cylindrical and spherical composition B charges.

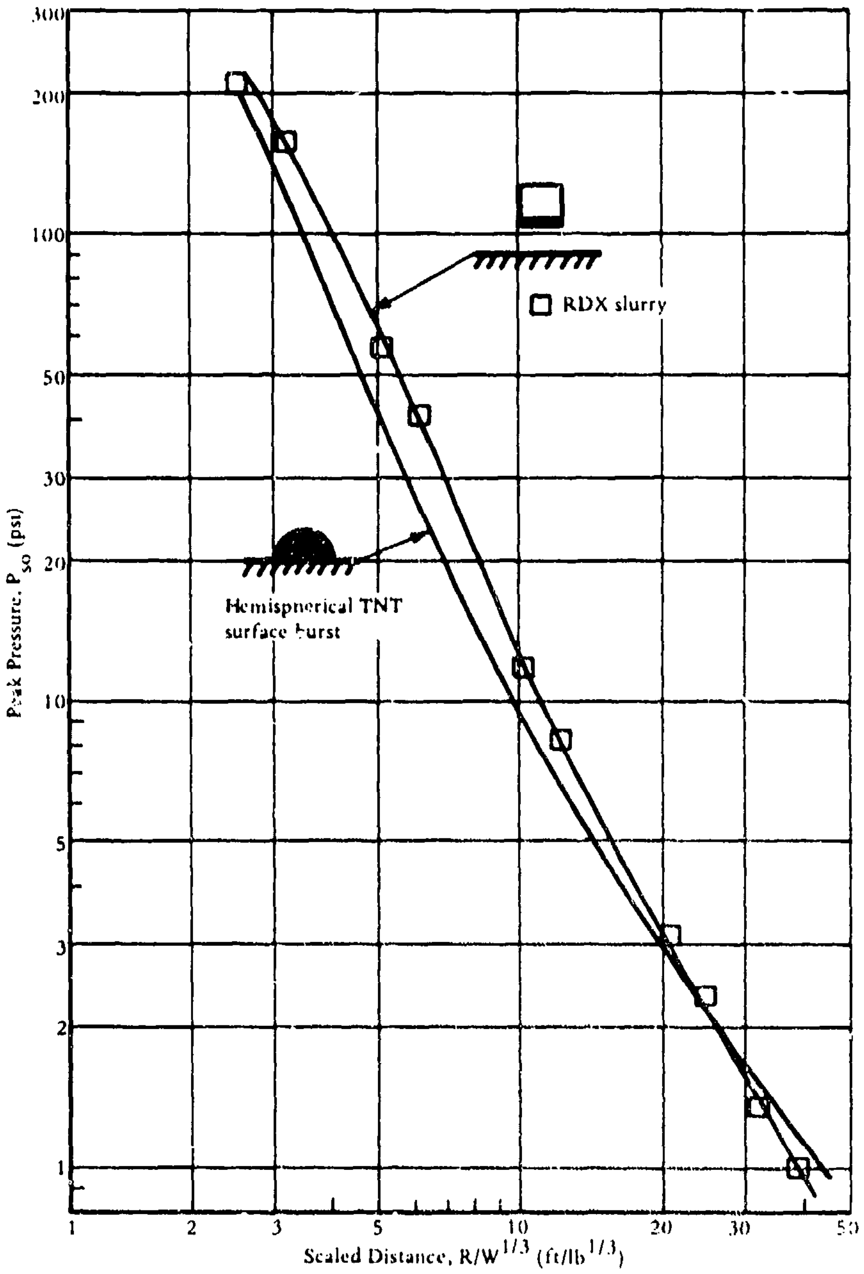


Figure 14. Peak pressure from RDX slurry and hemispherical TNT.

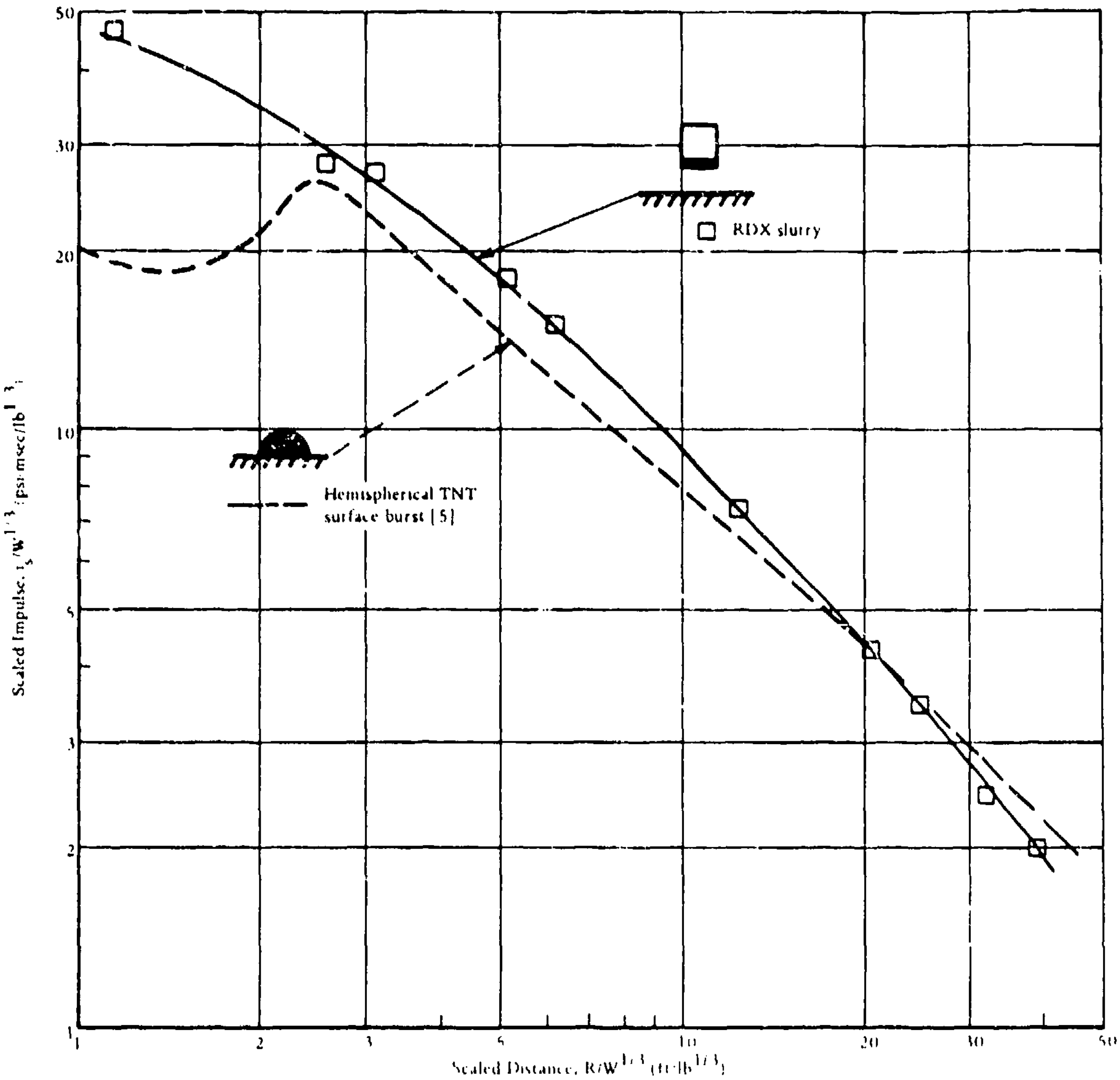


Figure 15. Scaled impulse from RDX slurry and hemispherical TNT.

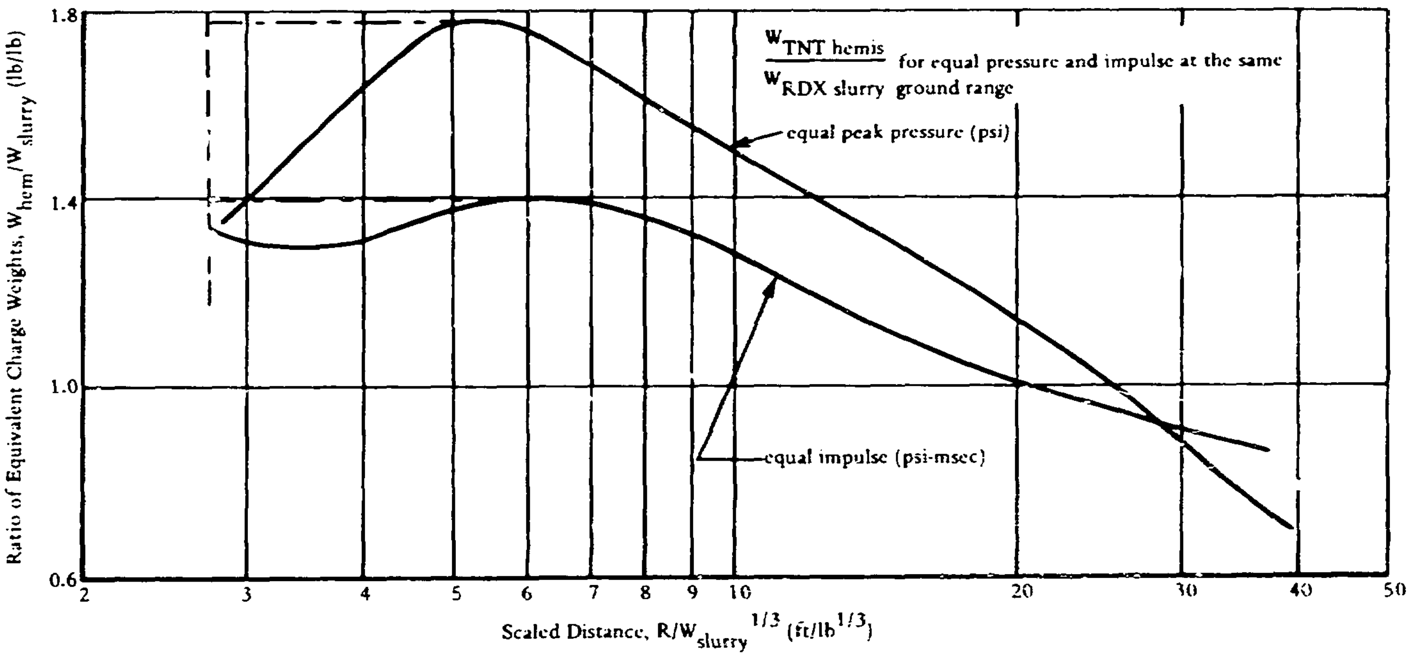


Figure 16. Equivalent weight ratios for equal peak pressure and impulse from cylindrical RDX slurry and TNT hemispheres.

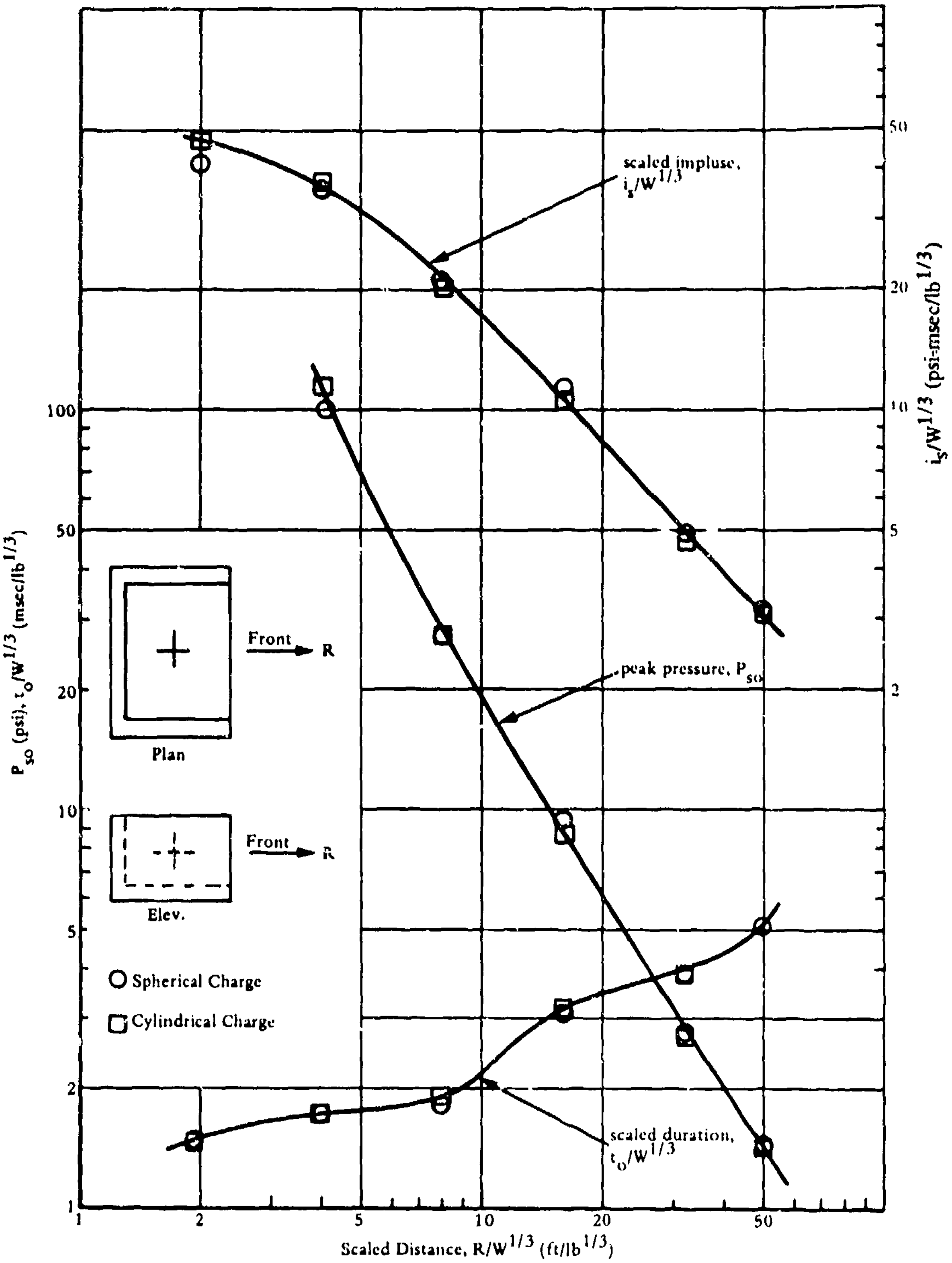


Figure 17. Blast environment out open wall of cubicle for spherical and cylindrical charges (W = 1.0 pound).

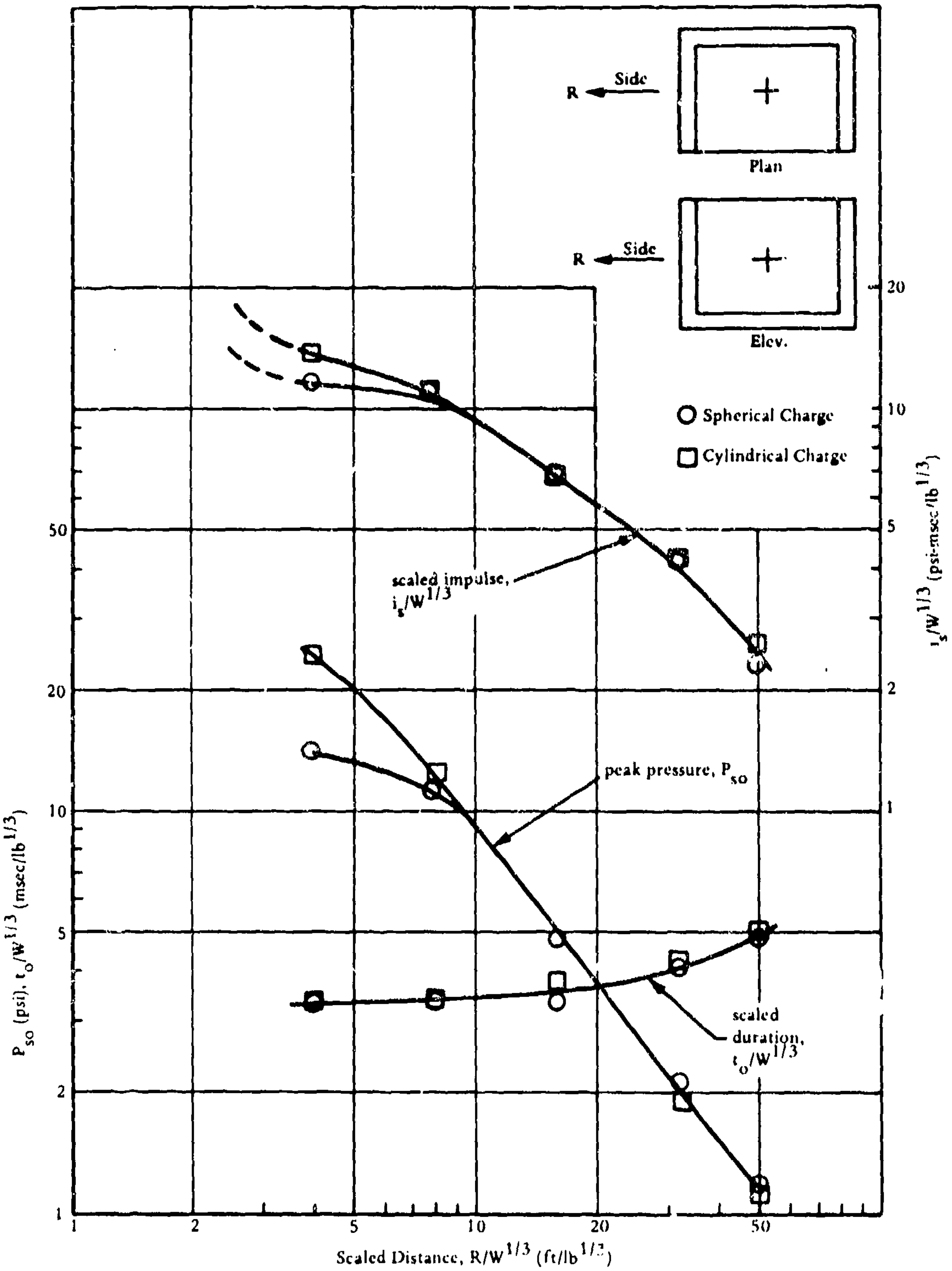


Figure 18. Blast environment behind sidewall of cubicle for spherical and cylindrical charges (W = 1.0 pound).

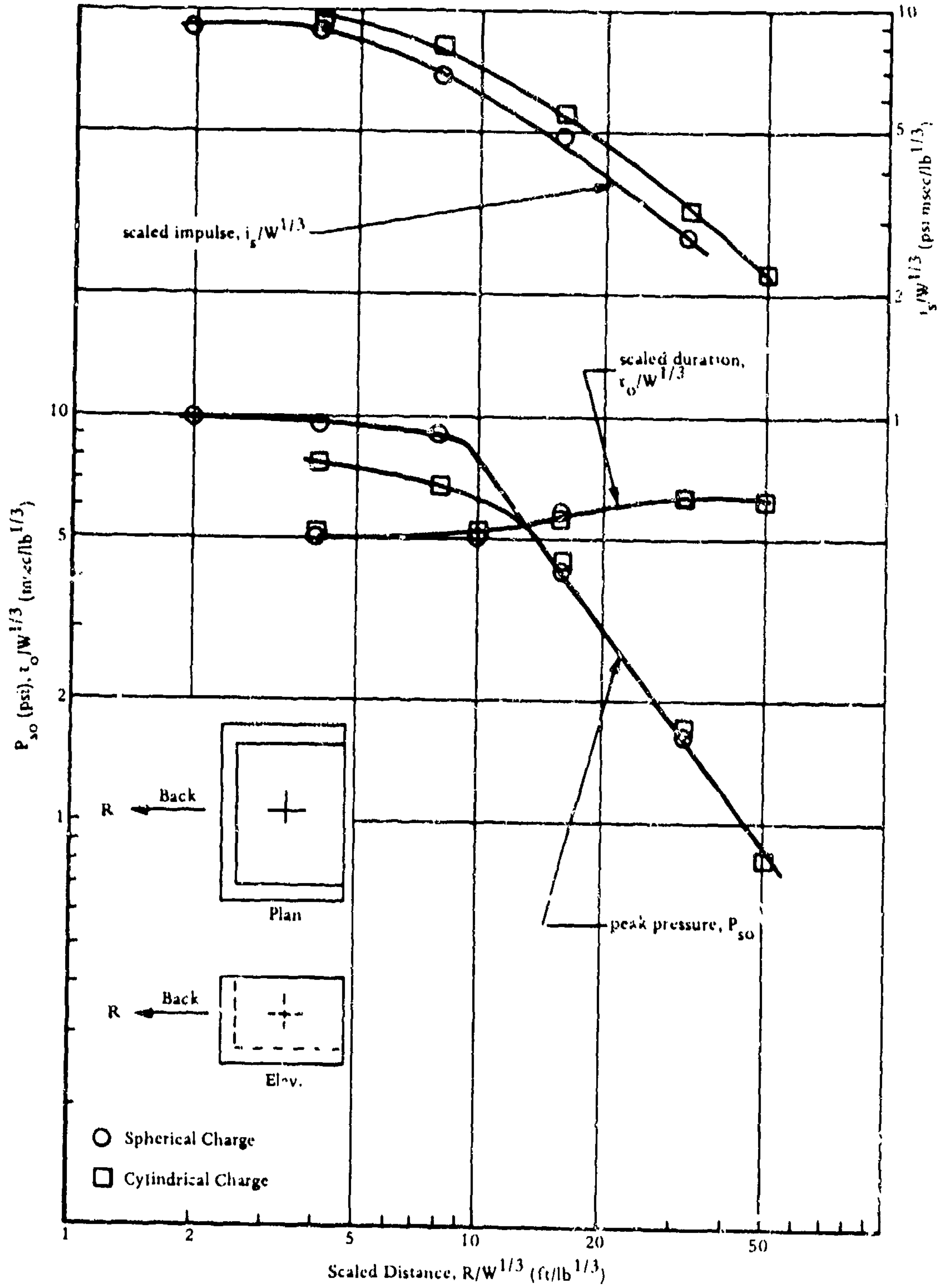


Figure 19. Blast environment behind backwall of cubicle for spherical and cylindrical charges (W = 1.0 pound).

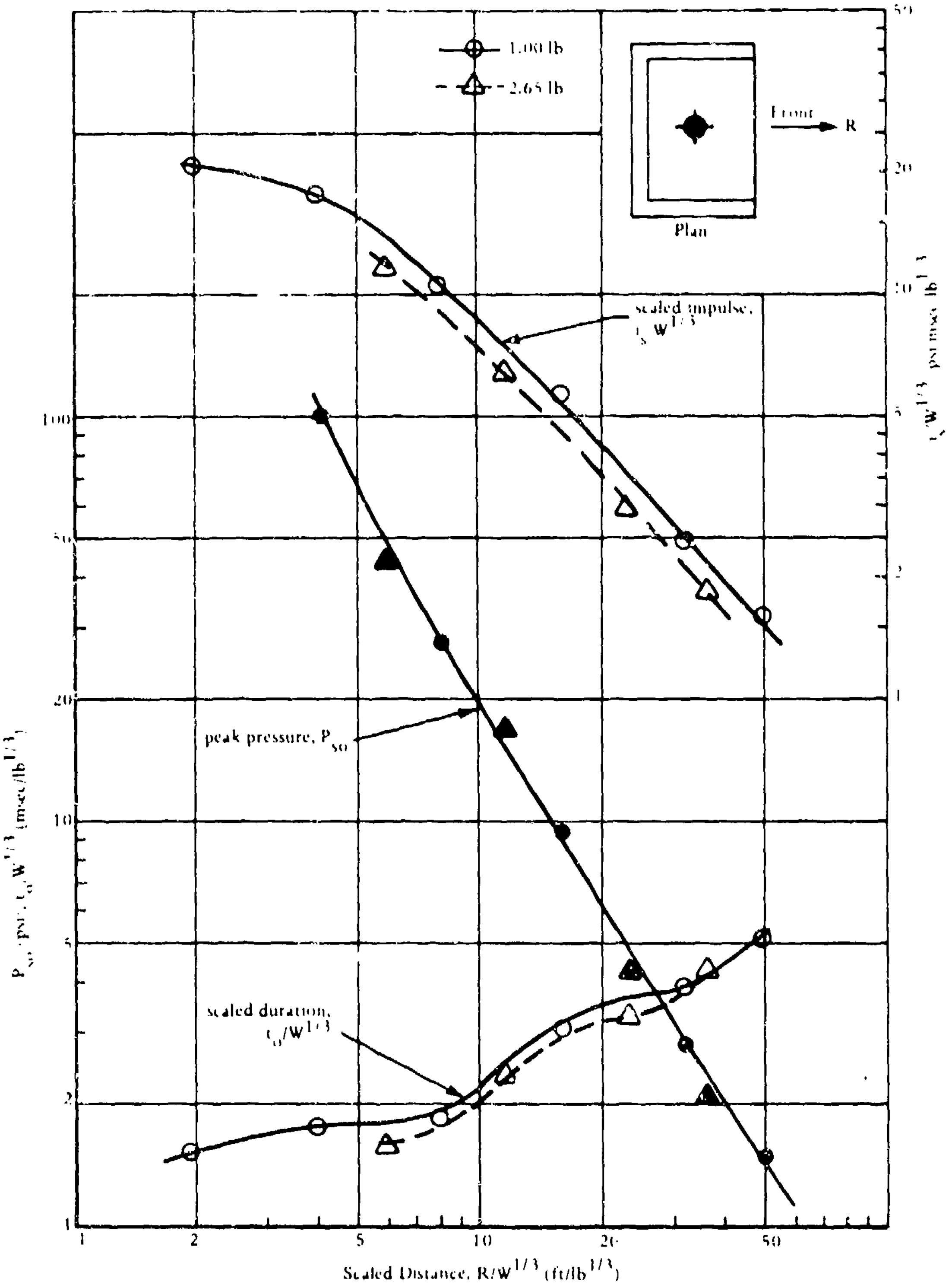


Figure 20. Blast environment out open wall of cubicle for 1.00- and 2.65-pound spherical charges.

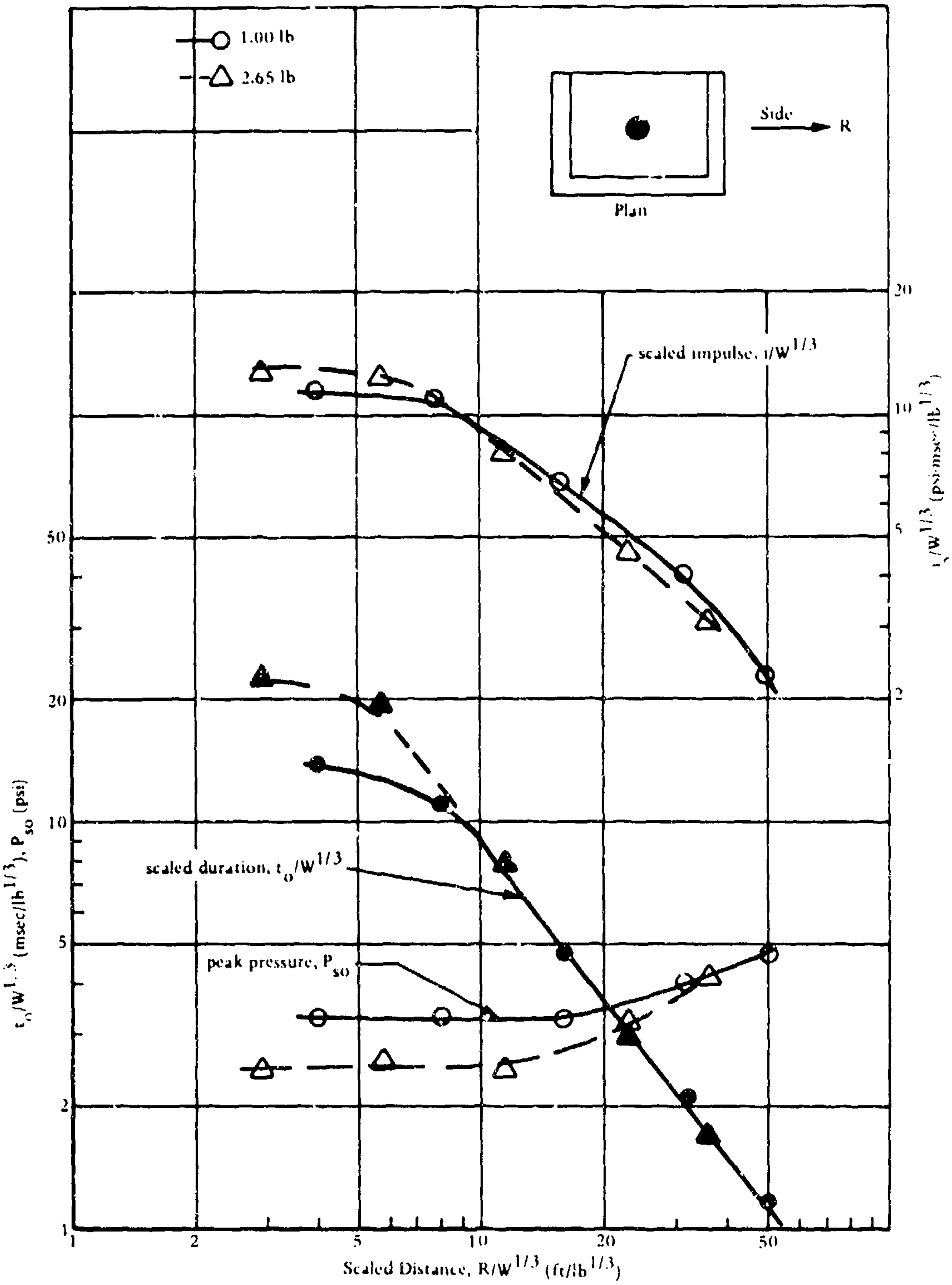


Figure 21. Blast environment behind sidewall of cubicle for 1.00- and 2.65-pound spherical charges.

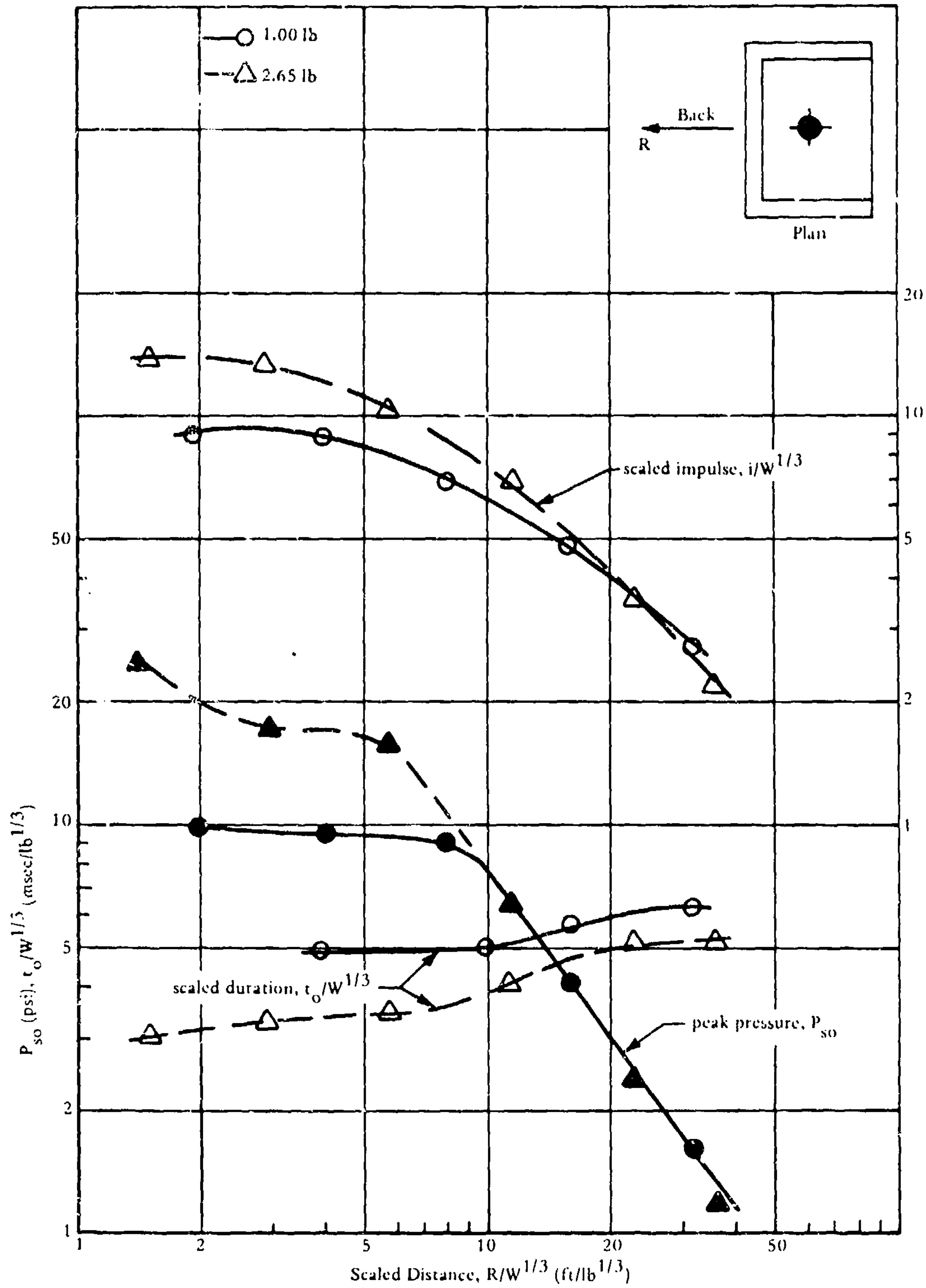


Figure 22. Blast environment behind backwall of cubicle for 1.00- and 2.65-pound spherical charges.

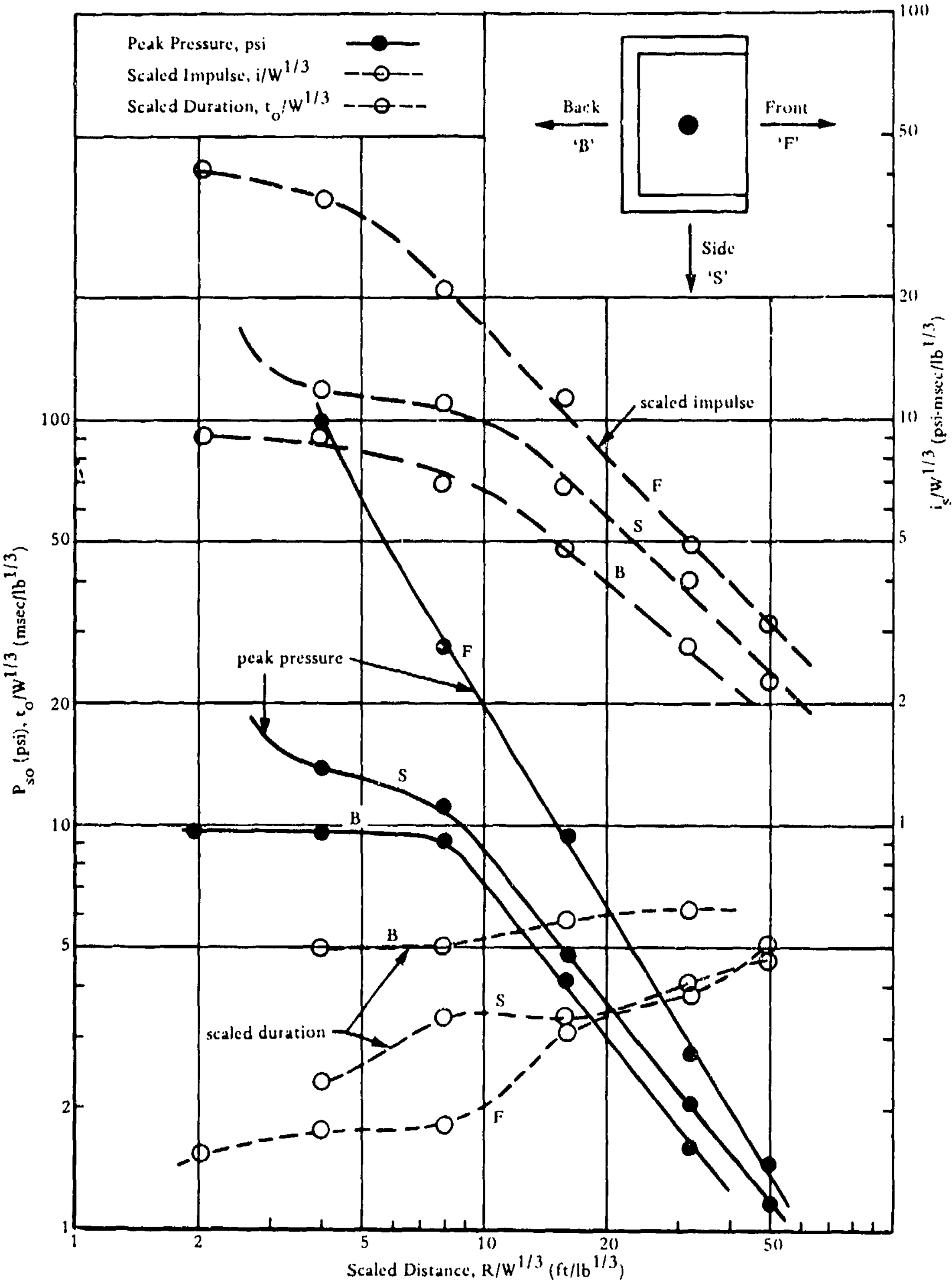


Figure 23. Blast environment outside three-wall cubicle (1.00-pound spherical charge).

THE QUANTITY/DISTANCE CATEGORY (OR HAZARD CLASSIFICATION) OF GUN AND ROCKET PROPELLANTS

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1 INTRODUCTION

The assignment of the correct quantity/distance category (or hazard classification) of explosive materials is becoming increasingly more important. Apart from the direct question of safety, the saving in land for storage of a lower risk material is a considerable factor.

In this paper we are concerned with the categorisation of gun propellants, and composite (plastic) rocket propellants; that is the consequence of ignition of boxes of such materials while in storage or during transport. The relevant categories and classes are shown in Table 1.

TABLE 1

Q/D Categorisation - Hazard Classification

Risk	UK	USA	NATO	UN
Fire	Y	2	2	1.3
Explosive	ZZ	9	5	1.1

Ideally every material should be tested in a full scale trial. This is usually prohibitively expensive. However trials involving one box or container with live propellant, surrounded by a number of boxes or containers filled with inert material are acceptable, and experiments of this type with composite (plastic) propellant are given in Section 4. Reference should be made to the extensive series of trials(1,2) at Aberdeen Proving Ground with MK7 steel, M25 stainless steel containers and metal lined M24 wooden boxes filled with a large variety of gun propellants, which together with earlier work laid the basis of the US Ordnance Safety Manual classifications.

However there is some merit in developing a test which uses less material than is stored in a full box or container, and which can be carried out in a laboratory firing chamber rather than on a range. Such a test is described in Section 2.

The quantity/distance tables are based on radiant heat output for fire risk materials and on blast pressure/fireball radius properties for explosive risk materials(3). If both these distances are plotted against explosive mass it can be shown that at a given distance for a certain mass of fire risk material, this same distance is required by 10-11 per cent of that mass for an explosive risk material. This is a useful guide when assessing the results of trials.

2 THE LARGE SEALED VESSEL TEST

A laboratory type test must have the following capabilities,

(a) it must be relatively simple to conduct, and the result relatively simple to assess

(b) it must be relatively inexpensive, so that the test can be carried out several times to obtain reproducible results in which confidence can be placed and

(c) it must reproduce in some way the inertia of large masses of material and the consequent pressure build-up and thus "scale up" correctly.

Tests which have to compensate for the use of unrealistically small quantities of a material are usually known as "penalty" tests and generally employ a means of relatively high confinement, i.e. most of the bulk of material surrounding the seat of ignition is replaced by a closed metal container. The first attempts at such an experiment were in early 1950's using a 5.5 inch shell body (Fig 1). This was filled with the material under consideration, and ignition was achieved by means of an internal heating coil in place of the exploder. These trials were quite successful except that the extent of fragmentation was usually large, and the results of different firings were sometimes not easy to compare because of the differing thickness of different parts of the shell wall(4).

To overcome this problem another vessel was designed with a constant wall thickness over its central section of similar value to that of the 5.5 inch shell. This has become to be known as the Large Sealed Vessel or LSV, (a smaller version known as the Small Sealed Vessel of similar bursting pressure being used for materials, usually liquids, available only in small quantities). The LSV is shown in Figure 2. The chief features are the long seamless cylindrical tube of cold drawn mild steel with 3/8 inch thick wall, 3 inch ID, sealed at both ends by a 1 inch thick steel disc welded in position, the tube end being peened over. The ends are thus stronger than the main body of the tube, the intention being that the tube should fail, the end discs not becoming detached before this happens. One disc has a small tapered plug hole so that material can be extruded under vacuum into the vessel via the larger tapered filling plug hole in the other disc. Appropriate plugs are screwed in for the actual test as shown in Figure 2. Ignition of the contents is effected by means of a

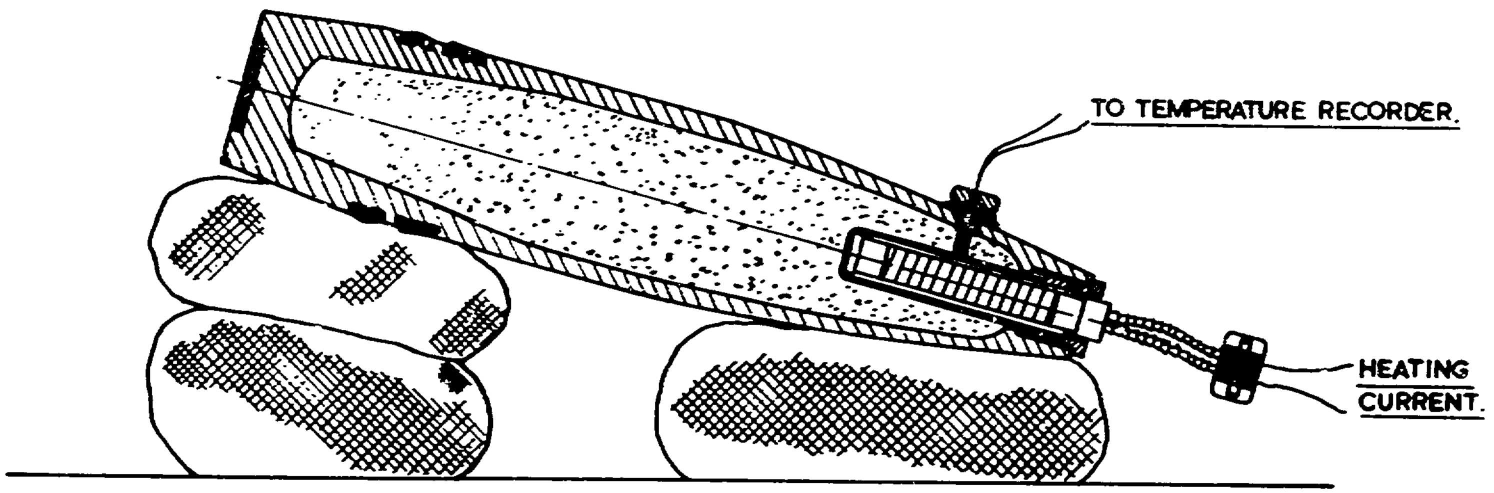
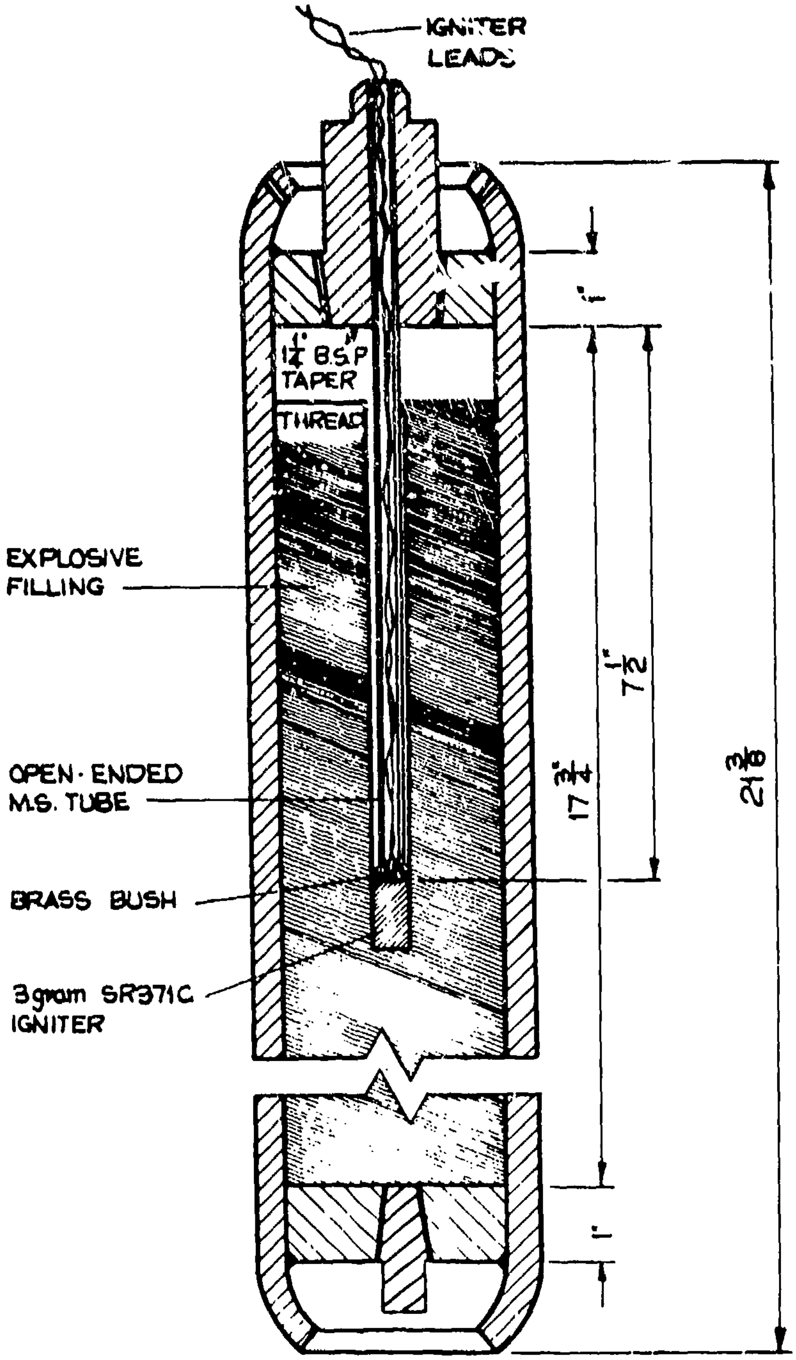


Figure 1



LARGE SEALED VESSEL (IGNITER TYPE)

Figure 2

pyrotechnic igniter fitted to the larger plug. (An alternative form of ignition is by means of external electrical heating, see Section 4). This vessel, of approximately 2 litres in volume, has a calculated static bursting pressure of 12,500 psi, and with all propellant materials ignition leads to the vessel bursting. The degree of fragmentation will obviously depend upon the rate of combustion and gas evolution, and these in turn depend upon the state of subdivision of the material and its energy content as well as its linear (strand) rate of burning. In earlier work names were given to the degrees of fragmentation obtained, such as pressure burst, low order explosion, explosion and detonation. Subdivision between the first two were devised since most of the interest was centered around these results; explosions and detonations were of less immediate interest in that there was no doubt that the material which produced such results was an explosive risk. These assessments were necessarily in some degree subjective, and one modification tried was to measure the length of new metal edge formed. However it has now been found simpler to count the number of fragments produced, excluding the bits of central tube, and it will be seen from the next section that it is possible to establish a criterion for the fire/explosive risk threshold on the basis of the number of fragments formed.

3 CATEGORISATION OF GUN PROPELLANTS

A number of gun propellants of which the correct Q/D category for storage in wooden boxes was known, either by trial or by accident, were subjected to the LSV test. These were ballistite (strictly a mortar propellant), FNH 014, FNH 024, WM 042/30 and WMT 124/040 of which the first two named are recognised explosive risks and the other three are known to be fire risks. Two other materials were studied for which the risk was also known: these were dynamite (65 per cent NG/35 per cent Kieselguhr) and blackpowder (G40) both of which are explosive risks. (See Appendix for compositions and sizes). Four trials were carried out with each material, excepting ballistite when only one trial was done and the results are shown in Table 2. Pictures of some of the results for the first three materials are shown in Figures 3, 4 and 5.

Figure 3

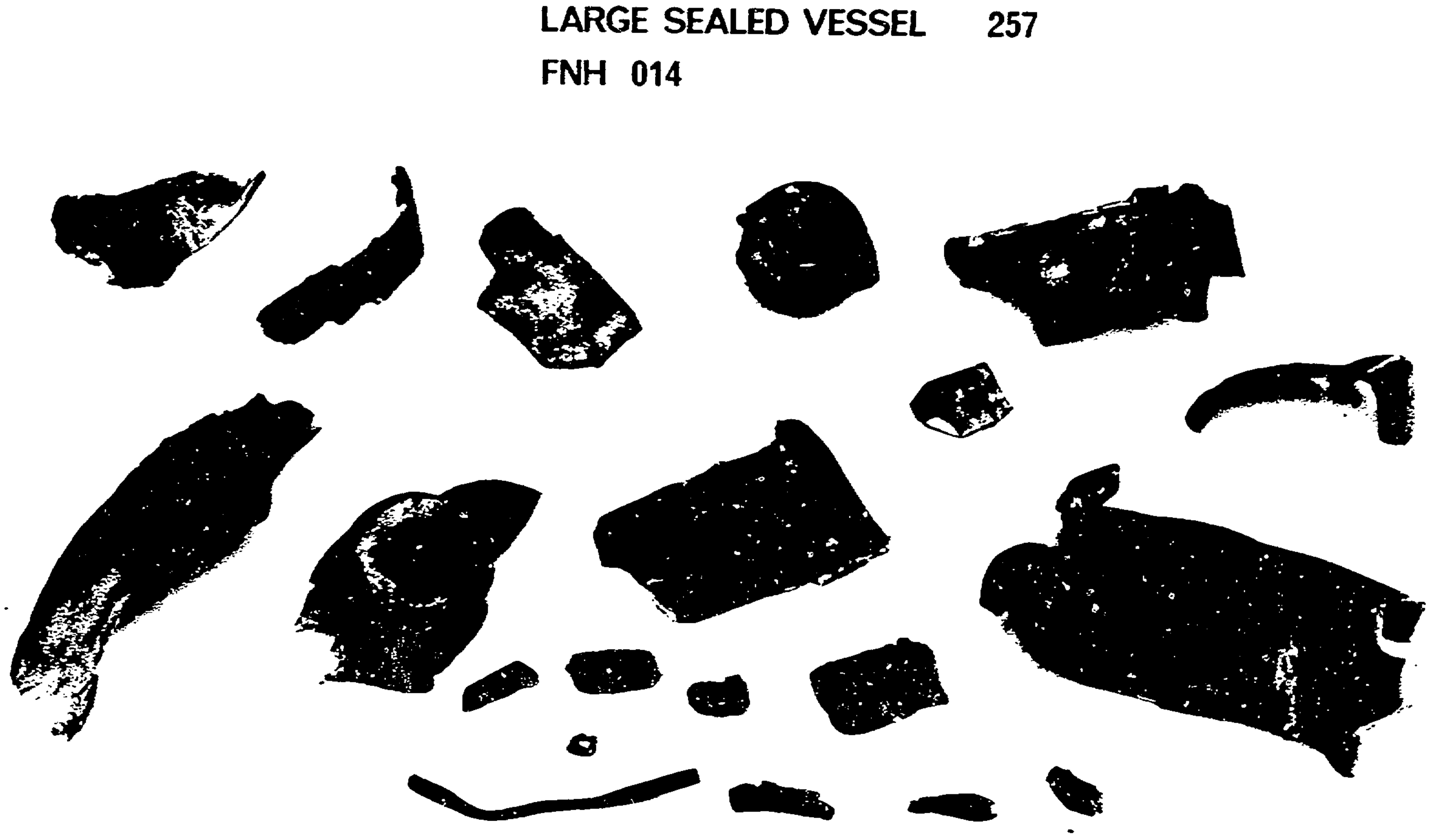


Figure 4

LARGE SEALED VESSEL 259
FNH 024

Figure 7

TABLE 2

LSV Tests on Granular and Cord Propellants

Material	Risk	Number of Fragments (1)	(2)	(3)	(4)	Total for Four Trials
Ballistite	Explosive	> 200				-
FNH 014	"	14	23	19	15	71
FNH 024	Fire	7	3	2	8	20
WM 042/30	"	7	5	5	8	25
WMT 124/040	"	11	7	8	13	39
Dynamite (65% NG)	Explosive	15	25	25	50	115
Blackpowder (G40)	"	19	21	21	17	78

It will be seen that the results for each material are reasonably consistent, and that when the number of fragments for the four trials with each material are totalled, there is a fairly clear cut result. The smallest total for an explosive risk material is 71, and the largest number for a fire risk material is 39. This suggests that a criterion for division into the two risks is the formation of say, 50 or more fragments in four trials for an explosive risk, and less than 50 for a fire risk. This somewhat arbitrary figure seems a reasonable one and may in fact err slightly on the safe side.

4 CATEGORISATION OF COMPOSITE PROPELLANTS

It was obviously of interest to extend the test to non-granular material following the promising results obtained with granular and cord materials. In particular there were doubts about the appropriate Q/D category for composite (plastic) propellants i.e. those based on ammonium perchlorate and a hydrocarbon binder, in some cases containing also aluminum, ammonium picrate and/or burning rate catalysts. As a consequence of their method of manufacture - a simple mechanical incorporation - which leads to entrainment of air, they can be n an undeaerated or, following treatment under vacuum, in a deaerated state.

When these propellants were first studied in this way, the tests were done with undeaerated material, the vessel being filled with lumps small enough to be pushed through the large tapered plug hole, followed by tamping down. This resultant charge was not truly representative of the undeaerated material since it was not really one large piece and owing to the tamping it did not have the original void content. However tests showed that the less energetic and slower burning rate materials gave relatively few fragments and were thus indicated to be fire risks. The more energetic and faster burning compositions gave considerably larger numbers of fragments, in some cases more than twenty from a single vessel suggesting an explosive risk category.

However it was decided that a more realistic assessment of composite propellants would be to test them in the deaerated state, and thus a vacuum filling technique was necessary utilising the bottom plug hole, as indicated in Section 2. Table 3 shows the results of trials carried out in duplicate for a group of plastic propellants in the deaerated state, the majority of them being regarded as fast burning compositions. (See Appendix for formulations.)

TABLE 3

LSV Tests on Composite (Plastic) Propellants

Material	Strand Burning Rate at 10 MN/m^2	Number of Fragments (1)	(2)	Total for Two Trials
RD 2427	4.8 mm/sec	1	2	3
RD 2435	15.0 "	1	2	3
E 4265	35.9 "	3	3	6
RD 2409	43.7 "	7	3	10
RD 2403	48.4 "	3	9	12
RD 2418	48.8 "	5	1	6

It will be seen that the number of fragments obtained is always quite small and for the two trials carried out on each composition the total is in each case considerably less than 25 (being the proportionate figure as required by the criterion given in Section 3).

A number of trials were also carried out with the alternative form of ignition, i.e. by external electrical heating. These usually resulted in a large number of fragments particularly with the faster rate of burning compositions. This was presumably because a greater mass of propellant was brought to or near ignition temperature before ignition occurred. Some porosity may have resulted from pre-ignition reaction as a consequence of this heating, so that the material may to some extent have resembled the undeaerated material. In addition the burning rate of such preheated propellant would be expected to be greater. In contrast, tests with the heated LSV using the granular gun propellants of Section 3 usually gave about the same number of fragments as with the igniter version. Because of this marked difference with plastic propellant in the two versions of the test, it was thought necessary to complement these trials with a series of single box and small stack trials, especially as there had not been any major incidents with plastic propellants from which levels of risk could be deduced.

Standard plastic propellant boxes (Figure 6) containing the standard quantity (55 lb) of each of the following propellants, RD 2427, RD 2420 (burning rate at 10 MN/m^2 of 5.8 mm/sec), RD 2435, E 4265, RD 2428 (R_b = 46.5 mm/sec) and RD 2403, both undeaerated and deaerated were studied. Single box igniter trials were carried out in duplicate; the igniter being embedded in the propellant. With RD 2427 and RD 2420, undeaerated or deaerated, and with deaerated RD 2435, the lids remained in position during combustion of the contents of the box. With undeaerated RD 2435, and either form of E 4265, RD 2428 and RD 2403, the lid was blown off very quickly. With the undeaerated propellants lumps of burning material were thrown out; with the deaerated materials combustion of the remaining material proceeded in an open box. No measurable blast was recorded in any of these trials.

Standard fuel fire trials on single boxes of the same materials (both deaerated and undeaerated) were also carried out, but in view of the results of the igniter trials, were not carried out in duplicate. No measurable blast was obtained in any of these trials either.

Since with the faster burning propellants relief of internal pressure in the box was effected by the failure of the lid fastenings, it was considered desirable to carry out a series of trials on "small stacks" more representative of practical conditions of storage, with ignition of the contents of one of the bottom row of boxes in the stack. Three boxes of propellant were placed side by side in a brick lined concrete pit, and nine "mock-up" boxes filled with sand, each equal in weight to a box of

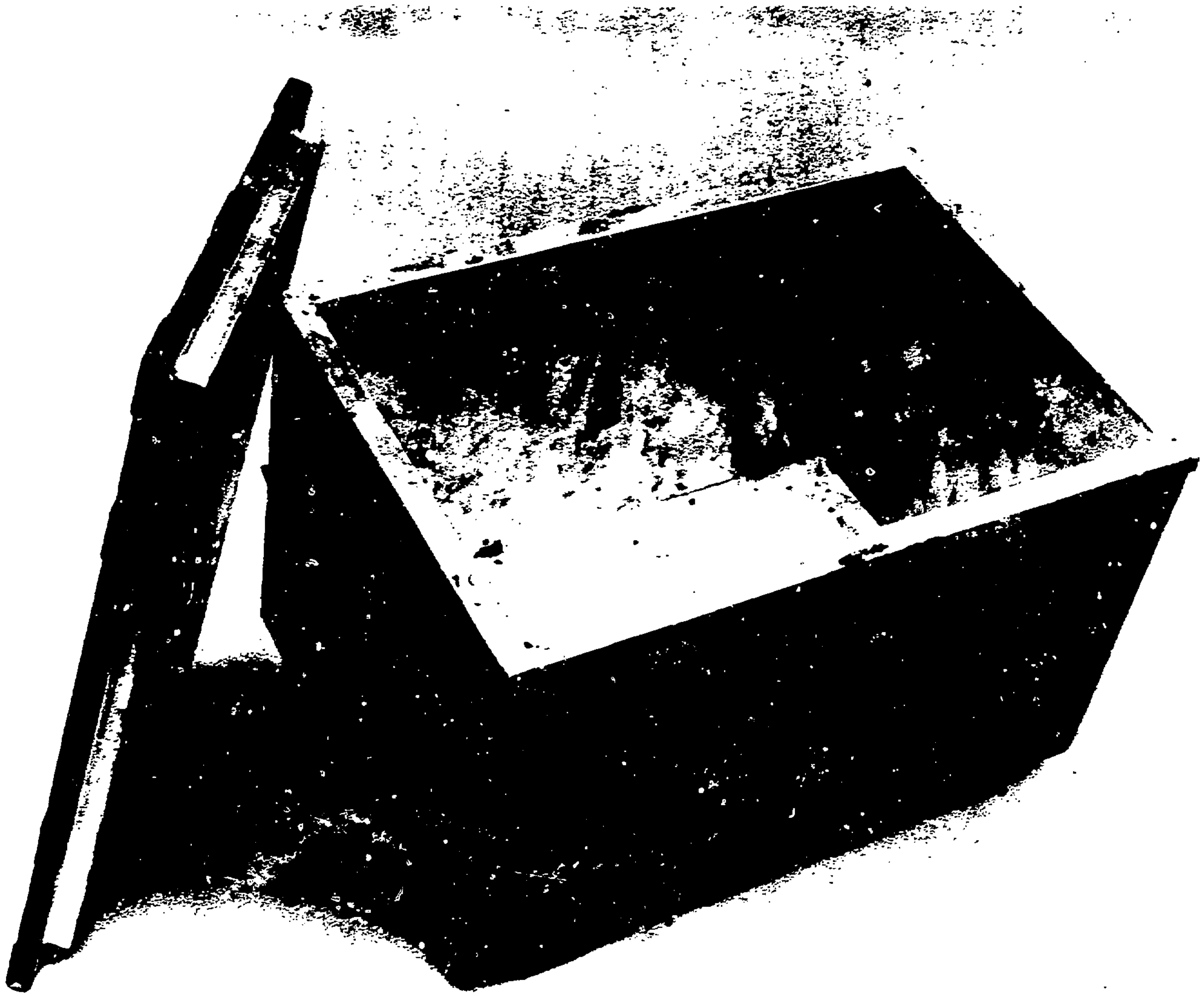


Figure 6

propellant, placed on top in a three by three array. (Figure 7). The propellant in the central box was ignited by means of an igniter embedded in it.

With RD 2435, a medium rate of burning material, undeaerated, a slow burning took place such that initially the central group of sand-filled boxes moved up and down several times as a chuffing type of combustion ensued. Eventually all the boxes including the contents of the two acceptor boxes were set alight. No measurable blast effect was detected in this trial.

With RD 2403, a fast burning rate material, deaerated, a more rapid event took place. Eventually all the sand filled boxes were set alight but the contents of the two acceptor boxes were unaffected. The first measurable blast response was approximately equivalent to that obtainable from 0.5 g TNT.

With RD 2403, undeaerated, a very rapid event took place, disrupting the stack and throwing pieces of burning propellant up to 100 feet. The two acceptor boxes were charred externally but their contents were unaffected. The blast response was assessed on an overpressure basis as roughly equivalent to that obtainable by 0.5 kg TNT (i.e. 2 per cent of the mass of propellant in the box).

Thus these trials showed that the resultant blast under conditions of confinement similar to that appropriate to boxes stacked in a magazine is small and well within the figure of 10 - 11% allowable for fire risk category materials as noted in Section 1. The conclusion drawn from these trials was that composite propellants with rates of burning not in excess of those tested, are to be categorised as a fire risk not only in the deaerated state, but also in the undeaerated condition, provided they are contained in standard plastic propellant boxes and that these boxes are not stacked more than four high. (It should be noted, however, that mixing of the ingredients in an incorporator is regarded as an explosive risk).

5 MODERN GUN PROPELLANTS

The test is being extended to studying gun propellants of more modern formulations including those of higher energy. The results so far confirm that NQ(m) propellant (of web size 0.044 inch) is a fire risk. Some higher energy formulations of similar or greater web thicknesses are giving larger numbers of fragments. However an insufficient number of trials has so far been carried out to suggest their Q/D category. This work is proceeding.

6 DISCUSSION AND CONCLUSIONS

It is felt that this test is a very useful one in determining the Q/D category of an explosive composition. The sharp distinction in result

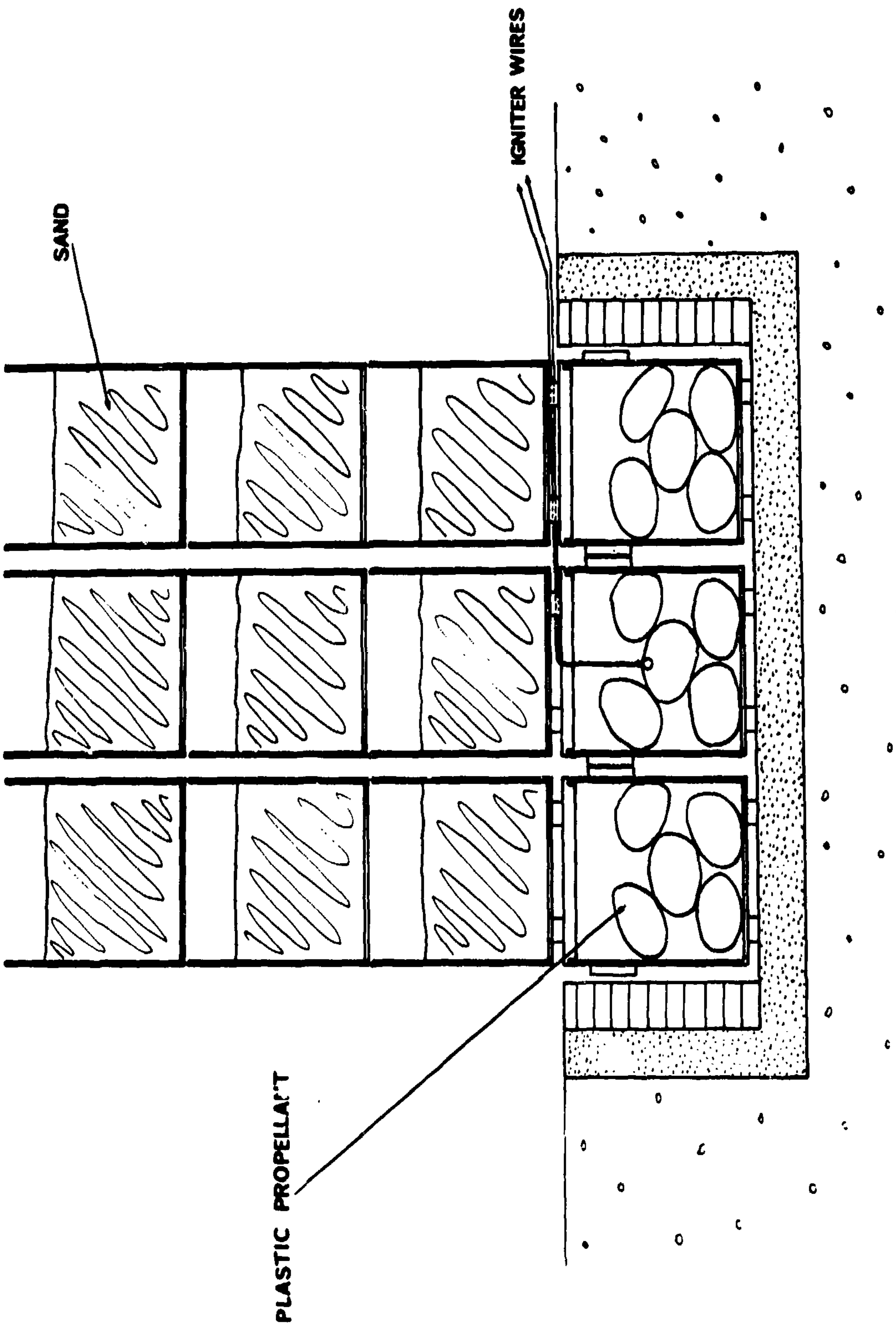


Figure 7

obtained with say FNH 014 on the one hand and FNH 024 on the other indicates the good discrimination provided by the test for granular and cord materials. This also illustrates the well known difference in risk of single base propellants with a web size smaller and larger than 0.019 inch. As indicated in Section 5 above, it is intended to study gun propellants of a wider range of composition and size, particularly the modern types with faster rates of burning. It is of interest here to note that whereas this test may be satisfactory from the point of view of categorisation for transport and storage, the LSV has a bursting pressure appreciably less than the chamber pressure of a modern gun and in this context ultra high pressure rate of burning experiments of the type carried out by Wachtell and Shulman(5) are extremely valuable in indicating those propellants likely to lead to run-away reaction in a gun chamber with consequent detrimental effects. The LSV test should however sort out those propellants prone to this runaway process at pressures less than its bursting pressure.

The application of the LSV test to solid composite (plastic) propellant has been the subject of much argument in the UK. As the test was originally conceived, the results of the two types of trial i.e. ignition by internal igniter and ignition by external heating, were to be taken into account and in fact were given equal weight. Since the early tests with small lumps of undeaerated propellant and even with deaerated propellant most of the heated LSV trials, particularly for the faster rate of burning compositions, gave considerable fragmentation, declarations of explosive risk had to be given in the absence of information to the contrary. The general feeling of those whose job it was to devise, develop and manufacture plastic propellant compositions was that none of them was in fact an explosive risk. Thus it was essential to carry out the box trials outlined above and the results with one of the fastest burning composition in the undeaerated and deaerated state shows that though combustion can be very rapid the blast output is quite small. When the combustion is rapid ignition is unlikely to spread even under magazine conditions to adjacent boxes sufficiently rapidly for reinforcement of the blast wave; with slower burning compositions though the combustion may spread to adjacent boxes, the blast overpressure will in any case be very small.

The results discussed above suggest the heated LSV is too great an overtest for categorisation of plastic propellant (though probably not for granular materials) and it is felt that the proportion of propellant brought to a high temperature with the consequent changes in physical and chemical properties is far higher in the test than it would be in practice if a box or boxes is engulfed in flame. The results of the standard fuel fire trials on single boxes with their lack of blast output are in agreement with this.

Heated trials are however still of value in particular cases especially with granular materials, and obviously if the degree of fragmentation is small the result can be taken to add confidence to categorisation as a fire risk. As we have seen however, the converse, i.e. considerable fragmentation may not necessarily be indicative of an explosive risk.

Though the question of low temperatures should not arise in storage and transport, the igniter version of the test could be of some use, particularly in those cases where ignition is liable to fracture the composition and provide a much increased surface area for combustion.

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APPENDIX 1

Compositions and Sizes of Gun Propellants

Ballistite: NC (12.65 per cent N) 60.0 per cent, NG 38.0 per cent, carbamite 0.5 per cent, potassium nitrate 1.5 per cent.

Plates 0.06 inch square, 0.008 inch thick are graphited.

FNH: NC (13.15 per cent N) 84.0 per cent, dinitrotoluene 10 per cent, dibutyl phthalate 5.0 per cent, diphenylamine 1.0 per cent.

(a) FNH 014, single perforated tube, external diameter 0.041 inch, web thickness 0.014 inch.

(b) FNH 024, multiperforated tube, external diameter 0.128 inch, web thickness 0.024 inch.

WM: NC (13.1 per cent N) 65.0 per cent, NG 29.5 per cent, carbamite 2.0 per cent, mineral jelly 3.5 per cent.

(a) WM 042, cord of diameter 0.042 inch.

(b) WMT 124/040, single perforated tube, external diameter 0.124 inch, web thickness 0.042 inch.

(Blackpowder: Potassium nitrate 75 per cent, charcoal 15 per cent, sulphur 10 per cent.

For size G 40, all granules to pass No 30 BS sieve, and not less than 88.5 per cent to be retained on No 52 BS sieve.)

APPENDIX 2

Compositions of Composite (plastic) Propellants

Number	Ammonium Perchlorate	Binder	Ammonium Picrate	Aluminium	Copper Chromate	Titanium Dioxide	Oxamide
RD 2427	42	13	38	5	-	-	2
RD 2435	63	11	14	12	-	-	-
E 4265	68	13	-	18	1	-	-
RD 2409	66	12	20	-	1	1	-
RD 2403	85	13	-	-	2	-	-
RD 2418	77	12	-	10	1	-	-
RD 2428	74	11	-	14	1	-	-
RD 2420	51	12	27	10	-	-	-

APPLICATION OF LATEST SAFETY ENGINEERING CONCEPTS TO MUNITION PLANT MODERNIZATION

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ABSTRACT

A brief review of the magnitude of the Army Plant Modernization Program planned through 1992 is presented. Attention is focused on a typical major facilitization project at Lone Star Army Ammunition Plant entailing modernization of the 105mm load, assemble and pack line. Emphasis is placed on safety features embodying recently developed concepts. The paper discusses and contains some examples of wall design for close-in blast effects, optimum quantity distance building layouts, safe separation distances of explosive items, buildings designed for far-out blast effects, explosive waste collection, building-access designs to avoid direct line of sight of flying projectiles and protection afforded by low cost innovations such as earth mounded structures.

INTRODUCTION

The U.S. Army has underway a multi-billion dollar munitions plant modernization program destined to continue beyond the next decade. Although cost effectiveness through automation and advanced process technology are major considerations in the program, the areas of personnel safety as affected by an explosive incident or through environmental pollution is receiving primary attention.

The Army's program deals with both explosive and propellant manufacturing facilities as well as load assemble and pack plants. There are 17 plants serving Picatinny Arsenal mission item needs.

In consonance with the subject of this paper, a specific example of a major facility to be built, will be presented with attention drawn to major safety considerations using latest technology.

DISCUSSION

GENERAL

The facility to be discussed is the advanced load, assemble and pack facility dealing with the 105mm HE, M1 projectile to be produced at Lone Star Army Ammunition Plant (LSAAP), Texarkana, Texas. General production characteristics of the round are described by Fig 1. The planned modernized 105mm projectile LAP facility, Area E at LSAAP is shown in Fig 2. The identity of the building numbers are shown on Fig 3.

PROPAGATION PREVENTION

The one million rounds per month production rate of the Lone Star 105mm projectile melt/pour facility requires the use of minimum spacing between explosive items to achieve full production. The following is a brief discussion of safe spacing, shielding and/or other means utilized to prevent propagation of an explosion.

Safe Spacing between Boxes and Buckets of Flake Explosive

In the case of bulk explosives, recent separation tests have indicated that when carboard boxes and/or plastic buckets (with covers) containing 60 pounds of Composition "B" are separated by 12 feet, propagation of an explosion between adjacent items is negated. However, spread of fire is not prevented. Movement of box explosives in the Lone Star facility is required between the Bulk Explosive Distribution Building (Bldg. E-161) and the Box Opening Building (Bldg. E-174) (Fig 4). In this latter building (Fig 5), the flake explosive is removed from the boxes and placed in 60-pound plastic buckets for movement to the Automatic Explosive Inspection Building (E-125). Passage of the boxes through the ramp connecting Buildings E-161 and E-174 is by means of a belt type conveyor, whereas, the plastic buckets are transported on two overhead power-free conveyors from the Box Opening Building to Inspection Building. As mentioned, each box on the belt conveyor is separated by 12 feet from a box in front of it and to the rear of it. The two conveyors carrying the plastic buckets are separated by 12 feet. The dual conveyors permit spacing between adjoining buckets on any one conveyor to be greater than 12 feet. This increased spacing can be reduced to 12 feet in the event future expansion (increased production rate) of the facility warrants it. Both ramps connecting the three buildings are furnished with fire retardant systems (water curtains) to prevent the spread of fire in the event of an explosion in one of the ramps or the buildings.

Bucket conveyors containing 60 pounds of explosive are used in other parts of the facility; namely, (1) where the explosive risers are transported between the Funnel Pulling Building and the Riser Melter Building and (2) where the riser flake is transported from the Riser Melter Building to the Inspection Building. However, the spacing between adjoining buckets is larger than the minimum 12-foot in the ramp between the buildings, and therefore, protection against the spread of fire is not required.

Spread Flake on Belt Conveyors

Uncontaminated flake explosive which has already been inspected for foreign material is transferred to one of the two melt buildings using a Belt Conveyor. Here, the flake is spread on the belt approximately one inch thick. By limiting the depth of the explosive to one inch, propagation of an explosion along the conveyor is prevented. Tests demonstrating this retardation of propagation were performed as a part of the Navy's Modernization Program and are reported in the minutes of the 13th Safety Seminar.

Shielding Between Explosives

After the empty projectiles are filled, they are transported to the Projectile Cooling Buildings from the Melt/Pour Facility by means of a high speed power-free conveyance system carrying 16 projectiles on each carrier. Initially, it was planned to separate these carriers by 109-inches which is the separation distance specified for pallets of 33-Composition "B" loaded 105 mm projectiles by AMCR 385-100. However, a series of tests performed by

Picatinny Arsenal has indicated that at separation distances as large as 170 inches, propagation of explosion will occur between pallets of 16-105mm projectiles. Therefore, in order to determine another means to prevent propagation, tests will be made to establish whether the use of structural steel or aluminum shields will be effective substitutes for safe spacing.

If the shields are found effective in negating the propagation of an explosion, then they will be made a part of the conveyance system. Rather than mounting the shields on the carriers, they will be attached to turntables which are used to change direction of the carrier flow.

Figure 6 illustrates the method of utilizing shielding. Here, two aluminum or structural steel plate shields are mounted on a turntable with the stationary shields positioned between the turntable and the protective structure. As a carrier reaches the turntable, it is in an unprotected position. Once the turntable rotates 90 degrees, the shields attached to the table will protect the carrier from the effects of an explosion in an adjoining unprotected carrier and, thereby, eliminate the propagation from one carrier to another all the way down the line. In the illustrative example, after the turntable is in the closed position, the protected carrier can move into the building through the stationary shields and the concrete mazes. This operation is continuously performed with alternately shielded turntables in the open and closed position.

Protective Barriers

If the above shielding is not effective, then an alternate method will be considered in the facility design (Figure 7). The spacing between explosive items in a ramp connecting two buildings need not be limited if both buildings are protected from an explosion within the ramp with separating protective barriers and adjoining buildings are separated from the ramp by intra-line distances based upon the larger of the explosive quantities in the ramp or the building.

For the Lone Star AAP, the above principles can be incorporated without significantly modifying the facility.

Maze Concept

For a protective barrier to be effective, it must be provided with a maze or other means to prevent a line of sight between the ramp and the interior of the building. There are two types of mazes, namely, (1) line of sight, and (2) safe zone mazes. Line of sight type of maze is used when the building is located at the end of a ramp, where the items within the ramp are spaced at safe separation distances, and protection is required primarily from an explosion in adjoining building. Safe zone maze is used when the ramp having safe separation between ramp items, passes in front of the protective barrier, or when the building is at the end of the ramp and the ramp items are spaced at less than minimum safe separations. In the latter case, a turntable shield may be used in combination with a line of sight maze to achieve the same protection afforded by a safe zone maze.

For the Lone Star facility, the use of line of sight type of mazes was originally contemplated. However, when safe separation distances could not be established for palletized projectiles, then all mazes were revised to conform to the safe zone arrangement. Here, when an item passes through the maze, it must enter a "safe zone" where it will be shielded from items located at the exterior and interior of the building.

Figure 8 illustrates the passage of explosive items through a "safe zone" maze. Here, in stage No. 1, lot numbers 1, 2 and 3 are located interior of the building, within the safe zone and exterior of the building, respectively. In stage No. 2, lot No. 1 will move further into the building with lot No. 2 leaving the safe zone and entering the building. While the first two lots move into the building, the third lot will begin to enter the maze. However, the speeds of the second and the third lots will be adjusted as such to insure that the line of sight between the two lots will not occur. In the third or the final stage, lot No. 2 enters the building, the third lot passes through the safe zone and the first lot enters the maze to repeat the operation.

FACILITY PROTECTION

Overall safety for the facility is provided by various means, such as (1) safe separations between buildings, (2) use of protective construction using barricade walls, strengthened frangible construction and igloo construction, (3) separation of hazardous operations from less hazardous operations, and (4) the use of remote operating procedures or hazardous operations. In general, full protection has been provided for personnel and equipment in buildings with conveyors and ramps, which are assumed to be expendable in the event of an explosion.

Building Separation

The buildings of the bulk explosive receiving and processing portion of the facility are separated as shown in Fig 9. Here, both the Box Opening and the Automatic Inspection Buildings are separated from the Bulk Explosive Receiving Building based on unbarricaded distances corresponding to the explosives in the two former buildings. Also, protective barricades are placed at these two structures. The separations of these buildings differ from the criteria of AMCR 385-100 which require that all separations be based upon the largest quantity of explosive in either building. In this particular case, even though the explosive quantity in the Receiving Building is much larger than that of the other two buildings, the potential hazard is much less.

In order to reduce the length of conveyors and, therefore, the overall operating costs of the facility, a minimum (barricaded intraline) distance is used to separate the Melter Buildings from the adjoining Inspection and Cooling Buildings. The latter two buildings as well as the Melter Buildings are remotely operated; and minimizing the building separations does not create a hazard for personnel.

Other hazardous operations such as cooling, funnel pulling, and facing operations are performed remotely in earth covered steel arch igloos. Separations between igloo structures conform to earth covered steel arch separation distances of Safety Manual AMCR 385-100.

Protective Structures

As mentioned, where separation distances are barricaded intraline distances, protective barriers are provided to protect the acceptor structures from low flying debris and relatively high reflected pressures associated with the blast pressure output. Because these barriers are required to remain intact in the event the structures containing barriers become donor structures, the protective walls are constructed utilizing laced reinforced concrete as detailed in DA Tech Manual TM5-1300. The process equipment within some of the buildings have laced walls are relatively tall. In order to limit the thicknesses of the protective barriers, several of the taller buildings including the Automatic Inspection, Melt/Pour and Riser Melt Buildings are positioned partly below the ground (Figure 9). In these cases only the above ground portions of the barriers require laced reinforcement.

At lower pressures, such as those corresponding to unbarricaded intraline distances, protection for personnel and equipment is furnished with use of "Strengthened Frangible Construction". The structural steel buildings provide the necessary strength to afford full protection for personnel from the effects of blast pressures while debris protection is afforded by the distances associated with this type of construction. For distances less than unbarricaded intraline distance, protective barriers as described above are used for debris protection.

To illustrate this type of protective structure, let us consider the X-ray Building (Bldg. E-138). As shown in Fig 10, only the west wall of the building is barricaded from an explosion in Building E-168 (X-ray Hold). Here, the shortest distance between Building E-138 and E-168 which could be maintained without violating unbarricaded intraline distance based upon the 15,000 pounds of explosive in Building E-132 is intermediate of unbarricaded and barricaded intraline distances based upon the 8,000 pounds of explosive in Building E-168.

To provide the necessary protection, the wall of Building E-138 facing Building E-168 is constructed of laced reinforced concrete whereas all other portions of the building are constructed of structural steel (Figure 11). The laced concrete wall was designed to resist the effects of 4,000 pounds of explosive which was distributed at various locations between the X-ray cells and walls. For the charge distribution as shown in Figure 11, a 5-foot wall thickness is required to sustain structural response for incipient failure. It may be noted that if this same wall were subjected to a single explosive, the capacity of the wall would be such to resist 9,300 pounds of TNT or a factor 2.3 times the explosive weight of the distributed charge.

Minimized operational space requirements necessitate the use of earth covered steel arch magazine larger than the standard type magazine. Here, the required interior height and the floor width of the structure are 20 feet and 30 feet, respectively. To accommodate these space requirements, a corrugated steel semi-circular arch having a radius of 16 feet is used. The bottom of each end of the arch (spring line) is mounted on a 2-foot thick and 4-foot high concrete side wall. Both end walls of each arch are constructed of laced reinforced concrete. Use of this igloo construction was authorized by cognizant safety officers with the stipulation that the steel plate for the arch will be 3/8-inch thick and that the arch will have a full 180-degree cross-section (Figure 12). The end walls of the arch are designed to resist the effects of an explosion within a ramp exterior of the walls. On the other hand, in the event of an explosion within the igloo, the structure will fail relieving the explosive effects to the atmosphere.

Separation and Remote Operation of Hazardous Processes

The separation of hazardous operations from other operations, and remote operation of these hazardous processes are interrelated. For Hazard Category II operations, prevention of a propagation is required; whereas complete protection for both the personnel and the equipment must be afforded for Hazard Category III operations. In general, all Hazard Category II and III operations involving large quantities of explosives (greater than approximately 30 pounds) should be located in separated structures. This has been achieved in the Lone Star facility by utilizing igloos and other types of protective construction and by performing high hazard operations (Category II and III) remotely. As may be expected, remote operating of processes will require surveillance system. This is achieved with the use of complete telemetering and remote visual monitoring (Television) systems. All monitoring equipment are located in a centralized control facility; the construction of which provides full protection for operating personnel.

EXPLOSIVE WASTE COLLECTION SYSTEM

The explosive waste collection system used in the proposed 105mm projectile melt/load facility at LSAAP essentially mixes the waste explosive in water and then transports the mixture to a treatment building where the explosive is removed from the water prior to being sent to an incinerator.

The waste is either passed directly into process scrubbers within the process building where it is generated when the quantity of waste is relatively small. For larger explosive quantities, the waste is transported by pneumatic lines to a wet collector building situated adjacent to the process building, Fig 13. Within the collector building, the waste also enters an air scrubber. When the explosive enters these scrubbers, it passes through a water spray and forms an explosive/water mixture.

The waste in water suspension passes out of the bottom of the scrubbers where the mixture is pumped to a settling-basin reservoir where the explosive waste is initially concentrated. Each building containing an explosive dust generating operation is equipped with both process or equipment air scrubbers and environmental air scrubbers. The latter serves to collect that explosive dust which leaks past the process air scrubber and is subsequently distributed throughout the building. The environmental air scrubbers are sized to reduce the explosive contamination of the air discharged from the buildings to a safe level for personnel as specified by the design criteria. As for the process scrubbers, the explosive/water mixture collected in the environmental scrubbers are pumped to the settling basin reservoirs.

A settling basin reservoir (Fig 14) is provided for each building or group of buildings generating explosive waste. Each reservoir is designed to provide a minimum retention time of one hour for the contaminated "pink water" from the scrubbers. Solids carried in the water are collected in "sump pits" which are periodically emptied by pumping a water/solid mixture (approximately 5 to 10 percent solids) to the pink water treatment building storage reservoir where it is held prior to treatment in the treatment building. Clear water overflows a weir to a clear water chamber from which the scrubbers within the process buildings draw their water supply. This recirculation of water between the reservoir and the process building will minimize the amount of pink water that must be treated in the treatment buildings. Sufficient capacity is provided in the settling basins to accommodate the potable water used for washdown of the process buildings during non-production hours. This water is pumped by sump pumps from the building being washed to the treatment building where it is filtered and then transferred to the settling reservoir. This accumulated washdown water serves to "make-up" for a major portion of the evaporation that takes place in the air scrubbing equipment.

For each pneumatic line leading from the process building, two scrubbers are provided in the wet collector building; namely, primary and secondary collector scrubbers. The explosive dust first enters the primary collector where it passes through a water spray similar to the process and environmental scrubbers. Because of the large quantity of explosive waste handled by the wet collection system, a portion of the dust entering the primary collector may escape the water. The "non-captured" dust is exhausted to the secondary collector where the collection process is repeated. The air passing through the secondary collector is exhausted to the atmosphere. The explosive/water mixture from both collectors are pumped directly to the treatment building storage reservoir without passing through a local settling basin reservoir. Water supply for each wet collector building is furnished from the treatment building reservoir.

Piping for the pink water treatment system is divided into four units. Three of these units connect the local collection systems (wet collectors buildings and settling reservoirs) to the three treatment buildings. The fourth unit interconnects the three treatment buildings to provide operational flexibility in the event one of the treatment buildings is non-functioning.

The three treatment plants are essentially identical. The water treatment process (Fig 15) is based on the system in use at the Iowa AAP. Contaminated water enters the process through a rotary filter within the building that continuously removes solids in suspension. Explosive waste removed by the filter is discharged into a collection bin where it is retained for disposal in a wetted condition. The maximum quantity of explosive waste accumulated is approximately 600 pounds before it is removed to the incinerator. The filtered water is directed to a storage reservoir immediately adjacent to the treatment building. This reservoir is designed in a manner similar to local settling reservoir. Explosive waste collected in the reservoir is periodically pumped to the rotary filter for removal.

Water containing dissolved nitro-bodies and solid matter of minute size is drawn from the clear water chamber of the storage reservoir of each treatment building and directed to one of two sets of water purification equipment. The two sets of equipment are arranged in parallel with one another. This will permit dual operation at any one time. Each set of equipment has a treating capacity of 20 gallons per minute for a total capacity of 120 gallons in all three buildings. The treatment requirement is estimated as 90 gallons per minute. This arrangement will permit any one of the six sets of equipment to be inoperable without compromising the facility needs.

Each set of equipment consists of a pair of diatomaceous earth filters arranged in parallel, two "up-flow" carbon adsorption columns, a pre-coat tank and a body feed tank. The water with the nitro-bodies first passes through the diatomaceous earth filters. Prior to being placed into operation, a cleaned filter must be pre-coated with a mixture of diatomaceous earth fibers and water. A small amount of diatomaceous earth (mixed in water) contained in the "body feed" tank must be added to the main stream of the process flow ahead of the filters. The discharge from the earth filters, which essentially contains only dissolved TNT, is directed to the inlet of the first of the two adsorption columns. The second column, which is in series with the first column, may be considered as a "polishing" column. After leaving the polishing column, the clean water can either be discharged from the facility as overflow or returned to the collection system.

Before recharging the carbon columns, the carbon is removed through a drain and then is passed through the rotary filter. The columns are charged hydraulically from a carbon charging vessel. This vessel charges all four columns in any one building.

CONCLUDING REMARKS

The future Lone Star Army Ammunition Plant 105mm projectile melt/pour modernized facility will encompass many new safety innovations which have stemmed from recent developments.

To achieve full production requirements within allocated land areas, minimum spacing between explosive items is a necessity. In the course of acquiring pre-design safety information, a safe spacing between 60 lb quantities of Comp B for boxes and buckets of 12 feet was established. By limiting the depth of explosive spread on a belt conveyor to one inch, propagation along the length of the conveyor is eliminated.

A problem area has been surfaced in which the AMCR 385-100 specification of 109 inches for 32-105mm projectiles loaded with Comp B was inadequate when applied to a 16 projectile carrier configuration. Further tests with suitable shielding will be made to achieve separation without propagation at reduced distances.

"Maze" concepts have been introduced to prevent line of sight propagation between ramps and interior of buildings. The concept of a "safe zone" has been developed for transit of palletized projectiles into buildings involving hazardous operations.

Explosive containing buildings are separated based upon barricaded or unbarricaded interline distances as specified by the safety manual AMCR 385-100. The use of earth covered igloos for cooling, funnel pulling and facing operations afford cost saving approaches.

Technical Manual, Army designation TM5-1300, employing proven structural techniques should be employed for such applications as protecting acceptor structures from low flying debris and high reflective pressures stemming from explosive blast effects. Where applicable, low cost, frangible construction should be employed at the lower pressure environments which would exist at unbarricaded interline distance.

Other safety considerations must include analysis and separation of hazardous processes and use of such aides as TV monitoring systems for remote operations. Explosive waste collection should stress capturing of explosive or propellant waste particles through filtration and scrubbing systems which can later be recycled into the basic process or destroyed by specially designed incinerators. Explosive wastes in water solution can be removed by activated carbon columns, with the latter being subjected to regeneration.

GENERAL PRODUCTION CHARACTERISTICS

MUNITION

- 105MM HE, M1 PROJECTILE

EXPLOSIVE

- COMPOSITION B

PRODUCTION RATE

- 1,000,000 SHELL / MONTH

SHIFT SCHEDULE

- 500 HOURS PER MONTH

EFFECTIVE TIME PER SHIFT

- 350 MINUTES

SHELL PER SHIFT

- PRESENT – 9524
- PROPOSED – 15,876

BULK EXPLOSIVE

- 175,000 LBS

MELT/POUR CAPACITY (PER UNIT)

- 9000 LBS/HR

Figure 1

MODERNIZED 105MM PROJECTILE LAP FACILITY
AREA "E"
LONE STAR ARMY AMMUNITION PLANT

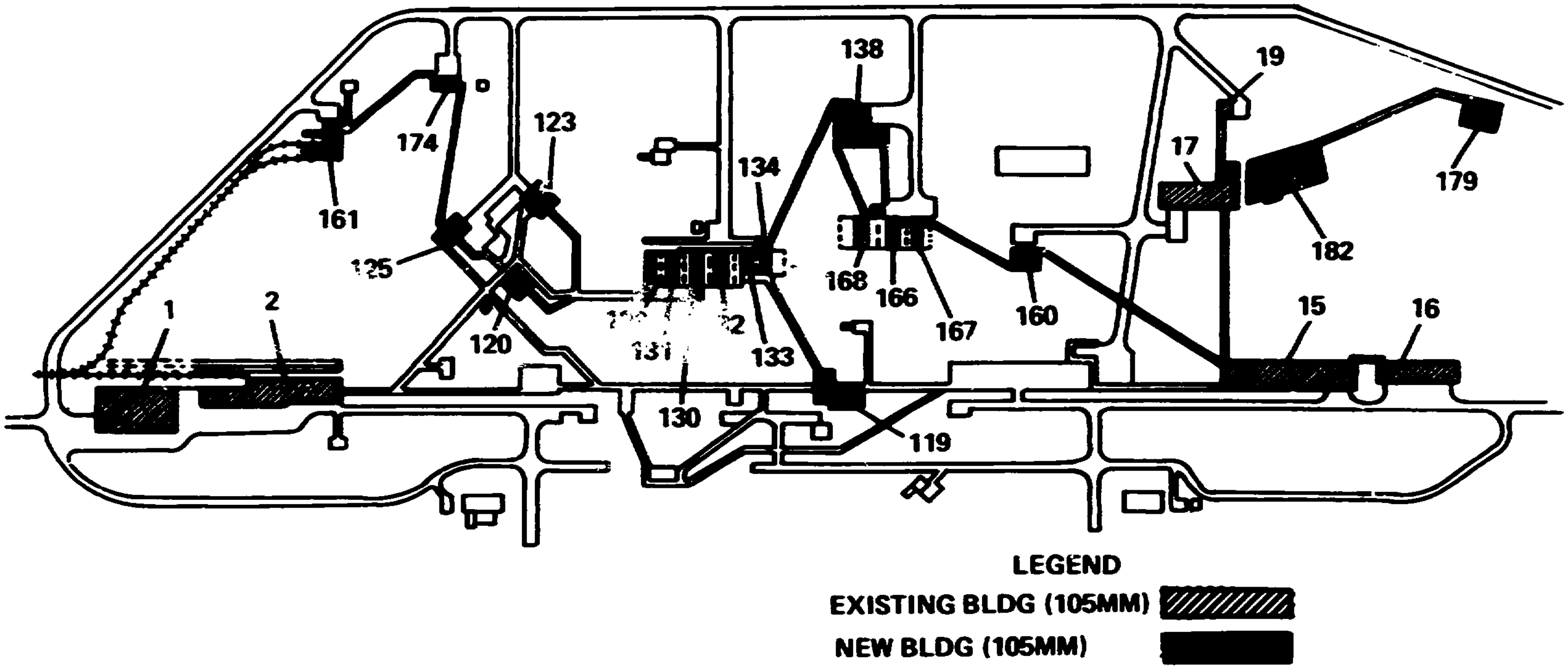


Figure 2

MAJOR BUILDING NOMECLATURE (CON'T)

LONESTAR AAP - 105MM HE, M1 LAP LINE
PROJECT NO 5752626

BLDG NO	TITLE	FLOOR SPACE SQ FT
138	PROCESS ASSEMBLY (X-RAY)	14676
168	PROCESS X-RAY HOLD	2190
166	FACING AND THREAD CLEANING	1800
167	FACING AND THREAD CLEANING	1800
160	LINER INSERTION	4800
15	ASSEMBLY AND PACKOUT	25400
119	PROCESS RISER MELT	11100
163	RISER FLAKE EXPLOSIVE DISTRIBUTION	1500
2	METAL PARTS PREPARATION (INERT WAREHOUSE)	20000

Figure 3 (cont)

MAJOR BUILDING NOMENCLATURE

LONESTAR AAP - 105MM HE, M1 LAP LINE
PROJECT NO 5752626

BLDG NO	TITLE	FLOOR SPACE SQ FT
161	BULK EXPLOSIVE RECEIVING	6100
174	BOX OPENING	3200
125	AUTOMATIC EXPLOSIVE INSPECTION	5210
120	MELT POUR	4680
123	MELT POUR	4680
129	COOLING IGLOO	2700
130	COOLING IGLOO	2700
131	COOLING HOLD	2190
132	COOLING HOLD	2190
133	FUNNEL PULLING	1200
134	FUNNEL PULLING	1200

Figure 3

EXPLOSIVE TRANSFER AND BUILDING LAYOUT

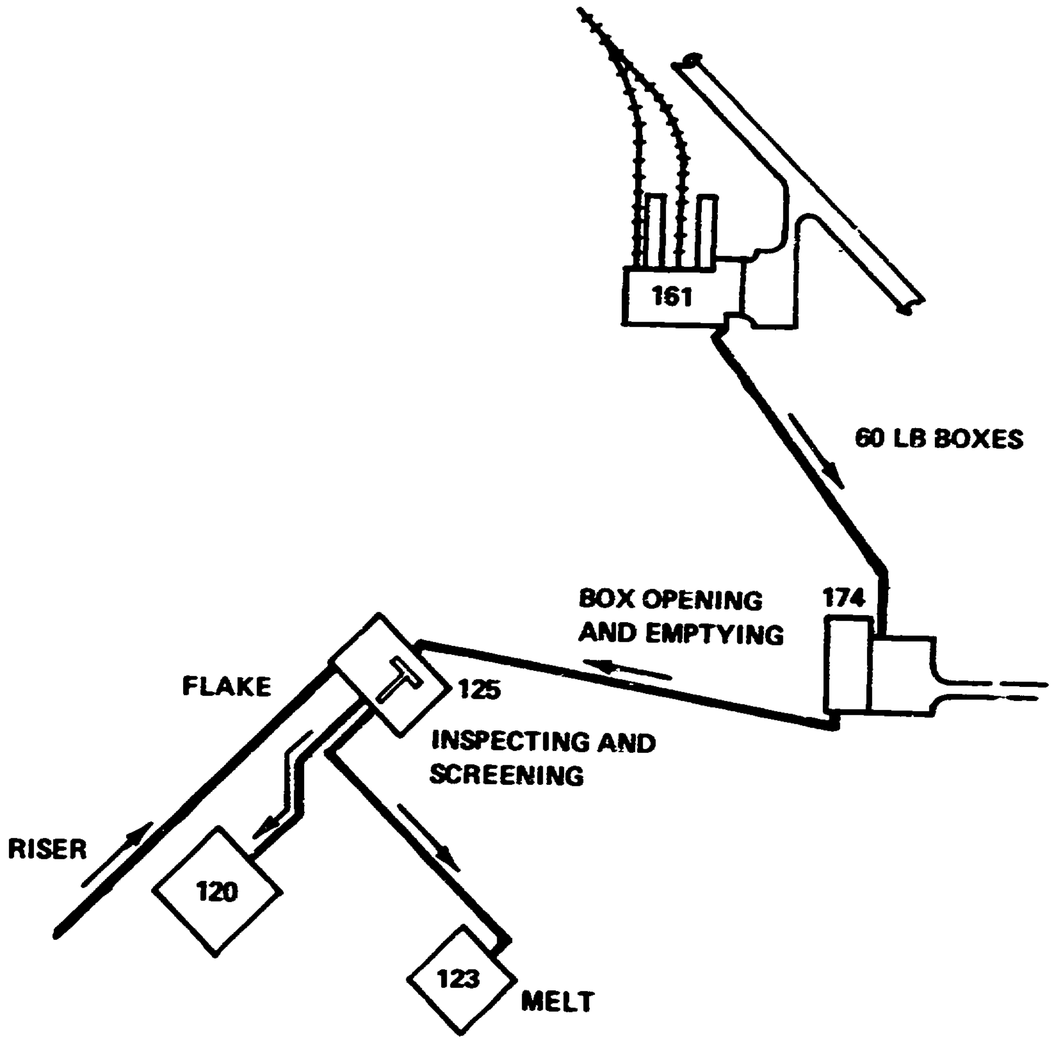


Figure 4

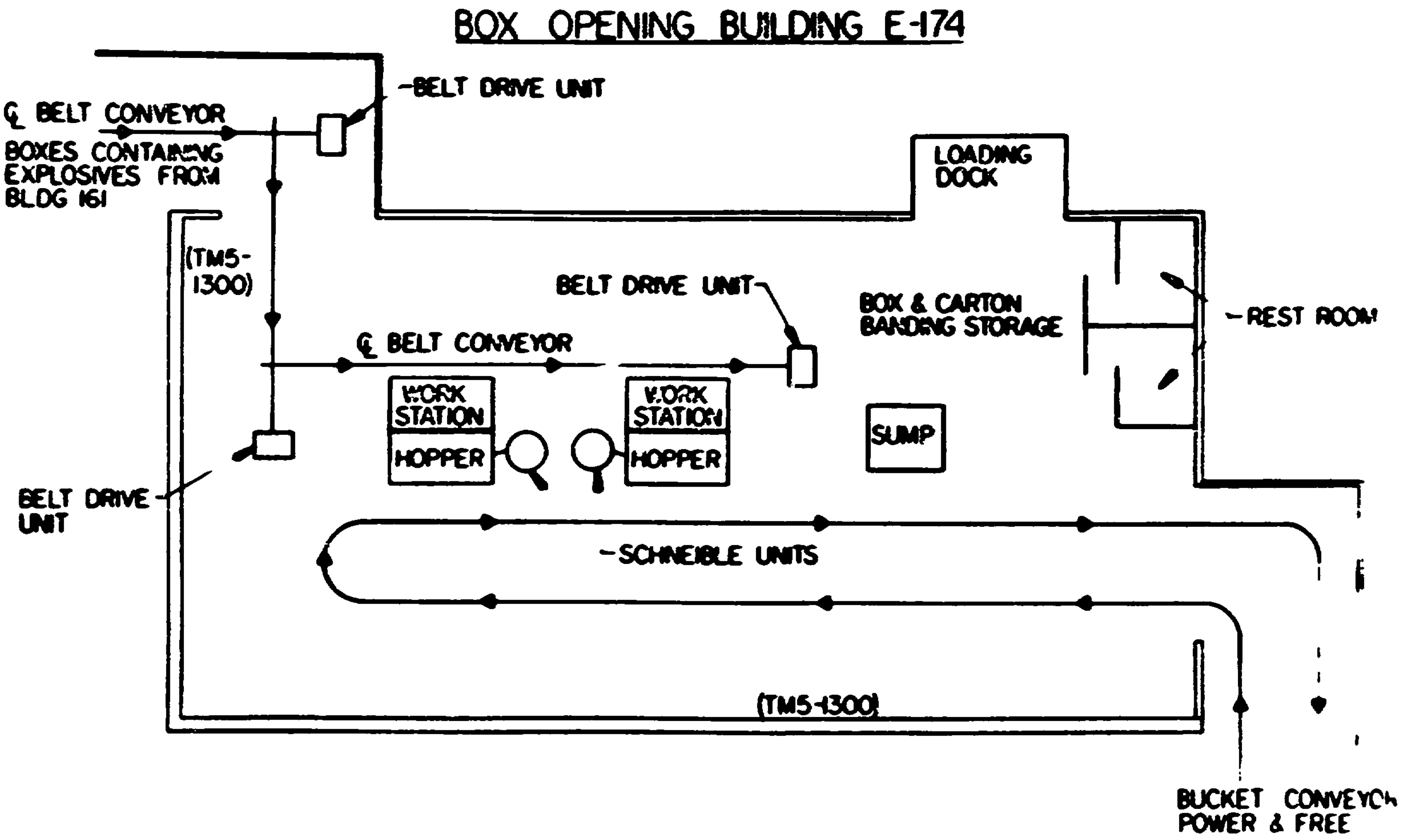

BOX OPENING BUILDING E-174
℄ BELT CONVEYOR
BOXES CONTAINING EXPLOSIVES FROM BLDG 161
-BELT DRIVE UNIT
LOADING DOCK
(TM5-1300)
BELT DRIVE UNIT
℄ BELT CONVEYOR
BOX & CARTON BANDING STORAGE
-REST ROOM
WORK STATION
HOPPER
WORK STATION
HOPPER
SUMP
BELT DRIVE UNIT
-SCHNEIBLE UNITS
(TM5-1300)
BUCKET CONVEYOR POWER & FREE

Figure 5

PALLET PPOTECTION NEAR BUILDINGS

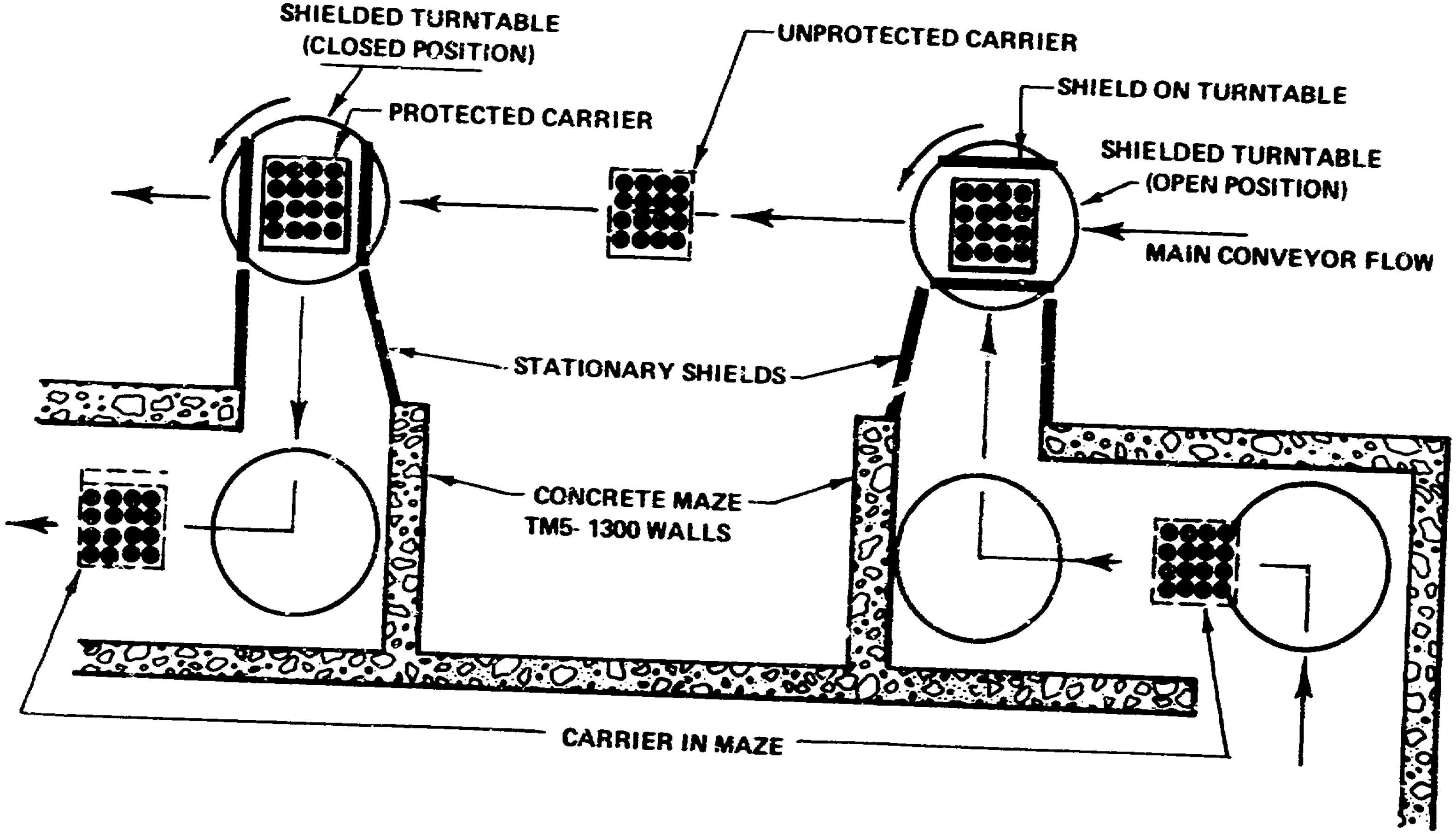


Figure 6

TRANSFER ARRANGEMENT NO 1

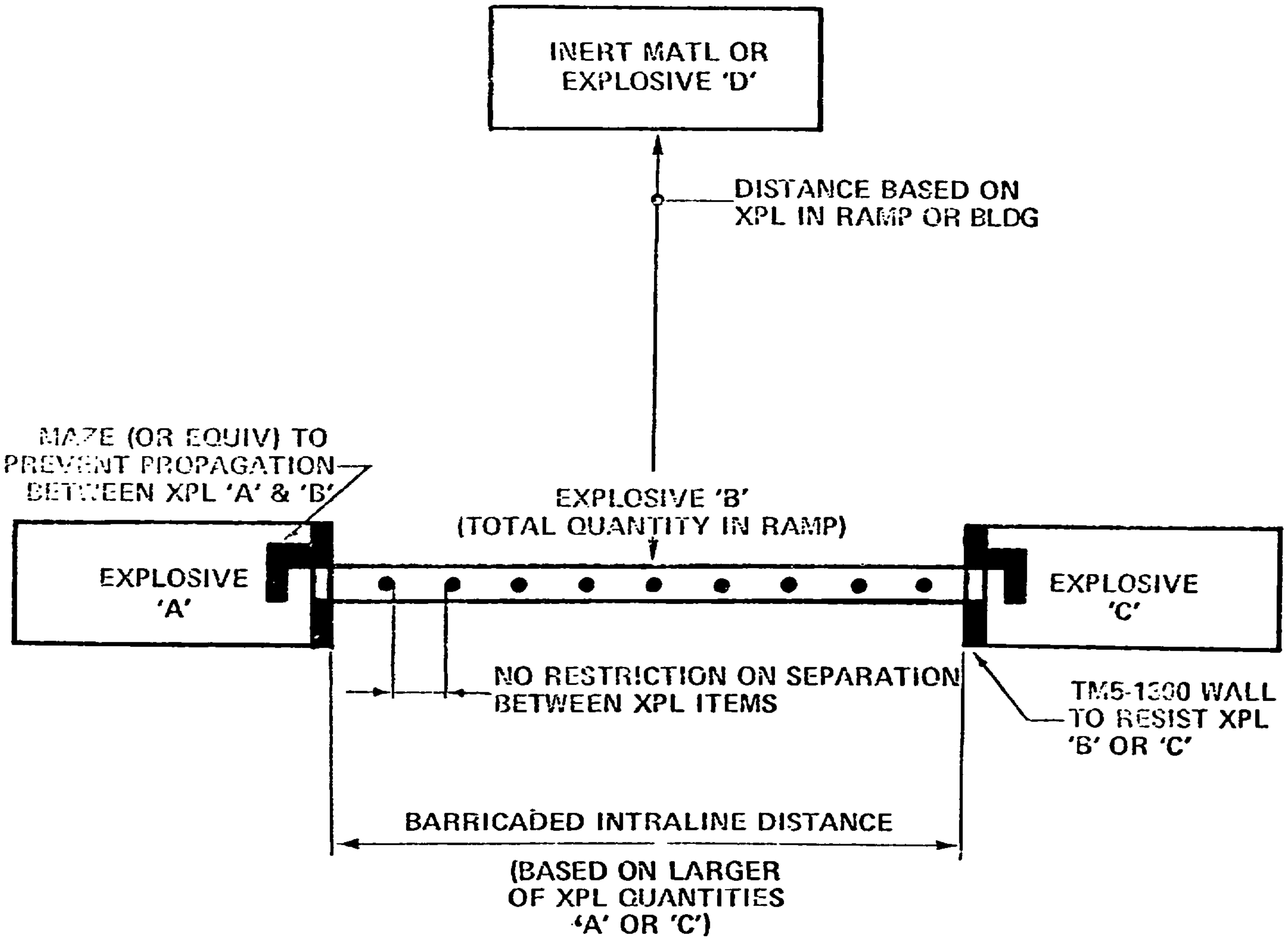


Figure 7

INTER-BAY PROJECTILE TRANSFER

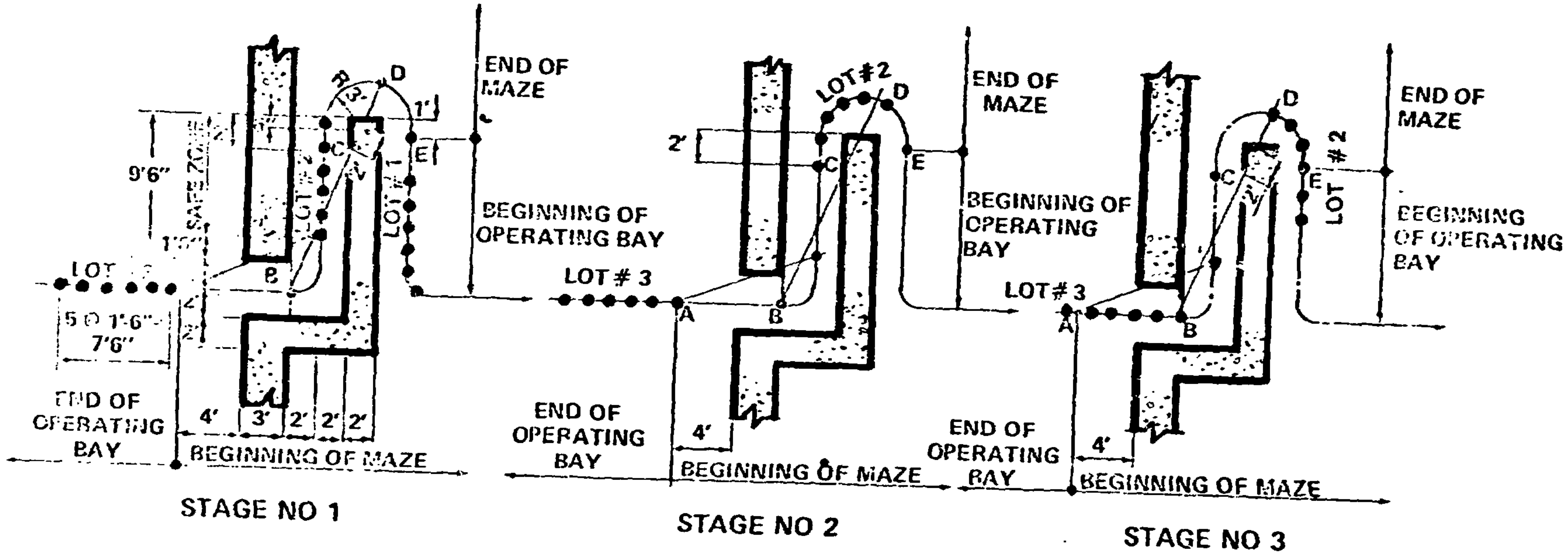


Figure 8

BULK EXPLOSIVE RECEIVING AND PROCESSING

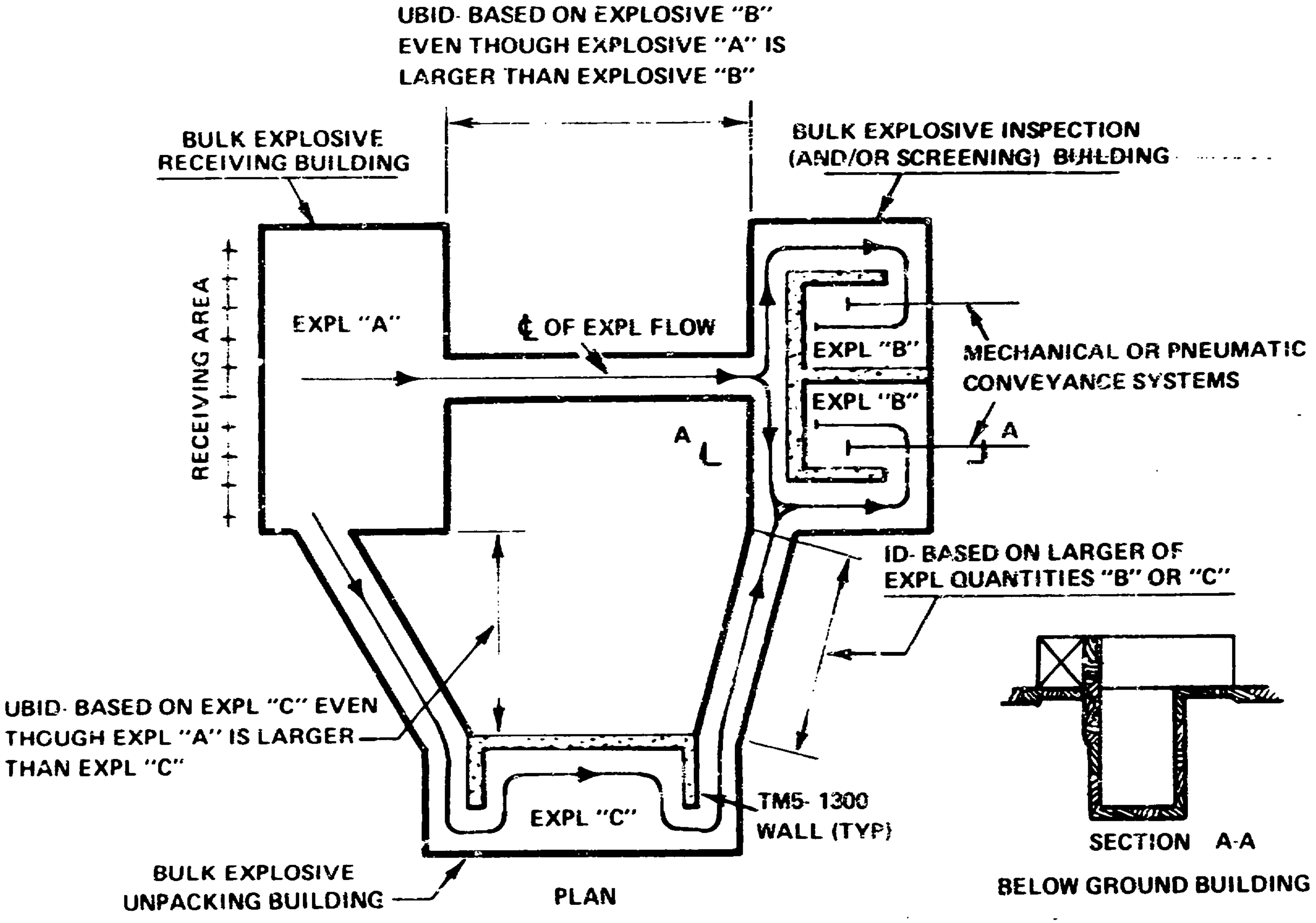


FIG 9

X-RAY BUILDING QUANTITY/DISTANCE SPACING

$$Z = \frac{R_a}{W^{1/3}}$$

BARRICADED SCALED DISTANCE Z= 9
UNBARRICADED SCALED DISTANCE Z= 18

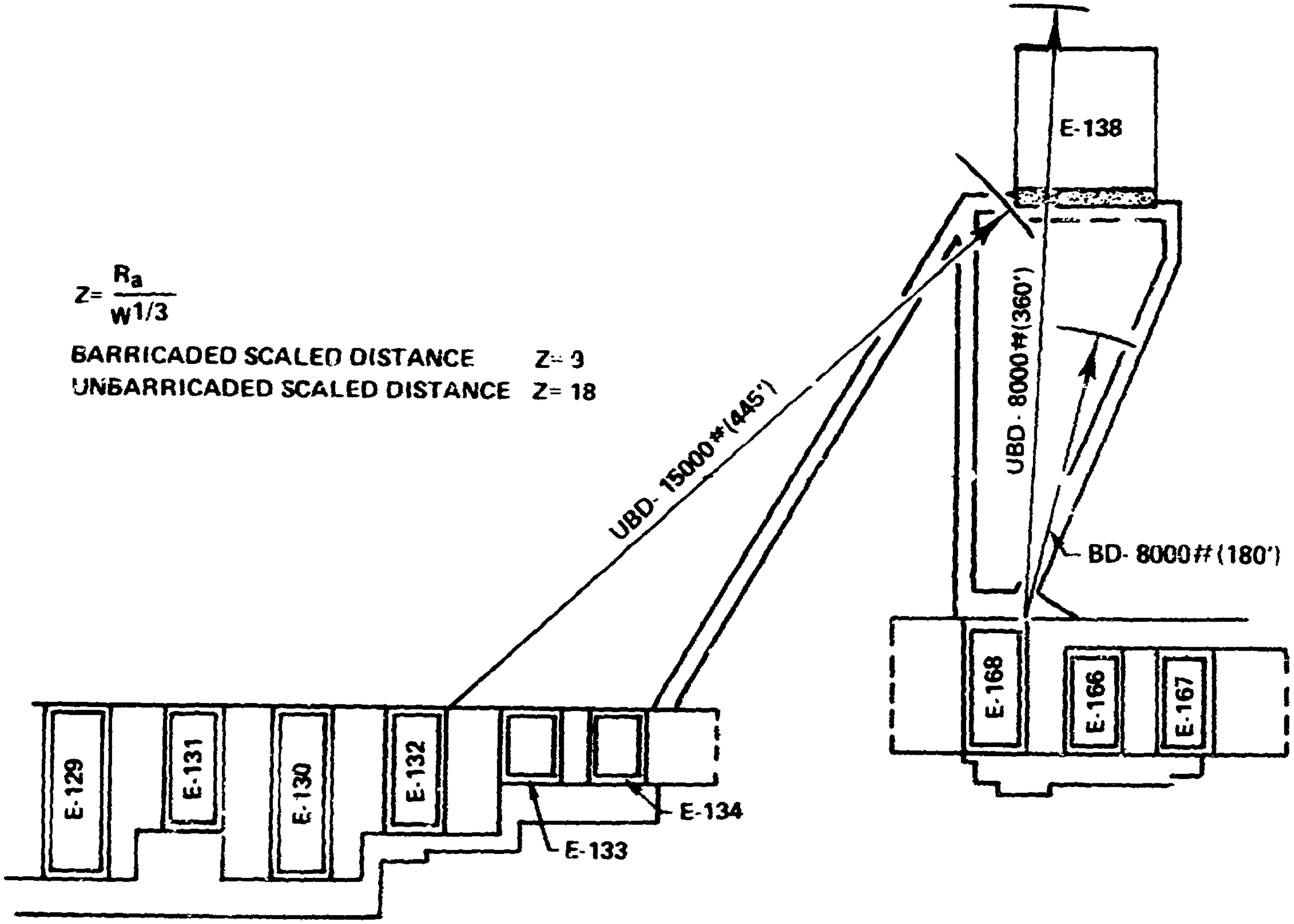


Figure 10

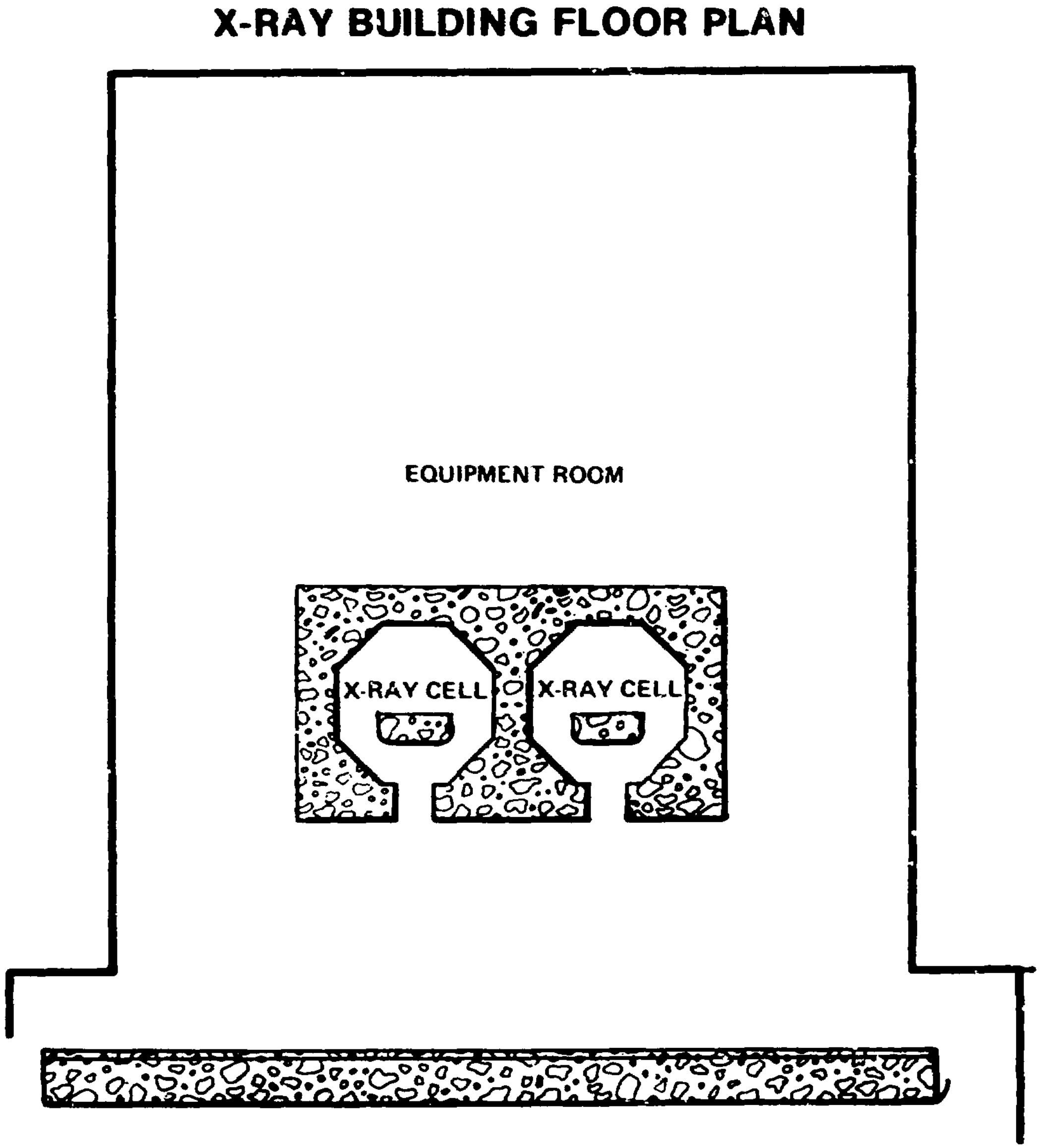

X-RAY BUILDING FLOOR PLAN
EQUIPMENT ROOM
X-RAY CELL
X-RAY CELL

Figure 11

STEEL ARCH IGLOO

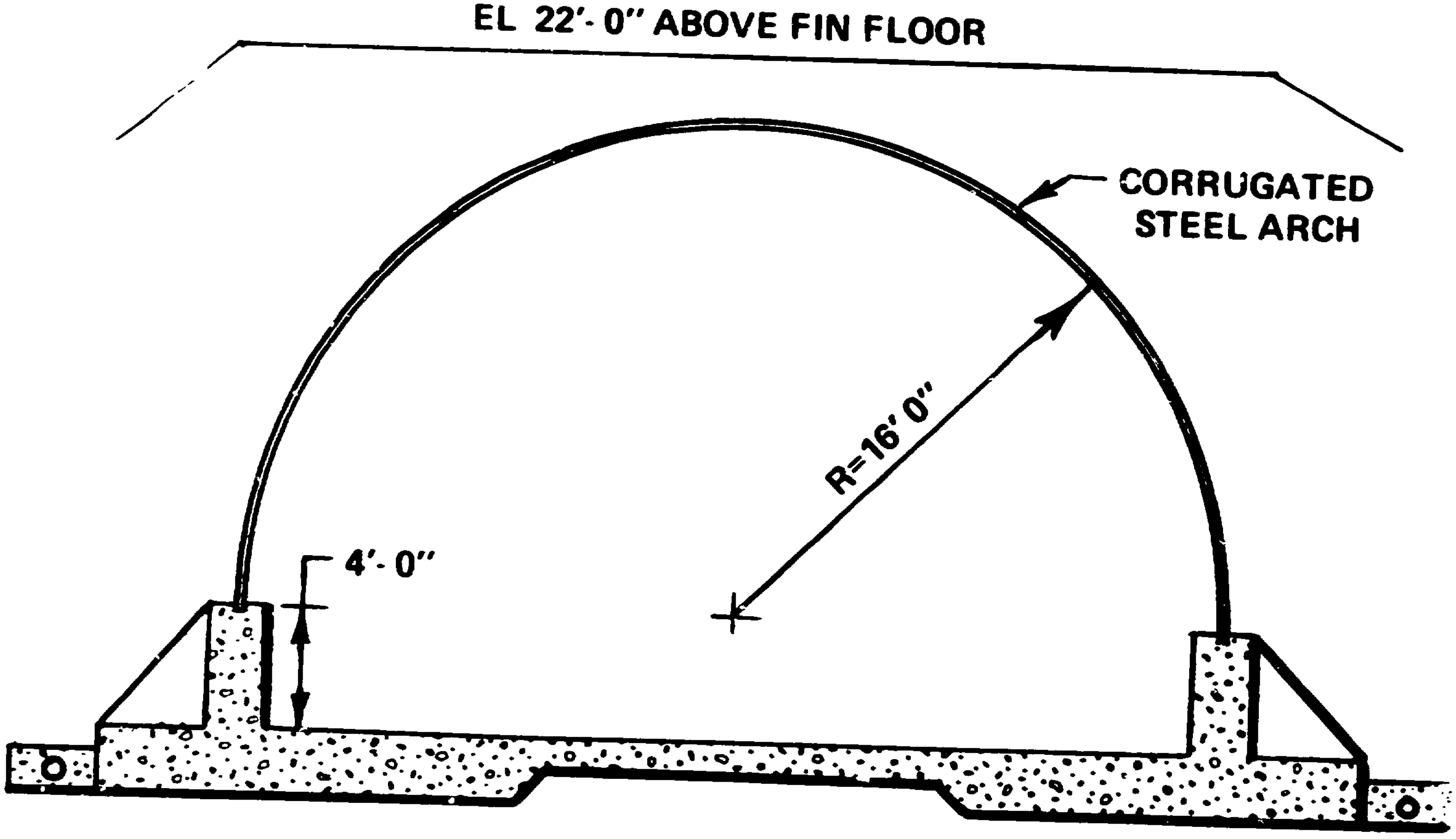


Figure 12

SCHEMATIC OF TYPICAL EXPLOSIVE WASTE COLLECTION SYSTEM

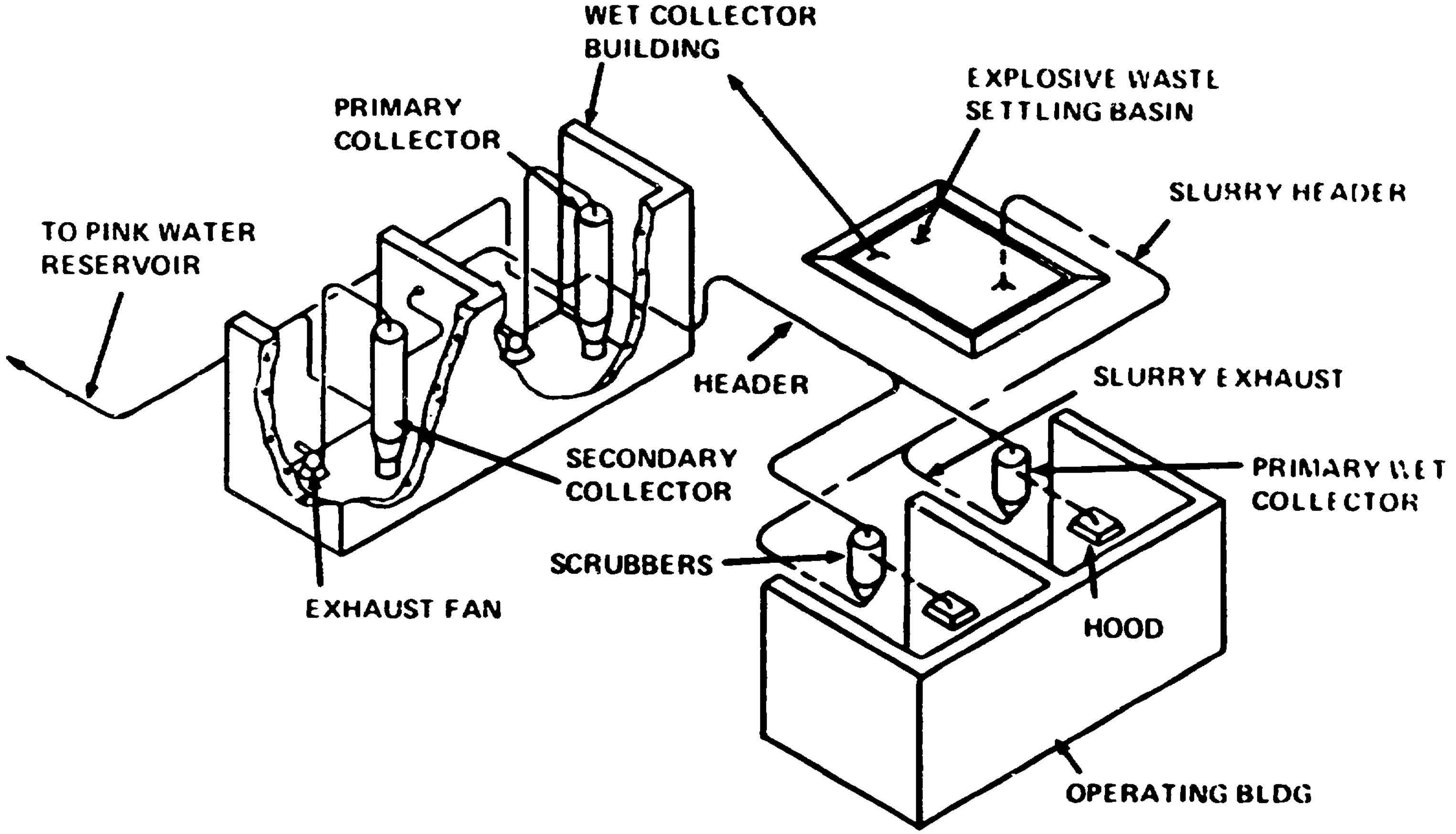
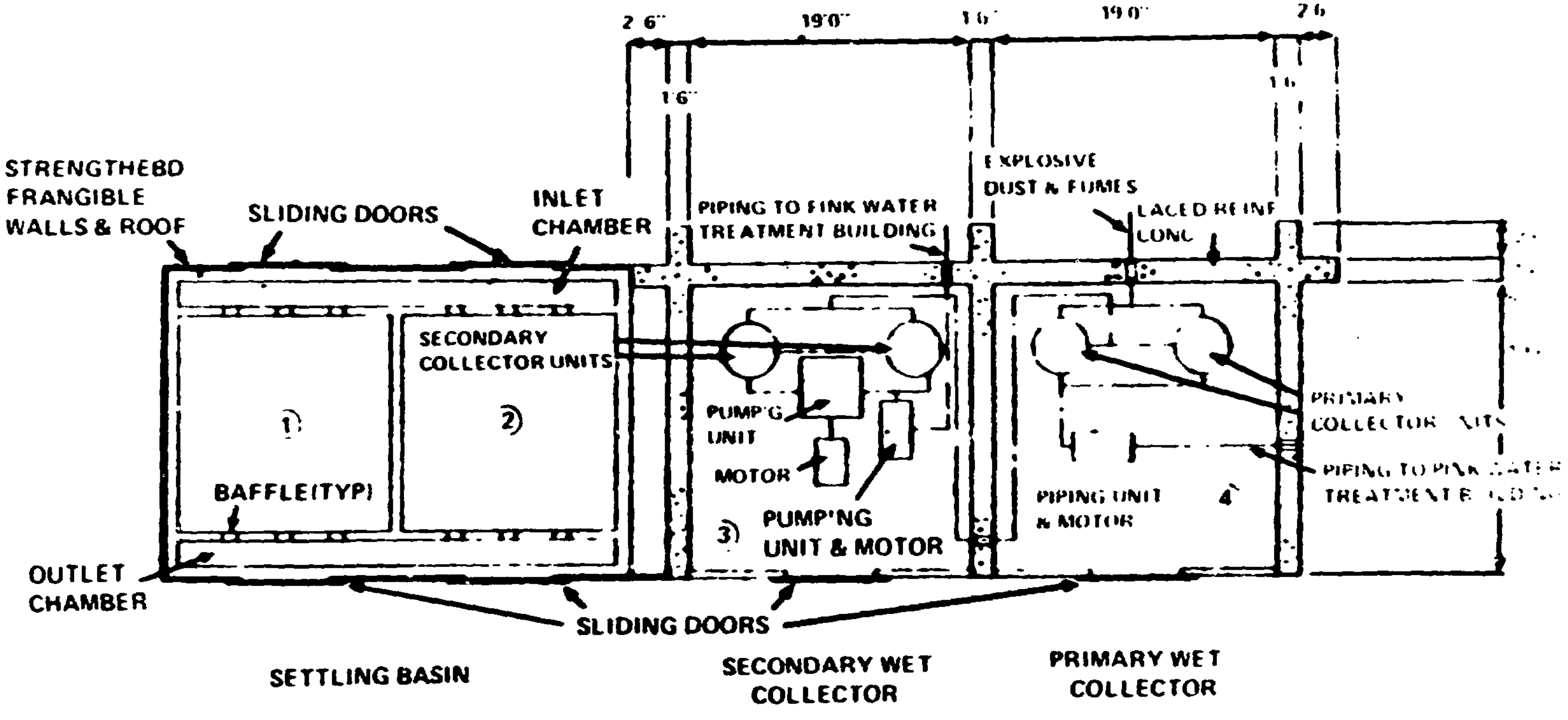


Figure 13

SETTLING BASIN AND WET COLLECTOR BUILDING



AREA DESIGNATION

① & ② SETTLING BASINS 200 LBS H.E
③ SECONDARY WET COLLECTOR 50 LBS H E
④ PRIMARY WET COLLECTOR 50 LBS H.E.

Figure 14

PINK WATER TREATMENT AND COLLECTION RESERVOIR

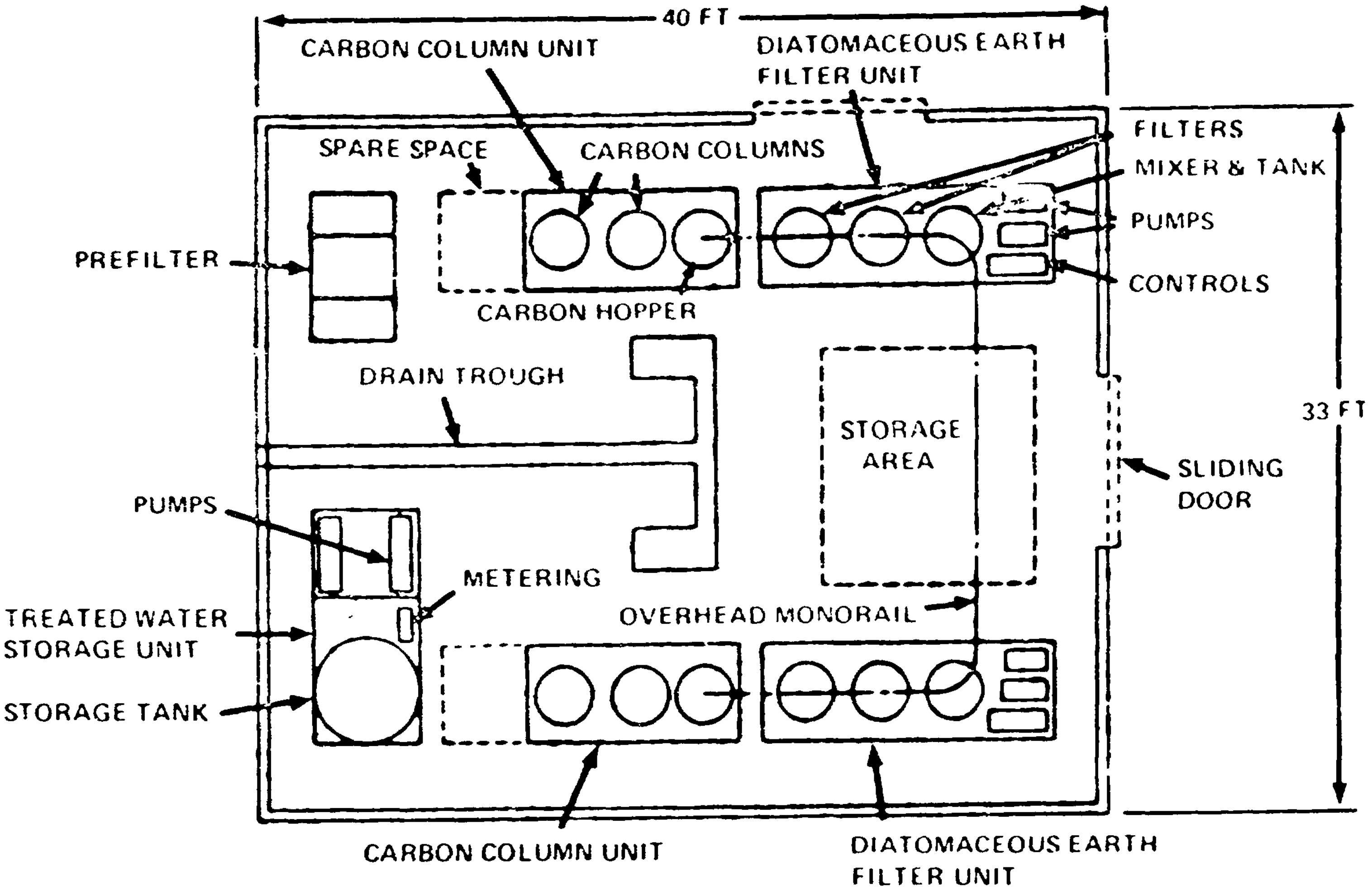


Figure [illegible]

EXPLOSIVE SAFETY DESIGNS IN A CONTINUOUS AUTOMATED MULTI-BASE PROPELLANT MANUFACTURING FACILITY

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Hercules Incorporated
Radford Army Ammunition Plant

ABSTRACT

System safety studies were integrated into the initial concept designs for an automated prototype plant for manufacturing double- and triple-base propellants at Radford Army Ammunition Plant. Quantitative hazard analysis studies in progress are assessing the safety of new equipment designs and process technology changes being advanced prior to implementation. All ingredients and combinations of ingredients to be encountered in this plant were subjected to hazard test analyses to establish relative initiation ease and explosive reactivity to mechanical, flame, and shock stimuli. This information, in conjunction with in-process energy measurements, established operating safety margins, introduced system design changes to achieve acceptable risks, formulated ingredient add sequences posing low probability for explosive reactions, and introduced safety design criteria for preventing explosive propagating reactions in a variety of process equipment and material flows.

Hazard logic modeling (Fault Tree Analysis) is programmed for the production facility currently in the design stage. This quantitative analysis will focus on assessing the probability for occurrence of a fire, explosion, or process interruption through the application of system failure rate data for components and human activities.

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INTRODUCTION

The plan to construct a modern automated multi-base propellant plant at Radford Army Ammunition Plant represents a new era in the propellant and explosive manufacturing industry. New equipment designs and manufacturing technology are being advanced to produce propellants more economically. More important, however, manufacturing concepts are being advanced for which propellant ingredients and ingredient mixture combinations are subject to new environments for which prior safety experience is unknown. The consequence of initiation within explosive and propellant plants is most acute since the combustible's response is capable of violent reactions of catastrophic proportions. Only within the last year, disastrous incidents across our nation attest to this fact and have added to the tally of personal suffering and economic losses. Today, the risk for an explosion, and the economic losses, are even greater when one considers the trend towards greater impulse-producing systems and the complexity of automated manufacturing operations being developed under the modernization program. Therefore, experience must be gained and satisfactory safety levels demonstrated for personnel, the facility, and the product, if the full economic potential of an automated multi-base facility is to be realized. This cannot be accomplished by costly and uncertain trial-and-error procedures, but requires the aid of advanced system safety analytical methods.

The Hercules-developed Hazard Evaluation and Risk Control (HERC) approach to system safety has been integrated into the design and development efforts for an automated multi-base plant at Radford. This safety program meets the requirements for system hazard analysis outlined by ARMCOM Regulation 385-4. As seen in Figure 1, the analytical safety disciplines consisting of Preliminary Hazards Analysis (PHA), Failure Mode and Effect Analysis (FMEA), and Fault Tree Analysis (FTA) are systematically programmed at the appropriate concept, design, pilot, and production development stages. Emphasis in these safety studies is placed on interfacing engineering and process designs with quantitative hazard analyses to prevent initiation, minimize the chance for explosive reactions, and maximize operational safety in terms of process economics. The numerous PHA and quantitative safety margin analyses performed on prototype equipment and processing procedures are documented[1/] and are not presented in this report.

The purpose of this report is to present the findings and conclusions regarding the sensitivity of in-process materials and the applications of flame transition and explosive propagation data for effecting safety designs to reduce the explosive hazard potential in operating equipment and between interconnecting bays.

DISCUSSION

A. PLANT DESCRIPTION BRIEF

The automated multi-base plant, in pilot development, is being designed to manufacture 2.4 million pounds per month of the M26 double-base or the M30 triple-base formulations. A process flow schematic is shown in Figure 2. In operation, preconditioned propellant ingredients nitrocellulose (NC), nitroglycerin (NG), nitroguanidine (NGu), stabilizer, and other additives are continuously weigh-fed into a ribbon blade premixer. Initial ingredient blending with some solvent is accomplished in this unit. The blend is then continuously weigh-fed into a horizontal twin paddle mixer for mix plasticization. Exiting pelletized green dough enters a screw extruder for further consolidation and final granule sizing. Green cut granules are then waterveyed to air dry modules for acetone and alcohol removal. Final processing consists of propellant blending and glazing prior to final packout at can pack.

In this plant, all equipment, ingredient, and in-process propellant flows are remotely monitored and controlled. Several explosive safety concepts were investigated and changes to equipment design or operating procedures were made on the basis of test data to reduce the chance for an explosion. They included:

(1) reducing the sensitivities of propellant ingredients by altering material physical characteristics;

(2) profiling the propellant formulation's response to flame and shock stimuli to establish safe ingredient add sequences during premixing operations;

(3) establishing nonexplosive propagation dimensions for ingredients and propellants on interconnecting conveyors;

(4) establishing materials of construction and dimensions for an in-line safety door concept for preventing explosive propagation reactions in pneumatic conveying systems.

B. ALTERING COMBUSTIBLE SENSITIVITY

Production continuity in an automated multi-base plant requires propellant ingredients be continuously fed to the process. This is accomplished by bulk storage or interfacing input feeds from ingredient manufacturing facilities as in the case of NC and NG. One potentially hazardous operation involved feeding the nitroglycerin to the premixer. The nitroglycerin feed system is designed to pressure transfer an NG/solvent mix* from a storage desiccator

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* Solvent mix: NG/acetone/alcohol/centralite
M26: 52/20/16/12
M30: 57/21/18/4

to a metering tank. This mixture then flows under gravity to the premixer. Overall process safety demands that explosive propagation be prevented between interconnecting equipment and operations.

As seen from data in Table I, nitroglycerin is easily initiated by mechanical stimuli, exhibits flame initiated explosive characteristics at low heights, and is capable of propagating an explosive reaction at a thin film thickness of <0.1 inch. Explosive safety design analyses investigated the relative safety benefit of altering the sensitivity of NG by dilution with acetone and ethyl alcohol process solvents. Of particular interest was establishing a nonpropagating explosive transfer line dimension between equipment for an NG/solvent ratio commensurate with manufacturing requirements.

In general, the sensitivity of NG to all initiating stimuli was found to be improved when diluted with acetone and ethyl alcohol miscible solvents. As seen from data in Table I, a 75/25 NG/solvent mix requires greater amounts of impact and friction energy for initiation. Also, diluting NG with 25 percent solvent reduces processing hazards by increasing the solvent mix dimensions for explosion when subjected to flame and shock stimuli. In particular, less confinement materials, such as rubber, increased the critical diameter for explosive propagation throughout the solvent mix. In rubber casting hose and steel confinement, the minimum dimensions determined which would not propagate an explosion were 0.75 and 0.25 inch, respectively.

On the basis of this information, NG/solvent mix transfer lines were sized for maximum of 3/4-inch ID rubber between the storage desiccator and premixer unit (Figure 3). This does not preclude explosive reactivity of the NG/solvent mix in the desiccator or metering tank, but precludes a shock induced explosion being propagated between equipment located in separated bays. The lower NG concentrations used in manufacturing the M26 and M30 formulations are expected to be less sensitive than the 75/25 NG/solvent mix tested; hence, an even greater degree of safety exists in this transfer system design for prevention of initiation and explosion propagation reactions.

C. INGREDIENT ADD SEQUENCE

Previous data[2] revealed an ingredient mixture of NC and NG was sensitive to flame and reacted explosively at low heights in the critical height-to-explosion test. Also, earlier investigators[3-6] had revealed that a "Hot Period" was present during triple-base propellant mixing. The term "hot period", conceived by earlier investigators, connotated that triple-base mix dough was more sensitive after the solid ingredient NGu was added to conventional sigma bladed mixers. Sensitivity tests were performed on selective ingredient mixtures to establish safe ingredient addition sequence to the premixer. Also, flame and shock explosive tests investigated the "hot period" during triple-base mixing.

1. Ingredient Addition

When compared to conventional M30 premix procedures, the alternate ingredient add procedure established for automated multi-base propellant manufacture offers the safety advantages of eliminating handling and addition of undiluted NG to the premixer and premixing of a sensitive ingredient mixture combination. As seen from data in Table II, addition of NG/solvent mix to dry NGu significantly reduced the impact and friction sensitivity when compared to the NG/NC/solvent mix ingredient combination used in conventional manufacture. When NC is added to the alternate mix, this ingredient mixture becomes more sensitive and exhibits sensitivity values comparable to the M30 final propellant matrix in conventional manufacture.

When assessed from an explosion hazard standpoint, a mixture of NG/NC at total volatile level of 7-10 percent was found to be sensitive to flame. This ingredient mix progresses from slow burning to an explosion at a low material height of 6 inches in 2-inch diameter steel confinement (see Table III). The alternate mix procedure in which NG/solvent mix is added to dry NGu then followed by the NC add results in a less flame sensitive mixture. This is readily apparent by the greater material height required for explosive reactions. This reduction in sensitivity is attributed to two factors, namely, (1) the solid ingredient NGu is not particularly sensitive to flame (see Table V), and (2) the higher total volatile solvent level introduces added safety by increasing material heights for explosive reactions.

On the basis of these data, the principal ingredient add sequence to the premixer was established as NGu, NG/solvent mix, NC, and additives for the M30 formulation (Figure 4). A similar analysis was performed for the M26 double-base formulation and an ingredient add sequence established on the basis of the sensitivity data profile.

The low explosion hazard for the M30 and M26 alternate premix was substantiated in simulated flame tests in a premixer model. These preliminary results affirm that the premixer design will vent (prevent destructive pressures) a burning reaction for premix ingredient blends at the 20 percent total volatile solvent level. Additional tests are planned.

2. Hot Cycle Period

Sensitivity testing was performed to define the impact, friction, flame, and shock sensitivity response for M30 propellant green mix immediately after the NGu additions and at other times during the mix cycle. This profile analysis was necessary to obtain data for comparing relative sensitivities between conventionally manufactured M30 green mix and the alternate ingredient addition sequence proposed for the automated multi-base line. Also, this analysis provided insight as to the validity of hazardous periods ("Hot Period") during triple-base propellant mixing noted by previous investigators.

Data in Table IV show no M30 green mix ingredient mixture combination which is exceptionally sensitive to impact or friction stimuli during mixing. The improvement in impact sensitivity shown for M30 green mix with mixing time is due to greater residual solvent levels and addition of ingredients NGu, cryolite, and ethyl centralite, which are not sensitive to this stimuli. No correlation is observed to exist between M30 green mix frictional sensitivity with mixing time or residual solvent content. It is noted that the friction threshold values for M30 green mixes after the NGu add are high and are comparable to that for dry NGu.

As seen from data in Table V, the M30 propellant green mix is not sensitive to bottom flame initiation during the mixing operation. The various green mixes tested after NGu additions and as a function of mixing times failed to react explosively up to material heights of 24 inches in 2- and 4-inch steel confinement. Failure of the M30 green mix to react explosively in the standard critical height-to-explosion test is attributed primarily to high residual solvent levels, mix homogeneity, minimal mix surface area exposure to the flame front, and the low sensitivity of NGu to flame initiation.

Date in Table V further confirm earlier blasting cap test results showing all M30 green mixes tested are sensitive to shock and exhibit a confined critical diameter for explosive reactions at 1.0 inch and below. The confined critical diameter of <1/2 inch shown for green mixes after the second NGu add might be attributed to the NGu itself, since the ingredient readily propagates shock-induced explosive reactions at dimensions >1/4 inch. Isolated dry pockets and thick layers of NGu coating the green mix would be exposed to the shock stimulus because long mixing times are required for incorporating the large amounts of this ingredient into the matrix.

The fractional blasting cap test employed by earlier investigators is based on a go-no-go criteria using <u>shock as the initiating</u> stimulus. This test yields no quantitative threshold sensitivity data for assessing operational hazards or safety margins for credible initiating stimulus such as impact, friction, thermal, etc., or for predicting explosive reactions if initiation occurred. Since shock is the aftermath of an initiation stimulus which has progressed to an explosion, it is reasonable to question the validity and interpretation of earlier cap test data regarding the hazard of conventional triple-base mixing operations. The likelihood that shock energies equivalent to that supplied by blasting caps would be the initial cause of an explosion during propellant mixing operations is unrealistic. Such energies would have to result from a violent reaction in an adjacent operation. Therefore, a more reasonable and realistic criteria for assessing hazards during mixing should be based on material reactivity to flame under existing processing environments. Initiation by flame is considered the more likely source should sufficient energy through impact, friction, electrostatic discharge, or thermal means ignite the mix.

On the basis of the above and the criteria that initiation and flame sensitivity data are more reasonable approaches for assessing explosion hazards than the cap test, it is concluded that no "hot period" exists during triple-base propellant mixing.

The low probability for an explosion during conventional M30 triple-base mixing operations is further supported by 24 years of operational history. Radford has experienced only two fires during M30 mixing operations. One fire occurred when cleaning an empty mixer and the other during the mix cycle. Neither transited to an explosion. When considering that approximately 173 million pounds of triple-base propellant have been manufactured at Radford since 1950 (equivalent to approximately 384,400 450-pound mixes processed), past operating experience demonstrates that the probability for mix initiation or explosion is quite low during triple-base propellant manufacture.

D. MATERIAL TRANSPORT

The transport and movement of solids is a common operation and usually involves some mechanical, gravitational, or pneumatic transport technique. In particular, pneumatics and gravity are considered efficient techniques for transporting solids, since such techniques provide low handling costs, flexibility, and adaptability to remote operation. These operations, however, are potentially hazardous because of atmospheric dust, electrostatic generation, friction, or particle impingement. Richardson, et al,[7] investigated the hazards associated with pneumatic conveying and established operating parameters for safely handling and conveying high-energy double-base formulations.

Two safety concepts studied for possible applications in the automated multi-base line were an in-line safety door in a pneumatic conveying system and right angle-vertical separation spacing of mechanical conveyors between manufacturing buildings.

1. In-Line Safety Door

The in-line safety door concept relies upon the alternate cycling of explosion interruptor gates to seal portions of a dual-leg conveying system. Solid transfer is semi-continuous; however, a straight through, open line does not exist at any time between operating buildings. The concept design in Figure 5 shows solids transfer in legs 1 and 2 while legs 3 and 4 are sealed off with in-line safety doors. When the cycle is alternated, propellant is transferred in legs 3 and 4. During this time, in-line safety doors seal off transfer legs 1 and 2. A barricade provided midway and between the intermediate surge hopper stations protects against missile hazards or sympathetic explosions between hoppers and in conveying legs containing propellant.

The test arrangement shown in Figure 6 was employed to establish the minimum safety door thickness necessary to prevent initiation of M26 and M30 propellant. This test is essentially a modified version of the card gap test. The candidate door material is placed between M26 or M30 propellant donor and acceptor samples. The door material thickness necessary to attenuate the shock of the donor initiator is then established which will prevent acceptor initiation. This test simulated the severe condition of propellant present on both sides of an in-line safety door in a pneumatic conveyor.

As seen from data in Table VI, Lucite, Lexan, or stainless steel thicknesses necessary for interrupting a shock propagating reaction are large and vary with material physical properties. The more dense stainless steel required a gap thickness of 1.12 inches to prevent M26 acceptor sample initiation as opposed to the 5.5 inches for the more brittle Lucite. This safety concept appears unattractive because of size and weight considerations in the practical design of an in-line safety door, particularly for the more shock sensitive M26 formulation. In view of these unattractive features, additional testing was performed introducing a frangible cellulose acetate line section a short distance in front of the simulated door material under test. This concept proved effective in dissipating the shock energy of the explosive donor and reduced the thickness barrier requirements for an explosion interruptor safety door. This is readily apparent from a significant reduction of 1.0 inch in gap thickness to prevent M26 acceptor initiation when the frangible line section concept is employed (Table VI). Although not tested, similar reduction in gap thickness to prevent acceptor initiation would be expected for the Lucite and Lexan materials.

Although considered in design applications, present plans are not to pneumatically convey propellants in the automated multi-base plant.

2. Mechanical Conveyors

Belt and vibratory conveyors will be used to transport propellant ingredients, premix, and solvent-wet cut powder between operating bays and buildings. The several methods available to prevent propagation of an explosion between buildings via the material train on conveyors include: (1) maintaining material bed depths below the critical dimension for explosive propagation, (2) incremental or pulse feeding, and (3) maintaining adequate vertical separation distance between conveyors positioned at right angles. The application of the above techniques in explosive safety design must be evaluated on the basis of material physical state in the process and production requirements. Maintaining material depth below the critical diameter is not always practical because it could limit production capacity. Incremental feeding, although a feasible safety concept, has the potential for adjacent increments to be dispersed from an initial shock and form reactive dust-laden atmospheres capable of propagating through the conveyor system.

The concept of right angle-vertical separation distance appeared most promising for continuous automated multi-base applications. This explosive safety concept, depicted in Figure 7, is predicated on the basis that (1) vertical separation introduced between conveyors would fluidize material flow, thus alter the combustible's critical diameter, and (2) positioning conveyors at right angles would provide material interruption and directional change to prevent an explosive reaction being propagated the entire conveyor length. Assurance that this design concept would function as an explosion interruptor was verified in simulated conveyor tests.

Data in Table VII show right angle placement of conveyors together with a minimum vertical separation distance of nine inches is necessary for preventing explosive propagating reactions between solid feed conveyors that may occur either upstream or downstream from conveyor junctions. Explosive reactions are propagated around right angle bends in conveyors when maintained at vertical separation distances of six inches or less.

NGu, approximately 15 percent alcohol-wet NC, M30 premix, and M26 and M30 finished granules failed to propagate explosive reactions between conveyors when tested in the above test configuration. Material bed depths exceeded their critical diameters in these tests.

On the basis of the above, this safety concept has been adopted in automated multi-base operations.

CONCLUSION

Although advancements in analytical hazards analysis are being continually pursued and applied for assessing and designing safety in explosive and propellant manufacturing operations, prevention of initiation cannot be absolutely assured. Understandably, the probability for incident occurrence is reduced or minimized through applications of the qualitative and quantitative procedures of Preliminary Hazard Analysis, Failure Mode and Effect Analysis, and Hazards Fault Tree Logic. However, the chance always exists for system failures, human errors, and deviations from procedures to be a primary cause for initiation. Therefore, the problem confronting the design and safety engineer becomes one of effecting equipment designs and processing procedures having low probability for explosive reactions. The combination of the critical height, critical diameter, and simulated equipment test provides the analyst with valuable tools for establishing equipment designs, operating quantities, and procedures for reducing the explosion probability in the event of initiation.

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5/ Final Production Engineering Report, Project OAC 55-59-CB54, "Develop Method for Eliminating or Reducing the 'Danger Period' in Mixing of Triple-Base Powders," RAD 130.40 (February 25, 1958).

6/ Zeigler, E., "Safety of Nitroguanidine Powders," Kenvil Report KEN 130-10 (July 15, 1953).

7/ Richardson, R. H., et al, "Hazards Analysis Through Quantitative Interpretation of Sensitivity Testing," Annals of the New York Academy of Sciences, Volume 152, Article 1 (October 28, 1968).

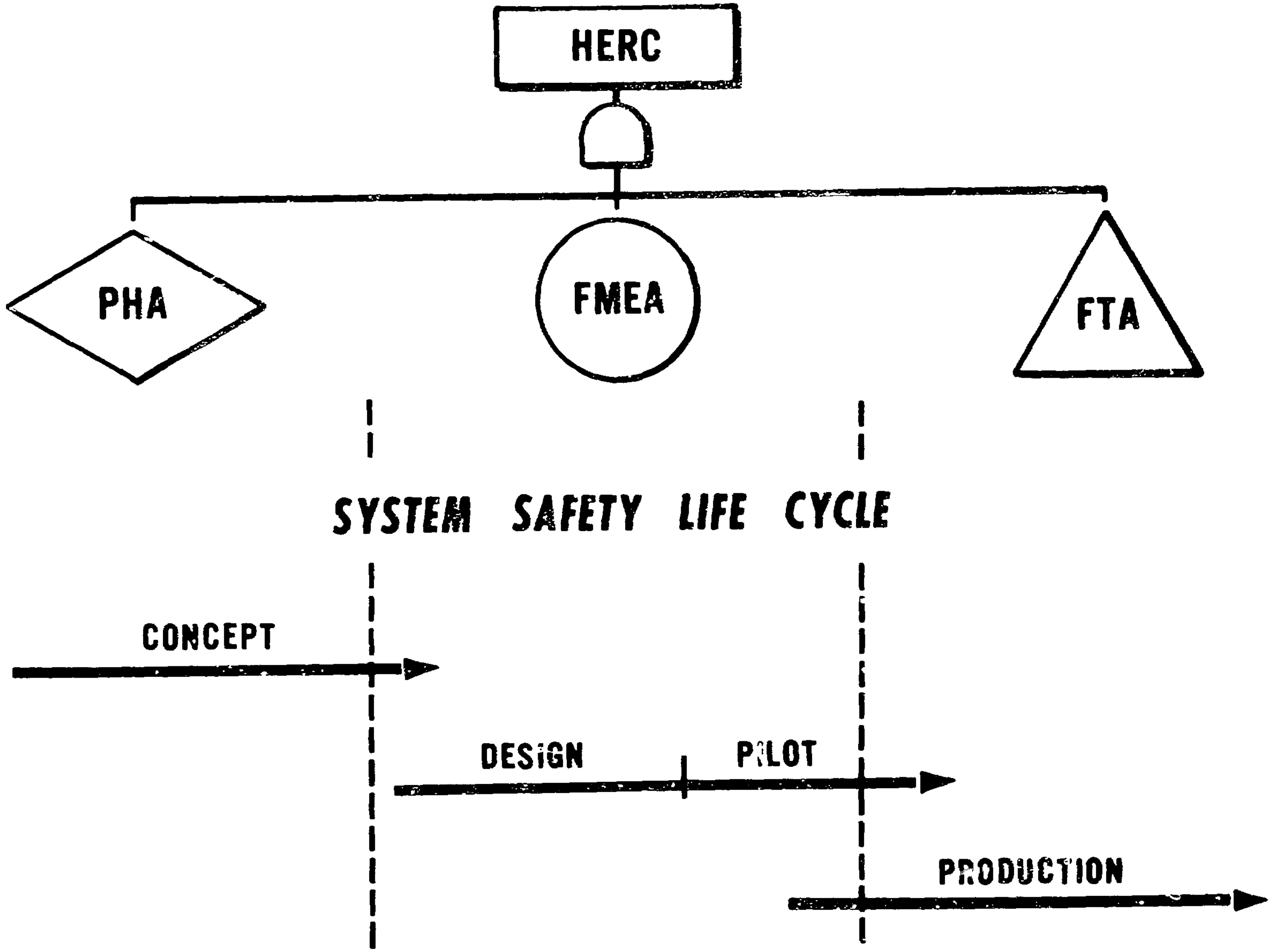

HERC
PHA
FMEA
FTA
SYSTEM SAFETY LIFE CYCLE
CONCEPT
DESIGN
PILOT
PRODUCTION

Figure 1

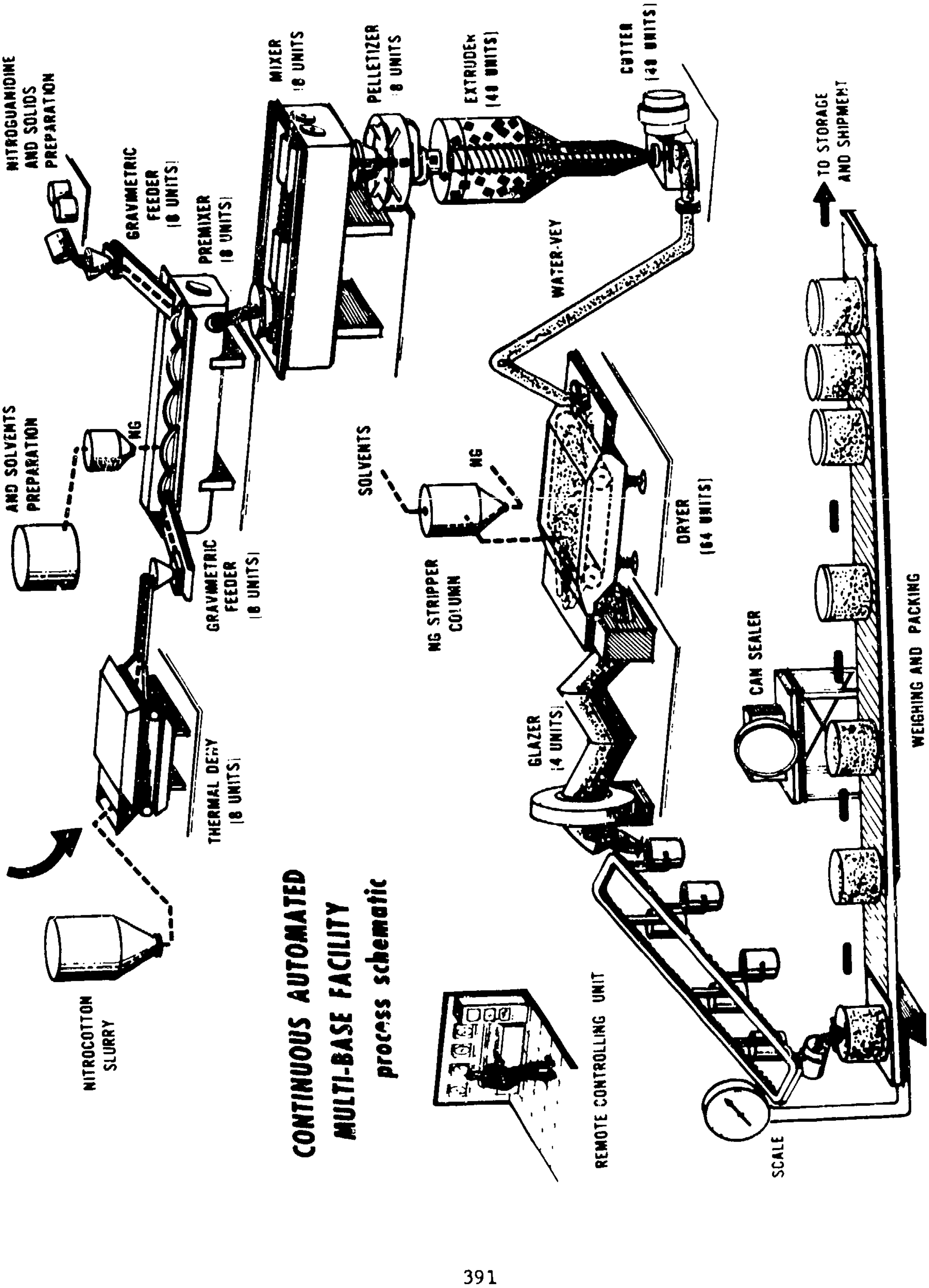
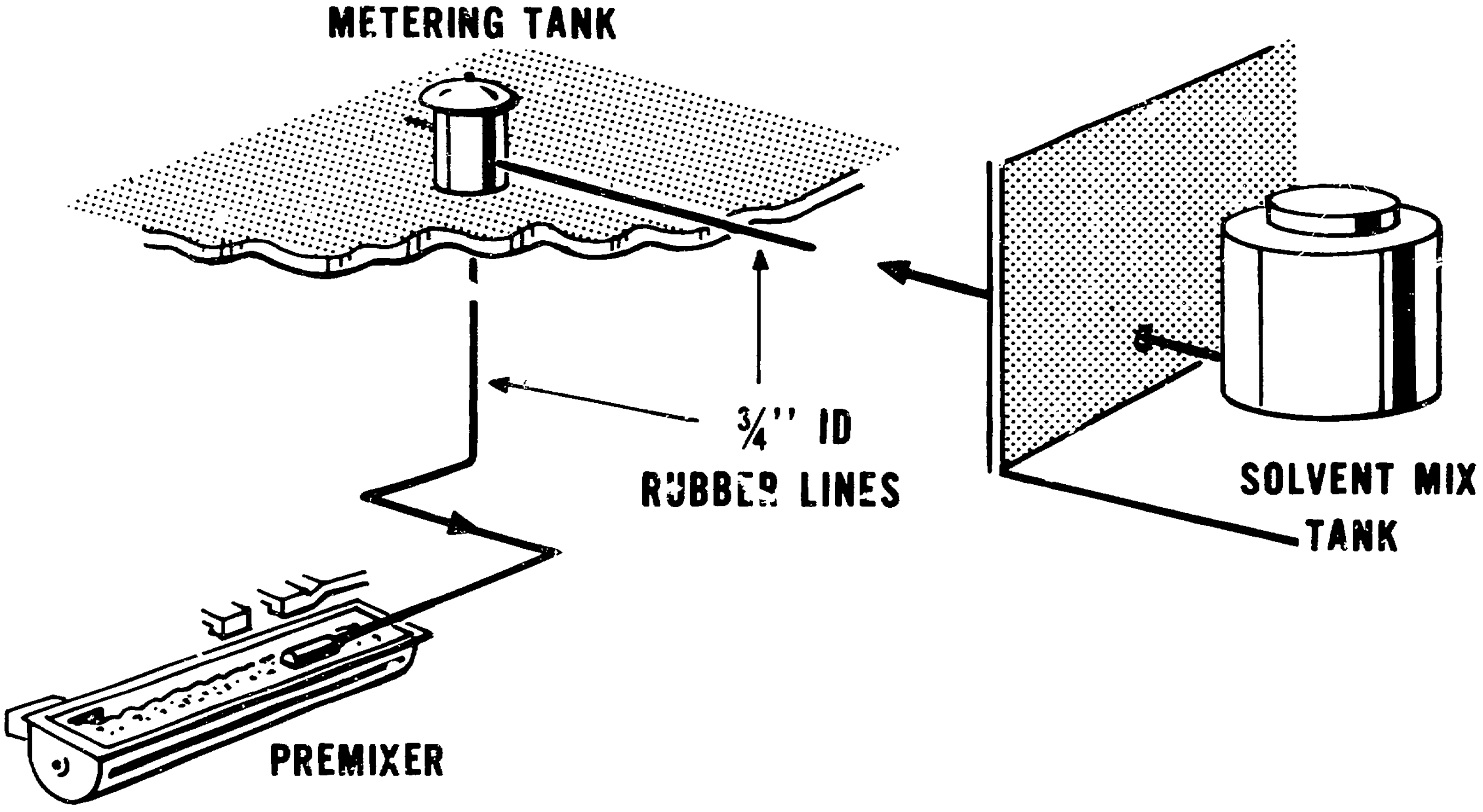
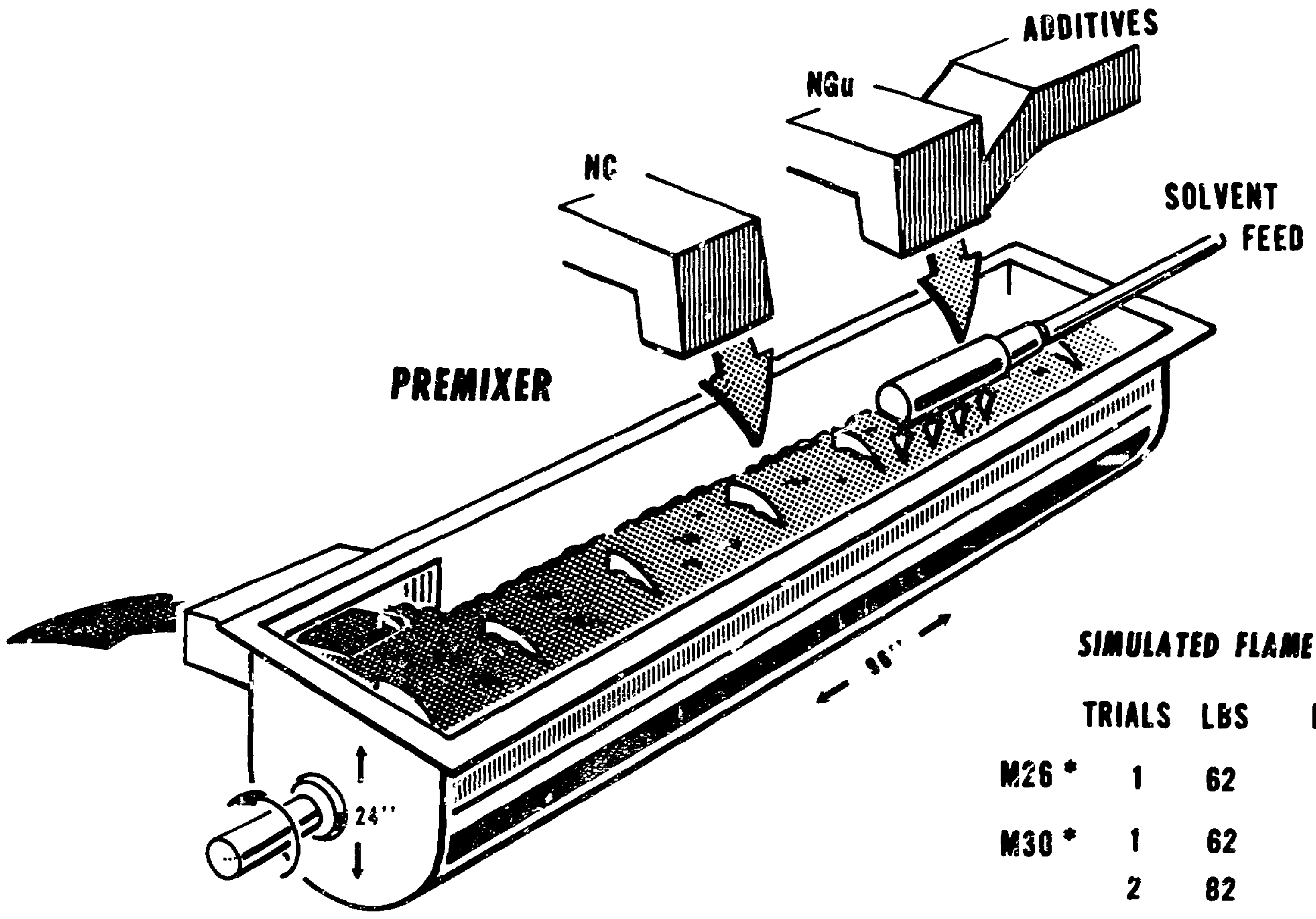

CONTINUOUS AUTOMATED
MULTI-BASE FACILITY
process schematic
NITROCOTTON SLURRY
THERMAL DEHY (8 UNITS)
GRAVIMETRIC FEEDER (8 UNITS)
NITROGLYCERIN AND SOLVENTS PREPARATION
NG
GRAVIMETRIC FEEDER (8 UNITS)
NITROGUANIDINE AND SOLIDS PREPARATION
PREMIXER (8 UNITS)
MIXER (8 UNITS)
PELLETIZER (8 UNITS)
EXTRUDER (48 UNITS)
CUTTER (48 UNITS)
WATER-VEY
SOLVENTS
NG
NG STRIPPER COLUMN
DRYER (64 UNITS)
GLAZER (4 UNITS)
CAN SEALER
WEIGHING AND PACKING (4 UNITS)
TO STORAGE AND SHIPMENT
REMOTE CONTROLLING UNIT
SCALE

Figure 2



NG SOLVENT METERING SYSTEM

Figure 3



SIMULATED FLAME TESTS

	TRIALS	LBS	REACTION
M26 *	1	62	BURNING
M30 *	1	62	BURNING
	2	82	BURNING

* ≈ 20% TOTAL VOLATILES

Figure 4

IN-LINE SAFETY DOOR CONCEPT

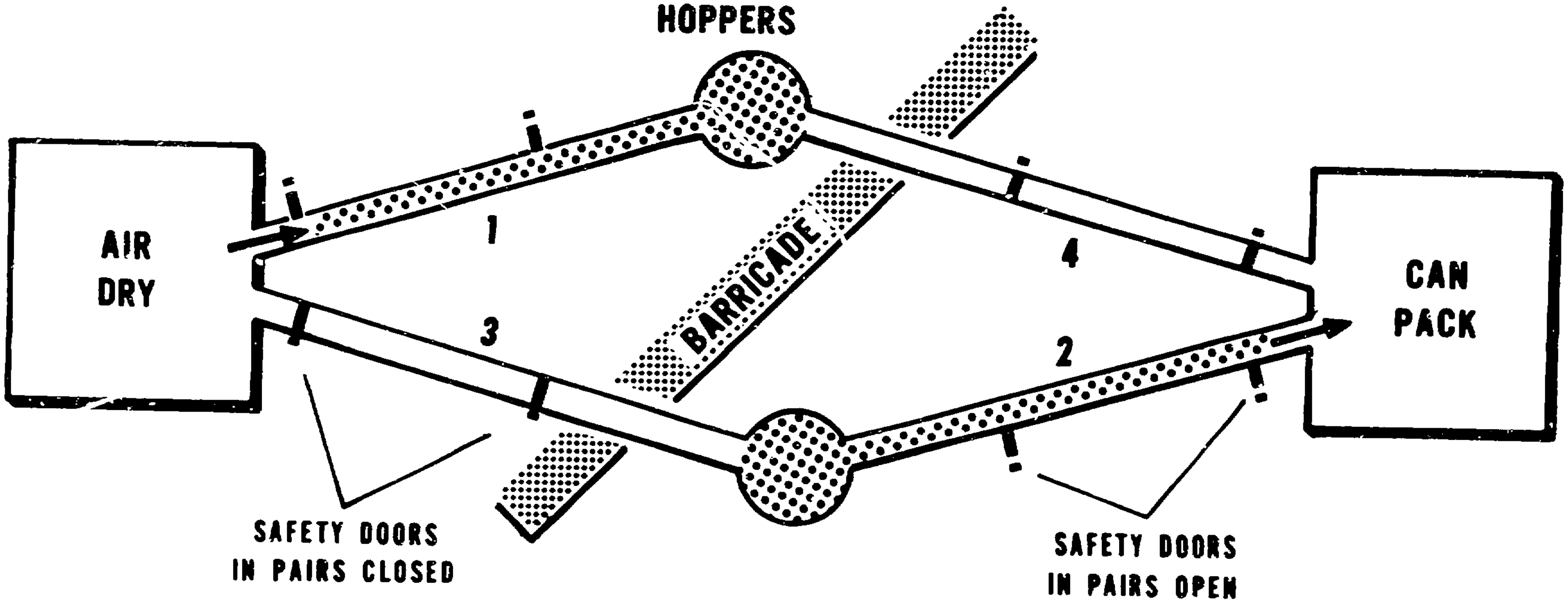
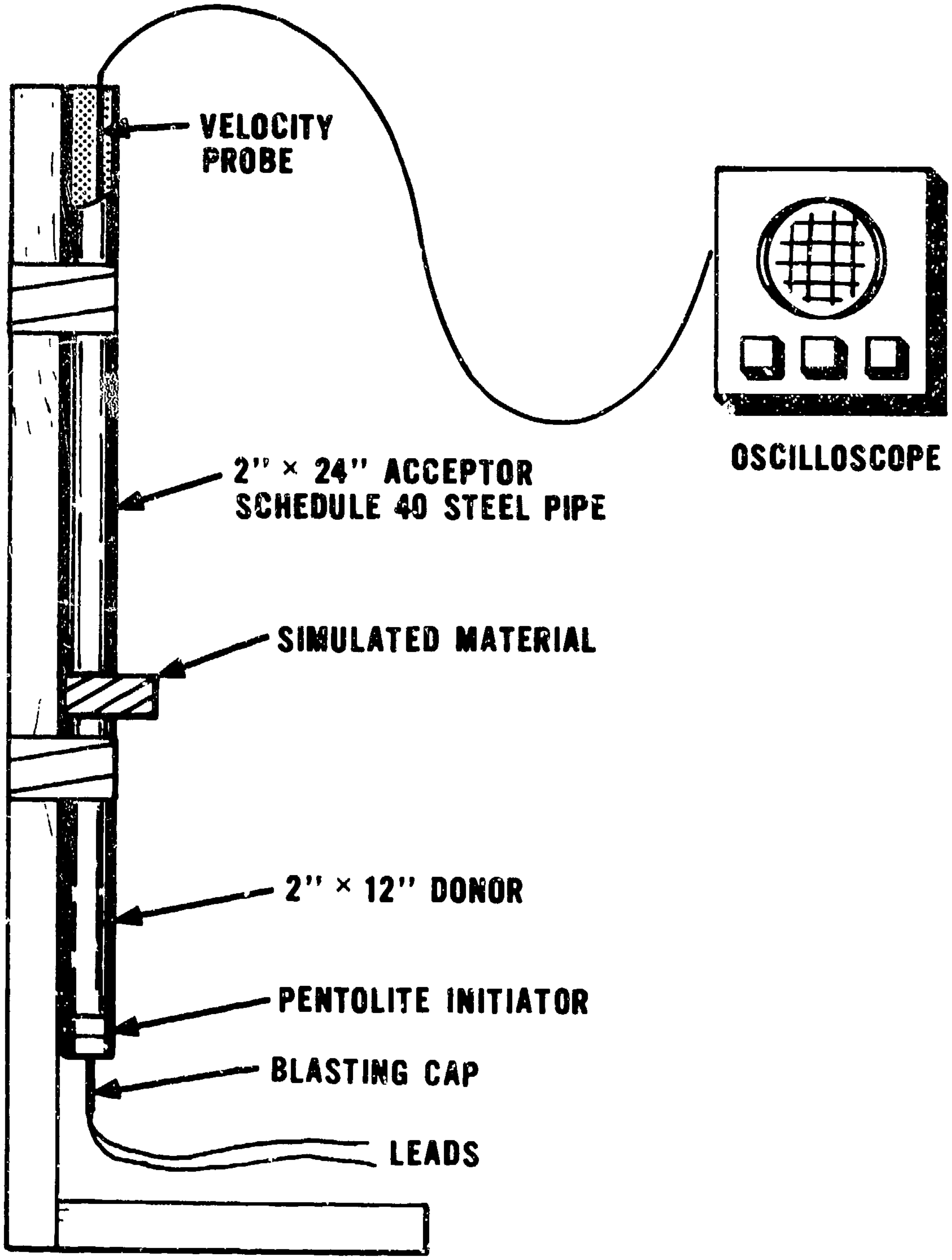


Figure 5



ARRANGEMENT FOR IN-LINE SAFETY DOOR TEST

Figure 6

RIGHT ANGLE VERTICAL SEPARATION CONCEPT

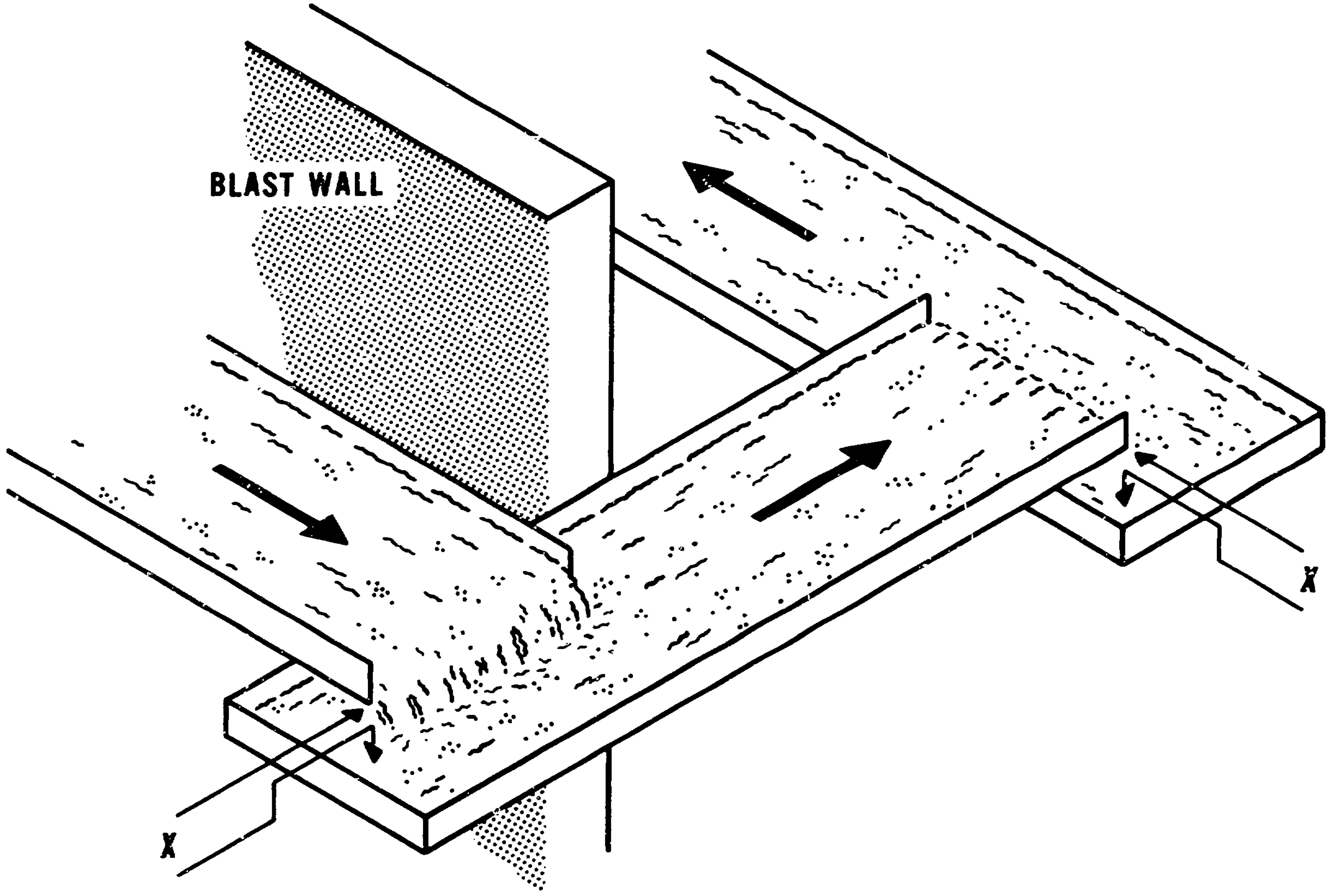


Figure 7

TABLE I

SENSITIVITY CHARACTERISTICS

	INITIATION		FLAME	SHOCK
	IMPACT FT-LBS/IN^2	FRICTION LBS/IN^2	CRITICAL HEIGHT * TO EXPLOSION (IN)	MIN. EXPLOSIVE DIMENSION (IN)
NG	6	16,800 AT 3 FPS	<1.0	<0.04
NG/VOLATILE SOLVENT 75/25	61	$>64{,}700$ AT 8 FPS	>9 <12	0.27 STEEL 0.75 RUBBER

* 2 INCH DIAMETER STEEL

TABLE II

M30 PREMIX INGREDIENT SENSITIVITY

		THRESHOLD INITIATION LEVEL		
		IMPACT FT-LBS/IN^2	FRICTION LBS/IN^2 AT 8 FPS	% SOLVENT
CONVENTIONAL	NG/NC/SOLVENT 40/ 50 /10	3.5	86,600	5-7
ALTERNATE	NG/ NGu/ADDITIVE/SOLVENT 25.6/54.3/ 2.1/ 18	$\geq$ 63.5	> 129,200	9.8-10.5
	NG/ NGu/NC/ADDITIVE/SOLVENT 18.4 /39.1/23 / 1.5/ 18	21	155,600	9.3-9.8

TABLE III

M30 PREMIX FLAME & SHOCK SENSITIVITY

		CRITICAL HEIGHT * TO EXPLOSION (IN)	CRITICAL DIMENSION FOR EXPL PROPAGATION (IN)	% SOLVENT
CONVENTIONAL	NG/ NC/ SOLVENT 40/ 50/ 10	6	< 1.0	7-10
ALTERNATE	NG/ NGu/ NC/ ADDITIVE/ SOLVENT 18.4/ 39.1/ 23/ 1.5/ 18	$> 34 < 37$	< 1.0	≈ 18

* 2 INCH DIAMETER STEEL PIPE

TABLE IV

INITATION SENSITIVITY

		THRESHOLD INITIATION LEVEL		
		IMPACT FT-LBS/IN^2	*FRICTION* LBS/IN^2 AT 8FPS	% SOLVENTS
M30 GREEN MIX				
	BEFORE NGu ADD	16	75,000	11-12
1st NGu ADD	2 MIN AFT	32	146,000	17-18
	20 MIN AFT	40	76,200	17-19
2nd NGu ADD	2 MIN AFT	32	108,000	15-19
	20 MIN AFT	26	103,000	14-16
	END OF MIXING	16	88,600	7-8

TABLE V

FLAME & SHOCK SENSITIVITY

		CRITICAL HEIGHT TO EXPLOSION DIA (IN)	CRITICAL HEIGHT TO EXPLOSION HT (IN)	CRITICAL DIAMETER FOR PROPAGATION (IN)	% SOLVENTS
NGu		2	>22 <25	< ¼	DRY
		4	>46		
M30 GREEN MIX					
1st NGu ADD	2 MIN AFT	2	>24	> ½ < 1.0	17-22
		4			
	20 MIN AFT	2	>24	> ½ < 1.0	21-22
		4			
2nd NGu ADD	2 MIN AFT	2	> 24	< ½	7-15
		4			
	20 MIN AFT	2	> 24	< ½	10-13
		4			

TABLE VI

IN-LINE SAFETY DOOR

	TEST MATERIAL	FRANGIBLE SECTION	MINIMUM ATTENUATOR THICK (IN)
M26	LUCITE	NO	5.50
	LEXAN	NO	3.75
	STAINLESS STEEL	NO	1.125
		YES	0.125
M30	STAINLESS STEEL	NO	0.375
		YES	0.125

TABLE VII

SIMULATED CONVEYOR TESTS

	FLOW RATE LBS/HR	*SEPARATION DISTANCE (IN)*	*RESULTS*
NGu	STATIC	NONE	PROPAGATES AROUND CORNERS
	120-250	0-6	PROPAGATES AROUND CORNERS
		9	NO PROPAGATION
NC (15% VOLATILES)	420	9	NO PROPAGATION
M30 PREMIX	480		
M26 & M30 FINISH PROP.	180		

A MANAGEMENT APPROACH TO SAFETY DURING PLANT MODERNIZATION AND AN EXAMPLE OF ACTUAL APPLICATION

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Naval Ammunition Production Engineering Center
Crane, Indiana

One technique for obtaining "built in" safety while conceiving or planning modernized ammunition facilities is to utilize the expertise of safety specialists as members of the project team. Nothing earth-shattering about this, except it isn't usually done. Figure (1) illustrates a typical project team, which consists of: an explosive loading engineer, a contracting officer, an industrial or mechanical engineer, a field activity representative, a structural engineer and a product engineer.

The normal use of safety specialists seems to come toward the end of a phase of a project or study, and if safety has objections, that usually means starting all over again. If this occurs during the preparation of final drawings and specifications, the redrawing and rewriting could cause a considerable delay in the project, or if the objections come after a feasibility or other type study, the conclusions may be meaningless or at least questionable.

The case we will present today is the Western Demilitarization Facility at NAD Hawthorne, Nevada.

The original study was found to be unacceptable in some parts to our safety office. The study was re-examined incorporating safety specialists as project team members.

In doing this, two alternatives were considered: (1) hire a consultant and (2) utilize Navy authorities. Two factors were against hiring a consultant - one was the time required for contracting, and the other was budget constraints. Therefore, it was decided to employ in-house authorities.

This type of safety review has been used before for plant modernization and in one study review, we have utilized as many as 13 people for the safety review panel. This sized group worked well, but was rather expensive. The main advantage was quick response and a variety of viewpoints on the subject under discussion. The main disadvantage was cost.

The right number seems to be three. These three individuals should be competent in safety concerning structures, equipment, and processes. However, they should be free to call on any other authority that may be required for specific problems. This Safety Review Panel (SRP) simply added another block to our organization chart shown by Figure (2).

This team should meet regularly (about every two or three weeks) with the full project team to review current data, report on any tests or calculations performed between meeting periods and provide input and data to overcome current problems.

The main task of the SRP should center on hazard analysis of innovative features of the proposed facility and production equipment design; and the cause of, and consequences of, accidental explosions. An informal system safety analysis should be conducted in accordance with Military Standard 882. Some of the evaluation techniques that should be employed are: (1) a complete review of the study if there was one already prepared, or work closely with a contractor during the study phase if a study is just starting; (2) perform a conservative paper study of potential hazards that might be involved in the process; (3) make on-site visits to inspect the facilities if existing buildings are to be used or visit the site if new construction is planned; (4) take field trips to view similar operations or manufacturer's plants; (5) hold discussions of possible controversial issues with DDESB representatives for guidance or help in solving problems; (6) perform or verify previously performed overpressure calculations of a building's structural integrities based upon the proposed explosive limits; (7) hold in-depth discussions of all facets and areas to achieve a complete review of the project; (8) a final written report should be compiled at the end of each phase (study, test, operational, construction). This report should document what the SRP did and their conclusions.

Two other techniques may be used by the project leader to define and clarify responsibility. One is the well known PERT or CPM chart; an example is shown by Figure (3) and the other is a linear responsibility chart (LRC) shown by Figure (4). This type of chart demands that a project be thought through before work begins and it will assist management in controlling the tasks and functions of the project team, as it specifically identifies responsibility.

Our latest use of the SRP was during the modernization study of our LAP plants. The SRP, as a member of the project coordinating team, reviewed each phase of the study as it was completed by the contractor and provided guidance so that safety became "built in" to the study.

As a part of the modernization study, a complete hazard analysis was performed and reviewed by the SRP before the study was published.

The demil project we are going to present today had a feasibility study made of it. This study was oriented toward processes and site layout and did not specifically address new safety techniques or findings.

As previously mentioned, the study was re-examined incorporating safety specialists and they applied the latest safety criteria and in doing so, helped the project by:

a. Increasing flexibility by going from end item orientation to process orientation.

b. Lowering the construction cost by developing acceptable overpressure design requirements that reduced wall thickness.

c. Reduced compatibility problems by requiring safety process separation.

This effort of reviewing for safety as part of the engineering effort resulted in a faster completion time than expected because all finished work was almost assured of approval. This effort was also cost favorable due to the shortened approval time and extra benefits to the facility.

The actual cost of increasing the size of the project team by three or more additional people in this instance amounted to about eight man months, because they did not apply full time to the project and no lengthy tests or calculations were required. The data collected and applied will have application to other projects.

I would like now to introduce Mr. Jack Kress, who will present some of the before and after results of applying new safety criteria to one of our on-going projects: the Western Demilitarization Facility.

The Western Demilitarization Facility concept was initially generated by awarding a feasibility study and resulted in the facility as shown in Figure 5. This initial facility concept provided for a departure point in developing the final facility configuration.

The feasibility study facilitv layout had the following shortcomings:

a. Munition end-item oriented.

b. Building explosive incident has major facility capability impact.

c. Through-put restricted.

d. Process compatibility deficient.

e. Building over-pressure design costly.

After safety involvement as a part of the project team, the new facility resulted in the following (see Figure 6 and 7):

a. Process oriented facility.

b. Building explosive incidents have minimal facility capability impact.

c. Through-put optimized.

d. Process compatibility practically non-existent.

e. Building separations greatly reduce costs to meet overpressure design.

The following is a general description of the over-all facility capability and characteristics.

The facility will be capable of demilitarizing nearly all of the Navy's varieties of conventional munitions plus a large number of Army items. The most stringent environmental protection will be provided in all operations. Operating personnel will be protected by the latest construction, site layout, operational procedure, and process equipment techniques. Demilitarization down-loading processes will be used to provide significant tangible monetary gains by sale of salvage material and reuse of explosives and munition components.

All gun ammunition from .30 caliber bullets through 16" projectiles; all bombs, mines, and depth charges up to 3,000 pounds net explosive weight; many solid propellant rocket grains; all cluster weapons; and many rocket warheads, grenades, cartridge-activated devices, demolition materials, and pyrotechnics can be processed with this facility. Facility construction methods will provide for building capability to handle such a vast variety of munitions as well as varied equipment and process configurations.

The facility will be located on a 390 acre site at the west side of the Naval Ammunition Depot, Hawthorne, Nevada. Included in the facility will be six process buildings, a boiler plant, sewage treatment plant, water treatment plant, administration building, off-loading dock, service magazines, and sufficient roads, railroads, water distribution, electrical distribution, and lightning protection. The six process buildings include: a preparation building, a mechanical removal building, a steamout/washout building, an incinerator preparation building, a decontamination building, and a refining building. The administration building will house locker facilities, luncheon area, offices, and a QA laboratory. The boiler plant will have the capacity to supply all the necessary steam for heating buildings as well as the steam required for the various processes. Safety to personnel has been given the highest consideration in all the facility design criteria. The site plan for the building locations was predicated on providing the most safety to operating personnel. All buildings have been spaced so as to afford ample protection from an incident in any other building. All buildings have been designed to withstand the overpressurization resulting from an incident at any other building, in accordance with the latest requirements of NAVFAC P-397. Process building corridors have been hardened against any overpressurizations caused by explosions in cells or any other external incident. Locations of buildings have been established which will dictate a flow of materials left to right or most sensitive to inert. This provides a consistency of established hazardous areas which avoids the possibility for unseen incidents. Remote operation of processes by the latest in equipment designs will also enhance the safety aspects. Demilitiarization processes are to be developed, pilot run tested, and safety proved before being acceptable as a process. Basically, this facility has been designed to protect the personnel against all possible incidents, not just on a probability of incidents; the probability for an incident was considered to be 100 percent.

An explanation of the specific functions of each process building with the safety features is provided for the following:

Off-Loading Dock (see Figure 8)

Most items delivered to the facility by rail or truck will be off-loaded at the off-loading dock. No processing other than handling will be conducted. The items will be transported by fork lift truck from rails or trucks to the electric cart system (driverless tractor) for movement to other buildings. The dock will accommodate two box cars or two trucks with a total explosive limit of 100,000 pounds. A non-propagating dividing wall will separate box cars or trucks with a limit of 50,000 pounds of explosive per platform. Quantity distances will be based on a 50,000 pound limit due to the non-propagating dividing walls between the two platforms. The dock will be constructed of an earth covered steel plated arch. Items will be transported around the earth barricade at proper distances to insure non-propagation between the electric carts.

Safety features of the off-loading dock include the following:

a. Change from T-barricade type to an earthen covered metal arch which provides increased protection and increased flexibility at a lower cost.

b. Added safer truck and rail unloading and simplified driverless tractor on movement.

c. Added safer and less costly dunnage removal capability.

Preparation Building (see Figure 9)

Items will be prepared in this building for further processing in other buildings by such methods as remote control of fixed round disassembly, defuzing, smokeless powder separation, removal of components from bombs, mines, and depth charges. All hazardous operations will be performed in barricaded cells while non-hazardous operations will be performed in the on-loading and off-loading areas. The six cells are designed to contain an explosion of 300 pounds each. Concurrent non-hazardous and hazardous operations may be performed with a total building limit of 6,000 pounds. The off-loading, on-loading, control room, equipment room, and the corridor are hardened against the effects of a 300 pound explosion in any one of the six cells as well as any other process building. The building quantity distance limit is based on 6,000 pounds of explosive.

Safety features of the Preparation Building include:

a. First step in process oriented facility.

b. Remove dunnage.

c. Reduce hazard level (by removing initiators, i.e., fuzes, boosters, primers, etc.).

d. Personnel protection from any other building incident as well as from incidents within cells of preparation building.

e. Single direction flow-through.

f. Facility distribution and central control point.

g. 300 pound net explosive cell capacity.

h. Remote operations for hazardous processes.

Smokeless Powder Accumulator Building (see Figure 10)

Smokeless powder is collected from fixed ammunition and cartridges located in the Preparation Building and conveyed via a pneumatic and/or mechanical (belt) conveyor to the smokeless powder accumulator. The building consists of two accumulator rooms, two pump rooms, and a boxing area. Non-granular smokeless powder is fed to the accumulators via the pneumatic lines while smokeless powder pellets are belt-fed to the boxing area. There is an off-loading dock at the boxing area which is protected from the accumulator room with fire protection type walls.

Safety benefits that are provided include:

a. Remote process capability to eliminate capability problems.

b. Operating as well as off-loading personnel safety.

Mechanical Removal Building Complex (see Figure 11 and 12)

The Mechanical Removal Building Complex function is to perform such operations as contour drilling, core drilling, sawing, and punching of high explosive loaded items. The Mechanical Removal Building Complex consists of a three small cell section, an accumulator section, hardened control room, equipment room, and a remote large cell section. The operating rooms or cells are serviced by a hardened control room and equipment room. The accumulator area consists of pump rooms, accumulator rooms, and a boxing area. High explosives removed from operations in the cells will be collected in the accumulator rooms. A hardened corridor services the accumulator and three small cell areas. Each small cell is designed to accommodate 300 pounds of high explosives, while each of the three large cells can accommodate 3,000 pounds of explosives. Each accumulator and boxing area is designed to withstand a 500 pound explosion. The control room, equipment room, and corridor are hardened to protect personnel against the effects of an explosion in any cell, accumulator, boxing room, or any other process building.

Safety features of the Mechanical Removal Building Complex include:

a. Personnel protection from any other building incident as well as from incidents within cells of Mechanical Removal Building Complex.

b. 300 pounds net explosive cell capacity plus large fragment high velocity capacity.

c. Remote operation for hazardous processes.

Safety features of the large cell complex are:

a. 3,000 pounds net explosive cell capability each.

b. Remote operations controlled in mechanical removal building.

Bulk Incinerator Building (see Figure 13)

The operations in this building will prepare bulk energetic material for incineration in either a liquid or bulk incinerator. Bulk solid explosives will be ground into a powder and then mixed with water to form a slurry; liquid waste will be diluted into solutions. The slurries and solutions will be remotely delivered to their appropriate incinerator. The incinerator facility will have a capacity to incinerate 1,000 pounds per hour in each incinerator.

Safety features for the Bulk Incineration Building include:

a. Remote operations to provide personnel safety; operations controlled and monitored by central control room.

Steamout/Washout Building (see Figure 14)

Operations in this building include washout, steamout, dewatering, flaking, and boxing of explosives from projectiles, mines, bombs, rocket motors, etc. The building consists of two operating bays separated by equipment and control rooms. The entire building will be designed to protect personnel from an incident in any other building. The building quantity distance is based on 18,000 pounds of explosive.

Special features of the Steamout/Washout Building include:

a. Personnel safety by incorporating over-pressure designed structure from incident in any other building.

b. Two-bay operation capability for concurrent non-compatible operations.

Refining Building (see Figure 15)

Operations in this building include processes for refining of bulk quantities of explosives and chemical decontamination of munition components. The building consists of one large work bay and appropriate control rooms and equipment rooms with a rail service off-loading dock. The building and its control and equipment rooms are to be designed to protect personnel from the effects of an explosion in any other process building. The building quantity distance is based on 50,000 pounds of explosive.

Safety features of the Refining Building include:

a. Personnel protection from an incident in any other process building.

b. Remote operational control from a control room.

Decontamination Building (see Figure 16)

The Decontamination Building will contain decontamination furnaces, small items popping furnaces, and large item furnaces, preparation cells, equipment rooms, and control rooms. Decontamination furnaces will decontaminate items that have a small amount of residual explosives left in them which can be exposed to a flame. Typical items which can be decontaminated in this manner are munitions which have been sawed into and the explosive has been washed out, items which have a residual of explosive after high pressure washout, and various items which are subpected of having explosive contaminates. The popping furnaces will accommodate small explosive items causing them to detonate in the furnace. Scrap and decontaminated items will be outloaded from the building as saleable salvage material. The building consists of eight cells and adjacent furnace pads, a distribution area, and an outloading area. Each cell is designed to contain an explosion of 50 pounds of explosive.

Special features of the Decontamination Building are:

a. Remote operations.

b. Single direction flow-through.

c. Hardened structure to protect personnel from incident in any other building and from incident or furnace pad or preparation cell of decontamination building.

Initial locations of ready service magazines were made adjacent to their particular process building; but, to enhance safety and reduce total project costs, these magazines were placed in two groupings (see Figure 17).

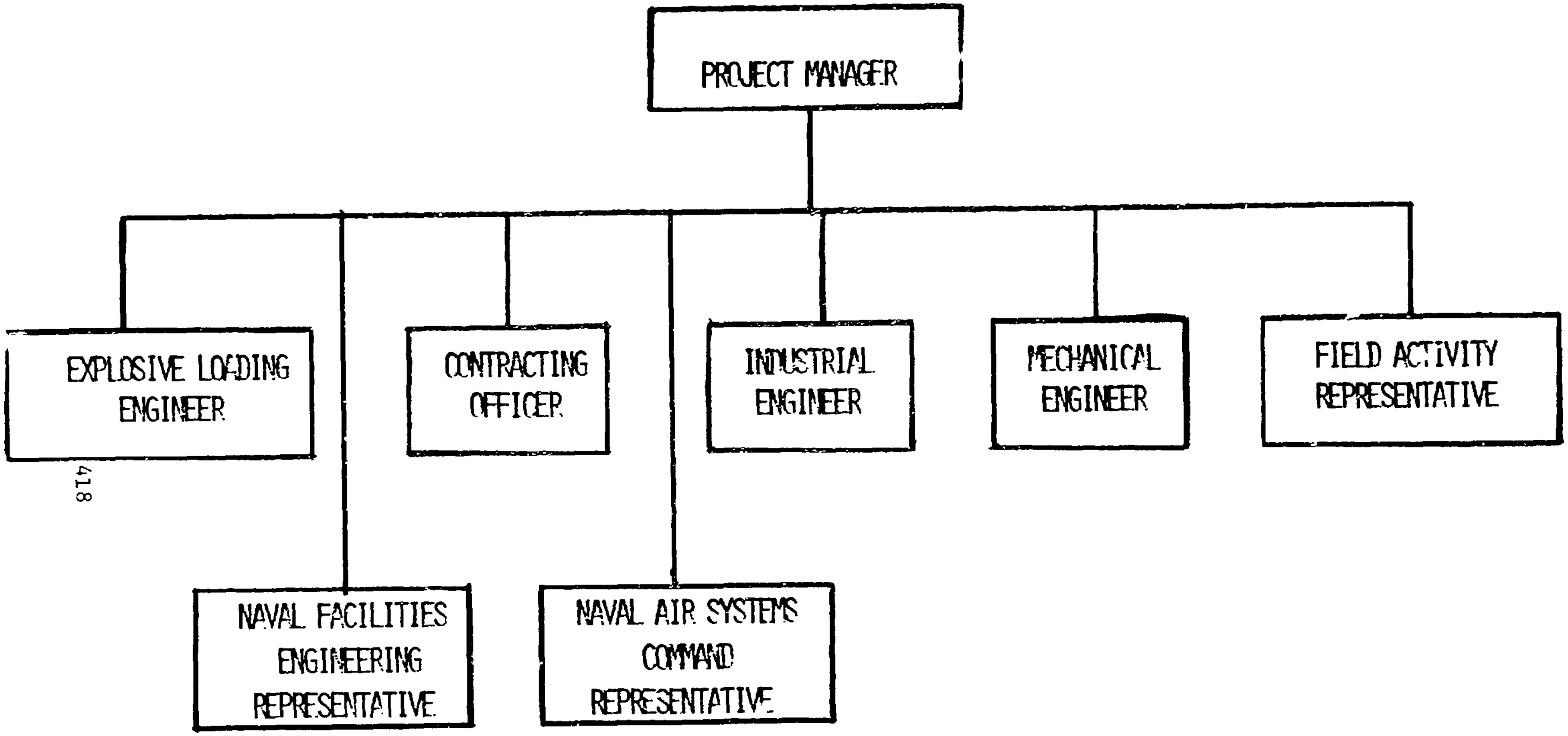

PROJECT MANAGER
EXPLOSIVE LOADING ENGINEER
CONTRACTING OFFICER
INDUSTRIAL ENGINEER
MECHANICAL ENGINEER
FIELD ACTIVITY REPRESENTATIVE
NAVAL FACILITIES ENGINEERING REPRESENTATIVE
NAVAL AIR SYSTEMS COMMAND REPRESENTATIVE

FIGURE 1

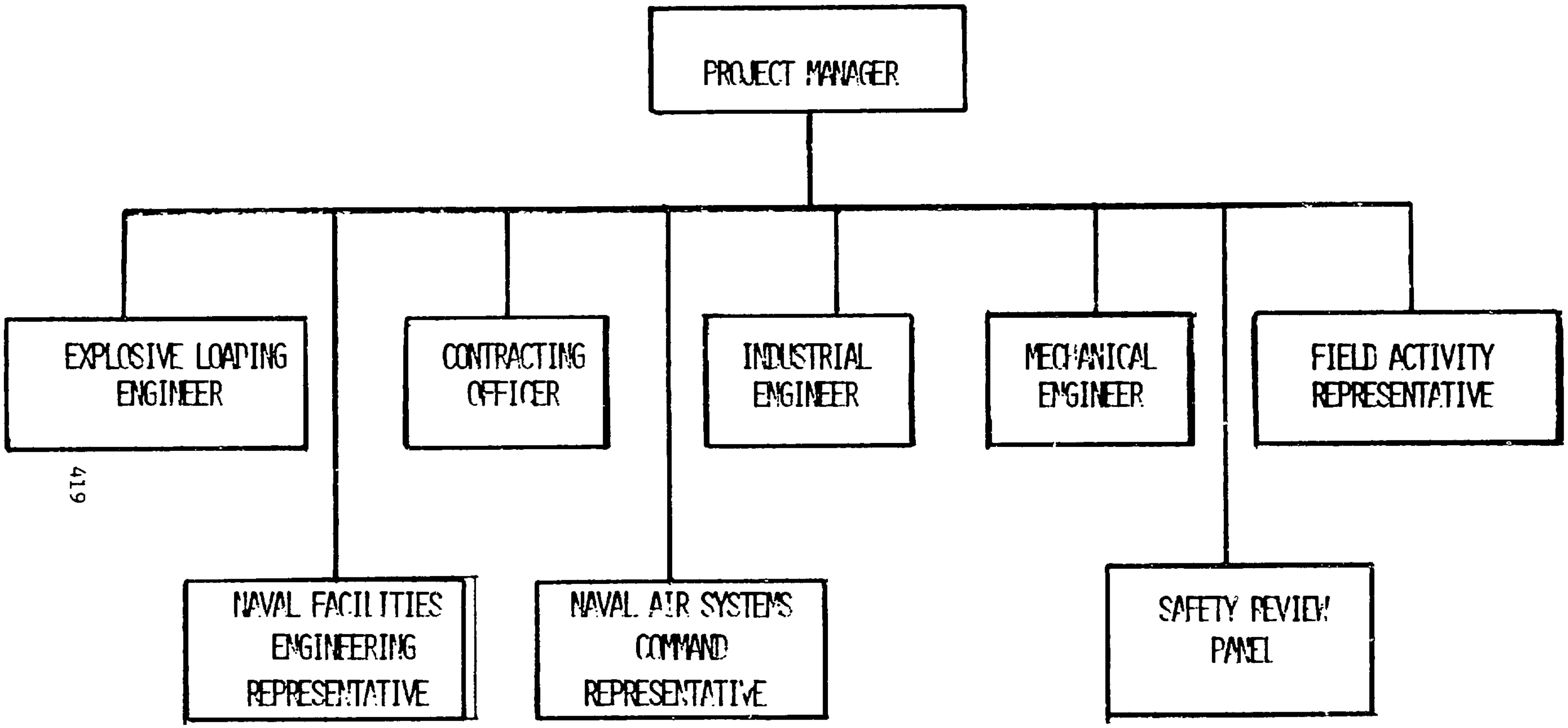

PROJECT MANAGER
EXPLOSIVE LOADING ENGINEER
CONTRACTING OFFICER
INDUSTRIAL ENGINEER
MECHANICAL ENGINEER
FIELD ACTIVITY REPRESENTATIVE
NAVAL FACILITIES ENGINEERING REPRESENTATIVE
NAVAL AIR SYSTEMS COMMAND REPRESENTATIVE
SAFETY REVIEW PANEL

FIGURE 2

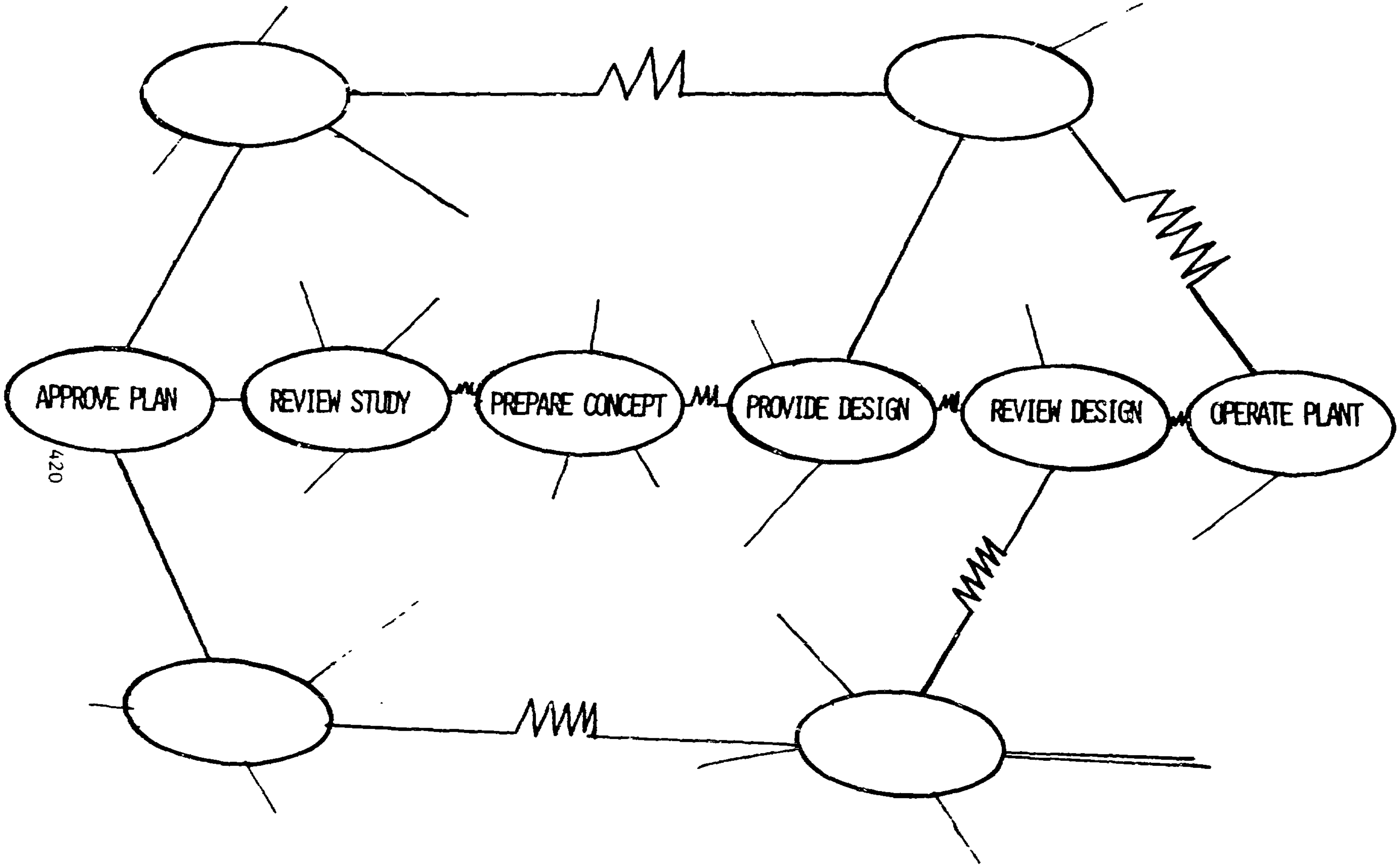

APPROVE PLAN
REVIEW STUDY
PREPARE CONCEPT
PROVIDE DESIGN
REVIEW DESIGN
OPERATE PLANT

FIGURE 3

LINEAR RESPONSIBILITY CHART

NAVSEA WESTERN DEMIL
FACILITY

DATE ___________

APPROVED ________________

	NAVSEA		NAPEC		NAVFAC		SAFETY REVIEW PANEL					
APPROVE PLAN	1		3									
REVIEW STUDY			1				2					
PREPARE CONCEPT			1		2		5					
PROVIDE DESIGN			2		1							
REVIEW DESIGN							1					
OPERATE PLANT												

1 = PERFORM WORK

2 = MONITORS WORK

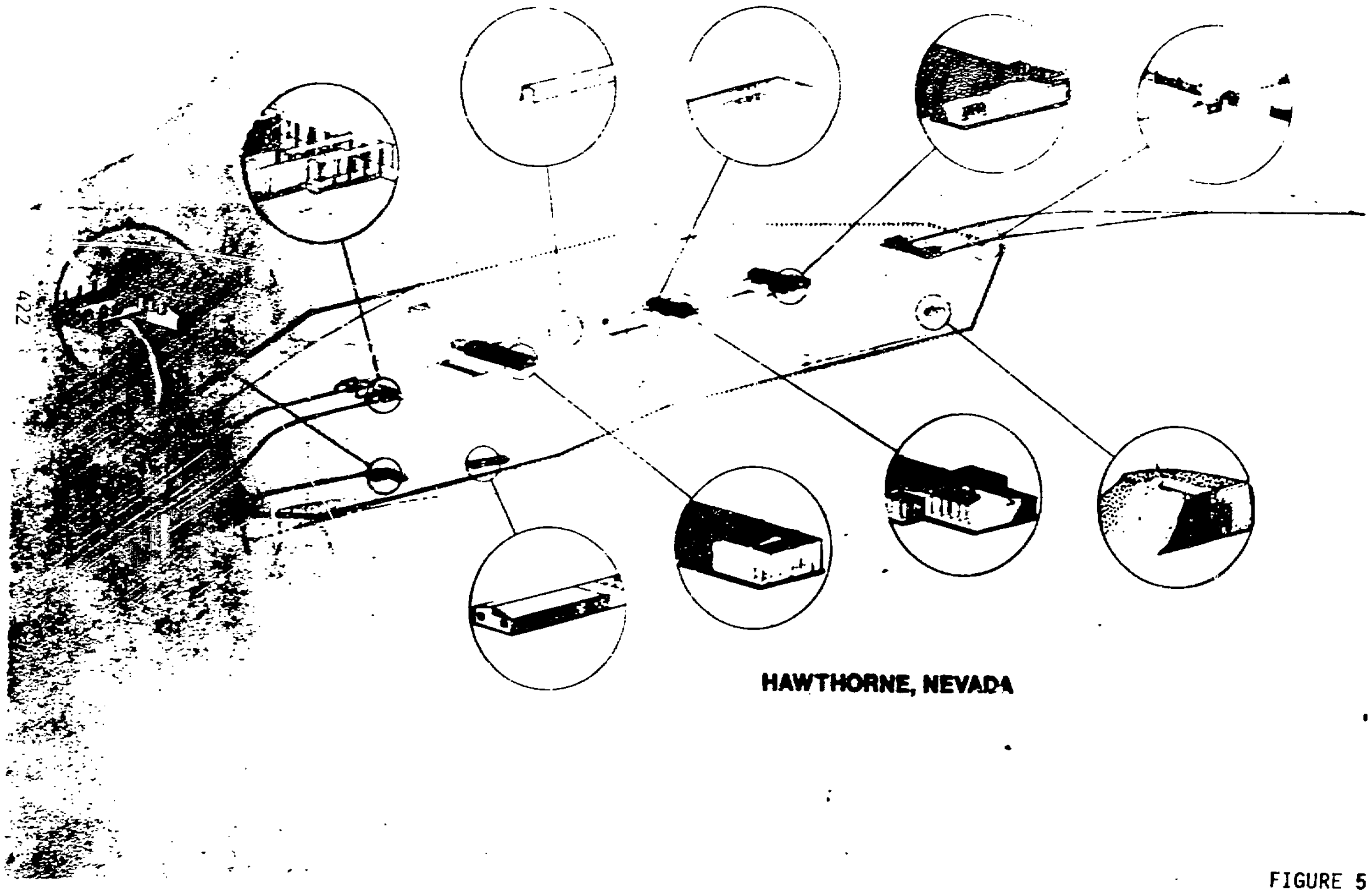
3 = COORDINATES

4 = CONTRACT AUTHORITY

5 = DECISION ON SPECIFIC POINTS

FIGURE 4

DEMILITARIZATION/DISPOSAL FACILITY



HAWTHORNE, NEVADA

FIGURE 5

WESTERN DEMILITARIZATION FACILITY
GENERAL SITE PLAN

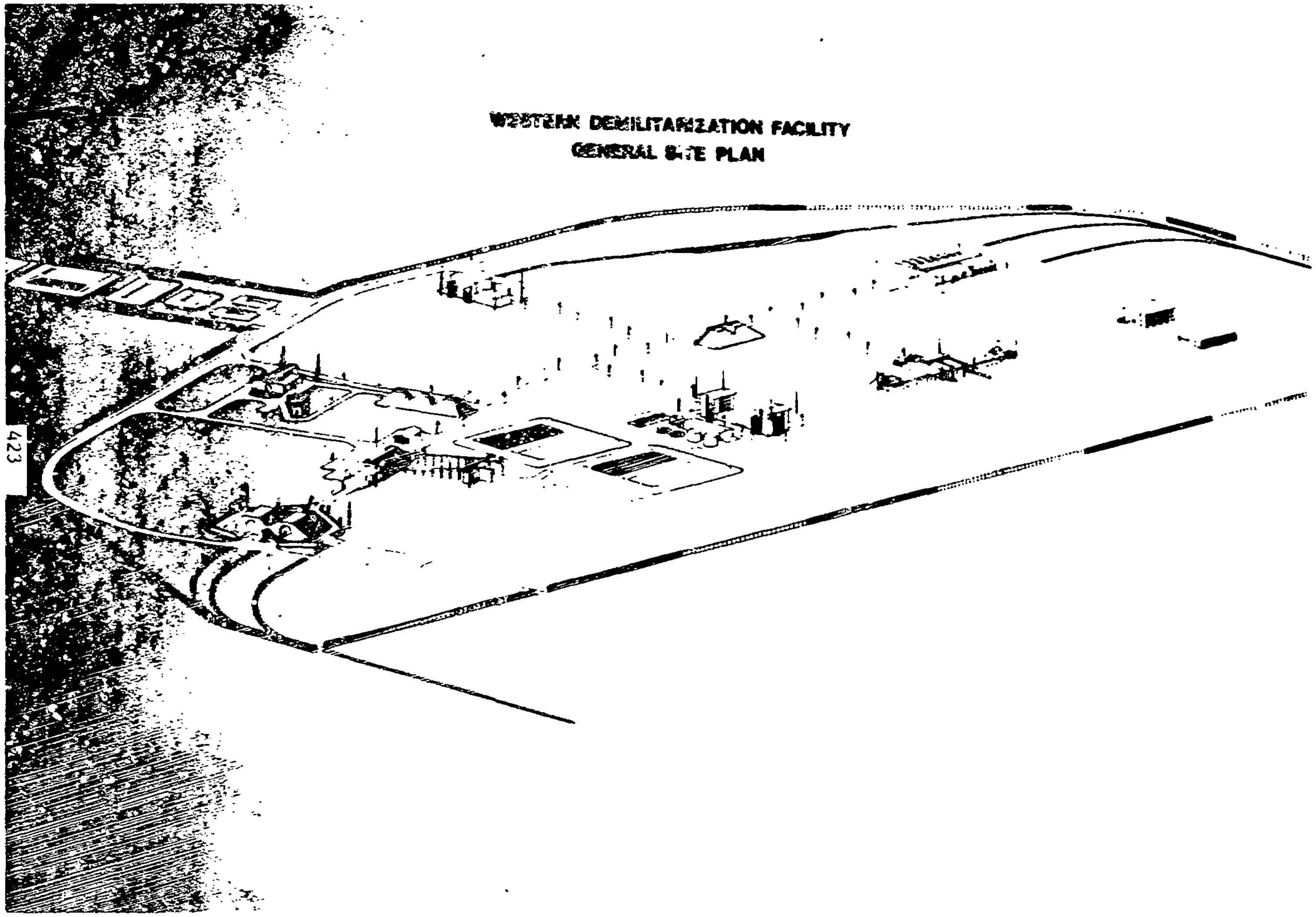


FIGURE 6

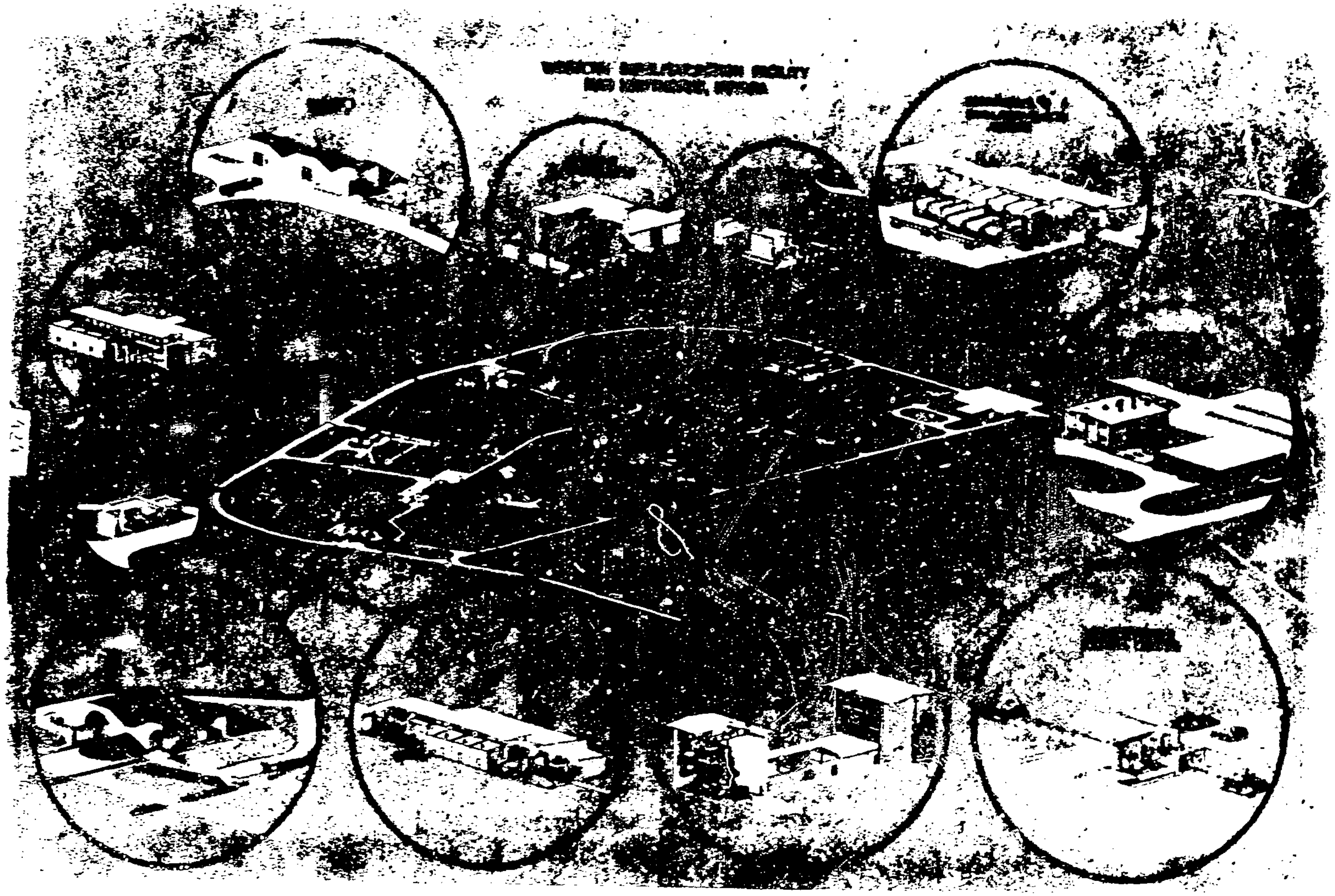


FIGURE 7

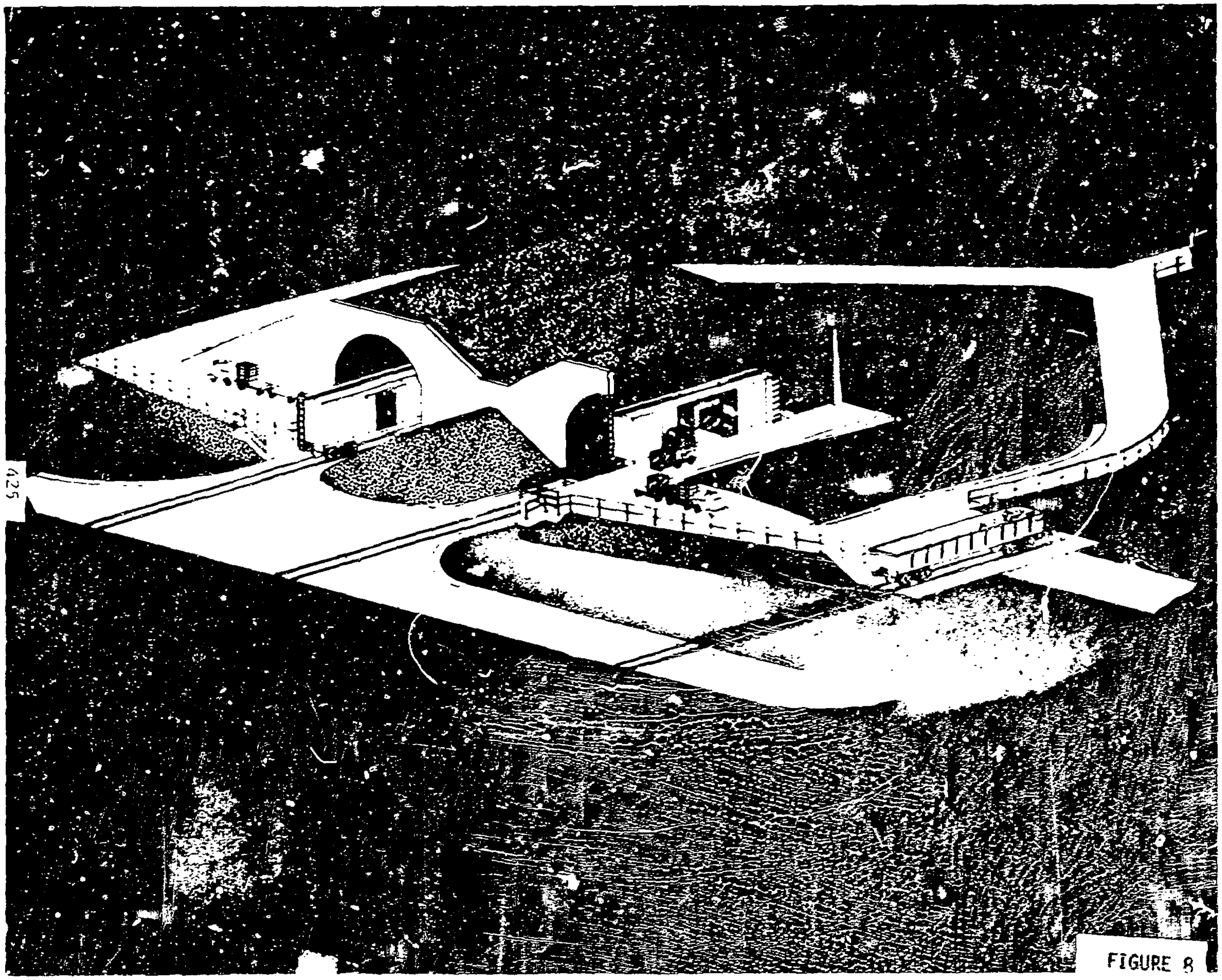


FIGURE 8

WESTERN DEMILITARIZATION FACILITY
PREPARATION BUILDING

FIGURE 9

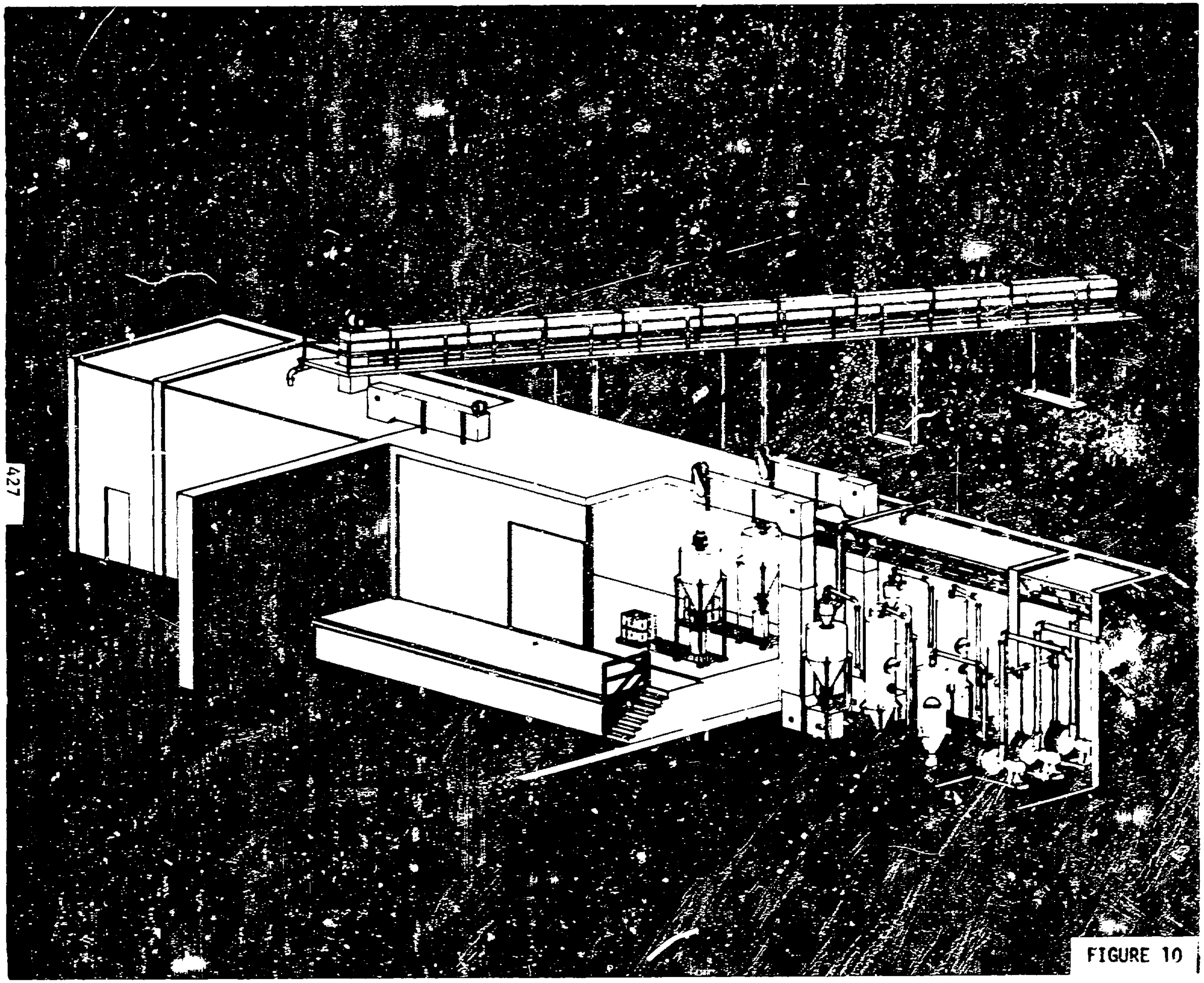


FIGURE 10

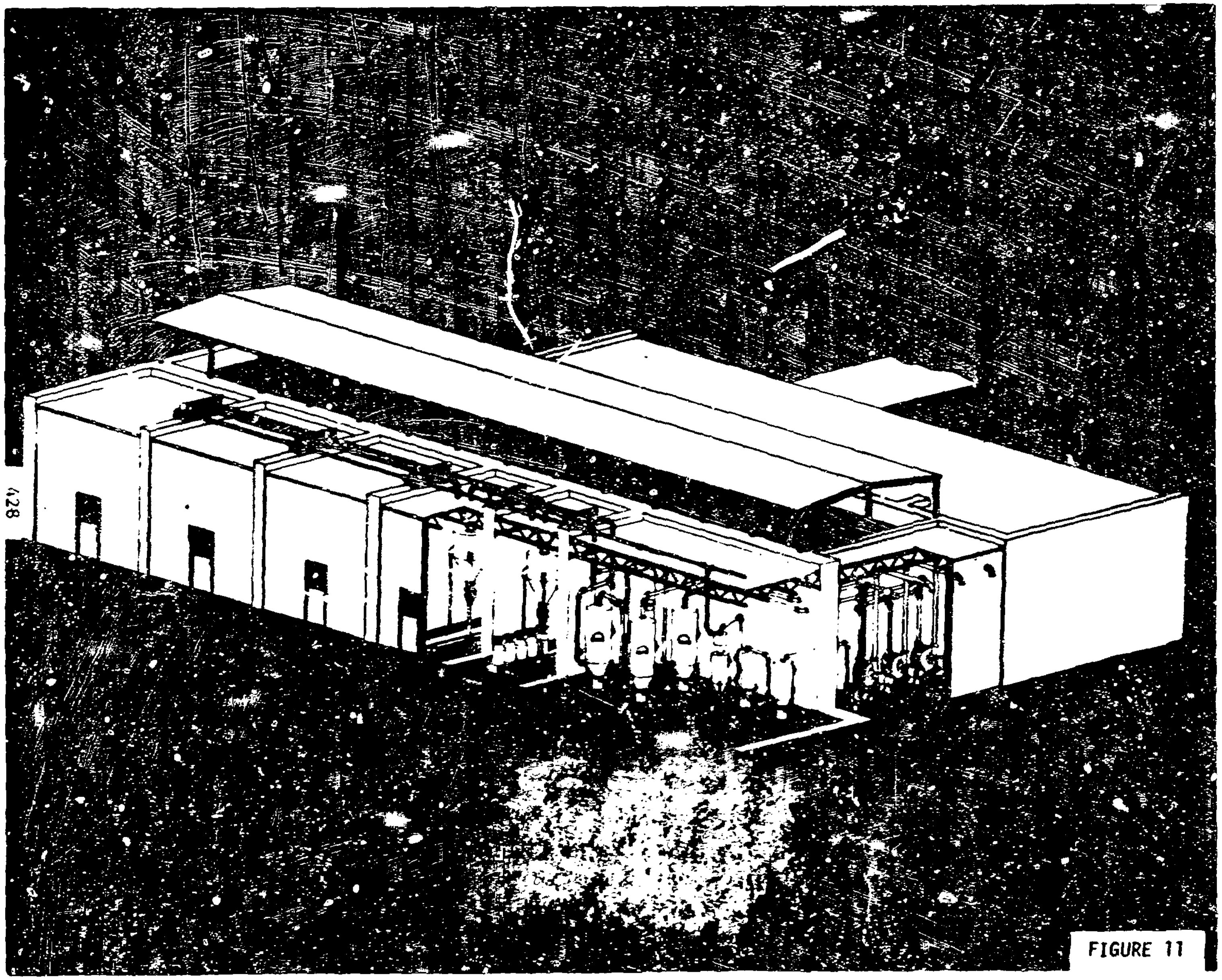


FIGURE 11

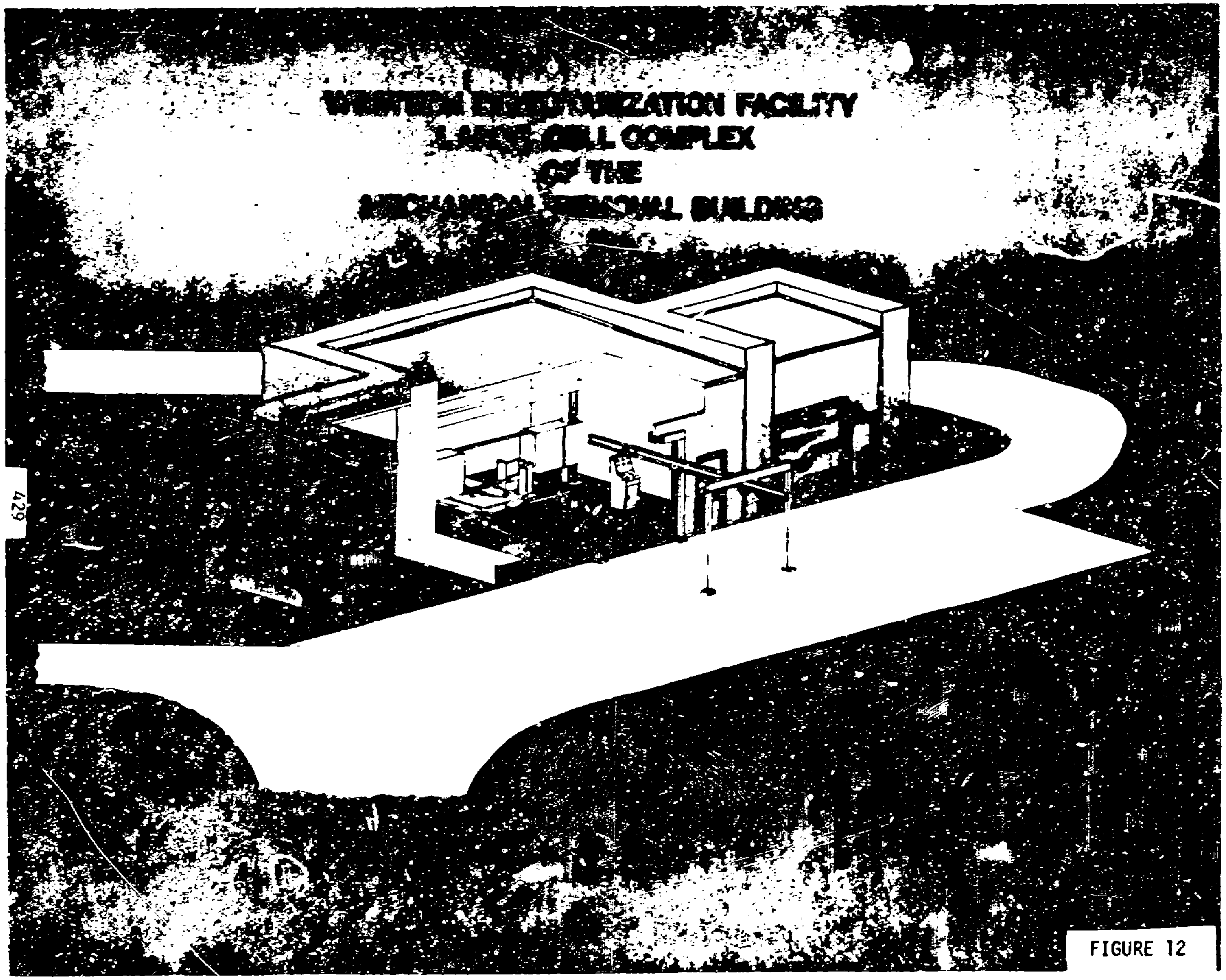

WESTERN [illegible]NIZATION FACILITY
LARGE CELL COMPLEX
OF THE
MECHANICAL [illegible] BUILDING

FIGURE 12

WESTERN DEMILITARIZATION FACILITY
BULK INCINERATOR BLDG.

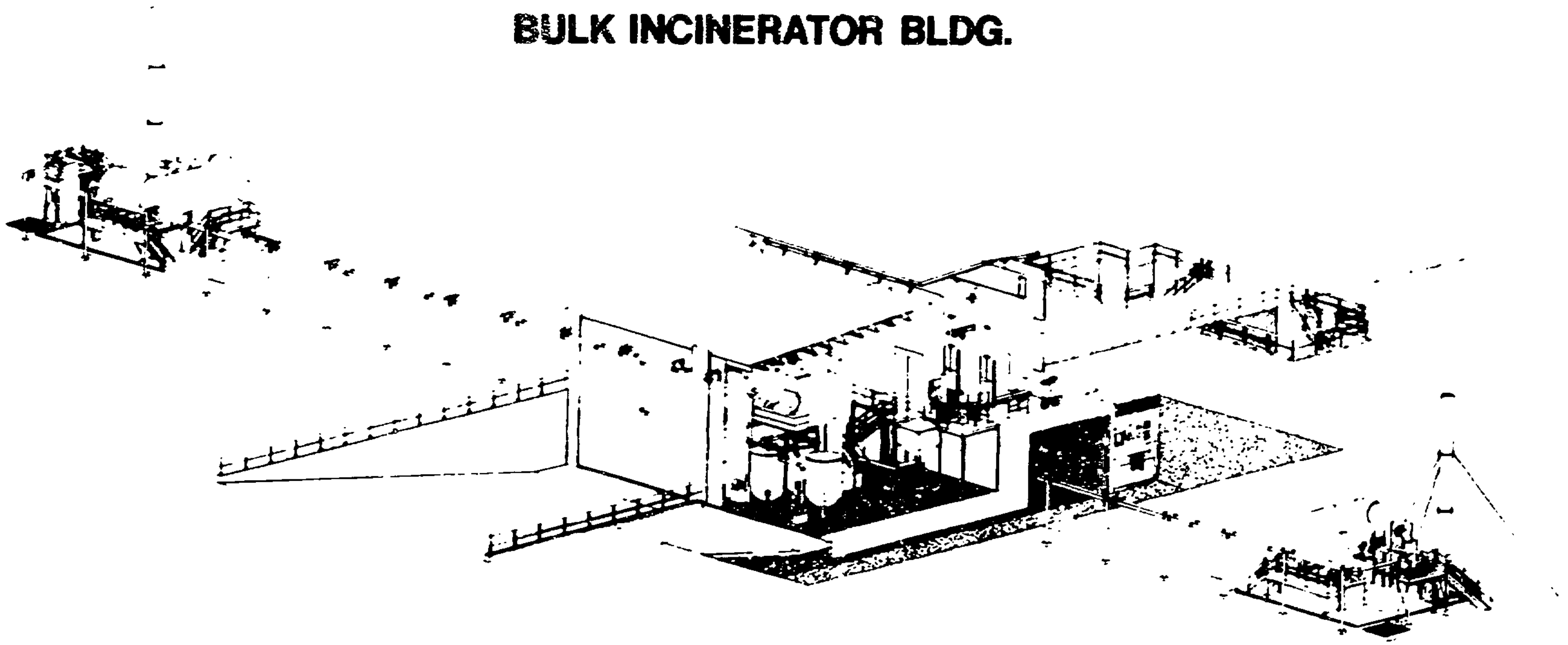
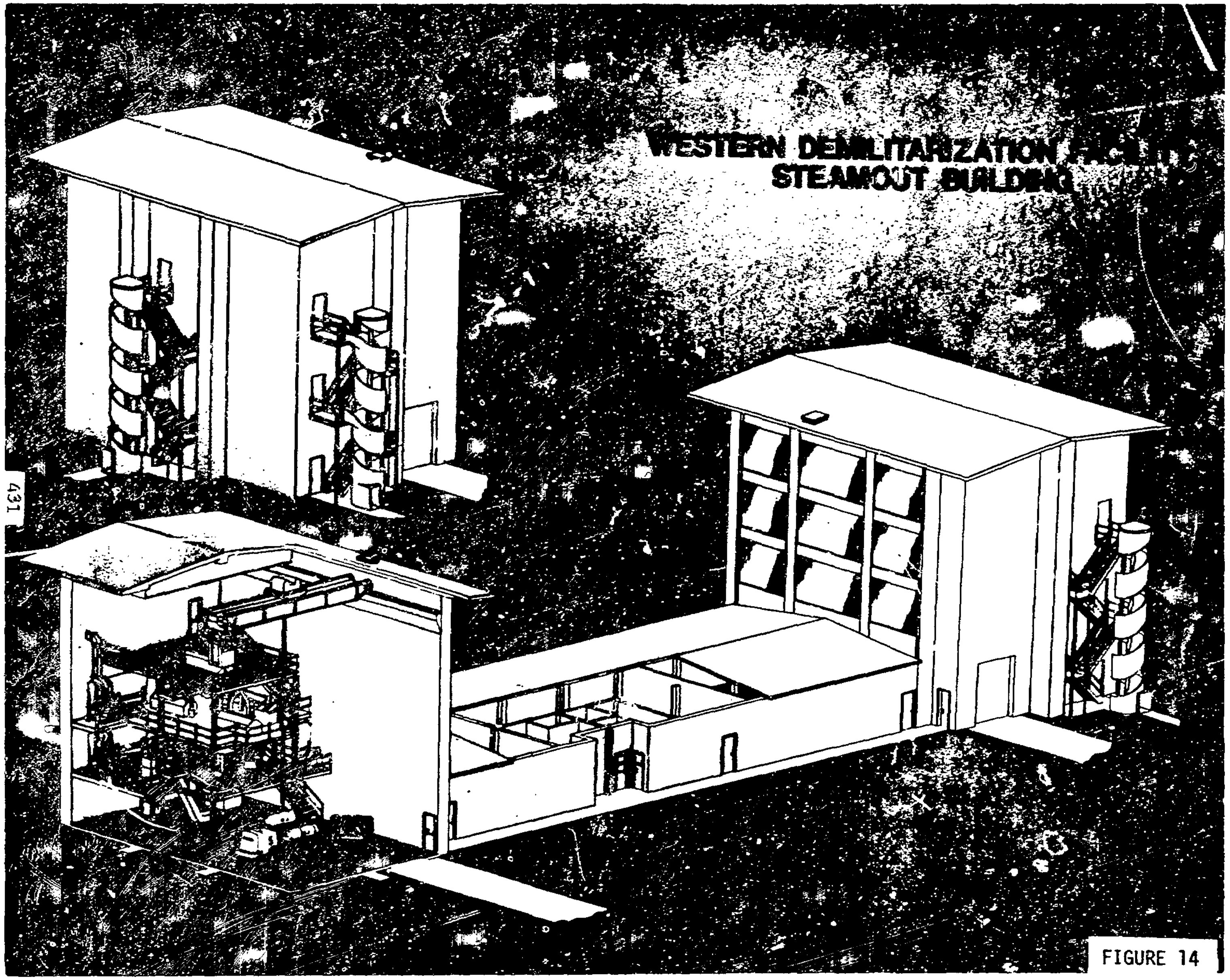


FIGURE 13



WESTERN DEMILITARIZATION FACILITY
STEAMOUT BUILDING

FIGURE 14

WESTERN DEMILITARIZATION FACILITY
BULK EXPLOSIVE REFINING
BUILDING

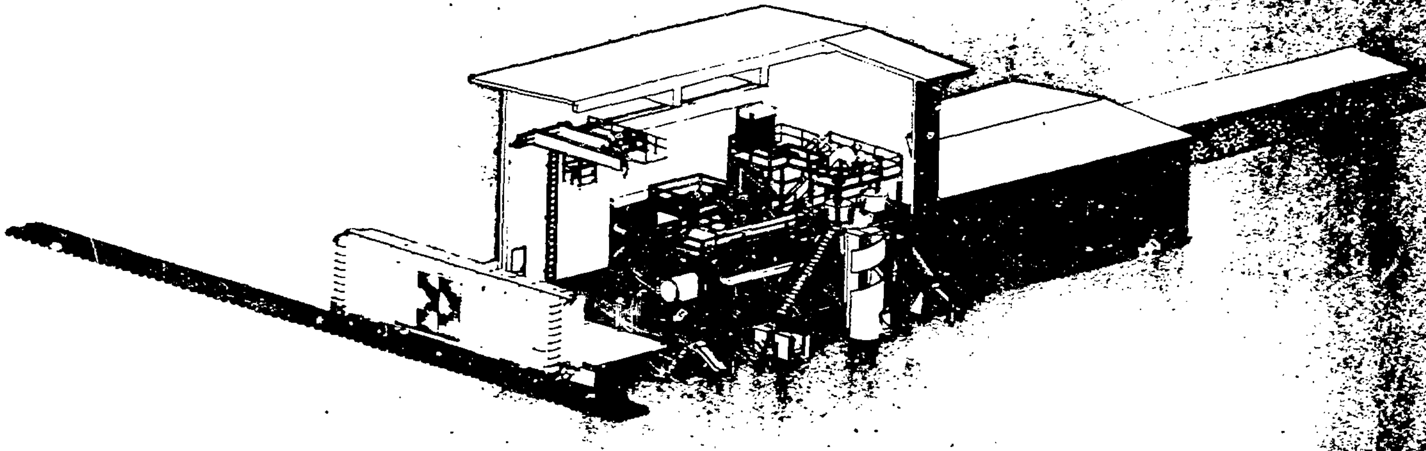


FIGURE 15

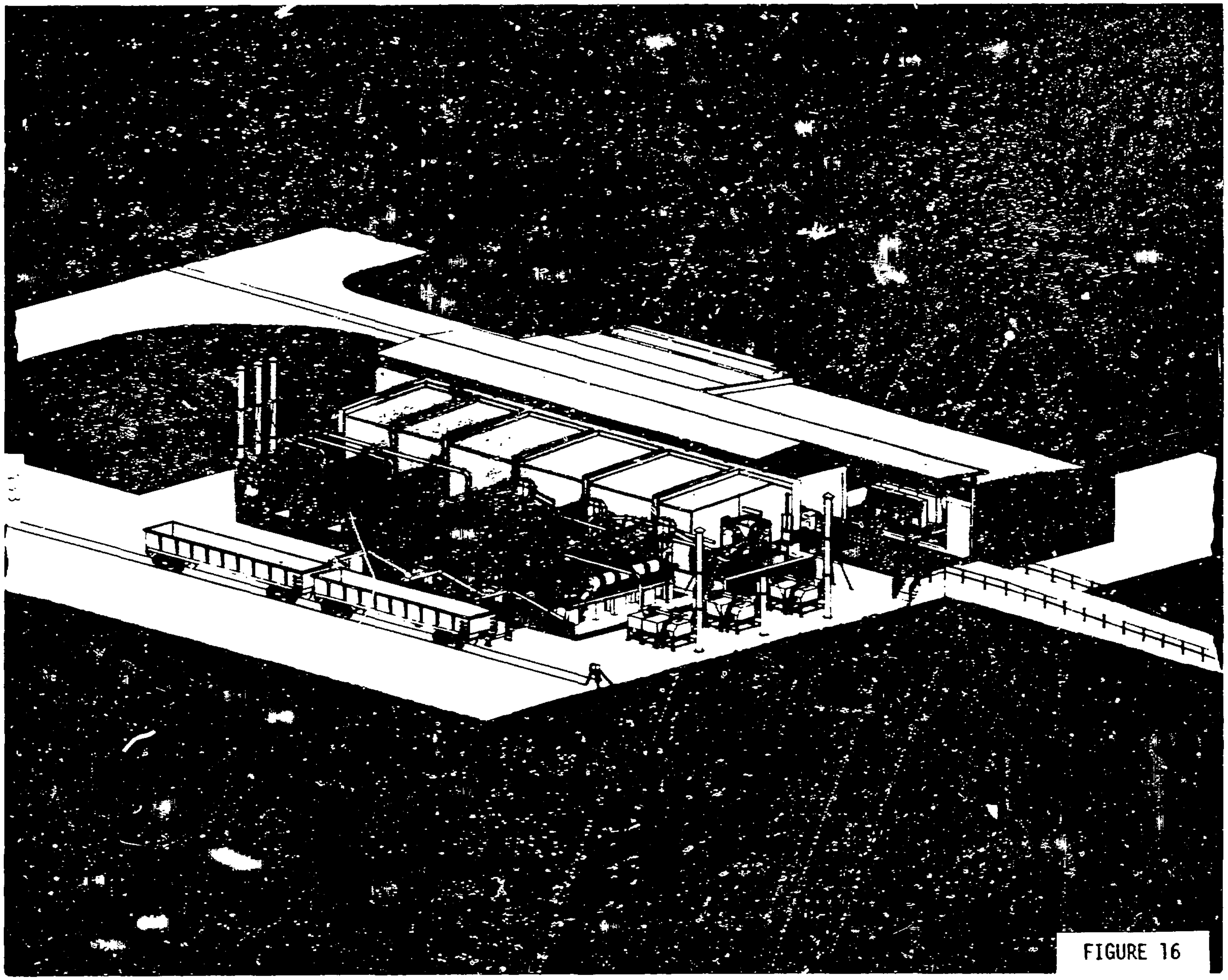


FIGURE 16

FIGURE 17

THE QUANTIFICATION OF EXPLOSIVE ORDNANCE SAFETY

Sidney B. Andrews, Jr.
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I. INTRODUCTION

One mission of the Weapon Safety Division of the Naval Weapons Laboratory, at Dahlgren, Va. is to quantify explosive safety of Naval ordnance systems. To quantify safety, the science of statistics is combined with explosive system safety engineering (explosive safety). This paper discusses the need for doing this, and our approach in accomplishing this mission.

Inductive inferences are frequently made in explosive safety. An inductive inference is one made by reasoning from the particular to the general. Examples of this type of inference made in explosive safety include: the suspension of a lot of ammunition because a few rounds in the lot have prematured; another is the prohibiting of the use of torpex because it has produced some safety problems in the past; and still another is the insistance that a fuze contain no stored mechanical energy because some wound springs have been known to release their energy inadvertently, thus detonating a warhead. In each of these cases, reasoning goes from the particular to the general, for example: Some rounds prematured, so the entire lot is considered unsafe; problems occurred at some times with the use of torpex, so it is assumed that it is unsafe for future use; and since stored mechanical energy has been released in some instances, it is assumed unsafe for future designs. System Safety engineering abounds with many more examples of such inductive inferences; in fact, most inferences made are inductive.

However, in making an inductive inference concerning a course of action there are two opportunities for making decision errors. In deciding upon a course of action there are risk and reward associated with the decision. In the torpex problem, for example, the risk associated with using torpex is that its high degree of sensitivity may present severe safety problems. The reward for using it is high reliability and lethality. In using torpex, the opportunity for the error in deciding that the risk is far greater than the reward is present. Concersely, in not using torpex the opportunity for making a decision error exists in that a small amount of risk may have been eliminated at the expense of a large reward. These possible decision errors associated with inductive inferences are the result of the subjective way they are made, and the lack of a quantified assessment of both risk and reward.

Inductive inferences are made by engineers with different backgrounds and training. But, as sincere and diligent as they may be, engineers cannot totally eliminate the subjectivity of inductive inferences. To minimize the dangers of inductive inferences, they must be quantified. Specifically, the uncertainty of inductive inferences must be evaluated. Because statistics is the science that does this, it is combined with system safety engineering in quantifying the safety of explosive ordnance. Where it is not possible to totally quantify explosive safety, and judgements must be made without the benefit of numbers, it is necessary to have definitions, guidelines, formal rules, etc., so that two people making a decision independently will arrive at substantially the same results.

Quantification of safety involves four project areas:

(1) Maintenance of data banks needed to support quantification efforts. The two primary data banks used in direct support of quantification are the Accident/Incident Databank, acronymed AID and the ordnance monthly expenditure data bank.

(2) Conducting trend analysis of Naval accidents and incidents using existing methods and developing new statistical methods where existing ones do not suffice.

(3) Developing models to predict accident rates.

(4) Developing a safety index system that will provide program managers, weapon designers and safety engineers with a methodology to answer these three questions:

  (a) How safe will a weapon be in fleet use?

  (b) How safe should it be?

  (c) Where will a redesign or change in procedures of use, storage, transportation, maintenance, etc. produce the largest cost-effective increase in safety.

The safety index system is the ultimate tool in safety analysis.

A schematic plan showing the relationship between each of these project areas has been developed and is being followed to quantify safety. This plan is designed to accomplish the ultimate, a safety index system. This plan is also, designed, so that while it is being implemented, immediate and useful tools will result. Therefore, the milestones contained in this plan are not only inputs to the next stop in developing the safety index system, but are also useful products in themselves. The schematic plan is so large that it had to be sectioned into six parts, figures 1 through 6.

II. EXPLANATION OF EXPLOSIVE QUANTIFICATION PLAN

Eliptical figures in this schematic diagram (Fig 1 through 6) contain descriptions of milestones. Rectangular figures contain descriptions of tasks that must be performed to achieve the milestones. The first project area in quantification is the maintenance of data banks. As previously mentioned two data banks are the foundation of the quantification of safety. The first is the explosive ordnance Accident/Incident Databank, acronymed AID. When an explosive accident occurs in the fleet or at a Shore establishment, it is reported in accordance with one of three Naval instructions. Those instructions are NAVORDINST 8025.1A, OPNAVINST 4790.2A and MCO 8025.1 (NOTAL). When an accident report is received by the Safety Technology Branch it is entered in AID. AID is a key-word data bank. When an accident report is received, key words are selected that characterize the accident. These key words are entered in the data bank as descriptors.

For example, if a Sidewinder was inadvertently released from an F-4 aircraft during arrested landing on a carrier, some of the key words selected would be: Sidewinder, F-4, arrested landing, and CVA. Searches are made on key words. Entry of Sidewinder in the search program would provide a printout with a description of the above accident plus all other accidents where Sidewinder had been entered as a descriptor. Entry of "Sidewinder" and "inadvertent release" would limit the printout to those accidents where "Sidewinder" and "inadvertent release" had been entered as descriptors.

In 1963 efforts were completed to develop AID (Block 1, Fig. 1). The result is shown in block 2, Fig. 1, labeled AID. This key-word data bank was primarily designed to be used as a storage program and not as a statistical data base. It has served quite well in the manner for which it was designed by providing explosive ordnance designers, program managers and safety engineers with printouts showing what has happened to ordnance in the past. However, now that it is to be used as a statistical data base, certain changes must be made. The efforts needed to make these changes in AID are described in blocks (3) (4) and (5), Fig. 1.

The instructions requiring the reporting of accidents presently do not request enough data for meaningful and detailed statistical analysis of accidents. For example, these instructions do not request data relating to the amount of training, experience, years of service, etc. of people involved in accidents when they are caused by personnel. To obtain data for more meaningful statistical analysis, it is necessary that the reporting instructions be rewritten to require additional data elements, block (3), Fig. 1. These data elements are principally related to personnel; for example: more positive identification of hardware, hardware components, ancillary equipment and ammunition lots; and past history of the ordnance involved.

When the submission of these additional data elements are made mandatory by the reporting instructions, it will be necessary to enter the additional data received in AID. This is shown in block 4, Fig 1. Because of the way AID works, no programatic changes are necessary. To incorporate this additional data it is necessary only to decide the format of the new key words associated with the new data. For example, when the number of captive flights is routinely provided for missile accidents, the way that the key word descriptor (associated with this datum) is to be entered, must be decided. In other words, (i.e., "NO OF CAPTIVE FLIGHTS - NUMBER" or "CAPT FLTS - NUMBER", etc.).

Another task that needs to be done is to restructure AID (block 5, Fig 1). Restructuring does not mean the tearing down and rebuilding of the existing data bank. It means making changes in the format of some descriptors, and formalizing rules for the more important existing descriptors. For example, one job in restructuring AID is to formalize the rules of entering descriptors so that precise counts can be made. The result of the tasks described by blocks (3), (4) and (5) is block (6) labeled "Improved AID", all in Fig. 1.

The use of AID as a storage program to provide printouts of accidents will continue. However the capability to use it as a statistical data base has to be added. The way that AID is used to furnish this capability is to provide counts of the number of accidents of the particular type under study. The number of accidents involving a particular weapon is not a good measure of its safety history because it does not consider the number of weapons in use. For example, if weapon "A" has been involved in 5 accidents and weapon "B" has been involved in 20 accidents in a year, it is not fair to say that weapon "B" is 4 times more dangerous than weapon "A" because there may have been a greater number of weapon "B" used than weapon "A" during the same period of time. A better measure of the safety histories of the two weapons is their accident rates. Accident rates are found by dividing the number of accidents by the number of weapons used. Therefore, if 1000 weapon "A's" and 100,000 weapon "B's" were used the accident rate for weapon "A" would be 5 divided by 1000 or 5.00×10^{-3}; while the accident rate for weapon "B" would be 2.00×10^{-4}. On the basis of accident rates, weapon system "A" is 5.00×10^{-3} divided by 2.00×10^{-4} or 25 times more dangerous than weapon system "B".

Since an accident rate is the best measure of a weapon system's safety record, to quantify safety it is necessary to have a capability to calculate them. To calculate accident rates, it is necessary to have a data bank of ordnance expenditures. Establishment of this expenditure rate data bank is shown in block 7, Fig 1. This data bank has been established in close cooperation with the Navy Ships Parts Control Center (SPCC), Mechanicsburg, Pennsylvania. The first milestone in establishing this data bank was to place in it data as far back as Aug 1973 (Block 8), Fig 1. Now that this data bank is established, and being maintained current on a monthly basis, the next effort (shown in block 9, Fig 1) was to back-enter expenditure data to July 1972 and this was done. The ordnance expenditure rate data bank is shown in block 10, Fig 1.

The key to accessing the expenditure rate data bank is the Department of Defense Identification Code (DODIC). This code is an alpha-numeric sequence which identifies ordnance items that are functionally interchangeable though they may have different Federal Stock Numbers. For example, two 5 inch 54 caliber projectiles whose DODIC's are both D 330 have different federal stock numbers. The common DODIC indicates that they are functionally interchangeable and this can be verified by the Navy's official noun nomenclature. Their federal stock numbers differ because one projectile is loaded with comp A-3 while the other has explosive D. Each month, SPCC, Mechanicsburg, provides NWL with a tape of the monthly ordnance world wide expenditures for the previous month. These tapes are extracts of the world wide ammunition asset summary reports that SPCC publishes. They contain the monthly and cumulative fiscal year that number of ordnance items expended during training, combat, and other operations for each item which is assigned a DODIC.

A sample output with fictitious data is seen in figure 7. The first column is the DODIC; the second column is the year and month of the expenditures (7307 meaning July 1973); the third column lists an alphanumeric code that designates the cognizant manager; the fourth; fifth, and sixth column provide the total number expended during the month in combat, training, and other operations, respectively. The seventh column gives the total number expended during the month. The eighth, ninth, and tenth columns give the fiscal year cumulative expenditures for combat, training, and other operations; and the last column gives the cumulative total fiscal year expenditures in all operations. Each of these entries can be manipulated, printed out, displayed by histograms, and used as input to other programs.

Now for a discussion of the second project area - the conducting of trend analysis. As previously mentioned, the expenditure rate data bank is used to calculate accident rates. It provides the denominator, and AID provides the numerator. We call the calculation of accident rates, shown in block 11, Fig 1 or Fig 2, Trend Analysis-Branch II. Trend Analysis-Branch I will be discussed later. Trend Analysis-Branch II is a computer program that uses inputs from AID and the expenditure rate data bank to calculate accident rates for any type of event associated with any type of ordnance to which is assigned a DODIC. To use this program, the DODIC of the ordnance item and the key word describing the event are entered in the program. The computer searches AID and counts by the month, the number of times that the DODIC and event have been entered as descriptors. These numbers are retained in memory. The program then branches to the expenditure rate data bank and records by the month the number of each item having the entered DODIC. The number of accidents for each month is divided by the number of items expended. The results are displayed by histograms or graphs generated by the computer. Figure 8 shows samples of accident rates of the D324, 5 Inch 54 Caliber Propelling Charge for all types of accidents.

Block 12, Fig 2 shows that accident rates (calculated for a specific item of hardware and a specific event) are the milestones of Trend Analysis-Branch II. In trend analysis we are looking for trends and patterns in Naval ordnance accidents. One of the areas to search is in accident rates. In Trend Analysis-Branch II, trends in accident rates over the weeks, months, seasons, and years are sought to learn how accident rates vary with changing environmental and operation influences.

These accident rates provide estimates of probabilities of accidents occurring in the future to a specific type of system. Because there is a great deal of interest in such probabilities we plan to publish them in the future (Block 13, Fig. 2). Periodic publishing is planned for ordnance items of most interest; and upon request, for other items.

In Trend Analysis-Branch I (shown in block 14, Fig 2) we are still looking for trends and patterns in Naval Ordnance mishaps. But here we are concerned with more than the trends of accident rates over a time period. In Trend Analysis-Branch I we are asking such questions as: Is there a typical profile of the sailor who is most likely to be involved in an ordnance accident? Are personnel of one age group more likely to have an accident than those in another age group?; Are career sailors less likely to have an accident than non-career sailors?; Are some combinations of explosive components more likely to be involved in accidents than other combinations?; and so forth. In Trend Analysis-Branch I we are looking for the subtleties of accident causation. The results of Trend Analysis-Branch I are shown in block 15, Fig 2 . These results are useful products (in themselves) because they provide quantitative assessment of the causes of accidents and insight into where to place the most safety effort.

In addition to the results of Trend Analysis-Branch I being useful products in themselves, they are input to the next step in the quantification of safety. This step is Accident Rate Prediction (block 18, Fig 2) the third project area previously mentioned in the quantification of safety. There are three other inputs to Accident Rate Prediction - the logistic history features, (block 16, Fig 2), safety features, (block 17, Fig 2), and past accident rates of the ordnance items for which future preditions of accident rates are desired. The outputs are models used to predict the rates of various types of accidents associated with a particular type of ordnance item, (block 19, Fig 2).

Accident Rate Prediction is the key to quantifying explosive safety. Statistical analysis is used to uncover the relationships between the inputs in blocks 15, 16, and 17, Fig 2 and accident rates. Once the models for relating the various types of accidents have been established, these models can be combined to develop a composite model to predict accident rates for an ordnance item under development. This is done by first specifying the new hardware configuration and properly defining the components of the hardware under development. Accident rate prediction models for existing components and configurations similar to the components and configurations of the ordnance items under evaluation can then be selected. These models are combined to produce the composite model for the new ordnance item. However, before combining models it may be necessary to modify some of them so that they more nearly conform to the hardware configuration for which they are predicting accident rates.

There is ample analytical evidence to justify the assumption that the frequency of accidents can be described by a Poisson process with a non-stable parameter λ. Of course the accident data must be normalized by the expenditure data. The model proposed for λ for any specific type of accident associated with a specific item of hardware is:

$$\lambda = a_1 + a_2 + a_3 + \dots a_\kappa \qquad (1)$$

where the a's are the κ inputs (blocks 15, 16, and 17, Fig 2) needed to account for the variability in accident rates.

Models to predict accident rates are useful to program managers, and safety engineers because they provide a basis for decisions, the management of funds allocated for safety programs, and the management of safety efforts. Models to predict accident rates are useful to designers because they can provide insight into the type of hazards that must be countered. Models to predict accident rates are useful to us because they lead to the final step in quantifying explosive safety.

Up to now, only the probability of the occurrence of an accident has been considered. The results of an accident, given that one has occurred, have not been considered. When an explosive mishap occurs, many different types of resources can be lost. Chief among those are capability, lives, and dollars. These resources will be called "The Most Important Resources (MIR)." Recall that the Safety Index System is to be designed to answer three questions. The first question is "How Safe is the Weapon System?". The answer to this question is a numerical safety assessment. It is reasonable to define numerical safety in terms of predicted loss of the MIR due to accidents. The numerical safety assessment of a weapon system is therefore defined to be the expected losses of the MIR from accidents experienced by the system during its logistic cycle for "T" years. Normally, the value of "T" will range from 3 to 5 years.

To calculate the numerical safety assessment of a weapon system, it is necessary to estimate the expected dollar loss, life loss, and capability loss per accident. This is shown in blocks 20-22, Fig 3 , however, before capability loss per accident can be estimated, it is necessary to determine the best way to measure capability, (block 23). All of these inputs, the models to predict accident rates, and estimated expenditure rates (block 24, Fig 3) enter into block 25, Fig. 4) labeled "the calculation of the predicted safety level" (or numerical assessment) of the weapon system under evaluation. Blocks 26, 27, and 28 show respectively the expected losses of capability, lives, and dollars.

To clarify these ideas, let us consider the case of dollar loss. For a specific type of accident the following symbols are defined as:

T = The time period for which the loss in dollars is to be calculated.

R_τ = The average accident rate for a specific type of accident for year "τ" measured in accidents per weapon-year.

N_τ = The number of weapon-years for year τ

D_τ = The average cost per accident for year τ

$E_\tau(D)$ = The average number of dollars lost due to accidents for the next T years.

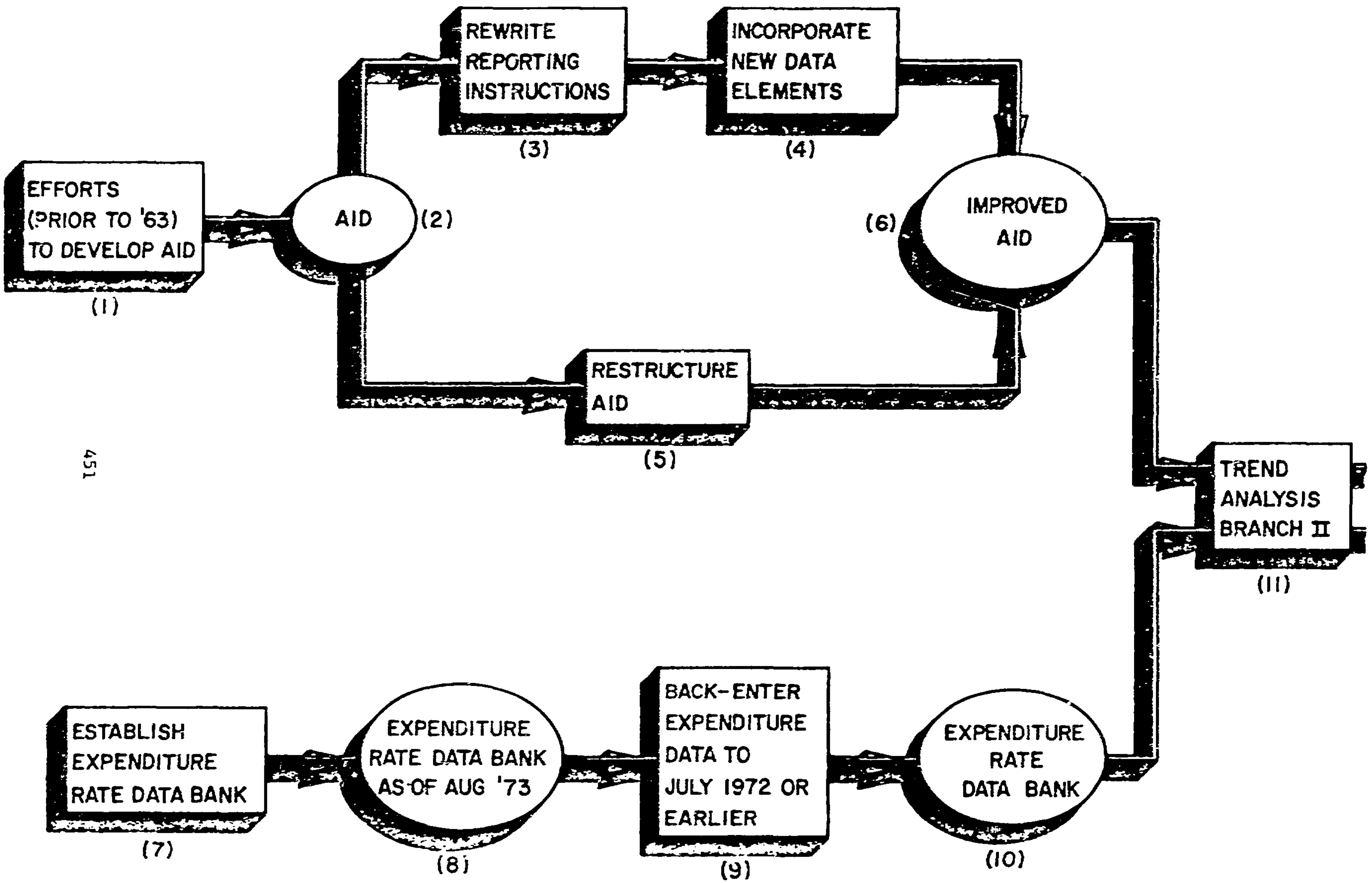
$$E_\tau(D) = \sum_{\tau=1}^{T} R_\tau N_\tau D_\tau \qquad (2)$$

The product $R_\tau N_\tau$ is the number of accidents for the year "τ". The number of dollars lost for the year "τ" is the average amount lost per accident, times the average number of accidents for the year "τ". The summation sign indicates that the number of dollars lost each year is summed over the "T" year time period. The result is $E_T(D)$, the average number of dollars lost during that time period for the particular type of accident for which R_τ is the average accident rate. To find the total expected loss of dollars over the T years, it is necessary to calculate the expected loss of dollars for each type of accident that the system can experience and calculate the sum of the expected dollar losses. This is what is meant by the expected loss in dollars (block 28, Fig 4). The other two numbers in the safety assessment have analogous formulas and meanings. The expected losses of lives, dollars, and capability are the risks associated with the adoption of the weapon system for fleet use.

The second question that the safety index system is to answer is "How Safe should the Weapon system be?". The answer to this question is the pass/fail criteria shown in blocks 34, 35, and 36, Fig 5. The pass/fail criteria are the capability, life, and dollar losses that the Navy can tolerate. Before the pass/fail criteria can be calculated (block 33, Fig 5), it is necessary to determine the "M" factors influencing the pass/fail criteria in block 32, Fig 5. Because the type of system, its capability, reliability, maintainability, mission, intended use, and other factors determine the amount of each resource that can be lost, the pass/fail criteria are dependent on these variables. Consequently, if there are "M" variables influencing the pass/fail criteria, each set of M variables in a M-way classification table would give the corresponding criteria. The expected loss of each MIR is compared to each pass/fail criterion. If any of the expected losses exceed the corresponding pass/fail criterion, the explosive system fails (in other words Navy use of that weapon system would produce more losses of the resource than the Navy can tolerate). The third question that the Safety Index System was designed to answer is "Where can a redesign or procedural change produce the biggest pay off in safety?". The answer is the three sets of ranking factors shown in blocks 29, 30, and 31, Fig. 5. Each input necessary for calculating the expected loss of the MIR is responsible for a portion of these losses. These ranking factors are those percentages of the expected losses for which each input into the expected loss model is responsible. If an expected loss exceeds the pass/fail criterion, the corresponding ranking factors would be examined to determine if a change in design, or its intended logistic cycle would produce expected losses lower than the pass/fail criteria. Using the information contained in the ranking factors and the cost associated with design and procedural changes, it is then possible to make changes that are the most cost-effective, subject to the constraint that the expected losses that caused rejection be reduced below the corresponding pass/fail criteria.

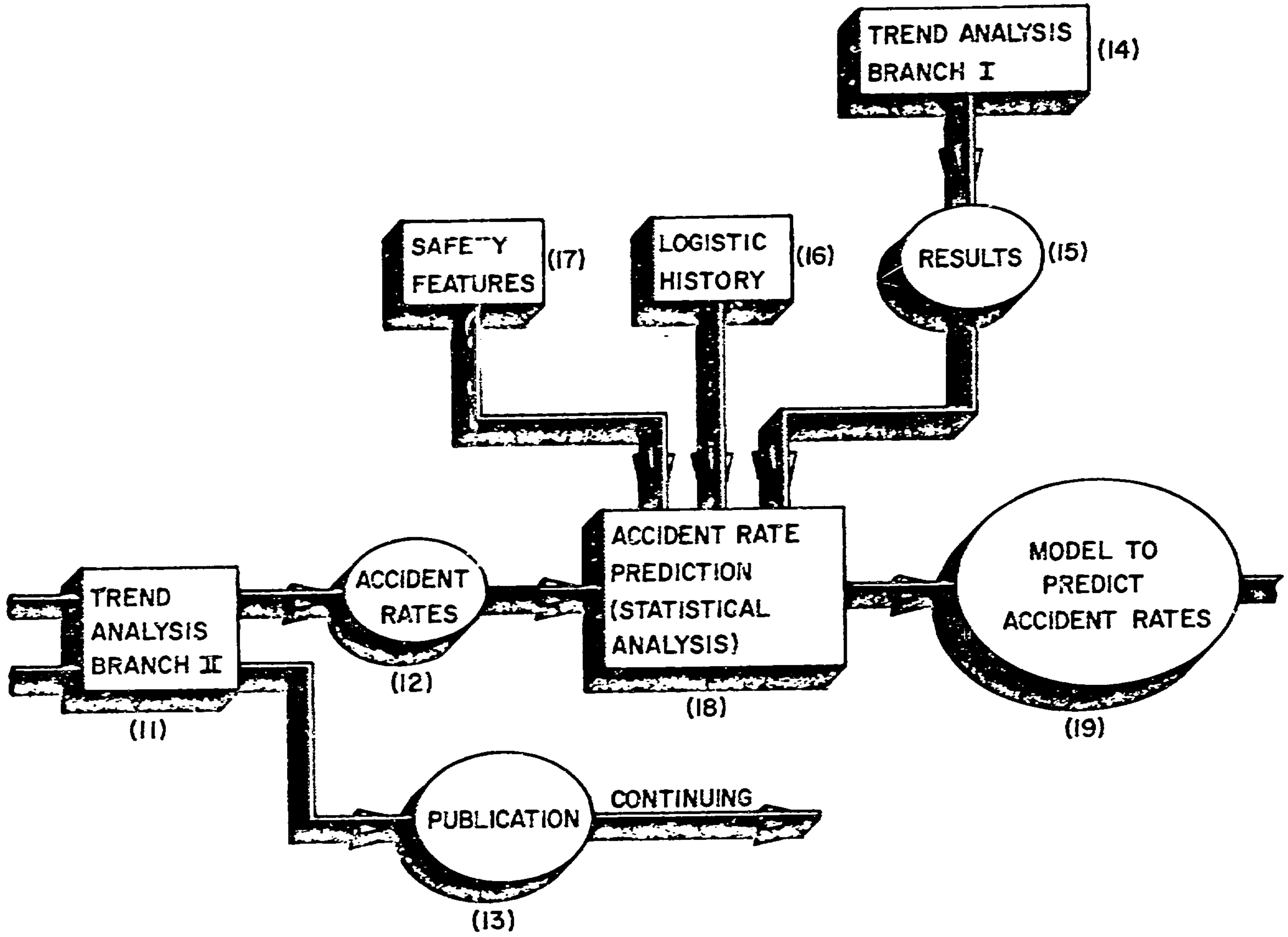
The last two blocks in Fig 6 show that once the parameters associated with the models for predicting expected losses of the MIR have been worked out for one class of weapon system, they will be worked out for the remaining classes.

Quantification of safety is a must if the subjectivity of System Safety Engineering is to be minimized. In this paper, NWL's plan for the quantification of safety has been explained. This plan shows the relationship of the four project areas in the quantification of safety-maintenance of data banks, trend analysis, accident rate prediction, and the safety index system. This plan contains milestones which are useful products in themselves and are stepping stones to the next task in quantifying safety.



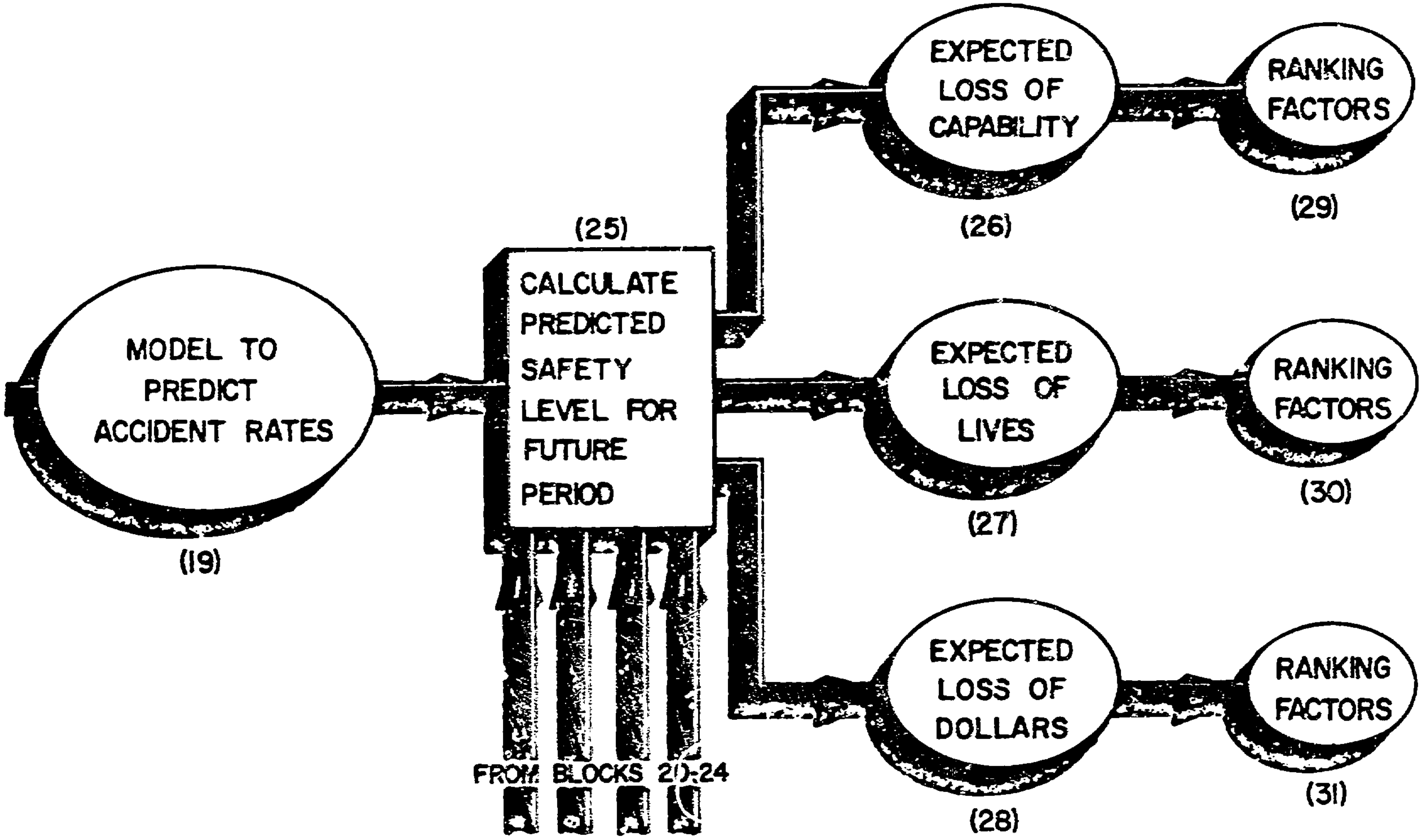
PLAN FOR QUANTIFYING SAFETY (SECTION I)

Fig 1



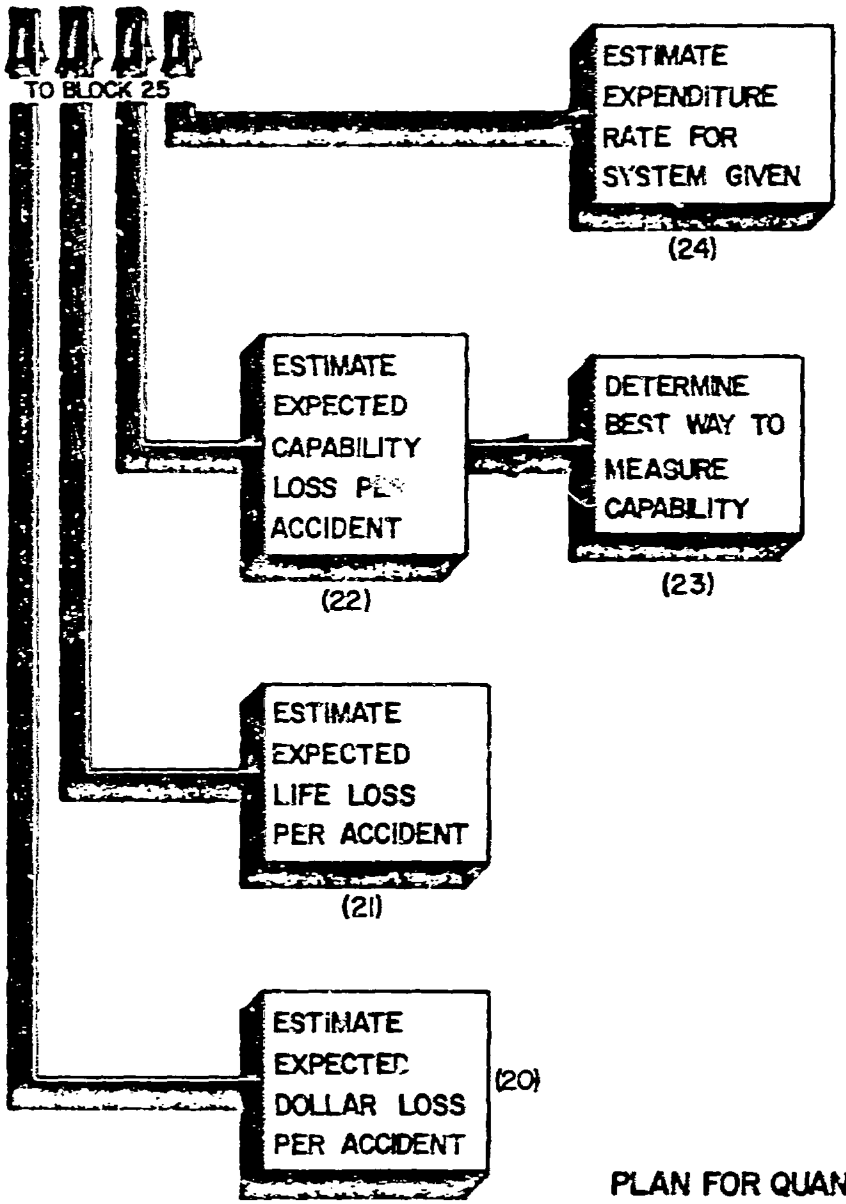
PLAN FOR QUANTIFYING SAFETY (SECTION 2)

Fig 2



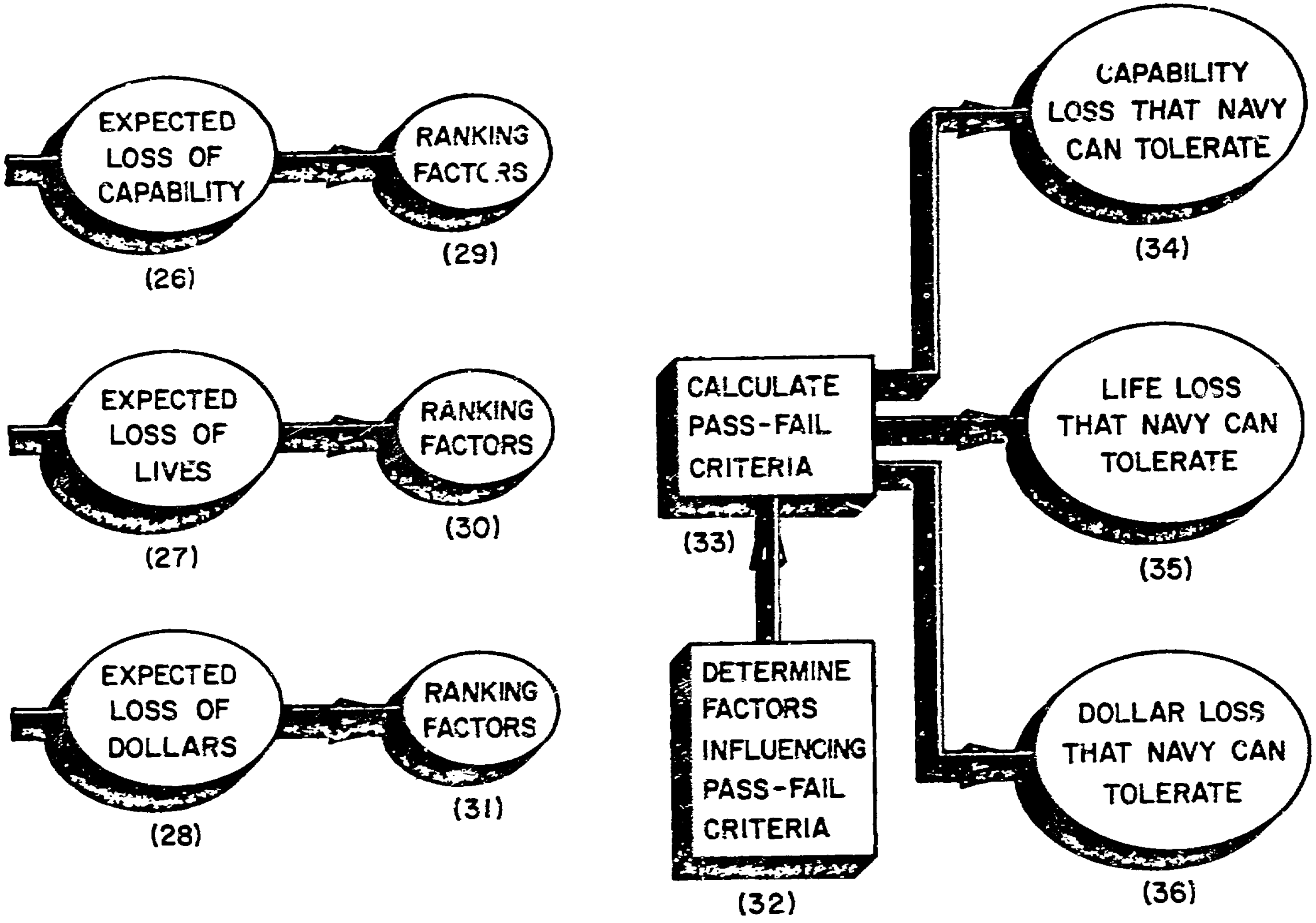
PLAN FOR QUANTIFYING SAFETY (SECTION 3)

Fig 3



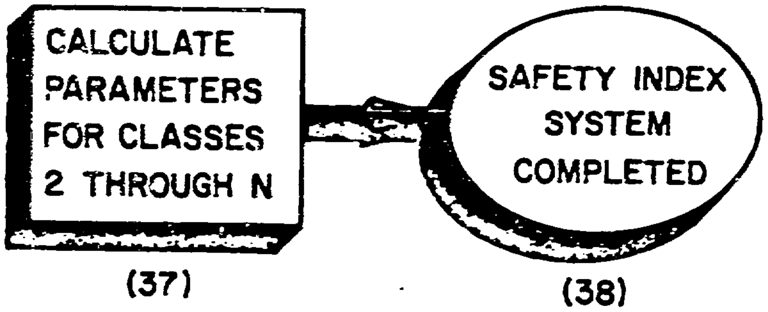
PLAN FOR QUANTIFYING SAFETY (SECTION 4)

Fig 4



PLAN FOR QUANTIFYING SAFETY (SECTION 5)

Fig 5



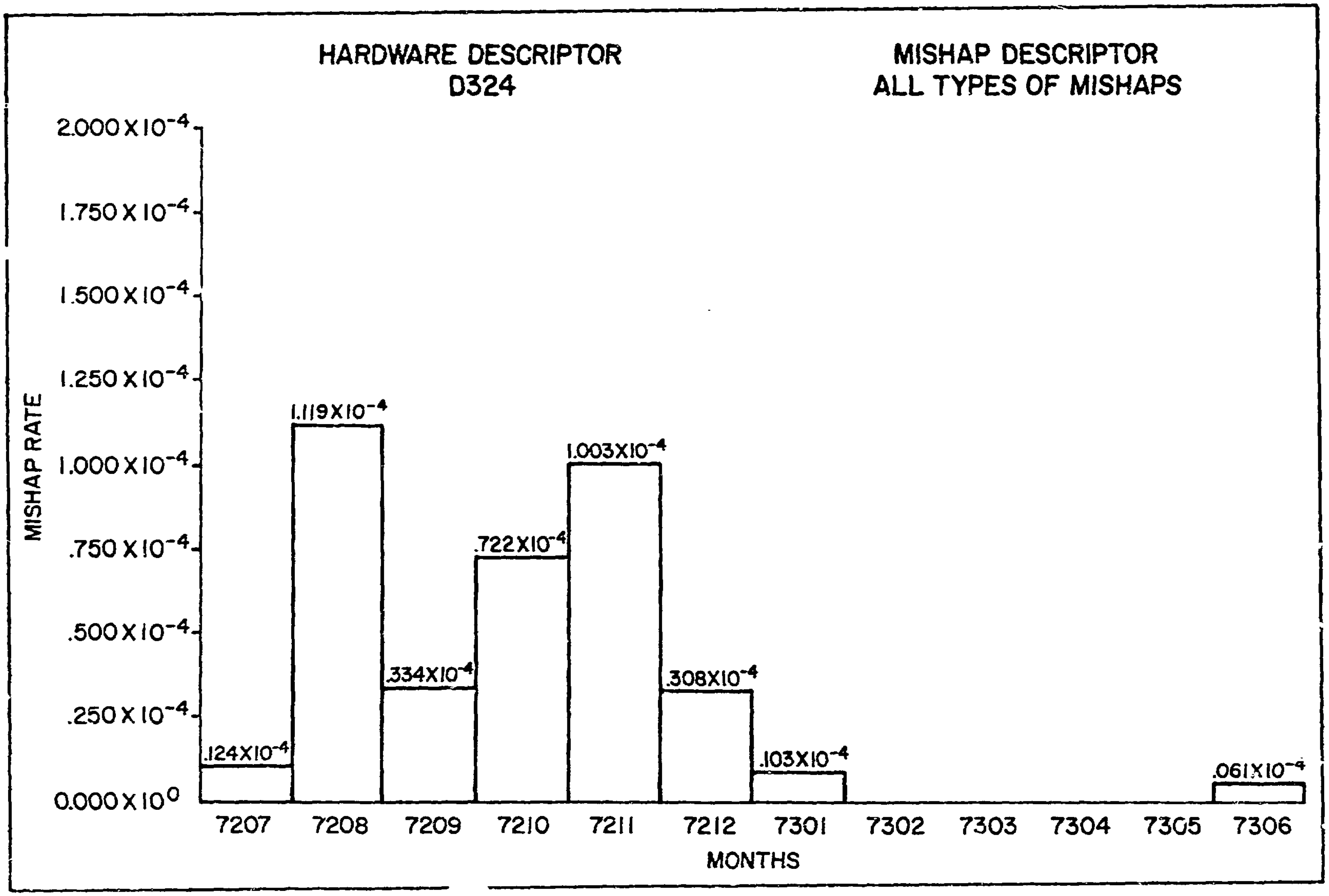
PLAN FOR QUANTIFYING SAFETY (SECTION 6)

Fig 6

ORDNANCE EXPENDITURE DATA BANK, SAMPLE PRINTOUT

DODIC	DATE	COG	MONTHLY TOTALS				CUMULATIVE FY TOTALS			
			COMBAT	TRAINING	OTHER	TOTAL	COMBAT	TRAINING	OTHER	TOTAL
M190	7307	2E	0	25000	10	25010	0	25000	10	25010
M190	7308	2E	0	23000	0	23000	0	48000	10	48010

Fig 7



HISTOGRAM OF ACCIDENT RATES
D324, 5 INCH 54 CALIBER PROPELLING CHARGE

Fig 8

NAVY/JCAP Accident-Incident Data and SAFEORD Information Systems

Charles E. Hart
Naval Weapons Laboratory
Dahlgren, VA

I. INTRODUCTION

Modern information systems using the digital computer have caused a revolution in information technology. These computer based information systems are used to store, analyze, retrieve and display all types of data.

Since our seminar is, principally concerned with explosives safety in this paper I will discuss and describe the Naval Weapon's Laboratories information systems that are specifically designed to support our explosives safety programs.

II. ACCIDENT-INCIDENT DATA (AID)

The explosives Accident-Incident Data Bank (AID) was established in 1963. It has the capability to store and retrieve mishap reports involving explosives and explosives ordnance (including systems and components). Since its inception over six-thousand (6,000) reports have been processed and stored in the system.

The requirements for reporting explosive mishaps including the report format are covered by these instructions:

- NAVORDINST 8025.1A
- OPNAVINST 4790.2
- TECHINST 8010-15/1B

The majority of the mishaps are reported under 8025.1A and 4790.2 A few reports are submitted under transportation accident reporting requirements. The basic data elements for the report are as follows:

- item nomenclature, FSN, stock number, DODIC/NALC
- item lot or serial number
- mishap narrative
- military and civilian casualities (dead & injured)
- damage (major, minor and dollar estimate)
- number of items involved in mishap
- explosives weight
- number of items remaining from lot involved
- unusual climatic or electromagnetic environment
- comment
- investigation

Upon entry into AID each report is associated with a set of uniterm or key work descriptors. These descriptors are selected on the basis of information contained in the report and are used by the search computer programs to identify information desired for retrieval. The search programs may use the descriptors singly or in series. For example the descriptor string 5 INCH 38 CALIBER, DETONATION, MAGAZINE, ASHORE would result in the printout or display of all reports of 5/38 caliber gun ammunition detonations in magazine ashore.

Output or user reports may be obtained in the following form:

- print-outs
- A/I Briefs (short reports)
- histograms

* event probability estimates

For users interested in the details of a particular mishap or a group of mishaps the print-out best meets his needs.

The accident brief report is designed to give users a quick reference to reports that are in the file. The accident brief is structured so the computer can sort and display them by weapon system. Because of this all AIM-9, CAD, Bomb etc. reports are grouped together in the listing. In some cases the short description may meet the users information needs. If it does not he can select the reports for which he wants more information he can obtain it by submitting the date number to NWL.

The histogram on the other hand provides a graphical presentation of the data for those whose needs are statistical in nature.

The event probability report is a new product and is still under development. Because of it NWL is re-studying each of the AID mishap reports to insure the completeness of its descriptors suite. The statistical nature of the report demands an accurate count of the events and the conditions under which it occurred.

The probability report consists of two parts. Part one is a plot of the event frequencies vs. a time base line incremented in months. Part two is a fit of this data to a Poisson distribution model. The model provides calculated event probabilities and a comparison of the observed to the predicted frequencies. The chi-square statistical test is used to measure the goodness of fit between the observed and predicted frequencies provided by the model.

ACCIDENT/INCIDENT DATA PLOT

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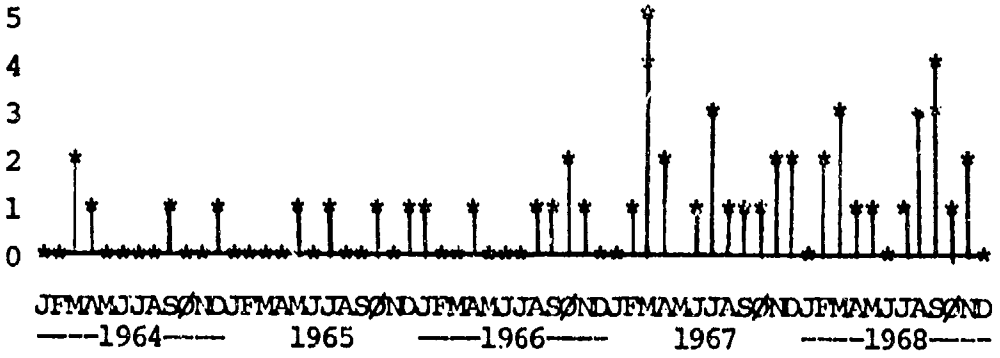
EXPLOSIVE SYSTEM-ALL NAVY AND MARINE

EVENT-FATAL ACCIDENT

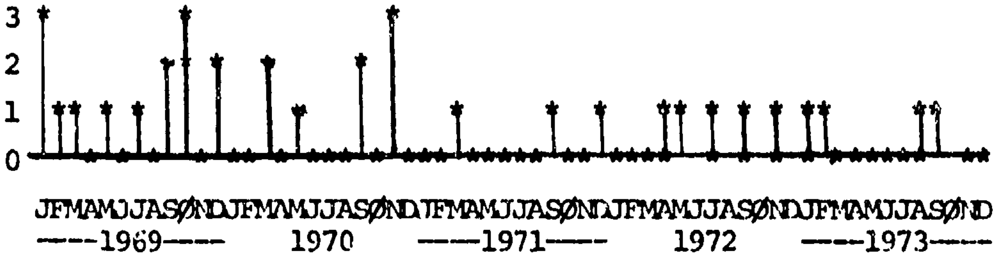
LOCATION-ALL

DATA BASE YEARS-1964/1973

PART 1



PART 2



ACCIDENT/INCIDENT PROBABILITIES

****

EXPLOSIVE SYSTEM-ALL NAVY AND MARINE

EVENT (X) - FATAL ACCIDENT

EVENT LOCATION - ALL

P(X) = PROBABILITY OF 0, 1, 2, 3, ECT. EVENT
IN A 1 MONTH TIME INTERVAL

EVENT (X)	P (X)	EXPECTED FREQ	OBSERVED FREQ
0	.468	56.21	62.
1	.355	42.63	38.
2	.135	16.16	11.
3	.034	4.09	6.
4	.006	.77	2.
5	.001	.12	1.
6	.000	.01	0.
7	.000	.00	0.

CHI SQUARE (NON-POOLED) = 3.05

THE CHI-SQUARE VALUE IS NOT SIGNIFICANT
AT THE .10 LEVEL OF SIGNIFICANCE.

III. JCAP ACCIDENT-INCIDENT DATA

JCAP is an acronym for the "Joint Panel for the Development of a Coordinated Management System for the DoD Ammunition Production Base". JCAP is a large tri-service effort and I am sure that many papers could be devoted to its work. Today I want to only discuss the explosives data exchange, storage and retrieval aspects of JCAP.

The many tasks that form the JCAP effort are carried out by Task Groups. For matters involving safety a Task Group on Safety was formed which in turn appointed a sub-committee to study the standardization of explosives mishap data elements, definitions and existing data systems. After reviewing all existing reporting instructions and studying the various services data systems the sub-committee recommended a standard reporting format complete with data elements for all JCAP reports. Since the recommended elements and format very closely resembled the Navy's it was recommended that NWL establish a data bank to store, process and retrieve the information until such times this function could be carried out by the the JCAP Management Information System.

A JCAP report has the following format and data elements:

- report symbol
- item nomenclature
- FSC, FIIN
- MK/MOD/MODEL

* DODIC/NALC
* QUANTITY
* LOT NUMBER
* DATE
* TIME
* LOCATION
* DAY
* DESCRIPTION
* NUMBER FATALITIES
* NUMBER INJURIES
* MATERIAL DAMAGE DESCRIPTION
* MATERIAL COST
* EMR/ENVIRONMENTAL CONDITIONS
* CAUSE
    Primary
    Contributing
* PROPOSED CORRECTIVE ACTION
* PRODUCTION BASE EFFECTS
* INVESTIGATION

The user report include:

* print-outs
* histograms
* JCAP Accident Briefs

The first two reports are generated on demand. To inform users of events that have occurred a complete set of accident briefs are generated and sent to the participating services each quarter. A print-out of the entire data bank is prepared and distributed annually.

IV. SAFEORD

SAFEORD stands for the "Safety of Explosive Ordnance Data Bank." This information system combines the sorting and indexing capabilities of the computer with the mass storage and retrieval capabilities of a large scale microfiche system. Unlike the data systems already described which require the transcription of data for computer entry the SAFEORD System stores the original document. This eliminates much data bias and permits the user to view original documents.

While SAFEORD was initially designed as a technical information system to store safety data on Navy and Navy procured weapon systems the general nature of its design permits it to be used for a variety of information handling tasks.

At the present time (September 1974) SAFEORD has stored over 14,000 safety or safety related documents. This represents over 162,000 pages of data.

SAFEORD consist of two major segments each of which may be considered as a separate data bank.* First we have the computer generated index which essentially stores input information pertaining to each document entered into the system. Second we have the microfiche system that stores the original document and is capable of retrieving, displaying, and copying it.

The purpose of the index to guide the searcher to the microfiche commands (tab codes) that will cause the display of the desired document. The index itself defines the scope of the data that SAFIDORD can handle and is in effect a kind of weapon system description.Seventeen codes or descriptive elements make up the basic index:

* 010 - weapon
* 020 - mission
* 030 - range
* 040 - projector platform
* 050 - projector
* 060 - fuze
* 070 - stabilizer
* 080 - guidance
* 090 - warhead
* 100 - warhead content
* 110 - propulsion
* 120 - power supply
* 130 - propelling charge
* 140 - auxiliary equipment
* 150 - container
* 160 - handling equipment
* 500 - references

A typical computer data bank printout index is shown in the next viewgraph.

TYPICAL COMPUTER DATA BANK PRINTOUT

RECORD	CODE	LINE	DESCRIPTOR	MICROFICHE TAB CODE	
2T00017	010	005	TERRIER RIM-2C-7 BT3 HE MK51 MOD 0	BC6743JWRB	(1)
2T00017	020	005	/SA / AIR TGT /		
2T00017	020	010	/SS / SURF TGT /		
2T00017	040	005	/MSL SHIPS /		
2T00017	050	005	/GMLS / MK10 MOD 1 /		
2T00017	060	005	/BSTR / MK 53 MOD 0 /		
2T00017	060	010	/S & A / MK 14 MOD 0 /		
2T00017	060	015	/TDD / MK7 MOD 2B /		
2T00017	060	020	/CONTACT DEV / MK 2 MOD 0 /		
2T00017	060	025	/SECTION / MK325 MOD 1 /	AC3602KTSV	(2)
2T00017	070	005	BSTR DORSAL FINS - CONTROL SURFACES		
2T00017	080	005	/MK 8 MOD 1 /		
2T00017	090	005	/HE / MK 51 MOD 1 /	BC2371BT4D	(3)
2T00017	100	005	/CYCLOTOL /		
2T00017	110	005	/BSTR / MK 12 MOD 0 /	BU7214FTBI	(4)
2T00017	110	010	/SUSTAINER / MK 7 MOD 0 /		
2T00017	120	005	/GAS GEN ELEC / MK 9 MOD 0 /		
2T00017	120	010	/GAS GEN HYDR / MK 10 MOD 0 /		
2T00017	500	005	NWL RPT NO. 1864		

(1) WEAPON SYSTEM EXPLOSIVES SAFETY REVIEW BOARD REPORT

(2) SHIPBOARD VIBRATION TEST REPORT

(3) 40 FT DROP TEST REPORT

(4) BULLET IMPACT TEST REPORT

The left hand column under <u>record</u> is a unique number that identifies the system within SAFEORD. The next two column are the codes and line numbers. These are followed by the descriptors. The last entry is the cross-reference command to the microfiche system. If a line has no microfiche tabs this indicates that no information has been stored on that component.

Supplementary indexes may also be generated by being on the descriptors or the data codes. Such an index using WRB as a code would list all weapon systems for which Safety review board data is available.

IV. CONCLUSION

In conclusion let me re-interiate the well known saying "if you desire to divine the future - know the past." The only purpose of informations systems is to record what has already occurred so we can learn from past experiences and hopefully prevent future accidents.

ULTRA HIGH SPEED FIRE PROTECTION SYSTEMS FOR ARMY AMMUNITION PLANTS

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At the 14th Annual Department of Defense Explosive Safety Seminar, we presented a paper on the development of a new fire protection system; we described its capability of detecting fire without a false signal problem and discharging a high speed water deluge system in time intervals measured in milliseconds. The development of this system made it practical to consider the possibility of controlling and extinguishing fires in many applications where instantaneous control is required. Much progress has been made since the 1972 meeting and this paper is a report to you on that progress, and will include films made by high speed photography for the control of black powder and other fast burning materials.

For those of you who may not be familiar with the system, its high speed operation is obtained by using ultraviolet radiation detectors and explosively detonated deluge valves.

This system was chosen by the ICI Corporation to provide fire protection to its new Black Powder Processing Facility at the Indiana Army Ammunition Plant. They have designed and engineered a high speed deluge system to control fires at their facility from the onset of the basic raw materials to the completed product and its packaging.

My paper will describe the ultraviolet detection system, the high speed deluge system and their application at the Black Powder Processing Facility.

Ultraviolet detection was selected because it would eliminate the false actuation attributed to other types of optical or radiation detectors and still maintain instantaneous response time.

The electromagnetic spectrum is probably the best means to describe ultraviolet detection. The electromagnetic spectrum can be divided into several categories. Starting with the shortest wave length to the longer, these categories are:

COSMIC RAYS
GAMMA RAYS
X-RAYS
ULTRAVIOLET RADIATION
VISIBLE LIGHT
INFRARED
RADAR, TV, RADIO

However,for purposes of our discussion we will only concern ourselves with the ultraviolet, visible light and infrared wave lengths. You will note by this slide, that photocells or light detectors not only respond to fire but to most forms of ambient light and therefore, are limited in application. Infrared detectors also respond to a wide spectrum and therefore are sensitive to sunlight, intense artificial light and hot refractory. It is easy to see that a narrow spectral response is necessary to reduce the possibility of false signals. The wave length of sensitivity of Detector Electronics UV detector is 1850 to 2450 Angstroms. This narrow spectrum of sensitivity prevents our UV sensing detector to detect radiation from sources other than fire. It is also important to note that radiation from the sun and artificial lighting does not fall into the detector's region of sensitivity and due to this feature, our UV detector can be used in areas of direct sunlight, intense light, either in or out of doors.

The UV radiation that a UV detector is sensitive to is the UV emitted from the chemical reaction of combustion. In a fire, UV is emitted from high temperature carbon atoms during formation of water, carbon monoxide and carbon dioxide. The flames from almost every fire result in the formation of these compounds and as a result will emit UV. The magnitude of the UV emitted will, of course, vary with the size and temperature of the fire.

Tests conducted for existing arsenal and industrial applications indicate fast burning munitions materials emit tremendous amounts of UV radiation. Therefore, a UV detector is sensitive to a very small ignition even at considerable distances.

The second phase of the fire protection system is the water delivery time required from the primer firing to open the water control valve to the time water makes its exit from the fire protection nozzles.

The high speed deluge system chosen for the Indiana Army Ammunition Plant is manufactured by the Grinnell Fire Protection Systems Company.

The basic hardware of their system is the primer explosive actuated valve. When the UV detection signal actuates the primer, a latch is released within the valve allowing the water pressure to open the valve and impress the line pressure on the priming water in all piping downstream of the control valve. This pressure is capable of rupturing or blowing off the closures at the discharge nozzles, which up to this point retained the priming water in the piping. Water is then discharged from the nozzles onto the fire at full line pressure. The time from primer firing to water delivery from the fire protection nozzles is measured in milliseconds. However, this time is dependent on several factors. One of these factors is the completeness of the water prime of the piping system from the control valve to the nozzle closures.

Another important factor is water supply pressure.

Water delivery time is also dependent on the size and directness of the system. Therefore, short and straight fire protection piping routes from water supply to nozzles are important. All of these factors played an important role in the design of this fire protection system.

The application can be best explained by this slide of the site plan of the new Black Powder Processing Facility. As you can see, there are four distinct and separate processing areas spanned by intra and inter building vibrating conveyor systems. These areas are the Process Building, the four Glaze Houses, the Screen House, and the Pack House. The raw materials for black powder - sulfur, carbon and potassium nitrate - are brought into the Process Building for blending on separate conveyors. Each conveyor's span is scanned by UV detectors mounted inside at 15 to 20 foot intervals. Additional detectors are field mounted to supervise the process equipment and operating areas.

The Process Building is partitioned into three separate processing areas with each area having a high speed water deluge system and water supply. The blended powder is then transported to the Glaze Houses via inter-building conveyors each having its own fire detection system. Each Glaze House has its own water deluge system. The in-process black powder is transported from the Glaze House to the Screen House by inter-building conveyors. Here again, each conveyor span has a complete fire protection system. Both the Screen House and conveyor span to the Pack House have a deluge fire protection system. The Pack House, where the black powder is packaged for shipment or storage, has two operating areas and two deluge systems.

A total of 23 deluge systems are required to protect this new black powder facility. All of the systems will be ultraviolet actuated high speed deluge systems. Three types of water sources will be used to operate the deluge systems.

One design will be a self-contained 300 gallon water supply stored in pressurized tanks for deluge systems protecting the inter-building conveyors. These tanks will be installed in gallaries above the conveyors at designated midpoint locations for best water delivery.

The second design is a combination 300 gallon self-contained supply and plant water supply. This system will be located at the two major inter-building conveyor junction points.

A third design is a combination 1000 gallon self-contained supply and the plant water supply to protect each of the seven buildings of the process facility. These systems will be located in the Environmental Service Centers adjacent to each of the Process Buildings. As already mentioned, the system will be UV actuated.

Those detectors required to view within the processing equipment will be a new miniature type to provide internal supervision. The detector's response is instantaneous to ultraviolet radiation existing in its cone of vision. The resultant signal from detector control panels actuates the deluge control valve. These control panels are housed in the Environmental Service Centers which are adjacent to the Process Buildings of the Black Powder Facility. These panels contain all the necessary circuitry, switches and readout devices to test manually and automatically the entire system's electrical integrity. The panels also continuously check the continuity of each deluge valve's actuation circuit. Visual indication will be provided for a confidence or no-confidence condition. In addition to the fire protection system's continuous self-supervision, it also has a built-in logic scheme to prevent the propagation of fire from entering into adjoining processing areas. The scheme provides multiple actuation of the deluge system and works like this:

> If fire ignites in the intra-conveyor span of the Process Building, the deluge systems for both areas 801 and 811 of the Process Building will be actuated. Another example, if fire breaks out in Glaze House #804, the water deluge system GH3 for the Glaze House would be actuated and the logic scheme would also actuate water deluge system C3 and C8 of the inter-conveyor system.

Therefore, it can be seen that the detection of an ultraviolet source by a single specific fire protection system will also result in actuation not only of that system, but also simultaneous actuation of designated "upstream' and "downstream" deluge systems. Provisions for manually over-riding this multiple actuation capability will also be provided in the control panel.

Due to the environmental conditions within the conveyors, it is essential that each of the detectors be periodically tested by an external ultraviolet light source. This ultraviolet source will simulate a fire condition by producing a beam of ultraviolet radiation capable of actuating the detector and amplifier controller circuit to verify the response of the system.

As you can see, UV fire detection with a detonated deluge valve system provides ultrafast fire protection for arsenal and like applications.

The concept is unique because arsenal areas can be monitored visually without any problem of false alarms due to lighting or reflected light sources. In addition, this system completely eliminates the necessity of building light barriers or shields required previously by other detection systems. Because of these advantages existing detection systems are being retrofitted with Detector Electronics UV fire detection equipment and specified for modernization programs.

To illustrate UV detection capabilities, a film of application tests on fast burning materials will now be shown. The first test was conducted by the MRC Corporation of Baltimore, Maryland on black powder fires. Other tests will illustrate the detection and suppression of gasoline, magnesium and black powder fires. The last film clip is of a new UV explosion detection and suppression system being developed for underground coal mines.

CLASSIFICATION AND ITS PITFALLS FOR PYROTECHNIC COMPOSITIONS

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ABSTRACT

Edgewood Arsenal has been actively engaged in the investigation of hazards evaluation and classification techniques. This study has culminated in reaffirmation of the classification techniques presently employed in TB 700-2 with suggested modifications for pyrotechnics. During the course of this ongoing investigation, certain pitfalls were noted and the subject matter of this presentation addresses itself to these pitfalls. Some of the pitfalls are (1) classification during manufacturing process, (2) initiating sources, and (3) classification versus hazards evaluation. Finally, I would like to comment on trends of today's technology. While pointing out pitfalls and commenting on today's technology, it is impossible in this paper to provide all of the solutions - rather it is intended to provide stimulation for thought.

I. INTRODUCTION

Edgewood Arsenal is actively engaged in the investigation of hazards evaluation and classification techniques. This ongoing study has resulted in recommendation for modification of Explosives Hazards Classification Procedure (Army Technical Bulletin 700-2)[1] that fulfills the voids necessary for pyrotechnic classification. During preliminary investigations it was found that the existing document did achieve the desired effects of categorizing a hazardous material except in the area of pyrotechnic materials. It was also found that deficiencies or problems would occur if the following situations were realized: Generalized assumptions such as changing the classification of a material during various phases of the manufacturing processes, too much emphasis placed upon the minimum prescribed initiating sources, and misconceptions as to definitions that distinguish between classification and hazards levels.

II. BACKGROUND

CLASSIFICATION DEFINED

Classification as it pertains to hazardous materials is the systematic arrangement into groups or categories according to established safety criteria. Cognizant DOD and DOT agencies accomplish this by subjecting the specimen material (i.e., explosives, propellants, or pyrotechnics) to standardized initiating influences as specified in Army Technical Bulletin 700-2. The output reactions being observed as either mass detonation or fire hazard are then utilized to determine into which class the specimen will be categorized so that it may be transported, stored, or handled within acceptable safety limits (see Figure 1).

The prescribed initiating influences are limited by the selected test methods, i.e., thermal stability, detonation test, card gap, impact sensitivity and ignition and unconfined burning. Unfortunately, these stimuli fall into one of two categories: minimal initiation sources or overkill initiation sources, so that the resultant reaction which we use to classify a material are ones of extreme at either end of the spectrum (see Figure 2).

III. DISCUSSION

Various regulations [2,3,4&5] specifically state what constitutes the classification of a hazardous material during its life cycle. These regulations describe the safety statements, safety releases and assignment of hazards levels required during the development, manufacturing, transporting, storage and ultimate consumption. In addition, these documents identify which agency is responsible for what type of certification or releases required for each step in the life cycle. However, derived through empirical data, historical events,

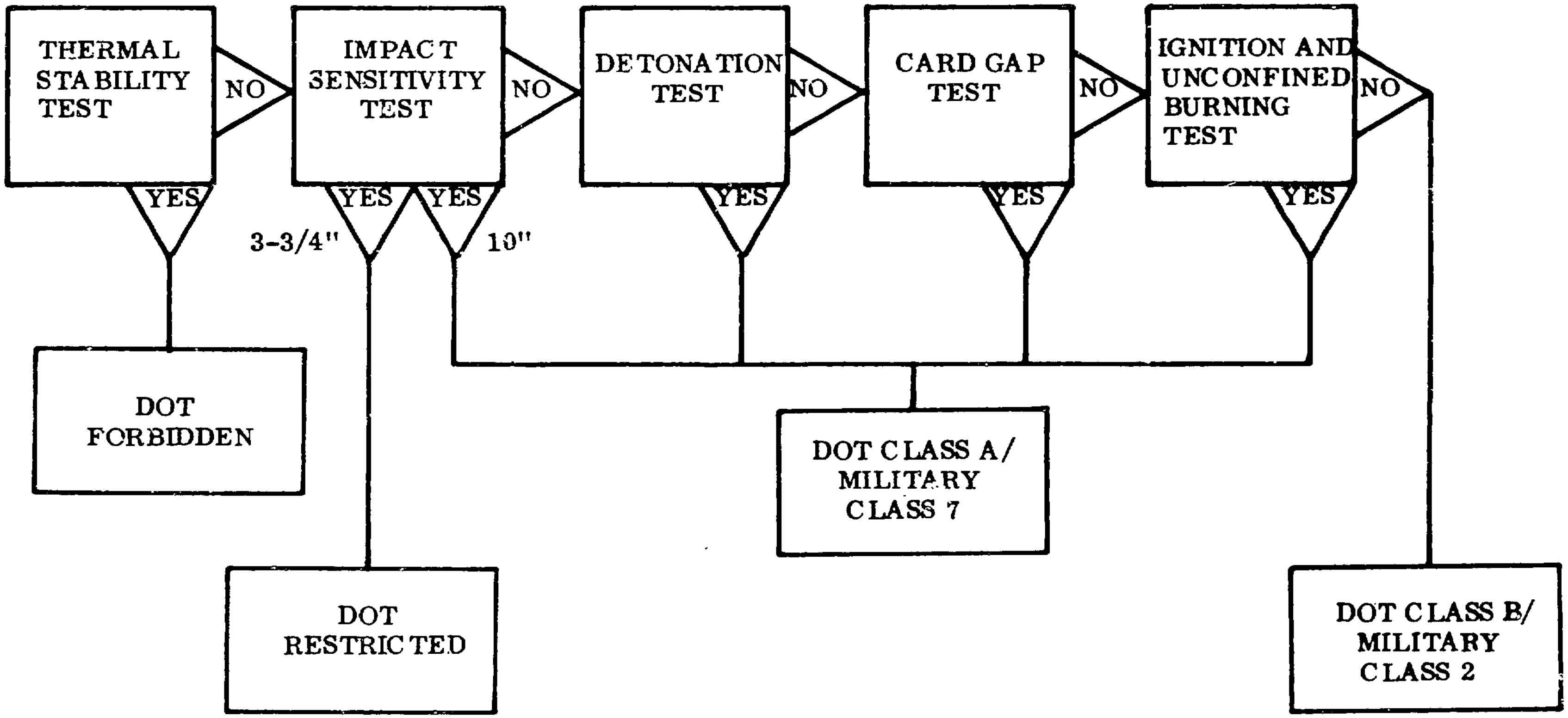

Figure 1. Explosives Hazards Classification Procedures Per TB 700-2

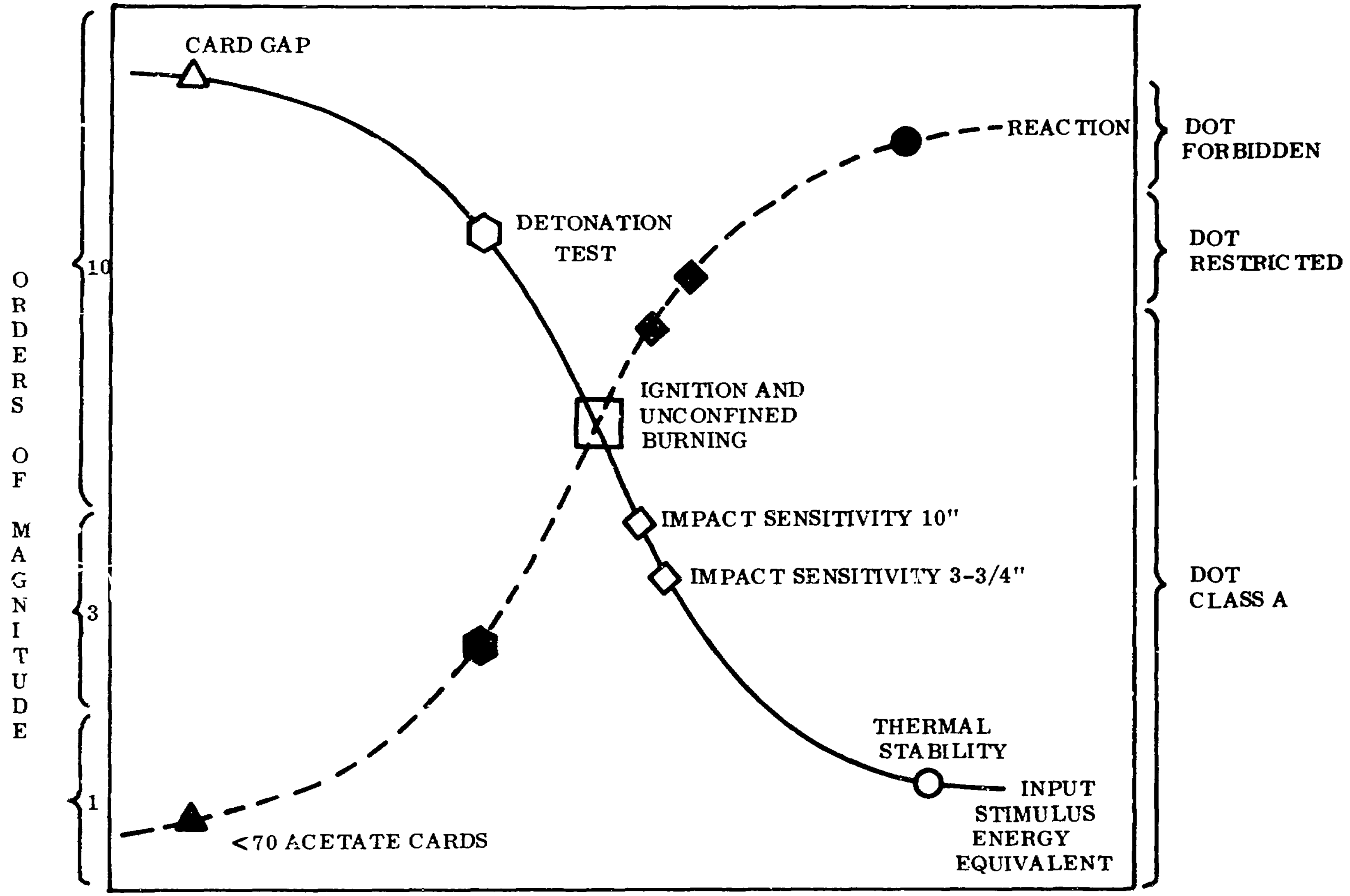

Figure 2. Classification of a Hazardous Material per TB 700-2 Tests Initiation Susceptibility versus Output Reaction

intuitive judgments, or sound safety practices utilizing the conservative safety principles these regulations have been detrimental in reducing potential hazards.

As these regulations evolve from their inception to practicalities of manufacturing, transporting or storage they are subjected to interpretation to satisfy economic conditions at a moment in time. Thus, waivers are granted and these interpretations of the original regulation alter their intent and these alterations now become the governing regulation. One such case is the arbitrary reclassification of a bulk pyrotechnic material during manufacture (which would be a Military Class 7/DOT Class A) to a lesser one (Military Class 2/ DOT Class B) because it has been processed into an end item. On the surface this would seem acceptable for we can rationalize that a pyrotechnic material is more sensitive in the unconsolidated state. But an end item pyrotechnic munition usually consists of the primary constitutents to perform its task (i.e., colored smoke or flare) plus a more sensitive starter mix and in some cases a first fire plus a propelling charge or any multiple combination of these ingredients. Each of these additional ingredients may or may not pose a problem in handling as they are usually more sensitive than the primary charge which could function and alter the downgraded classification. Without performing the prescribed standard tests, it may never be known until the historical data for accidents/incidents are gathered that we do in fact have a problem. Upgrading or downgrading of the classification of a hazardous material should not be based upon stages in manufacture or its shipping container but upon empirical evidence gathered to substantiate facts as they exist and not what we would like them to be for whatever reason.

It is significant to note that the current Explosives Hazard Classification Procedure specifically excludes the susceptibility to accidental initiation by electrostatic and electromagnetic influences. With the inception of the Army Arsenal Modernization Programs, current and proposed methods of manufacturing processes have these inherent stimulus designed into the systems. Also noted that electrostatic charge generation has been the probable cause for many unexplainable accidents that have occurred in various plants in the past twenty years.[6,7] For obvious reasons manufacturing of pyrotechnics has also been excluded from TB 700-2 thus these inherent conditions which cause electrostatic generation are not under present scrutiny. These conditions can also be found as the result of engineering in end item package methods for transportation and storage.[8] Then, too, electrostatic charge generation and electromagnetic influences should be considered for classification.

In conclusion then we cannot be lulled into a false sense of security by simply performing the minimum prescribed tests. Rather all aspects that affect the life of a hazardous material should be taken into account during the testing phase. It clearly states in TB 700-2 that additional tests shall be performed as conditions warrant it.

Hazards evaluation as it pertains to explosives, propellants, or pyrotechnics is the process of examining or judging a material or an event in a process during manufacturing, transporting or storage as a source of danger. Hazards evaluation identifies the most probable failure sequence and a numerical probability which represents a measure of systems safety. The value derived from hazards evaluation is detrimental in establishing quantitative values for safety criteria. As noted, there is a significant difference between hazards evaluation and classification definitions in that classification is based upon qualitative values and judgments and categorizes a material without examining a specific event. These definitions should not be confused as being synonymous.

IV. TODAY'S TRENDS

The need to perform evaluation, classification and risk analysis are ever increasing with today's technology. The advent of the arsenal modernization, new and varied munitions and environmental effects brings about gross changes in present established safety criteria. If we are to incorporate safety standards and classification on a global basis to be in keeping with NATO countries, then we too must accept the inevitable and structure our safety criteria to be compatible with our own needs and NATO requirements as well.

Figure 3 is an attempt to signify that classification, risk analysis and hazards evaluation should be valued separately, equally and quantitatively. Current Edgewood Arsenal programs are attempting to accomplish this. It would be premature to exemplify results at this time. Furthermore, it is anticipated that acceptability of such endeavors will be fraught with peril.

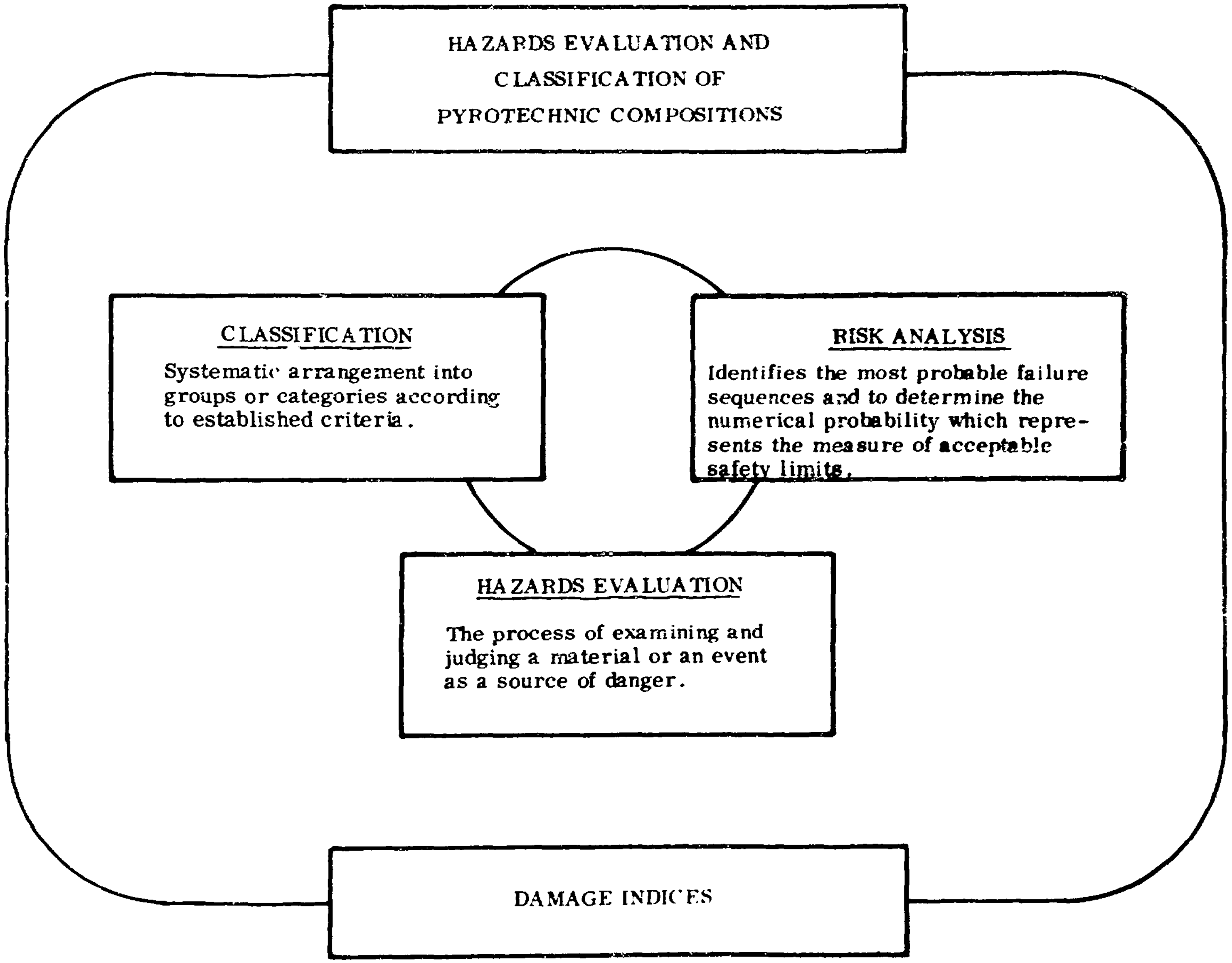

Figure 3. Interrelationships Initially Defined Parameters for Hazards Evaluation and Classification of Pyrotechnic Compositions

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SYSTEMATIC APPROACH TO HAZARD AND DAMAGE POTENTIAL

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ABSTRACT

A logical systems analysis approach to determination of hazard levels and damage potentials for generalized hazard evaluations was presented.

Previous attempts to outline detailed mathematical descriptions of hazardous process mechanisms have been directed toward specific ends: classification, risk analysis, or hazard analysis of engineering designs. An attempt is presently underway to base hazards evaluation descriptions on inherent parameters and to describe the magnitude of a hazard in terms of measurable properties. It is assumed that the primary problem associated with a potential hazard is the damage that might occur; accordingly, the model for a hazards analysis has been designed to yield the damage probability for a given set of input conditions.

The fundamental parameters of interest in a hazards analysis are considered to be (a) the thermochemical properties of materials; (b) the conditions under which these materials are observed; (c) the susceptibility of various entities toward damage; and (d) the mechanism by which damage can result. These parameters are further detailed in Figure 1. Attempts to combine these fundamental properties into mathematical or phenomenological descriptions result in extremely complex expressions, requiring the use of 5-space mathematics and 5-level matrixes. Since such descriptions are not amenable to normal interpretation and cannot be readily visualized, other methods must be considered for dealing with the manner in which these parameters are combined. At present the most promising approach is to consider that the damage mechanism can be described as a logical process, as shown in Figure 2.

Details of the general scheme in combinatorial logic format are shown in Figures 3, 4, and 5. Since these diagrams can be represented by corresponding logical mathematic descriptions, attempts are being made to derive formulas and equations based on this approach. It is anticipated that considerable simplification of the description can be derived once details of the combinatorial logic are obtained and evaluated. Furthermore, understanding of the process by which damage occurs may provide preliminary evaluations of preventive measures, system modification, or changes in constituency that could reduce damage probability. It is anticipated that subjects such as hazard classification and risk analysis can be obtained directly from such fundamental descriptions.

ENVIRONMENTAL CONDITIONS

INTENSIVE VARIABLES

- TEMPERATURE
- PRESSURE
- IMPACT LEVELS
- ELECTROSTATIC LEVELS

EXTENSIVE VARIABLES

- HEAT FLUX
- MASS (BULK) EFFECTS
- CONFINEMENT
- GEOMETRIC ARRANGEMENT

ENTITY SUSCEPTIBILITY

- ENTITY IDENTIFICATION
- DAMAGE THRESHOLDS
- ACCEPTABLE DAMAGE LIMITS

DAMAGE MECHANISMS

- BLAST (OVERPRESSURE)
- FRAGMENTATION
- THERMAL (FLAME AND HEAT FLUX)
- TOXICITY

THERMOCHEMICAL PARAMETERS

THERMODYNAMICS AND KINETICS OF PYROTECHNIC COMPOSITIONS

- COMPONENT STABILITY
- COMPATABILITY
- THERMAL EFFECTS
- PRESSURE EFFECTS
- IMPURITY EFFECTS
- MULTIPLICITY

Figure 1. Fundamental Properties of Hazards Evaluation

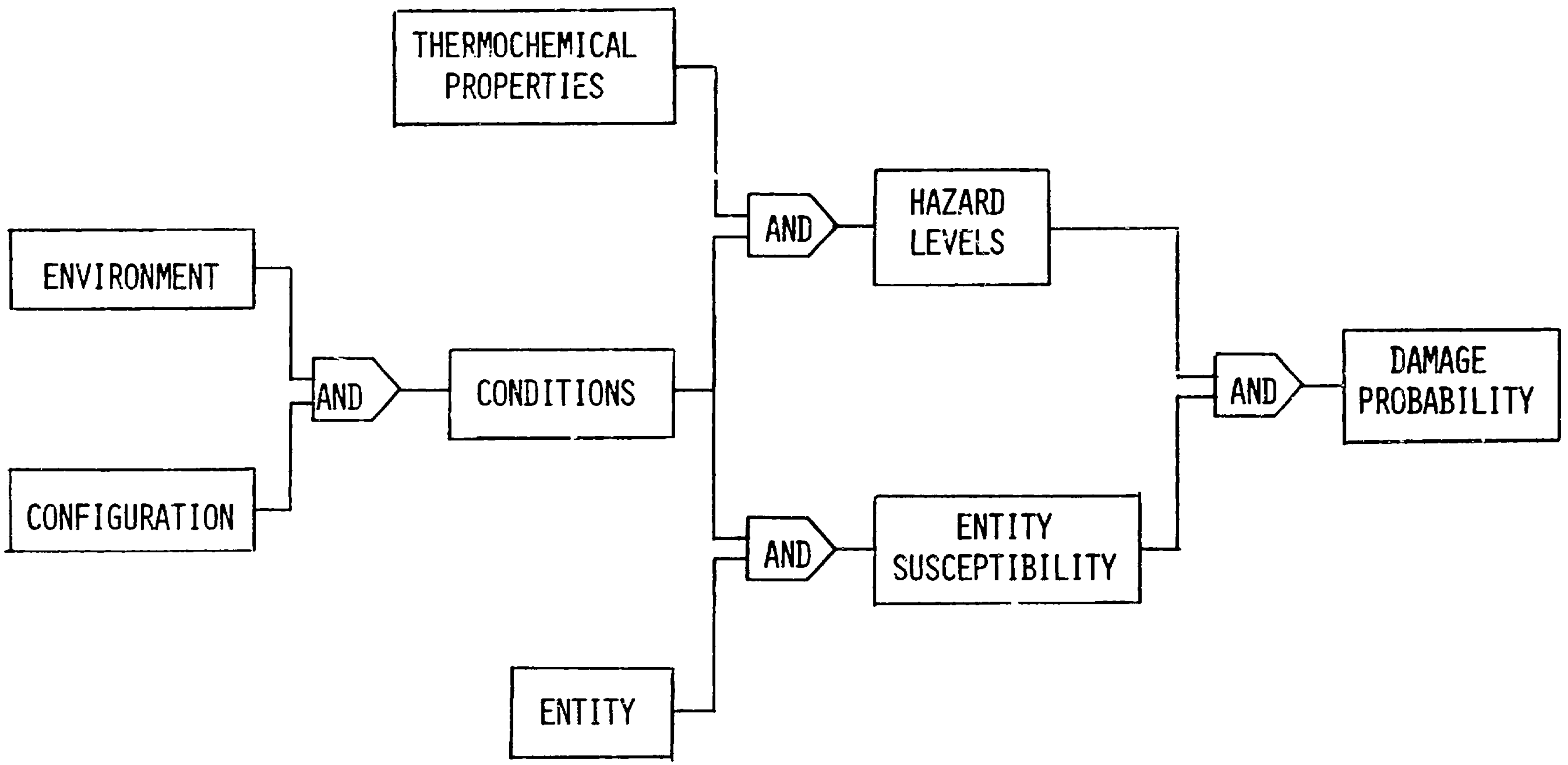

FIGURE 2. SIMPLIFIED LOGICAL DESCRIPTION OF DAMAGE PROCESS

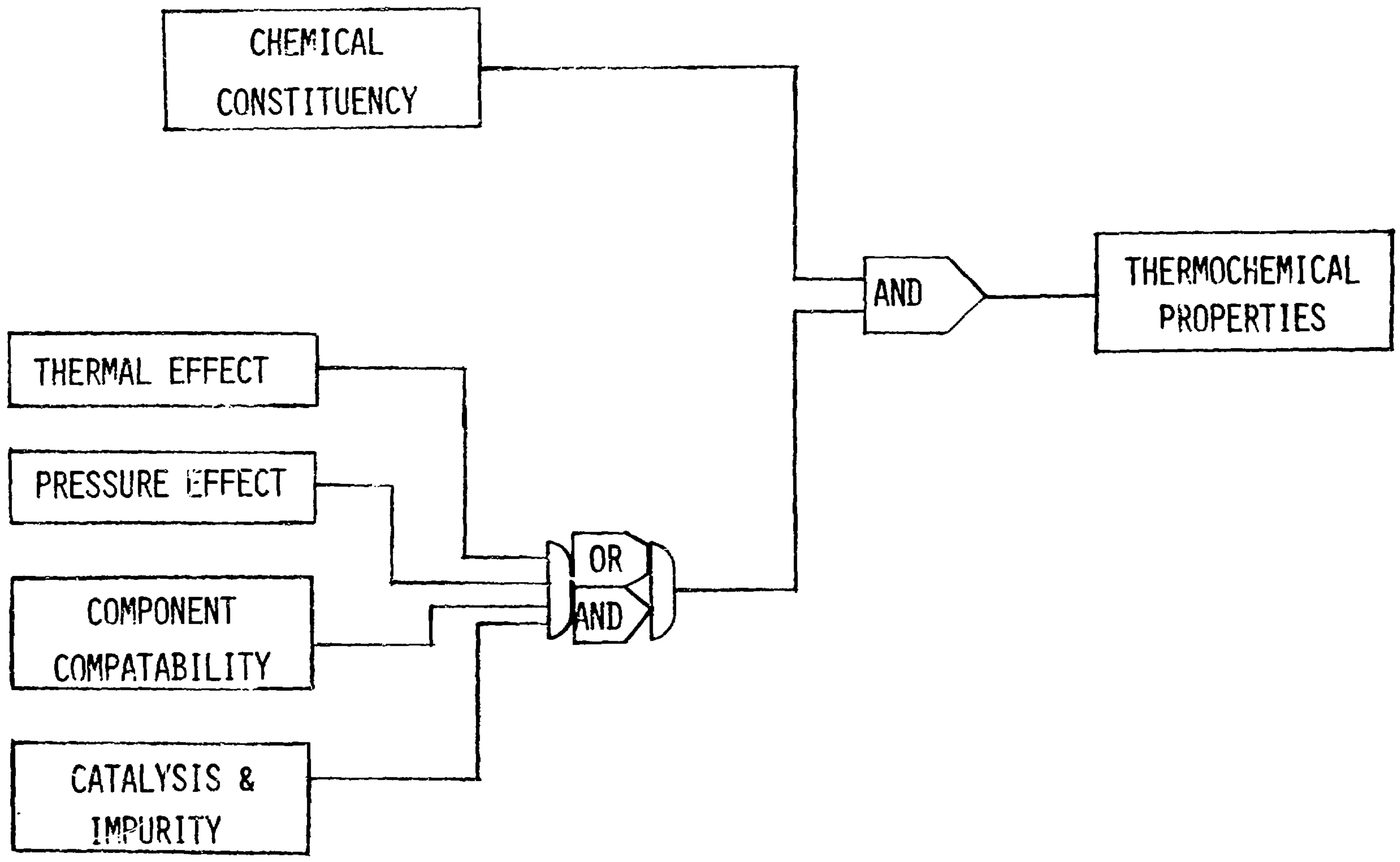

FIGURE 3. DETAILS OF THERMOCHEMICAL PROPERTIES

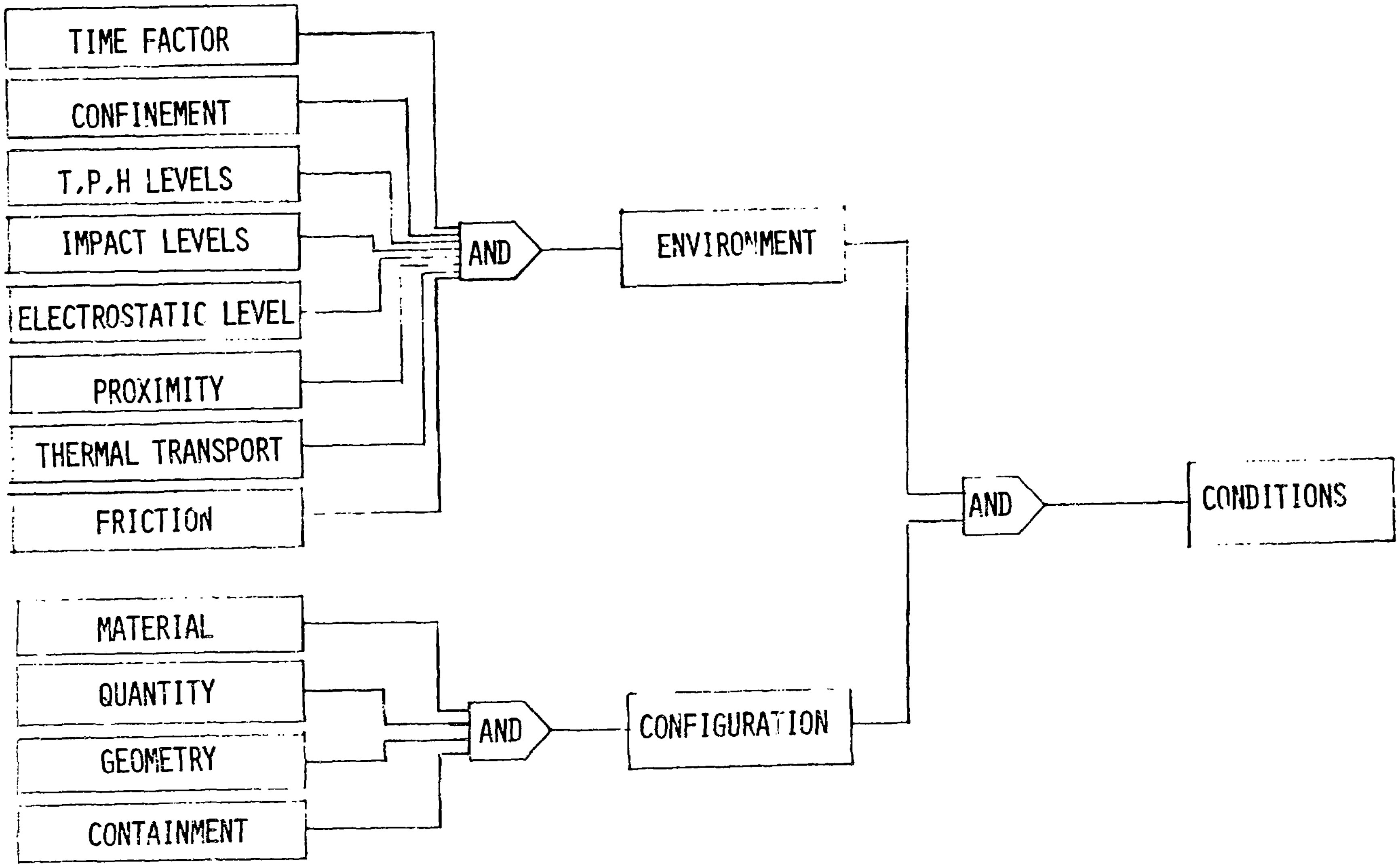

FIGURE 4. ENVIRONMENTAL CONDITIONS DETAILS

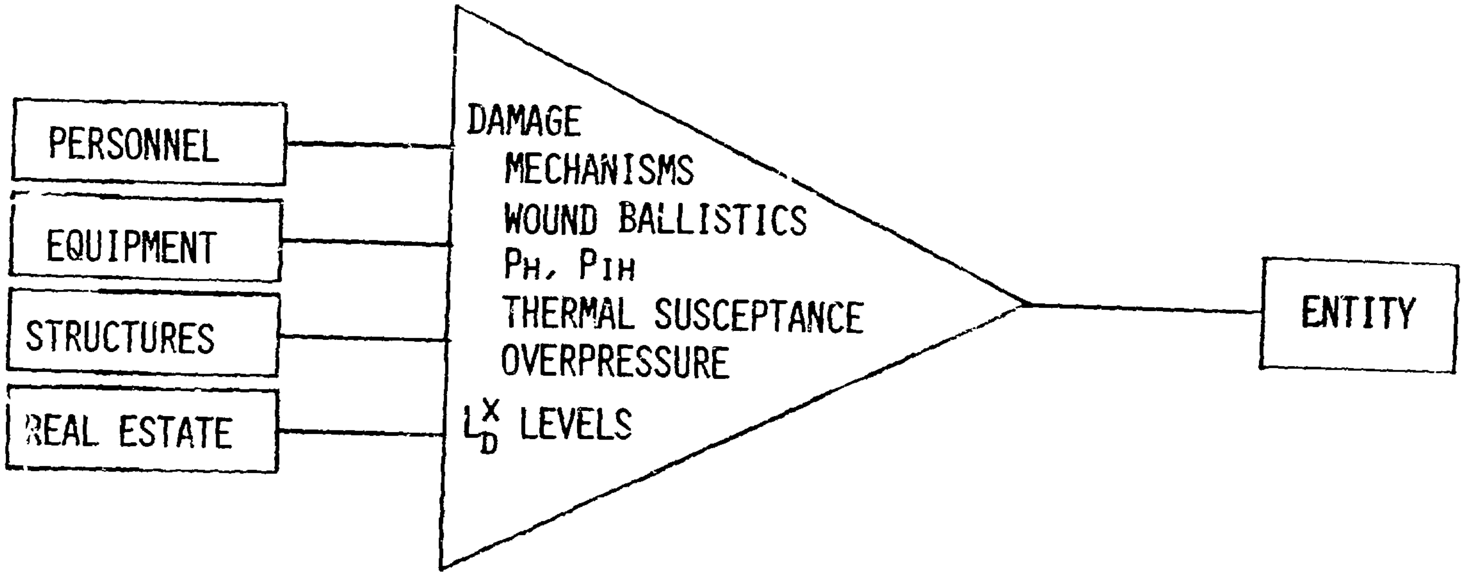

Figure 5. Description of Damageable Entity

EFFECTS OF ENVIRONMENTAL AND PROCESSING CONDITIONS ON COMPOSITION AND SENSITIVITY OF HC WHITE SMOKE MIX

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ABSTRACT

A program was conducted to determine sensitivity and energy release of HC White Smoke Mixes prepared under a variety of environmental and blending conditions. The effects of temperature, humidity, mixing rate and time on moisture content, initiation sensitivity, homogeneity, output energy and reaction mechanism were investigated. Impact sensitivity, thermal stability, electrostatic sensitivity, chemical analysis, differential thermal analysis, and Parr Bomb Calorimetry results are reported on samples prepared within the following matrix of conditions:

- Temperatures of 24° C and 41° C
- Relative Humidity of 35%, 65%, and 90%
- Two blending times
- Three sampling times
- Four HC mix compositions

This presentation will discuss some recent findings of projects dealing with the hazards associated with production of HC white smoke mix. HC white smoke mix is a fairly common smoke composition containing Aluminum powder (as the fuel), Hexachloroethane (as the oxidizer), and Zinc Oxide (as the diluent). In January of this year work was completed on a project to evaluate the hazards introduced by blending of HC white smoke mix in a Jet Airmixer, details of which are shown in Figure 1. Specifically, the objective was to determine whether unacceptably high hazard levels were present during the blending process. The results of this study are shown in Figure 2.

Tests were performed to determine whether the carrier gas and charging sequence would influence electrostatic charge generation in the mixer. It was determined that dry air represents the best carrier medium, and a preblend of zinc oxide and hexachloroethane prior to addition of aluminum was recommended. Tests designed to determine the susceptibility of the mix in 500 pound quantities and 3 feet in diameter to initiation either by a plane shock wave generator or a squib ignitor showed no tendency toward detonation either by propagation velocity within the mass or by resultant blast overpressure. Finally, full scale blending of 2170 pound quantities exhibited electrostatic charge buildup several orders of magnitude less than the initiation sensitivity of the mix. Only a nominal temperature change was observed during the mixing process.

Concurrent with and subsequent to the full-scale test program, a laboratory study of HC smoke mix was performed using the bench model (3 cubic foot) Jet Airmixer. The objective was to determine whether environmental parameters such as temperature and humidity levels and mixing parameters such as composition, rate and time had any effect on the sensitivity or output energy characteristics of the compositions. Samples were prepared within the range of parameters shown in Figure 3. 400 gram batches of the Formulary Composition were mixed in the small scale Jet Airmixer and subjected to impact sensitivity, thermal stability, and electrostatic sensitivity tests. Chemical analysis for all major components, differential thermal analysis, and Parr Bomb calorimetry. In addition to sensitivity and energy release characteristics, it was anticipated that information on moisture absorption by the mix, homogeneity of mixes, and changes in the course of reaction could be determined. Results of these tests are shown in Figures 4-6.

The electrostatic sensitivity tests showed no apparent positive reaction on some 30 samples tested up to a limit of five joules input energy. These observations support previous work on factory blended material. The thermal stability tests yield the weight loss of a 2" cube of material (165 grams) held at a temperature of 75° C for 24 hours. For all samples, weight losses of 45-69%, amounting to total loss of the hexachloroethane, were observed. The analytical results on % composition of 1 gram samples taken from the batches show variations 5-10 times greater than the method accuracy. If these standard deviations appear to indicate significant inhomogeneity, consider that samples ranged in % aluminum from 2.9 to 6%, a factor of two. No connection with the sample preparation parameters was observed.

The impact sensitivity results shown in Figure 5 conform neither to previous observation nor to the Class 2 designation based on that earlier work. While little significant variation of results with the environmental or mixing parameters was observed, this table shows the percentage of trials showing some evidence of positive reaction. (That is, smoke, noise, flame, explosion, etc.) The weight loss data is just as interesting. For 10 gram samples stored in dessicators held at 25° C with either low, intermediate or high humidity conditions, weight losses of 0.2% per day were observed over a 15 day period. In other tests on samples maintained in an oven for 24 hours at 41° C (105° F), total loss of hexachloroethane from the samples was observed.

In order to obtain information on energy release characteristics, a series of samples prepared in the ratios shown were maintained for 24 hours in the constant temperature and humidity environments. Bomb calorimetry results again showed no significant variation with such conditioning, except the 105° F oven-dried samples as would be expected. These results show:

1. The effect of inhomogeneities For an inhomogeneous blend, energy output could vary by a factor of four.

2. The effect of HC sublimation: Note that removal of part of the hexachloroethane could cause variations in output energy of 50%.

In summary, this study has shown that:

1. Sublimation of hexachloroethane is significant even at normal temperatures and under semiconfinement.

2. Gram-sized inhomogeneities of >5% were found in formulations prepared in the Lab Scale Jet Airmixer.

3. Impact sensitivity results were consistently inconsistent with prior data.

4. No evidence was found to indicate that significant moisture absorption from humid atmospheres occurs during storage or blending.

5. Output energy is a complex function of mixture composition and is independent of environmental humidity during short-term storage

6. Within the limits of the experiment, there was no evidence that the sensitivity of the mix varies with environmental conditions of mixing.

It should be pointed out that these experiments were performed using chemically pure components. It is possible that commercial grade materials would produce less sensitive mixes than those prepared from pure components, but this feature would not be expected. Also, absorption of moisture may be more significant in the case of impure materials. These considerations can be evaluated only by further experimental determination of impurity effects.

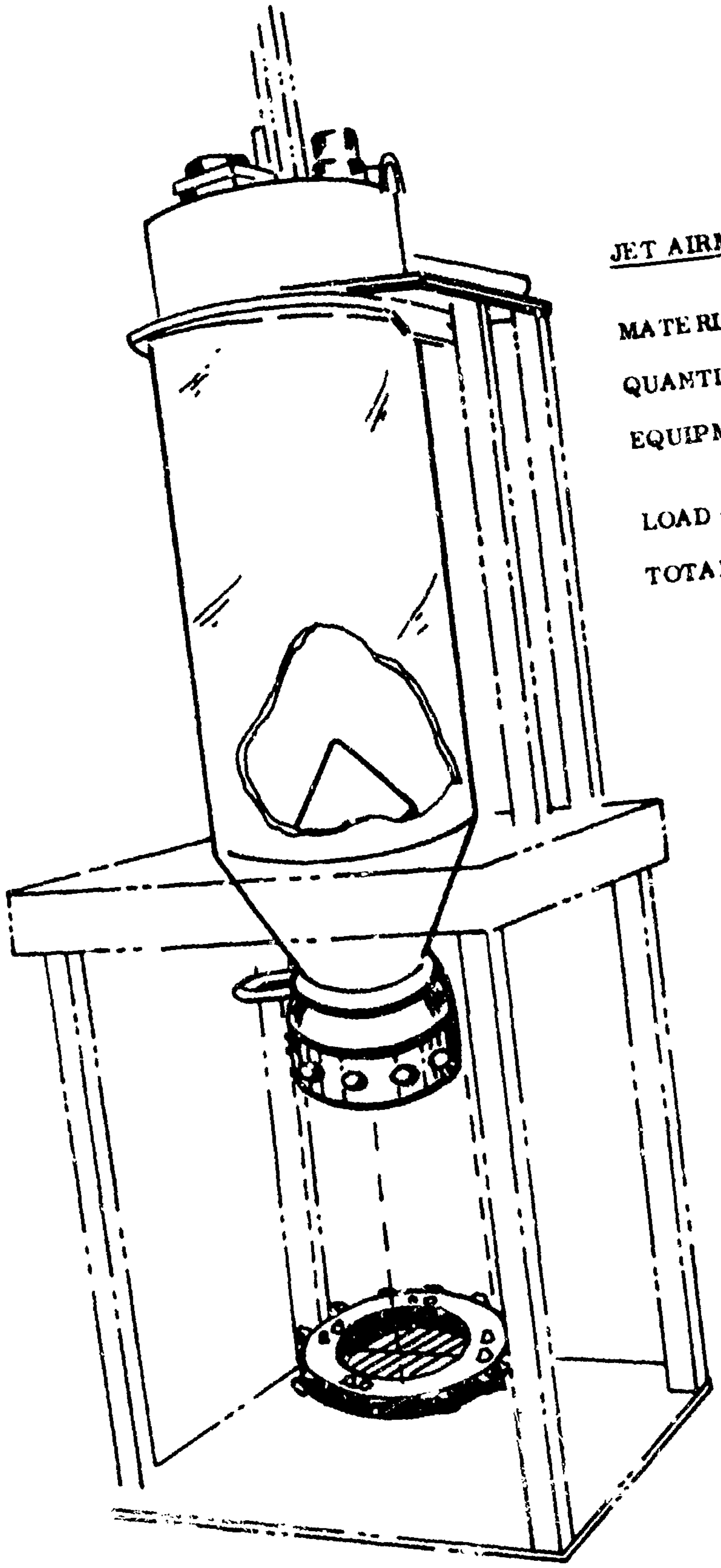

Figure 1.

JET AIRMIX$^{(TM)}$ HAZARDS STUDY

MATERIAL: HC WHITE SMOKE MIX

QUANTITY: 2170 LBS

EQUIPMENT: 3 FT DIAM X 8 FT HIGH

LOAD CAPACITY: 35 FT^3

TOTAL CAPACITY: 58 FT^3

Figure 2.

RESULTS OF LARGE-SCALE JET AIRMIX HAZARDS STUDY

TRIBOELECTRIFICATION EFFECTS CARRIER MEDIUM	AIR > CO_2 >> N_2
CHARGING SEQUENCE	1. ZnO/HC PREBLEND 2. ADD ALUMINUM
MASS EFFECTS SHOCK INITIATION, 500 LB	NO DETONATION WITH 7 LB HE
THERMAL INITIATION, 500 LB	NO DETONATION WITH SQUIB
FULL SCALE BLENDING	ELECTROSTATIC LEVEL, 28 μJ << 50 J TEMP. INCREASE 10°F

FIGURE 3.

LABORATORY STUDY, HC SMOKE MIX

(BENCH MODEL JET AIRMIXER)

PURPOSE: DETERMINE SENSITIVITY AND ENERGY RELEASE DEPENDENCIES DURING BLENDING AND STORAGE.

PARAMETERS:

TEMPERATURE	24°C, 41°C
REL. HUMIDITY	35%, 65%, 90%
MIXING TIME	5 X 2 SEC, 2 X 2 SEC
SAMPLING	< 15 MIN, 24 HRS.
MIX COMPOSITION	0%, 44%, 46%, 81% HC

FIGURE 4.

RESULTS, LABORATORY STUDY

ELECTROSTATIC SENSITIVITY

NO REACTION UP TO 5 JOULES (TEST LIMIT) CONFIRMS PRIOR WORK

THERMAL STABILITY

WT. LOSS 45-49%, 24 HRS. AT 75°C CONFIRMS PRIOR WORK
(TOTAL LOSS OF HEXACHLOROETHANE)

CHEMICAL ANALYSIS (41 SAMPLES)

COMPONENT	MIX	ACCURACY	RESULTS
% AL	5.0%	± .08%	4.7 ± 0.9%
% ZnO	48.6%	± 1%	49 ± 5.5%
% HC	46.4%	± 1%	46.2 ± 5.5%

FIGURE 5.

RESULTS, LABORATORY STUDY

IMPACT SENSITIVITY

HEIGHT	# TESTS	% POSITIVE
3.75"	70	6%
7.5"	70	43%
10"	70	59%
3.75" - 15"	340	39%

1. NO SIGNIFICANT VARIATION WITH PARAMETERS.
2. DOES NOT CONFIRM PREVIOUS RESULTS.

WEIGHT LOSS

1. SEMICONFINED, 25°C
   - 0.2% PER 24 HRS.
   - > 1% PER 72 HRS.
2. UNCONFINED, 41°C
   - > 45% PER 24 HRS.

FIGURE 6.

CALORIMETRY RESULTS

MIXTURE	Hg (CAL/GM)
2 Al + C_2Cl_6	2200 ± 200
2 Al + 3 ZnO + C_2 Cl_6	1230 ± 100
2 Al + 7 ZnO + 2 C_2Cl_6	830 ± 20
2 Al + 3 ZnO	1100 ± 20

NOTE: (1) EFFECT OF INHOMOGENEITIES
(2) EFFECT OF HC SUBLIMATION

SAFETY THROUGH DIRECT DIGITAL CONTROL

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ICI United States Inc.
Volunteer Army Ammunition Plant, Tenn.

In 1968, an extensive modernization was begun in the Government-owned, contractor-operated TNT manufacturing plants in the U. S. Army Munitions Command. As part of this program, 10 of the existing batch production lines built at the Volunteer Army Ammunition Plant in the early 1940's are being replaced.

A new continuous nitration process developed by Canadian Industries Limited will replace the old lines. The new manufacturing facility was to be a local, manual-control operation.

A primary benefit of the GOCO plant comes from a continued funneling of current industrial know-how into the military production base. This was exemplified when the operating contractor recommended that remote digital control be evaluated for use in the new facilities.

The proposal was evaluated and accepted by the Army for implementation at Volunteer. As a result of the implementation, Volunteer has the first completely automated and remotely controlled TNT production facility in the free world. Because of the system, we now consider our facility the safest.

When the system is installed on all 10 lines, Volunteer will rank among the world's largest chemical complexes being directly controlled by a single computer.

My purpose today is to present the sometimes forgotten -- but always important -- safety advantages inherent in applying remote direct digital control to industrial manufacturing facilities. The advantages are particularly applicable to the chemical industry and more specifically to the explosives industry.

The importance of these safety advantages was brought home to us on May 31, 1974, when the Radford Army Ammunition Plant suddenly took on this appearance. While property damage was extensive in this accident, miraculously there were no fatalities.

The Radford incident is not our topic. It serves, however, to remind us of the importance of safety in the explosives industry. A historical study performed at VAAP revealed that all recorded accidents in the explosives industry -- such as the one at Radford -- can be traced directly or indirectly to human error.

As a result of this accident, the review board at Radford made 32 recommendations for immediate implementation on CIL process facilities. At Volunteer, we found that fully half of these recommendations are either inherent to or designed into our DDC system.

Our DDC system at Volunteer is designed to safely control the production facility during plant startup, continuous operation, stepping to intermediate levels and normal or emergency shutdown. Further, it has the ability to operate all 10 lines -- plus the support facilities -- individually and yet simultaneously during all these stages while varying production rates on various lines to safely achieve optimum production.

By far, the greatest safety asset gained from DDC is that we can remove operating personnel from the explosive area.

The operator in his barricaded remote control house will be allowed to make rational decisions when an emergency arises. He can take appropriate action through DDC to eliminate the emergency without having to consider his own safety.

An inherent plus with digital control is that sequential operations can be programmed to take place automatically. This reduces or eliminates possibility of human error and the dangerous "one person crash decision."

Corrective action is programmed into the system as unsafe conditions are identified.

The operator is not eliminated from the operation. He can still manipulate the process within pre-determined safe bounds. If the operator initiates an action not within preset safe bounds, the system will consider the action an "illegal entry" and will not accept it.

All actions taken by the operator are recorded for review by management.

Preset bounds of operation and safety interlocks cannot be broached by the operator's panel.

An engineer's panel gives management operational flexibility and ease of modifications to the control and sequential schemes. This panel is locked and can be accessed only by qualified management personnel. With this system security feature, management can be assured that approved safety procedures are strictly inforced.

In addition to personnel safety, equipment safety and longevity will be increased due to the ability of the system to continuously monitor process and auxiliary systems. It will spot malfunctioning equipment before failure, allowing normal maintenance or replacement without interrupting production. While the first reaction to equipment safety and longevity may be thought of as an economic rather than a safety advantage, a second look shows a large plus on the side of safety.

Common knowledge tells us that sudden upsets to any process can produce a potentially hazardous condition and such upsets are inherent in startups and shutdowns. If we can eliminate an unscheduled shutdown and startup then safety is enhanced.

Along with personnel and equipment safety, DDC provides better process control and improved product quality. These advantages come from greater operating flexibility and better process information. Such features as adaptive self tuning, self diagnosis and the optimization models are programmed into the system.

Here again, this is not generally considered a safety advantage, but in the case of TNT production it is a big safety factor. For example, the drowning of a charge in the nitration phase is generally caused by an unsafe condition resulting from poor process control. Removal from the area and disposal of a drowned charge is a hazardous sequence which should be avoided.

The re-work of off-spec TNT is another hazardous operation and must be done manually at present. Any time these operations can be eliminated by better process control and improved product quality, safety is greatly enhanced.

Because of hazardous plant conditions, it was of the utmost importance that operating personnel have the most reliable system available to continuously monitor and control the TNT process, a system to provide necessary information to operate efficiently and to safeguard personnel and equipment.

In designing the VAAP system, safety received utmost consideration due to the hazardous production facility being controlled. As a result, certain specific areas of the process have up to five levels of backup for control. These levels are:

1. DDC computer control
2. Supervisor or Backup computer control
3. Remote analog control
4. Remote manual control
5. Local relay monitoring control
6. Local manual control

The very nature of such redundancy is a design problem within itself. In a complex system such as this, it is imperative that maximum safety requirements be fulfilled. Yet flexibility of operation must be provided without having safety interlocks locking out the ability to start up and operate the plant.

The system installed at Volunteer provides the redundancy required for monitoring, control and alarm functions. In the VAAP configuration, a single computer called the DDC computer is dedicated to monitoring, control and alarm functions. A separate computer called the Supervisor computer is used for logging and optimization functions. Both computers share all input data. In the event the DDC computer should fail, the Supervisor -- or Backup -- computer will assume control. The transfer of functions occurs with no loss of effectiveness in any of the functions.

What happens if both computers fail simultaneously? In this case, the system will take the process to a pre-determined safe condition. Operation at the remote analog or manual level would start, if required, as sufficient qualified personnel are made available. At any level of remote operation, if intelligence between the remote control house and the process building is disrupted, the local relay monitoring system will take that line to a safe condition and take required emergency action. All process instrumentation is rated for use in the area and will fail safe in the event of loss of power and/or instrument air.

The VAAP system is designed with a complete, dedicated panel for each facility under its control in addition to the operator consoles for computer operation. Upon complete loss of the computer control system, the complex can be operated from these line control panels. Any or all facilities can be taken off computer control and operated in the manual or analog control state.

Our control system is supplemented by a closed circuit television monitoring system with voice communication. This enables the remote operator to monitor the action of any personnel in the area during operation. Personnel making periodic inspection of the area are equipped with a two-way, low-powered radio unit for instant communication with the remote operator. These personnel can leave the area in an emergency while the remote operator copes with the situation without fear of his personal safety.

In our system, all required communications between operator and the system have been minimized. Interactions between the sequence logic and the process control is handled automatically by programs on a time-shared basis within the system. Integration of the sequence logic and process control is one of the more interesting and unique features of the system.

The CIL TNT process is continuous during normal operations, but must be considered a batch type process during the startup and shutdown stages. In performing these operations, control software has been developed to start and stop operations and monitor control and processing activities in a pre-determined, sequential order. Control functions involve opening and closing valves, starting and stopping pumps and motors and manipulating the set points of control loops which are implemented by direct digital control. Sequential control functions are executed at fixed intervals of time under control of a sequential executive program.

The program enforces control by checking to see that each specific action has been completed. If specific actions are not completed, the computer takes immediate action based on information in the program. The action may simply be halting all further action and printing an alarm message or it may be as complex as entering an entirely new sequence of steps.

This capability insures immediate response to dangerous conditions and reduces potential hazards. We take full advantage of this feature and through it have been able to attain safe operation and total automation of the processing area.

Production and Maintenance at VAAP were encouraged by the DDC engineering team to participate in design and implementation of DDC. The result has been a united determination to achieve success. It eliminated the problem of human operators accepting a "humanless" system.

When everyday operators gain confidence and begin to show pride in their work, you know you have a reliable, safe system.

This description of our system shows one application of how digital computers can be used to achieve safe operation and total automation of an explosive facility. There are many other computer configurations that can be designed for process control in our industry. They can achieve the degree of safety and automation desired by the user.

Only the user can determine what is best for him. For those contemplating a computer project for process control, I would recommend first a review of the systems available as a first step in any such project for a new or an existing facility.

THE "MINUTE MELTER"

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The "Minute Melter" is an entirely new method of melting explosives in preparation for cast loading ammunition.

The prototype system has been developed at Milan Army Ammunition Plant over the past five (5) years by the contracting operator, Martin Marietta Aluminum Sales Inc. in connection with the Army Ammunition Production Base Modernization and Expansion Program.

The prime objective in the development of this new explosive melting principle was to reduce the quantity of explosive involved in a conventional explosive melting system and still maintain adequate melting capacity for a typical LAP production line.

This prime objective has certainly been accomplished in the prototype system plus many other improvements over the conventional melting system.

The new and basic principle involved is the melting of the explosive with 15 PSIG saturated steam @ 250° F. in direct contact with the explosive.

The complete process is divided into two (2) parts, the melting of the explosive and the conditioning of the molten explosive.

The melting unit is capable of melting all new flake Composition "B", all Composition "B" riser scrap or a combination of the two simultaneously.

The actual melting of the explosive is continuous with intermittent batch charging and intermittent batch draw off.

The melting unit consists of an outer fixed steam jacketed drum, an inner rotary drum, a riser scrap interlock hopper and a flake interlock hopper.

The outer fixed drum is kept pressurized with 15 PSIG process steam, the inner drum which handles the explosive is suspended on the end of a shaft that passes through a steam seal in the outer drum. The melting unit is tilted back at a 45° angle. An opening in the front of the inner drum permits charging the unit with solid explosive through the interlock hoppers and drawing off the molten explosive while the drum is rotating.

The inner drum is 42 inches in diameter, 18 inches deep and has two (2) compartments separated by a partition perforated with 1/4 inch holes.

The front compartment, which handles the solid explosive while it is being melted, is 14 inches deep and the back compartment into which the molten explosive flows is 4 inches deep.

A 4 1/2 inch diameter sleeve detachably attached to the perforated partition protects a fixed draw off line and a mechanical level sensing device passing through the front compartment into the back compartment.

There are no fixed components in the front or melting compartment to create a pinch point while the explosive is in a solid state.

A special baffle arrangement in the front compartment provides thorough agitation of the flake and riser scrap during and after melting.

Charging the melting unit with solid explosive to be melted and drawing off molten explosive can and often takes place simultaneously.

Drawing off a batch of molten explosive from the melting unit into the conditioning units is accomplished by opening a diaphragm valve in a draw off line connecting the two units.

The inner drum of the melting unit continues to rotate during the draw off cycle. The process steam pressure (15 PSIG) acting on the molten explosive in the melting unit forces the explosive up the draw off line and into the conditioning unit.

A high and low level mechanical sensor senses the dynamic level of the molten explosive in the back compartment of the inner drum and provides a signal indicating when to open and close the draw off valve during a draw off cycle.

Two (2) final conditioning units are required in a system to condition the molten explosive at the rate the melting unit will melt the explosive.

The two (2) conditioning units in the prototype system will handle batch sizes of approximately 175 pounds or approximately 13.4 gallons.

The final conditioning units are similar to the melting unit in that they have an outer fixed drum and an inner rotating drum that handles the molten explosive and are approximately the same overall size.

The inner drum is also steam jacketed and suspended on the end of a shaft that passes through a seal in back of the outer drum. An eight inch (8") opening in the front of the inner drum permits filling and drawing off the molten explosive.

The molten explosive, as it is drawn off from the melting unit, is approximately 230° F. and is a mixture of molten explosive and water or condensate.

Approximately 9.5 pounds of condensate is generated in melting 175 pounds of explosive. This will vary somewhat depending on the temperature of the solid explosive going into the melting unit.

In conditioning a batch of explosive the following three (3) things are accomplished:

1. The condensate or water is vaporized to a level below 0.25%.
2. The temperature of the molten explosive is lowered to the desired pouring or cast loading temperature of approximately 185° F.
3. The explosive is deaerated.

A batch of molten explosive is drawn off from the melting unit and conditioned in the following manner:

The pressure in the conditioning unit prior to opening the draw off valve is approximately twenty-five inches (25 Hg) of mercury.

Upon a signal from the high level sensor in the melting unit the draw off valve is opened. As the molten explosive and condensate (water) flows from the melting unit into the conditioning unit rapid vaporization of the condensate takes place due to the pressure differential. The cooling effect of the rapid vaporization of the condensate during draw off lowers the temperature of the explosive to approximately 195° F.

The draw off valve is closed by a signal from the low level sensor in the melting unit.

The final conditioning cycle is completely automated and is controlled by a modified two pin recorder which records and controls pressure and temperature of explosive during the conditioning cycle.

Acceptance is based on the rate of temperature drop during a certain time period while the pressure (vacuum) and temperature are within certain limits.

During the conditioning cycle the explosive is completely deaerated by the high vacuum.

The prototype system has recently been relocated from the developmental area to a conventional melt building on a melt-load line at Milan AAP where it is currently being operated and debugged under actual production conditions.

Various parameters such as the maximum melting capacity of all flake Comp. "B", the capacity for all riser scrap Comp. "B" and the utilities requirements and usage will be determined during this final run-in period.

The system is currently being operated by semi-automatic controls but will eventually be completely automated and operated by remote control in the present location. This will include automated supply of new flake Comp. "B" and riser scrap to the system.

The system is currently being operated at a production rate of 2000 81MM Mortars per hour, which is approximately 6000 pounds per hour combination riser scrap and new flake.

In a building designed to house this system with substantial dividing walls separating the three (3) explosive processing units, the maximum concentration of explosive in the system could be as low as 400 pounds.

The concentration of explosive in a typical conventional melting system with comparable melting capacity is approximately 15,000 pounds.

HIGH PRESSURE WATER WASHOUT AS TESTED ON COMP A-3 LOADED 5" PROJECTILES

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Naval Ammunition Depot
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ABSTRACT

High Pressure Water Washout as Tested on Comp A-3 Loaded 5" Projectiles

This report deals with the high pressure water washout of Comp A-3 loaded 5" projectiles. Tests were conducted at Building 146 by NAVSEA/NAPEC at NAD Crane to determine if high pressure water (9000 psig) could be used to remove Comp A-3 safely and economically from 5" projectiles for downloading/demil operations. Included in the reports are problems encountered and results obtained from testing to yield a total washout system which includes explosive recovery and process water recirculation.

OUTLINE

TITLE

"HIGH PRESSURE WATER WASHOUT AS TESTED ON COMP A-3 LOADED 5" PROJECTILES"

I. INTRODUCTION
   A. EXPLANATION OF PROJECT
   B. DESCRIPTION OF SPECIFIC ORDNANCE USED IN TESTING
II. DESCRIPTION OF EQUIPMENT USED IN TESTING
   A. SPIN DEVICE FOR PROJECTILE
   B. HIGH PRESSURE WATER PUMP
   C. FILTRATION
III. RECOGNITION OF OTHER DEMILITARIZATION ALTERNATIVES
   A. CONTOUR DRILL AND WASHOUT
   B. CONTOUR DRILL AND FLASHOUT
IV. DEVELOPMENT OF A TEST PLAN FOR WASHOUT TESTING
   A. USE OF EXISTING DATA
   B. RATIONALE USED IN TESTING
V. NOZZLE DESIGN FOR TESTING
   A. RECOGNITION OF PROBLEM IN OBTAINING TOTAL WASHOUT
   B. NOZZLE DEVELOPMENTAL STAGES
   C. DESIGN CRITERIA
VI. TESTING OF HIGH PRESSURE WATER WASHOUT
   A. TEST PLAN VARIATIONS
   B. PROBLEMS ENCOUNTERED AND SOLUTIONS DURING TESTING

VII. PROCESS WATER RECIRCULATION AND EXPLOSIVE RECLAMATION

- A. FILTRATION EQUIPMENT RECOMMENDED
  - 1. BAUER HYDRASIEVE
  - 2. TWIN PRESSURE BAG FILTERS
- B. RATIONALE USED IN SELECTION OF EQUIPMENT
- C. SIEVE ANALYSIS OF COMP A-3 AND WATER EFFLUENT

VIII. ADDITIONAL WASHOUT TESTING

- A. TESTING OF COMP A-3 LOADED 3"/50 PROJECTILES
- B. TESTING OF EXPLOSIVE D LOADED 5"/38 PROJECTILES
- C. FILTRATION PROBLEMS ENCOUNTERED WITH EXPLOSIVE D WASHOUT
- D. ANALYSIS OF EXPLOSIVE D WASHOUT EFFLUENT

<u>ATTACHMENT I.</u>

LIST OF VISUAL AIDS

LIST OF VISUAL AIDS

SLIDE NO.	DESCRIPTION
1.	SKETCH (CUTAWAY) SHOWING 5"/38 AND 5"/54 PROJECTILES
2.	MODIFIED CONTOUR LATHE WITH OPERATOR IN POSITION
3.	HIGH PRESSURE WATER PUMP
4.	SET UP SHOWING NOZZLE SPRAY UNDER PRESSURE
5.	FOOT CONTROL FOR HIGH PRESSURE PUMP
6.	FILTRATION DEVICE USED FOR TESTING
7.	NOZZLE #1 USED BY ORDNANCE DEPARTMENT
8.	SPIN RATE AND TIME VARIATIONS USED IN TESTING
9.	TYPICAL CROSS SECTION OF A PROJECTILE AFTER FIRST INCREMENT OF TESTING
10.	NOZZLE #2 DESIGNED BY NAPEC FOR FINAL CLEAN-UP OPERATION
11.	NOZZLE #3 DESIGNED BY NAPEC FOR FINAL CLEAN-UP OPERATION
12.	NOZZLE #4 DESIGNED BY NAPEC TO BORE HOLE AND CLEAN BASE
13.	NOZZLE #5 DESIGNED BY NAPEC FOR FINAL CLEAN-UP OPERATION
14.	NOZZLE #6 DESIGNED BY NAPEC FOR FINAL CLEAN-UP OPERATION
15.	BAUER HYDRASIEVE AND TWIN BAG FILTERS
16.	SIEVE ANALYSIS BY WEIGHT OF COMP A-3 EFFLUENT
17.	EXPLOSIVE D EFFLUENT ANALYSIS

HIGH PRESSURE WATER WASHOUT
AS TESTED ON 5" COMP A-3
LOADED PROJECTILES

THIS PRESENTATION WILL DESCRIBE A PROJECT RECENTLY COMPLETED BY THE NAVAL SEA SYTEMS COMMAND/NAVAL AMMUNITION PRODUCTION ENGINEERING CENTER AT NAD CRANE, INDIANA. THE PROJECT FORMED THE BASIS FOR A NEW PROCESS/METHOD TO REMOVE COMP A-3 FROM 5" PROJECTILES. THE PROCESS ALSO INCLUDES THE RECLAMATION OF EXPLOSIVE AND PROCESS WATER RECIRCULATION.

THE TESTING WAS CONDUCTED FROM FEBRUARY 1974 TO AUGUST 1974. EARLY TESTING OF WASHOUT ON COMP A-3 YEILDED FEW RESULTS AND IN MAY OF 1974 A MEETING WAS HELD BETWEEN NAPEC AND THE ORDNANCE DEPARTMENT AT NAD CRANE. THE MEETING "SET THE STAGE" FOR FURTHER TESTING ON HIGH PRESSURE WASHOUT OF COMP A-3 LOADED 5" PROJECTILES. THE PROJECTILES UNDER CONSIDERATION AT THAT TIME WERE 5"/38 AND 5"/54 PROJECTILES AS CAN BE SEEN FROM THE FIRST SLIDE.

THIS PRESENTATION WILL CONCERN THE ATTEMPT FOR TOTAL WASHOUT OF COMP A-3 LOADED 5" PROJECTILES IN A SAFE AND ECONOMIC MANNER. THE EQUIPMENT USED IN TESTING CAN BE SEEN IN THE NEXT FIVE SLIDES:

1. Modified Contour Lathe with Operator in Position
2. High Pressure Water Pump
3. Set-Up showing nozzle spray under pressure
4. Foot control for pump
5. Filtration

The spin device used to rotate the projectile is an old contour lathe with a manual rack and pinion feed. The pump unit was rented from American Water Blaster and is capable of passing 20 GPM at 10,000 PSIG. Filtration is accomplished by the use of a burlap bag inside a 55 gallon barrel. The larger chunks of explosive are removed by an aluminum bucket with a heavy mesh screen in the bottom. From the 55 gallon barrel, the effluent goes to a sump for sedimentation and regular cleaning of the sump is necessary.

At the present time there are no activities with the capability of total washout of Comp A-3 from projectile bodies. The present methods of removing Comp A-3 from 5" projectiles are:

1. Controur drill and washout
2. Contour drill and flashout (Burn)

It is generally the opinion that contour drilling is inherently a hazardous operation. Also during flashout operations, the nose area of the projectile reaches nearly 1900° F. This temperature is capable of altering the metallic properties of the projectile. Also, a time consuming clean-up operation is required to remove residue from the nose thread area.

THE MAIN OBJECTIVE WAS TO DETERMINE IF HIGH PRESSURE WATER WASHOUT COULD BE USED TO REMOVE COMP A-3 FROM 5" PROJECTILES IN A SAFER AND MORE ECONOMIC MANNER THAN THE PRESENT METHODS MENTIONED PREVIOUSLY.

THE MAJOR PROBLEM ENCOUNTERED IN THE INITIAL TESTING WAS EXCESSIVE CHUNK SIZES WHICH COULD NOT EXCAPE FROM THE PROJECTILE NOSE AREA. BASED ON THESE FINDINGS AND NOZZLE DESIGNS, NOZZLE #1 WAS CHOSEN TO BEGIN TESTING. THE NOZZLE IS SHOWN IN THE NEXT SLIDE. 5"/38 PROJECTILES WERE TESTED FIRST DUE TO THE LARGER QUANTITY OF HAND FOR DISPOSAL. NOZZLE #1 WILL GIVE A ROUGH HOLE THROUGH THE CENTER OF THE 5"/38 PROJECTILE, BUT WILL NOT REMOVE THE EXPLOSIVE ALONG THE SIDEWALLS AND AROUND THE BASE AREA. THE NOZZLE WOULD BORE A HOLE APPROXIMATELY 2 1/2 INCHES IN DIAMETER THROUGH THE PROJECTILE TO WITHIN APPROXIMATELY 1/2 INCH FROM THE BASE AND FROM THIS POINT WOULD BORE A HOLE THROUGH TO THE BASE APPROXIMATELY 1 INCH IN DIAMETER. VARIATION OF LANCE FEED RATE AND PROJECTILE SPIN RATE RESULTED IN DIFFERENT HOLE SIZES AND VARYING DEGREES OF HOLE ROUGHNESS. USING SEVEN DIFFERENT SPIN RATES AND FIVE TIME VARIATIONS, A TOTAL OF 35 TEST SPECIMENS WERE OBTAINED. THE SPIN RATES AND TIMES ARE SHOWN IN THE NEXT SLIDE. REPEATABILITY TESTS WERE RUN AND 35 MORE 5"/38 PROJECTILES WERE OBTAINED WHICH GAVE TWO 5"/38 PROJECTILES FOR EACH LANCE FEED RATE AND TIME INCREMENT. THE NEXT SLIDE SHOWS A TYPICAL CROSS SECTION OF THE PROJECTILES AFTER THIS FIRST INCREMENT OF TESTING.

IT WAS REALIZED THAT NOZZLE #1 WAS NOT SUITABLE TO REMOVE THE REMAINING PORTION OF THE EXPLOSIVE DUE TO RESULTS OBTAINED BY THE ORDNANCE DEPARTMENT. THEREFORE, NAPEC WOULD HAVE TO DESIGN A NOZZLE THAT WOULD SATISFACTORILY REMOVE THE REMAINING PORTION OF EXPLOSIVE ALONG THE SIDE WALLS AND AROUND THE BASE.

WHILE AN OPTIMUM NOZZLE DESIGN WOULD REQUIRE ONLY ONE NOZZLE TO REMOVE ALL THE EXPLOSIVE, IT WAS MORE FEASIBLE TO TEST IN TWO STAGES. (OBTAIN A ROUGH HOLE AND THEN CLEAN UP THE REMAINING EXPLOSIVE.) THIS WOULD SIMPLIFY NOZZLE DESIGN FOR TESTING AND A FUTURE NOZZLE DESIGN COULD INCORPORATE BOTH NOZZLE DESIGNS FOR A SINGLE WASHOUT NOZZLE. ALSO, THE OUTPUT OF THE PUMP UNIT USED IN TESTING (20 GPM AT 10,000 PSIG) RESTRICTED THE USE OF ONE NOZZLE FOR TOTAL WASHOUT. IT WAS FELT THAT THE VOLUME OF WATER AND VELOCITIES REQUIRED FOR WASHOUT COULD NOT BE OBTAINED USING ONE NOZZLE WITH THE EXISTING PUMP UNIT.

AT THIS POINT, NOZZLE #2 WAS DESIGNED TO REMOVE THE REMAINING EXPLOSIVE WHICH NOZZLE #1 FAILED TO WASHOUT. NOZZLE #2 IS SHOWN IN THE NEXT SLIDE. SINCE ONLY TWO SAMPLES OF EACH TEST PERFORMED IN THE INITIAL TESTS USING NOZZLE #1 WERE AVAILABLE FOR CLEAN UP TESTING, A CORRECT/SATISFACTORY COMBINATION OF LANCE FEED RATE, TIME, PROJECTILE RPM, AND NUMBER OF RECIPROCATIONS NEEDED TO BE DETERMINED. IF THIS WAS NOT DONE, THE NUMBER OF PROJECTILES REQUIRED IN THE FIRST OPERATION (ROUGHING A HOLE THROUGH THE PROJECTILE) WOULD BE TOO TIME CONSUMING. THEREFORE, A VISUAL INSPECTION OF THE 70 PROJECTILES RUN IN THE FIRST SERIES OF TESTS WAS MADE, AND IT APPEARED THE BEST HOLE WAS OBTAINED AT 150 RPM

WITH A LANCE FEED RATE OF ONE MINUTS FOR 5"/38 PROJECTILES. BASED ON THIS FINDING, SEVERAL PROJECTILES WERE RUN AT 150 RPM AND ONE MINUTE FEED TO OBTAIN A HOLE THROUGH THE COMP A-3.

NOZZLE #2 WAS THEN TESTED AT VARIOUS SPIN RATES, TIME VARIATIONS, PRESSURES, AND LANCE RECIPROCATIONS TO REMOVE THE REMAINDER OF THE EXPLOSIVE IN THE PROJECTILE. A SPIN RATE OF 200 RPM, A CYCLE TIME OF ONE MINUTE, AND TWO LANCE RECIPROCATIONS (30 SECONDS IN AND 30 SECONDS OUT) YIELDED THE BEST RESULTS. REPEATABILITY TESTS RUN AT THESE PARAMETERS INDICATED THAT OPERATOR ERROR AND "SLOP" IN THE RACKFEED IN THE FIXTURE COULD ALLOW FOR RIBBON-LIKE BANDS OF COMP A-3 TO BE LEFT ON THE SIDEWALLS. THIS WAS DUE TO THE FACT THAT A SMALL JUMP OR ADVANCE OF THE LANCE WOULD NOT ALLOW PROPER TIME FOR CLEANING IN A SPECIFIC AREA. ALSO NOZZLE #2 WOULD NOT REMOVE THE EXPLOSIVE REMAINING ON THE BASE AREA OF THE PROJECTILES DUE TO THE PHYSICAL LOCATION OF THE FORWARD ORIFICE.

AT THIS POINT, IT WAS ANTICIPATED THAT A DWELL TIME AT THE BASE OF THE PROJECTILE WITH NOZZLE #1 WOULD REMOVE THE EXPLOSIVE FROM THE BASE. NOZZLE #3 WAS THEN DEVELOPED AS SHOWN IN THE NEXT SLIDE. WITH THE SLOTS OFFSET, THIS WOULD ELIMINATE SOME OF THE OPERATOR/MACHINE ERROR WHICH CAUSED RIBBONS OF EXPLOSIVE TO BE LEFT ON THE SIDEWALLS. UPON TESTING IT WAS FOUND THAT NOZZLE #3 SATISFACTORILY REMOVED THE EXPLOSIVE FROM THE SIDEWALLS. HOWEVER, NOZZLE #1 TESTED AT VARIOUS DWELL TIMES WOULD NOT CLEAN THE BASE AREA SUFFICIENTLY AND ALSO CAUSED EXCESSIVE CHUNKING IN THE BASE AREA.

NOZZLE #4 WAS THEN DESIGNED TO BORE A HOLE THROUGH THE PROJECTILE AS WELL AS TAKE CARE OF THE BASE AREA. NOZZLE #4 IS SHOWN IN THE NEXT SLIDE. THIS NOZZLE RESULTED IN EXCESSIVE CHUNK SIZES WHICH STOPPED THE OPERATION. IT EXHIBITED VERY POOR PENETRATION ABILITY. HOWEVER, NOZZLE #4 WAS TRIED ON SOME TEST PROJECTILES WITH ONLY THE BASE AREA COVERED BY EXPLOSIVE. THE NOZZLE SATISFACTORILY REMOVED THE EXPLOSIVE REMAINING AROUND THE BASE.

IT WAS THEN DECIDED TO USE NOZZLE #1 TO OBTAIN A HOLE THROUGH THE EXPLOSIVE, AND CLEAN THE SIDEWALLS AND BASE ON THE SECOND OPERATION. THUS NOZZLE #5 WAS DEVELOPED AS SHOWN ON THE NEXT SLIDE. NOZZLE #5 CAUSED LARGE CHUNKING DUE TO THE FORWARD SLOT CONFIGURATION. THE WATER JET GOT BETWEEN THE SIDEWALLS AND THE EXPLOSIVE AND BROKE THE COMP A-3 OUT IN LARGE CHUNKS. ALSO, RIBBON-LIKE BANDS OF EXPLOSIVE APPEARED AT VARIOUS LOCATIONS DUE TO THE SMALL, IRREGULAR ADVANCES OF THE LANCE.

IT WAS THEN DECIDED TO REDUCE THE LEAD ANGLE OF THE FORWARD ORIFICE TO REDUCE THE POSSIBILITY OF THE WATER JET FORCING EXPLOSIVE FROM THE SIDEWALLS BEFORE FINE CUTTING COULD BE OBTAINED. THIS LEAD TO THE DEVELOPMENT OF NOZZLE #6 AS SHOWN IN THE NEXT SLIDE. THE LEAD ANGLE OF THE FORWARD ORIFICE WAS REDUCED FROM 20° TO 5°.

UPON TESTING, IT WAS FOUND THAT NOZZLE #6 SATISFACTORILY COMBINED WITH NOZZLE #1 TO YIELD TOTAL WASHOUT ON 5"/38 PROJECTILES. THE CLEAN-UP OPERATION USING NOZZLE #6 REQUIRES A SPIN RATE OF 200 RPM AND A ONE MINUTE CYCLE TIME WITH TWO RECIPROCATIONS (30 SECONDS IN AND 30 SECONDS OUT).

THE TOTAL WASHOUT TIME FOR 5"/38 PROJECTILES IS TWO MINUTES, CONSISTING OF ONE MINUTE TO OBTAIN A HOLE THROUGH THE PROJECTILE AND ONE MINUTE TO CLEAN THE SIDEWALL AND BASE REGIONS.

FROM THE NOZZLE CONFIGURATIONS WITH VARIOUS ORIFICE SIZES TESTED BY THE ORDNANCE DEPARTMENT, IT WAS FOUND THAT APPROXIMATELY 16 GPM WAS REQUIRED TO SATISFACTORILY WASHOUT THE COMP A-3. THEREFORE, ALL NOZZLES DESIGNED AND TESTED BY NAPEC WERE DESIGNED TO PASS APPROXIMATELY 16 GPM AT 10,000 PSIG.

DURING TESTING OF 5"/38 PROJECTILES, WOOMA CORPORATION SENT A NOZZLE FOR TESTING ON THE WASHOUT OF COMP A-3. THE NOZZLE WAS DESIGNED AT 6000 PSIG AND PASSING 37 GPM. THE NOZZLE DID NOT ADAPT TO OUR SETUP SINCE OUR MAXIMUM FLOW WAS APPROXIMATELY 20 GPM. THE MAXIMUM PRESSURE OBTAINED BY THE WOOMA CORPORATION NOZZLE WAS 4000 PSI AND THIS WAS NOT ENOUGH TO WASHOUT THE EXPLOSIVE.

5"/38 PROJECTILES FURNISHED TO NAPEC FOR WASHOUT TESTING WERE UNSERVICEABLE DUE TO LOW DENSITY. THE WASHOUT METHOD DESCRIBED PREVIOUSLY WORKS SUFFICIENTLY WELL WITH THESE TYPE EXPLOSIVE FILLS. HOWEVER, DURING REPEATABILITY TESTING TO PROVE THE WASHOUT METHOD, SOME 5"/38 PROJECTILES WERE RECEIVED THAT WERE UNSERVICEABLE DUE TO CRACKED FILLS. THIS PRESENTED AN ENTIRELY NEW SITUATION TO OBTAIN TOTAL WASHOUT. OBTAINING A HOLE THROUGH THE PROJECTILES WITH CRACKED FILLS WAS NO PROBLEM, BUT CLEANING THE SIDEWALL AND BASE AREAS IN THE SAME MANNER DESCRIBED PREVIOUSLY CAUSED CONSIDERABLE CHUNKING. AS CAN BE SEEN FROM THE SLIDE, NOZZLE #6 HAS A SLOT CANTED 5° FROM THE VERTICAL TO REMOVE THE

EXPLOSIVE FROM THE BASE AREA. WITH PROJECTILES THAT HAVE CRACKED FILLS, THE LEADING WATER JET GETS BEHIND THE EXPLOSIVE ALONG THE PROJECTILE BODY AND CHUNKS THE A-3 OFF THE SIDEWALLS WHEREVER CRACK LINES ARE LOCATED. THIS ALLOWS NO WAY OF CONTROLLING CHUNK SIZES BECAUSE THE LARGE SECTIONS OF EXPLOSIVE ARE FREE AND TRYING TO ESCAPE BEFORE A SMOOTH CUT CAN BE OBTAINED.

TO SOLVE THIS PROBLEM, THE CLEAN-UP NOZZLE #6 IS INSERTED COMPLETELY TO THE BASE OF THE PROJECTILE AND THE CLEAN-UP OPERATION IS RUN IN REVERSE (30 SECONDS OUT AND 30 SECONDS IN FOR 5"/38 PROJECTILES). THIS ELIMINATES THE POSSIBILITY OF THE LEADING WATER JET GETTING BETWEEN THE PROJECTILE BODY AND THE EXPLOSIVE ALONG THE SIDEWALL BEFORE A FINE CUTTING OF THE COMP A-3 CAN BE OBTAINED.

REPEATABILITY TESTS ON 5"/38 PROJECTILES TOTALED 85 PROJECTILES WASHED OUT IN A SATISFACTORY AND SAFE METHOD. VISUAL INSPECTION REVEALED NO COMP A-3 PRESENT IN THE 5"/38 PROJECTILE BODIES.

UPON COMPLETION OF TESTING FOR 5"/38 PROJECTILES, THE WASHOUT SETUP WAS TOOLED TO HANDLE 5"/54 COMP A-3 LOADED PROJECTILES. SINCE 5"/54 PROJECTILES ARE LONGER THAN 5"/38 PROJECTILES, IT WAS ANTICIPATED A LONGER WASHOUT CYCLE WOULD BE REQUIRED. THE PROJECTILE RPM WAS VARIED AS WELL AS LANCE FEED RATE, AND IT WAS FOUND THAT A FEED RATE OF ONE MINUTE AND 30 SECONDS AT 200 RPM YIELDED A SATISFACTORY HOLE THROUGH THE COMP A-3. BASED ON THIS, CLEAN-UP WITH NOZZLE #6 WAS

TESTED AT ONE MINUTE AND 30 SECONDS AT 200 RPM CONSISTING OF TWO RECIPROCATIONS (45 SECONDS IN AND 45 SECONDS OUT). THE PROCEDURE SATISFACTORILY REMOVES THE REMAINING EXPLOSIVE FROM THE SIDEWALL AND BASE AREAS.

THIRTY-FIVE 5"/54 COMP A-3 LOADED PROJECTILES WERE RUN FOR REPEATABILITY AND ALL PROJECTILES WERE SATISFACTORILY WASHED OUT. ALL 5"/54 PROJECTILES RUN WERE UNSERVICEABLE DUE TO LOW DENSITY OF THE COMP A-3 FILL. IT IS ANTICIPATED THAT 5"/54 PROJECTILES WITH CRACKED FILLS COULD BE HANDLED IN THE SAME MANNER AS 5"/38 PROJECTILES WITH CRACKED FILLS. THE CLEAN UP NOZZLE #6 WOULD BE INSERTED TO THE BASE AND WASHOUT WOULD BE STARTED IN REVERSE (45 SECONDS OUT AND 45 SECONDS IN).

IT IS THE OPINION THAT 5"/54 WASHOUT COULD BE ACCOMPLISHED IN A ONE MINUTE AND TWENTY SECOND CYCLE TIME FOR EACH OPERATION (OBTAIN HOLE THEN CLEAN SIDEWALL AND BASE AREA), IF AN AUTOMATIC LANCE FEED WAS UTILIZED. ALSO, 5"/38 WASHOUT TIME COULD ALSO BE REDUCED SLIGHTLY WITH AUTOMATIC LANCE FEED WITH EXISTING NOZZLE CONFIGURATIONS.

PROCESS WATER RECIRCULATION AND EXPLOSIVE RECLAMATION ARE HIGHLY IMPORTANT FEATURES OF THE FINAL WASHOUT SYSTEM. FILTRATION EQUIPMENT RECOMMENDED FOR EXPLOSIVE RECOVERY AND RECIRCULATION OF PROCESS WATER AS SHOWN IN THE NEXT SLIDE ARE A BAUER HYDRASIEVE AND TWIN PRESSURE BAG FILTERS. THE EXPLOSIVE EFFLUENT WILL FIRST BE INTRODUCED TO THE

HYDRASIEVE. APPROXIMATELY 95 PERCENT BY WEIGHT OF THE EXPLOSIVE PARTICLES WILL BE REMOVED BY THIS ROUGH SCREENING. CHUNKS OF EXPLOSIVE LARGE ENOUGH TO BE REMOVED BY THE HYDRASIEVE WILL PASS ACROSS THE TOP OF THE SCREEN AND BE COLLECTED AND BOXED FOR RESALE/REUSE. THE PROCESS WATER WITH THE REMAINING FINE PARTICLES COMP A-3 SUSPENDED WILL PASS THROUGH THE SCREEN AND BE PUMPED TO ONE OF THE TWO PRESSURE BAG FILTERS. WITH TWO BAG FILTERS IN PARALLEL, CONTINUOUS FILTERING CAN BE MAINTAINED. WHEN THE PRESSURE DROP (ΔP) REACHES A PRESET LEVEL ACROSS ONE BAG FILTER, THE SYSTEM WILL SWITCH TO THE OTHER BAG FILTER TO ENABLE BAG REPLACEMENT/CLEANING.

THE ACCEPTABLE LEVEL OF CONTAMINATION FOR PROCESS WATER RECIRCULATION THROUGH THE PUMP IS PARTICLE SIZES 50 MICRON OR LESS. THIS CAN BE EASILY OBTAINED WITH BAG FILTERS. COMP A-3 IS NEARLY INSOLUBLE IN WATER AT THE OPERATING TEMPERATURE BETWEEN 70° F AND 100° F. THEREFORE, DISSOLVED SOLIDS WILL NOT CAUSE ANY MAJOR PROBLEMS IN FILTRATION FOR RECIRCULATION OF PROCESS WATER WITH COMP A-3 EFFLUENT.

EFFLUENT SAMPLES WERE SENT TO THE WEAPONS QUALITY ENGINEERING CENTER FOR ANALYSIS. THE RESULTS ARE SHOWN IN THE NEXT SLIDE. THE SIEVE ANALYSIS BY WEIGHT IS:

SIEVE OPENING	PERCENT COLLECTED BY WEIGHT
4.76 MM	64.1%
3.36 MM	9.1%
2.38 MM	7.3%
2.00 MM	2.5%
1.68 MM	4.2%
COLLECTION ON PAN	12.8%

ALSO ON SMALL EFFLUENT SAMPLES, SUSPENDED SOLIDS PASSING THROUGH A .45 MICRON FILTER WAS 55 PPM WITH 2 PPM COLLECTED.

ON THE ORIGINAL FILTRATION DESIGN TO HANDLE COMP A-3 WASHOUT EFFLUENT, LIQUID CENTRIFUGAL SEPARATORS WERE CONSIDERED TO REMOVE SOME OF THE FINER PARTICLES OF EXPLOSIVE AFTER THE HYDRASIEVE AND ELIMINATE SOME OF THE HEAVY CAKING OF THE BAG FILTER. HOWEVER, IT IS CONSIDERED THAT THE HYDRASIEVE COLLECTION EFFICIENCY WILL BE HIGH ENOUGH TO SHOW LITTLE BENEFIT IN THE USE OF THE LIQUID CENTRIFUGAL SEPARATORS. THIS WILL REDUCE THE COST OF THE SYSTEM AND STILL ALLOW THE RECIRCULATION OF PROCESS WATER.

UPON COMPLETION OF TESTING ON COMP A-3 LOADED 5" PROJECTILES, WASHOUT WAS ATTEMPTED ON EXPLOSIVE D LOADED 5"/38 PROJECTILES AND COMP A-3 LOADED 3"/50 PROJECTILES. USING NOZZLE #1 ONLY, TOTAL WASHOUT WAS ATTAINED IN 20 SECONDS CONSISTING OF TEN SECONDS IN AND TEN SECONDS OUT OF THE 3"/50 PROJECTILES. A SPIN RATE OF 200 RPM WAS USED FOR THE 3"/50 TESTS. REPEATABILITY TESTS WERE RUN FOR A TOTAL OF 30 WASHED OUT 3"/50 PROJECTILES.

WHILE THE ROUGH FILTRATION EQUIPMENT DESCRIBED PREVIOUSLY FOR COMP A-3 WASHOUT TESTS WORKED SUFFICIENTLY WELL WITH COMP A-3 EFFLUENT, EXPLOSIVE D POSED A PROBLEM FOR FILTRATION DUE TO ITS SOLUBILITY CHARACTERISTICS. THEREFORE, PRIOR TO TESTING WASHOUT ON EXPLOSIVE D LOADED 5"/38 PROJECTILES, SEVERAL 55 GALLON METAL DRUMS WERE OBTAINED TO CATCH ALL THE EXPLOSIVE D CONTAMINATED PROCESS WATER.

WASHOUT WAS ATTEMPTED ON EXPLOSIVE D LOADED 5"/38 PROJECTILES IN THE SAME MANNER AS COMP A-3 LOADED 5"/38 PROJECTILES DESCRIBED PREVIOUSLY CONSISTING OF USING NOZZLE #1 TO OBTAIN A HOLE THROUGH THE EXPLOSIVE IN ONE MINUTE AND THEN THE USE OF NOZZLE #6 TO CLEAN THE REMAINING EXPLOSIVE. HOWEVER, IT WAS FOUND THAT NOZZLE #1 ALONE YIELDED TOTAL WASHOUT IN THE ONE MINUTE CYCLE. VARIATION IN PROJECTILE RPM AND LANCE FEED RATE RESULTED IN A 30 SECOND TOTAL WASHOUT TIME WITH A SPIN RATE OF 250 RPM. THE PRESSURE REQUIRED FOR BOTH THE 3"/50 COMP A-3 LOADED AND THE EXPLOSIVE D LOADED 5"/38 PROJECTILES WAS 9000 PSIG. A TOTAL OF FIVE 5"/38 EXPLOSIVE D LOADED PROJECTILES WERE WASHED OUT AT THESE PARAMETERS.

EFFLUENT SAMPLES OF WASHOUT EXPLOSIVE D WERE SENT TO WQEC FOR ANALYSIS. THE NEXT SLIDE SHOWS THE ANALYSIS AS FOLLOWS:

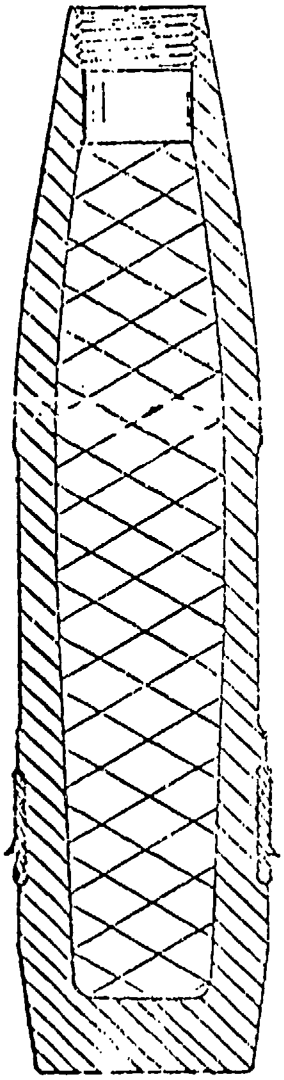
PH	7
TOTAL DISSOLVED SOLIDS (TDS)	1.56%
DISSOLVED EXPLOSIVE D	1.39%
TOTAL SUSPENDED SOLIDS (TSS)	.87%

NOTE: REMAINING EXPLOSIVE D SETTLED OUT

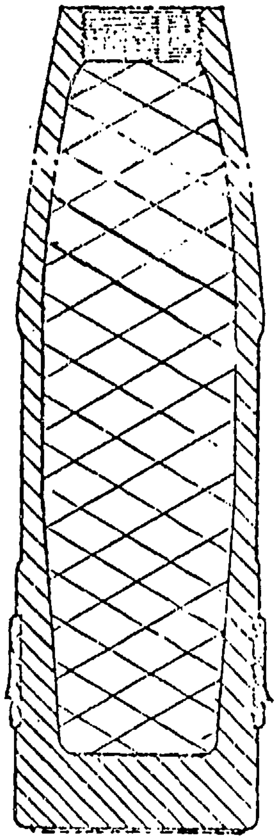
AT 20° C, EXPLOSIVE D AND WATER EXHIBITS 1.1 PERCENT DISSOLVED SOLIDS. THE TEMPERATURE RISE OF THE WATER DUE TO THE USE OF HIGH PRESSURE (APPROXIMATELY 25° F RISE) COULD ACCOUNT FOR THE SLIGHT INCREASE IN TDS IN THE EFFLUENT.

ALL TESTING ON HIGH PRESSURE WASHOUT WAS CONDUCTED WITH THE PROJECTILES AT A 15° WASHOUT ANGLE. THE FINAL PRODUCTION MACHINE WILL HAVE THE CAPABILITY OF ELEVATING THE PROJECTILE FROM HORIZONTAL TO A VERTICAL POSITION TO ENABLE THE DETERMINATION OF AN OPTIMUM WASHOUT ANGLE. THE WASHOUT SPIN FIXTURE WILL ALSO BE OF MULTISTATION CONFIGURATION (MOST LIKELY FOUR STATIONS/LOCATIONS) FOR VERSATILITY. BESIDES BEING USED TO SPIN THE PROJECTILES FOR WASHOUT, ONE OR TWO OF THE STATIONS ON THE SPIN FIXTURE MACHINE WILL BE USED FOR DESENSITIZING ANY COMP A-3 RESIDUE LEFT IN THE PROJECTILE FOLLOWING WASHOUT. THE MACHINE WILL ALSO BE CAPABLE OF ACCEPTING AND PROCESSING PROJECTILES AUTOMATICALLY POSSIBLY BY THE USE OF A WALKING BEAM CONVEYOR. VARIABLE SPEED SPIN STATIONS AND LANCE FEED SYSTEMS WILL ALSO BE DESIGNED INTO THE SPIN MACHINE TO ALLOW FOR FUTURE IMPROVEMENTS IN THE WASHOUT TECHNIQUES.

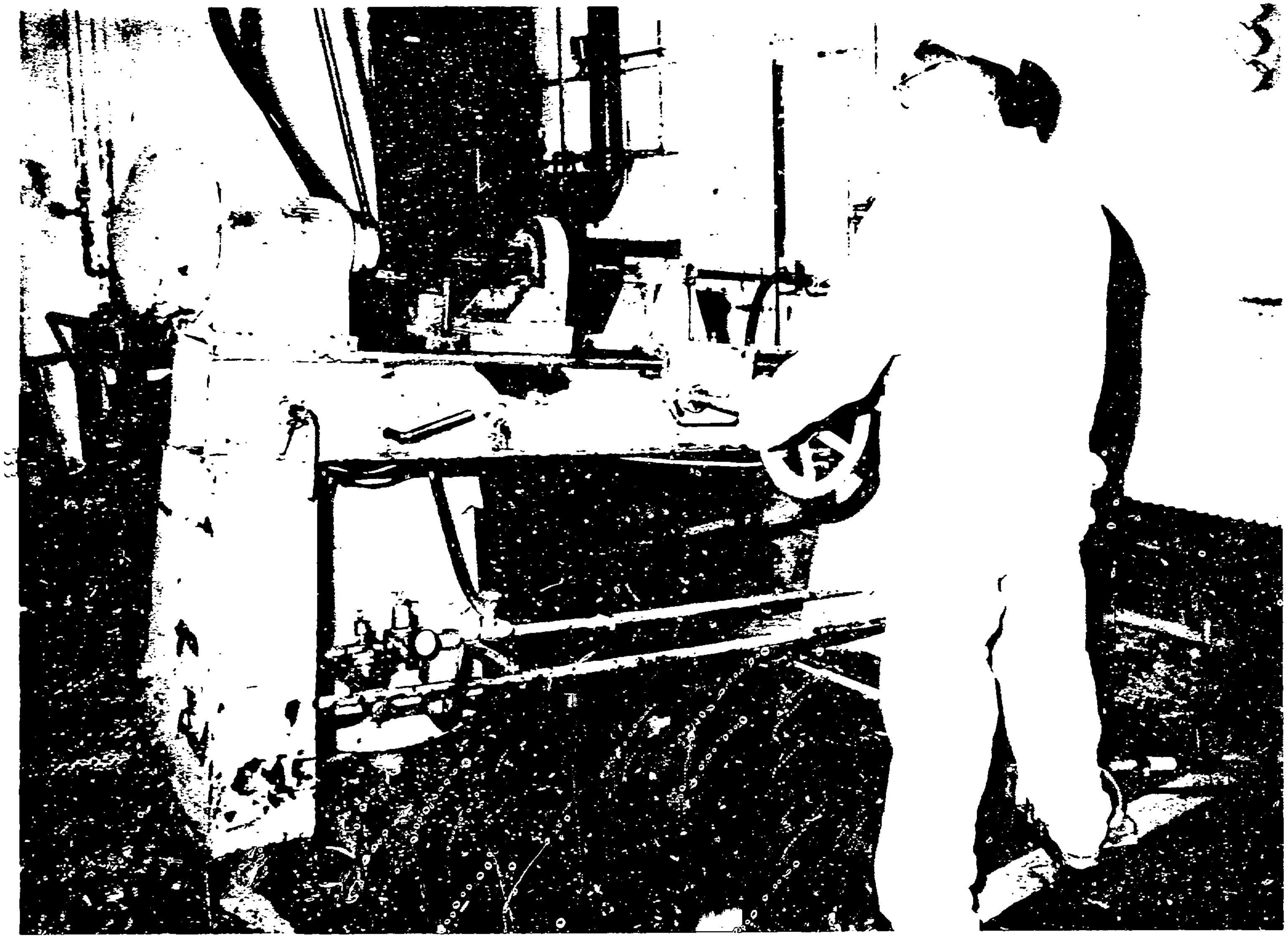
IT IS REALIZED THAT ONLY THE SURFACE HAS BEEN "SCRATCHED" ON AN OPTIMUM NOZZLE DESIGN AND HIGH PRESSURE WASHOUT OF COMP A-3. THE METHODOLOGY DESCRIBED IN THIS REPORT WILL GIVE THE NAVY/GOVERNMENT ANOTHER DEMIL/DISPOSAL ALTERNATIVE FOR PROJECTILES AND FURTHER TESTING WITH NEW NOZZLE DESIGNS IN THE FUTURE WILL CONTINUALLY IMPROVE THE TECHNIQUES PRESENTLY EMPLOYED FOR TOTAL WASHOUT OF COMP A-3 LOADED PROJECTILES.

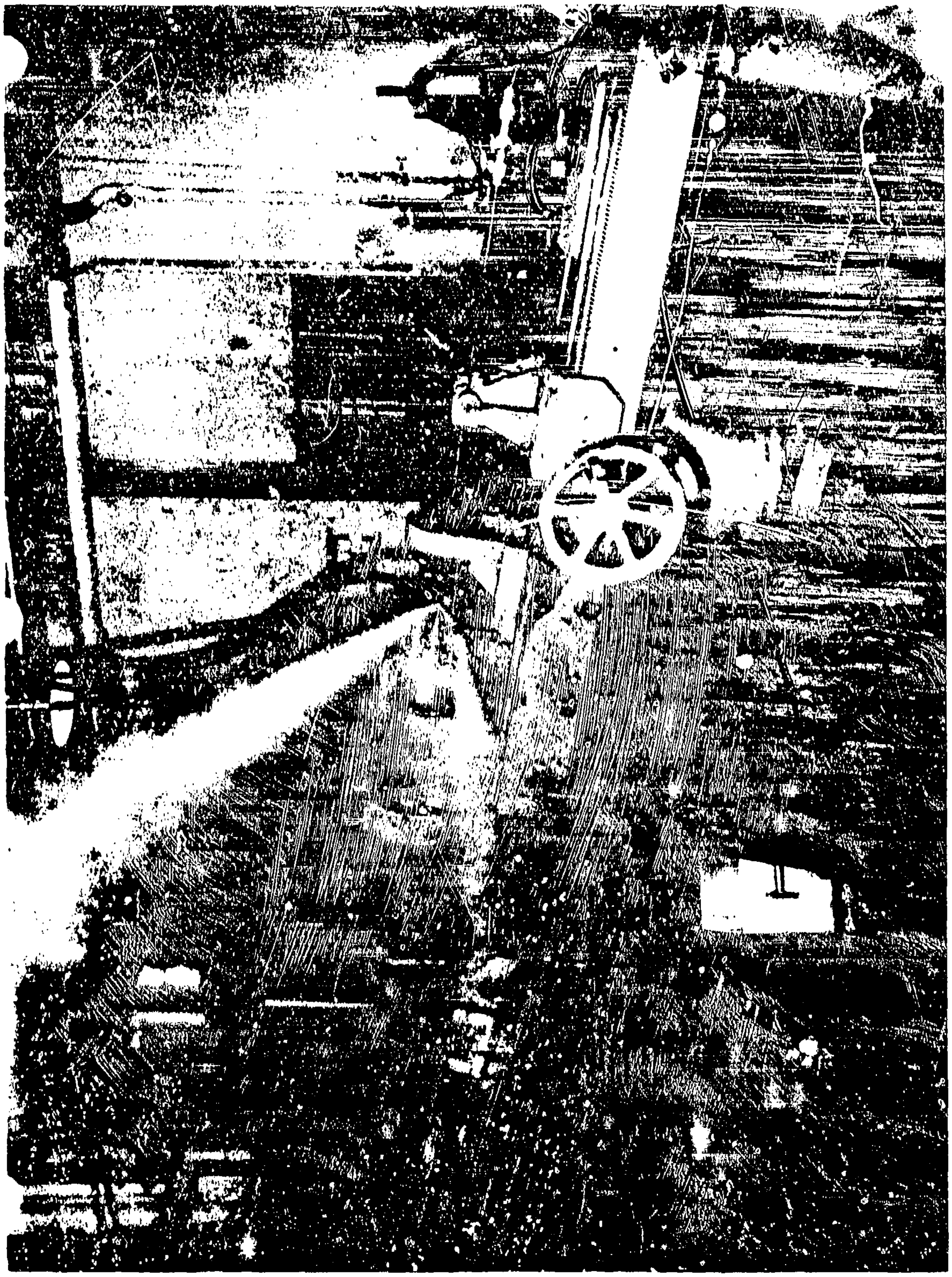


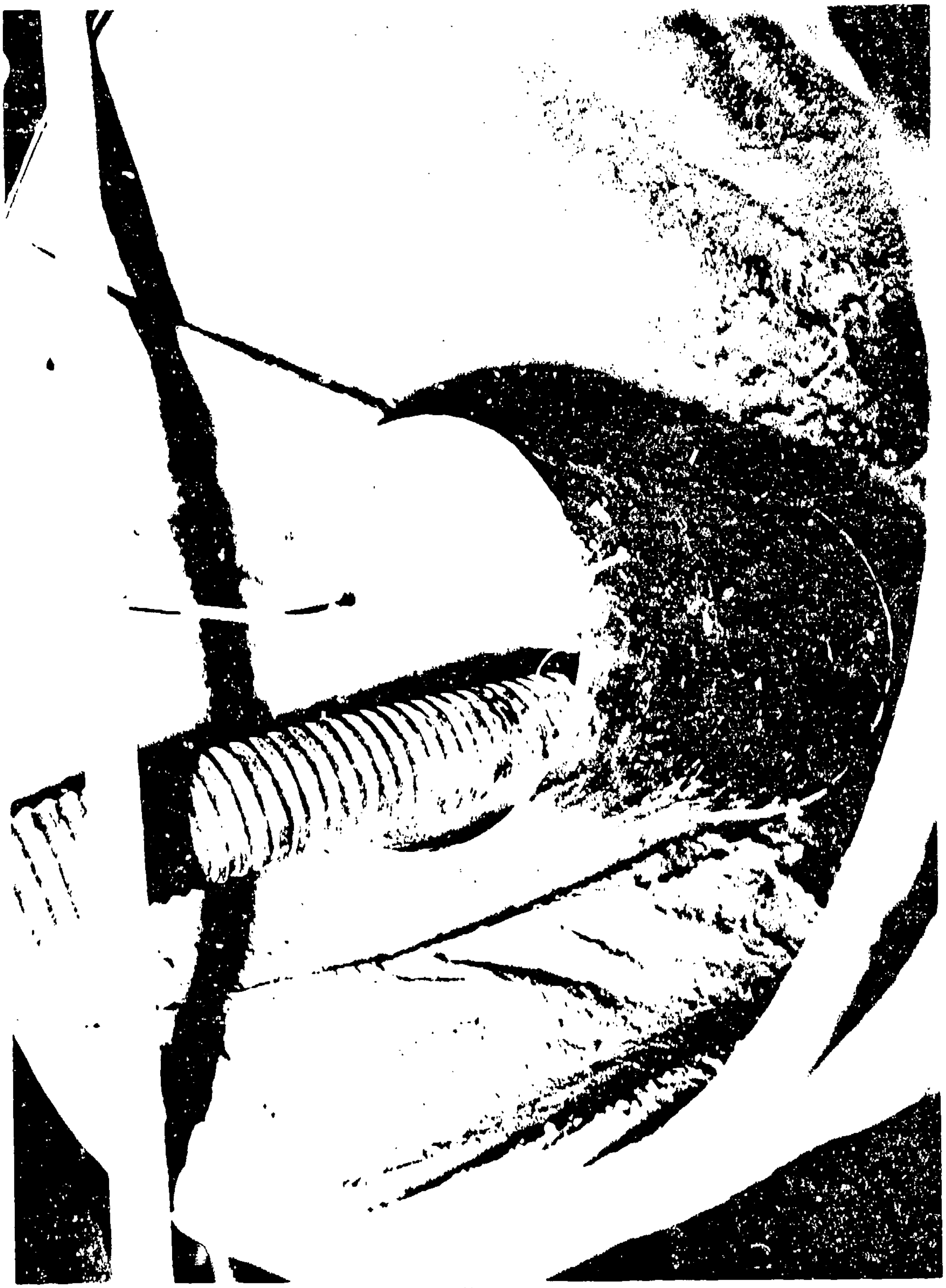
5"/ 54



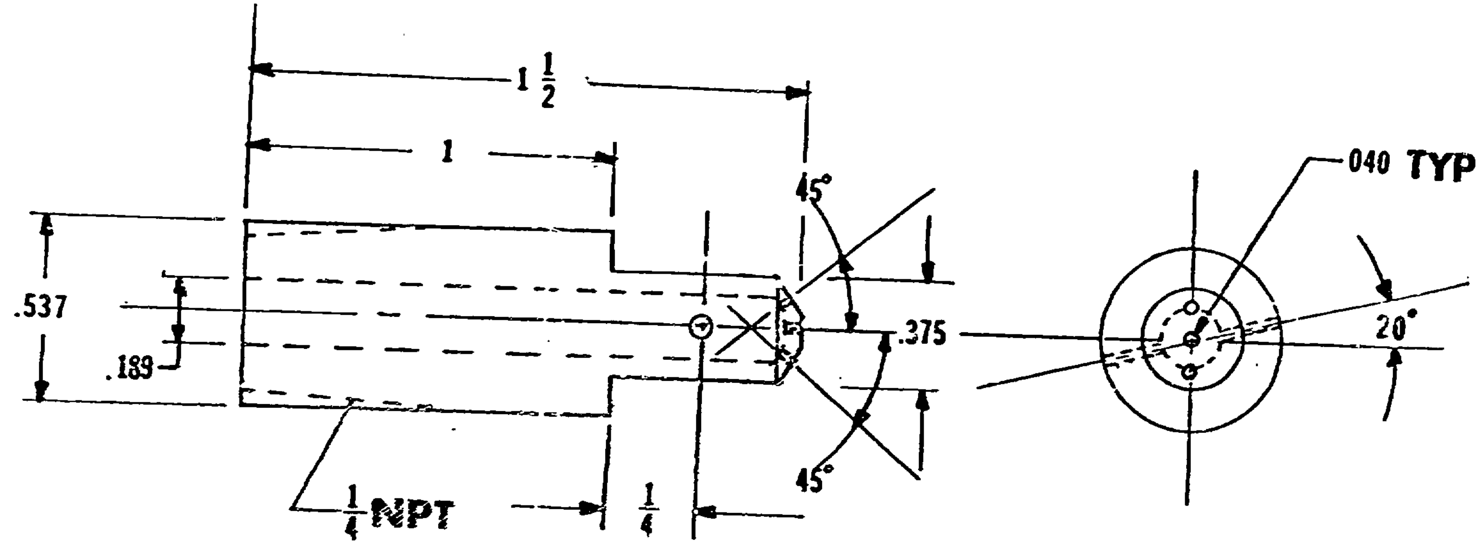
5"/ 38





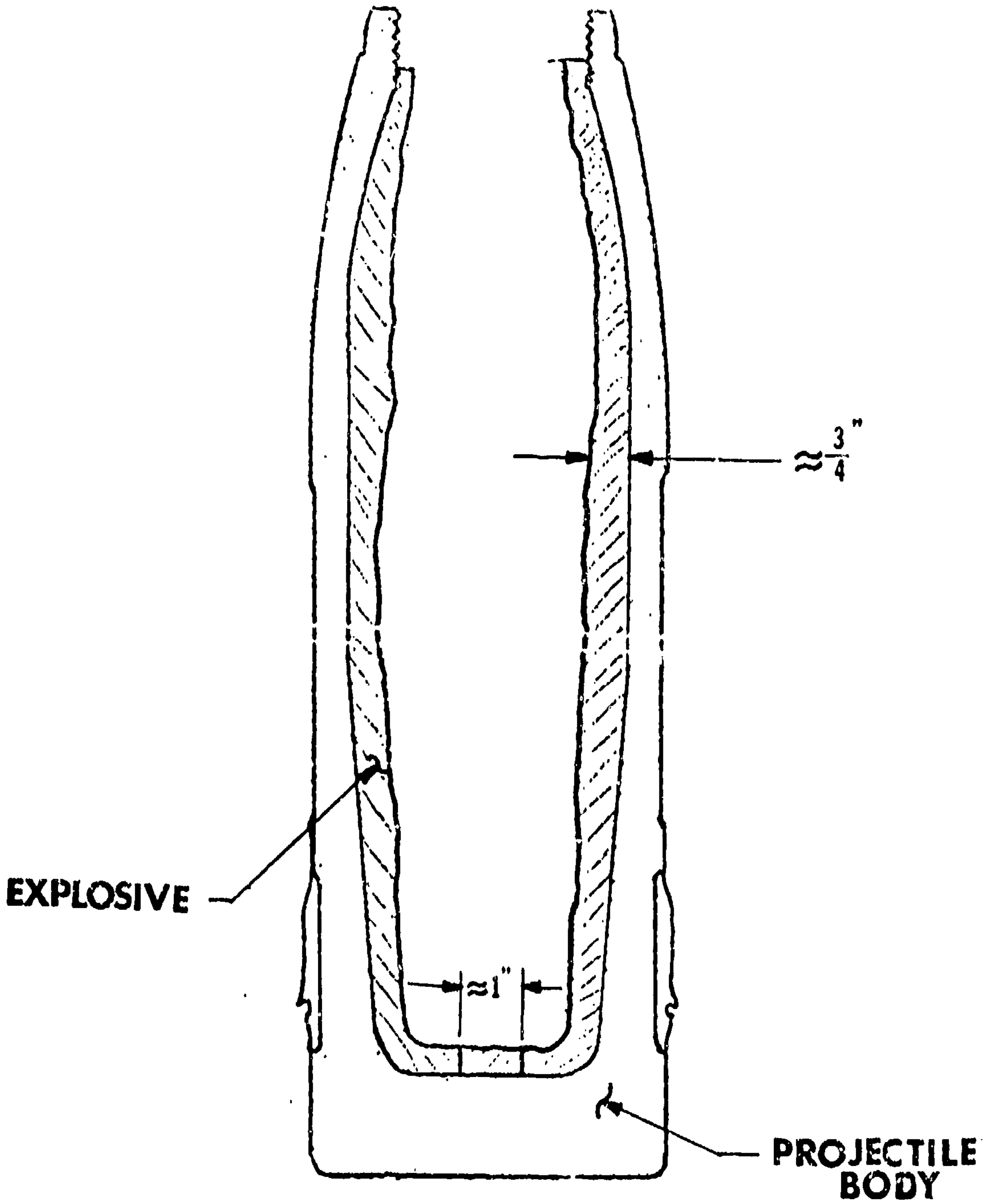


NOZZLE # 1

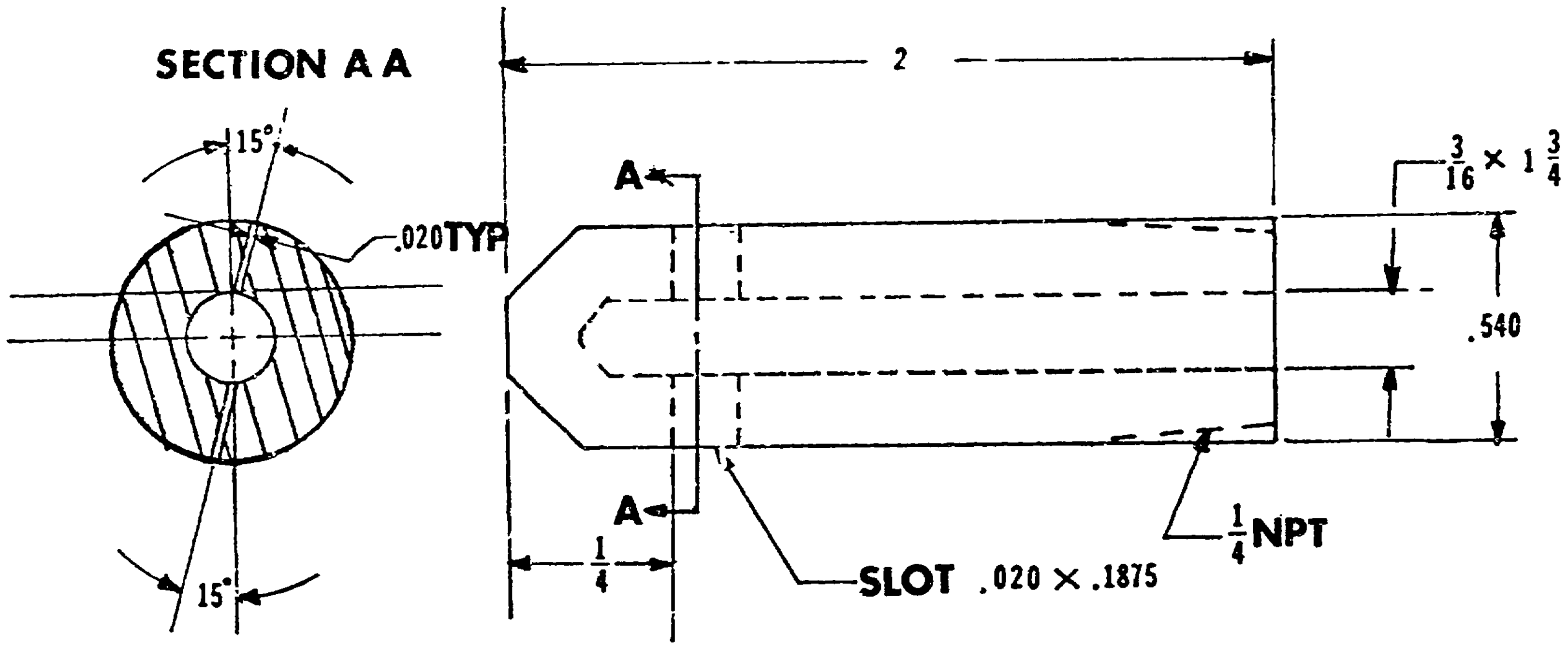


TEST VARIABLES

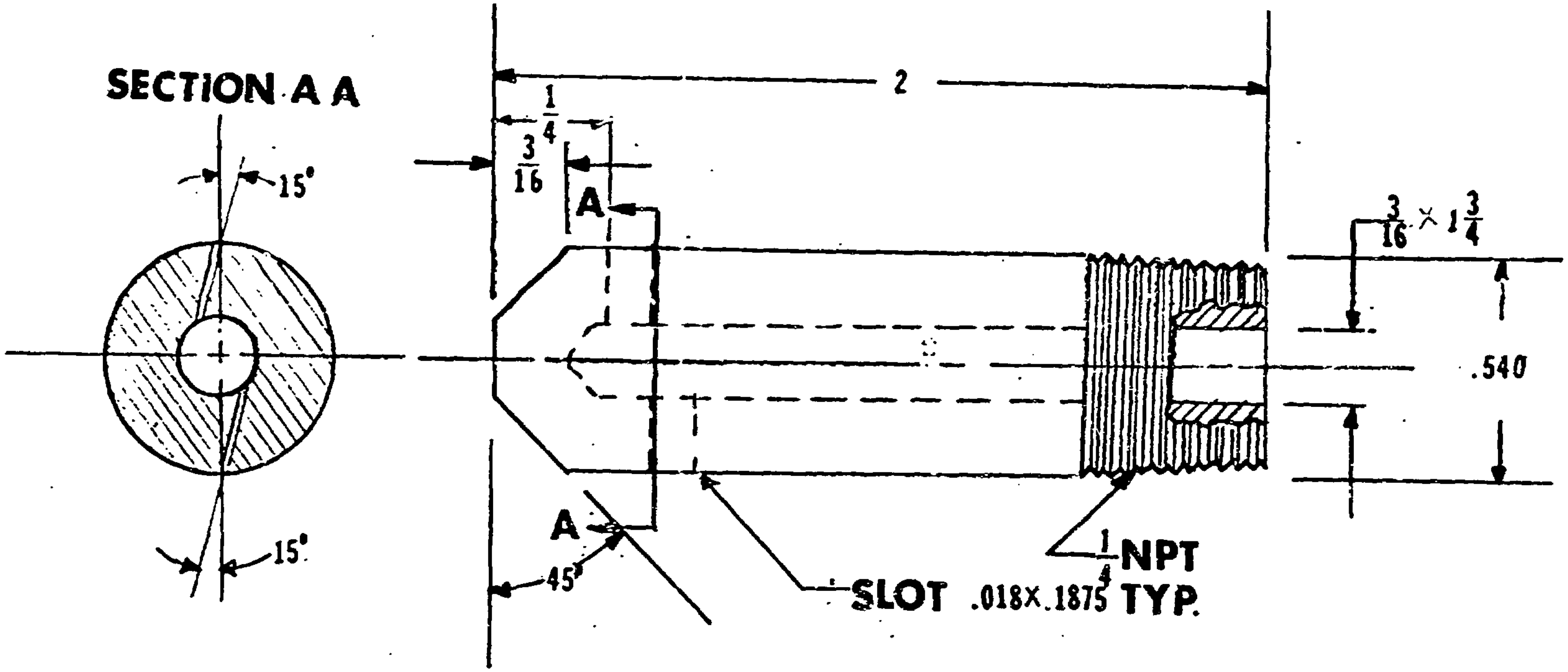
PROJECTILE SPIN RATE (rpm)	CYCLE TIME (minutes)
25	2
100	1.5
150	1
200	.75
250	.5
300	
340	


≈3/4"
EXPLOSIVE
≈1"
PROJECTILE BODY

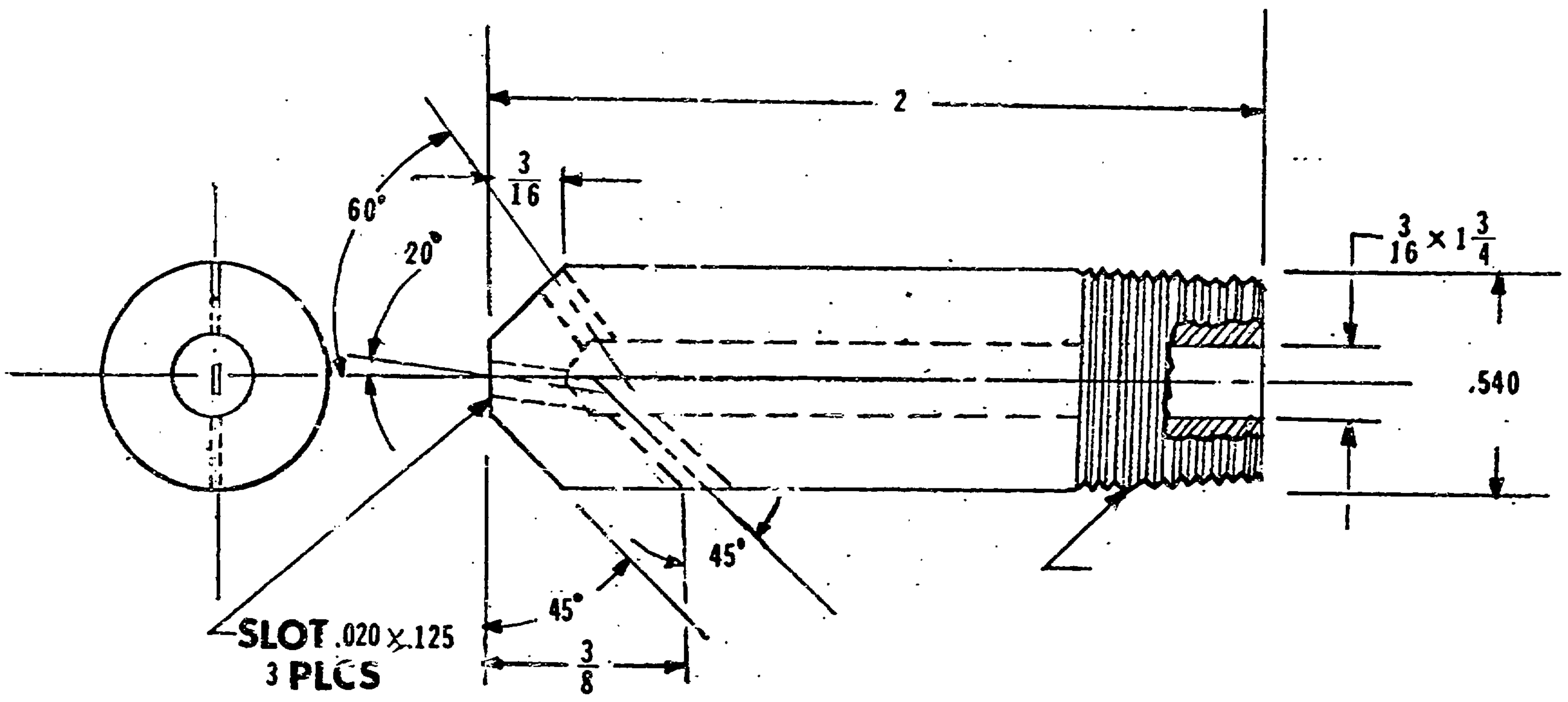
NOZZLE # 2

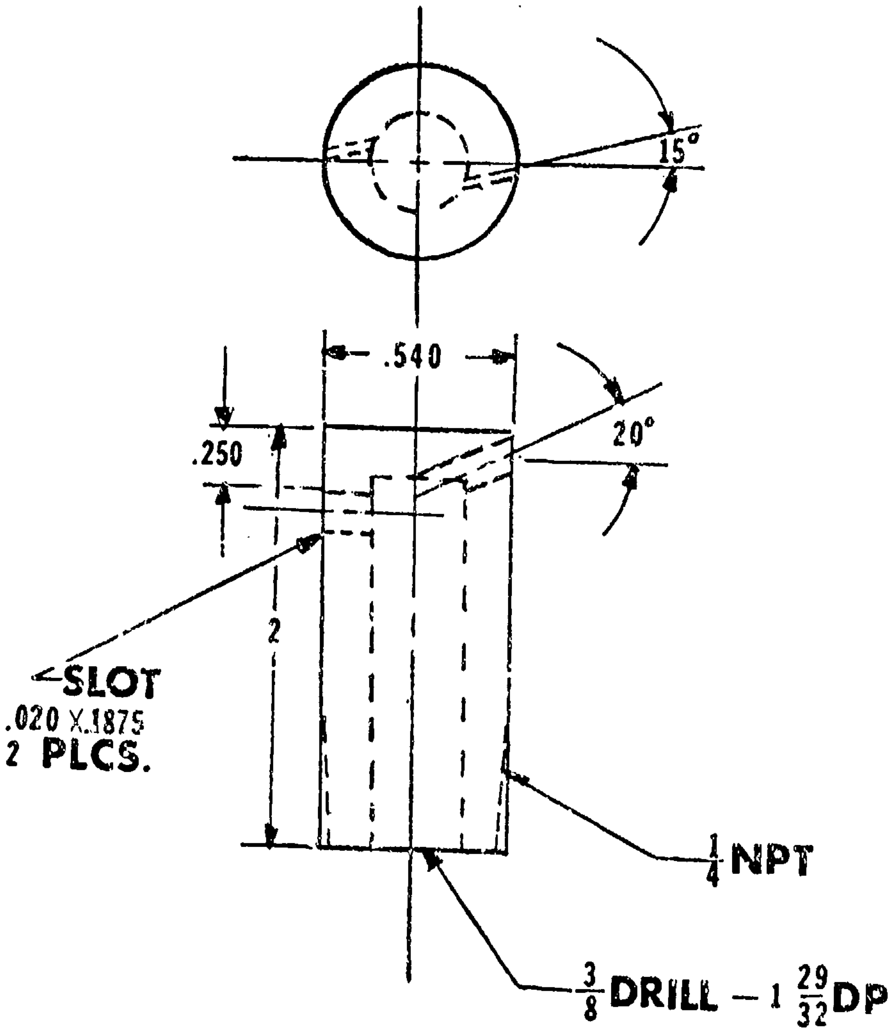

SECTION A A
15°
.020TYP
15°
2
A
A
$\frac{1}{4}$
$\frac{3}{16} \times 1\frac{3}{4}$
.540
SLOT .020 × .1875
$\frac{1}{4}$NPT

NOZZLE # 3

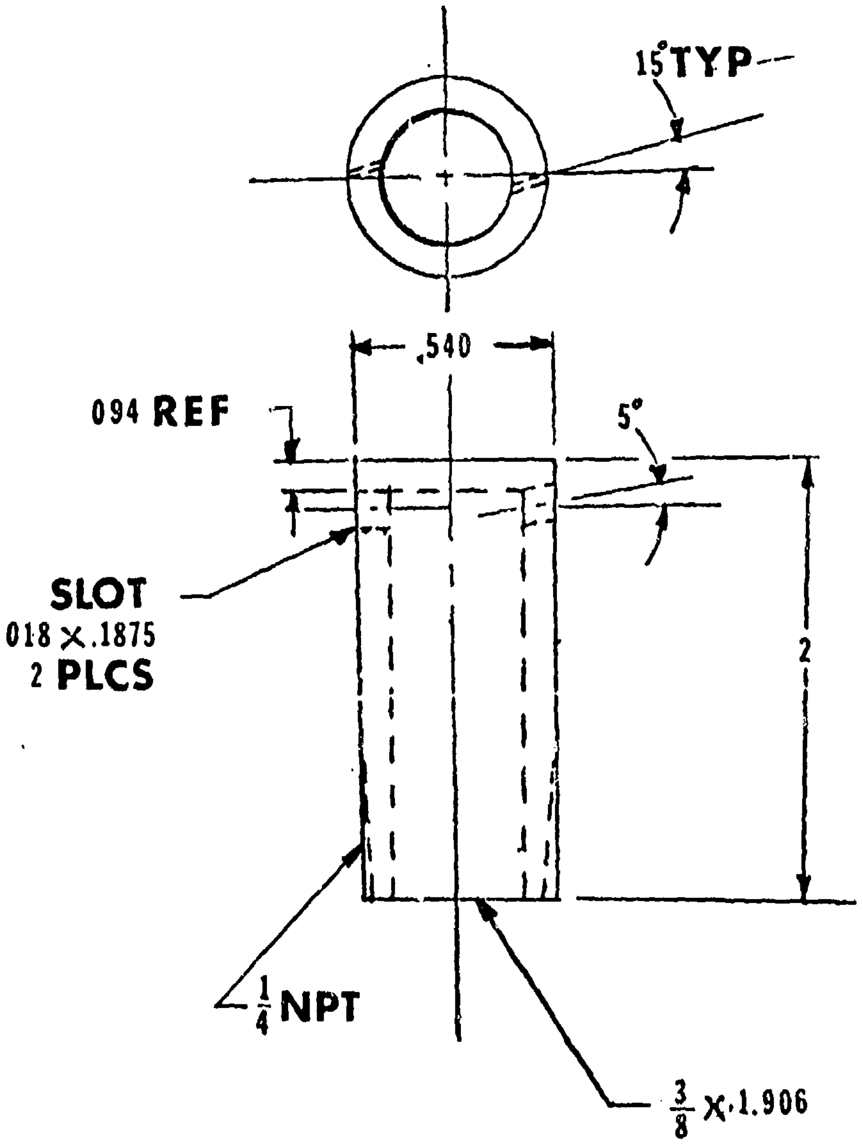

SECTION A A
15°
15°
2
1/4
3/16
A
A
45°
3/16 × 1 3/4
.540
SLOT .018X.1875
1/4 NPT
TYP.

NOZZLE # 4



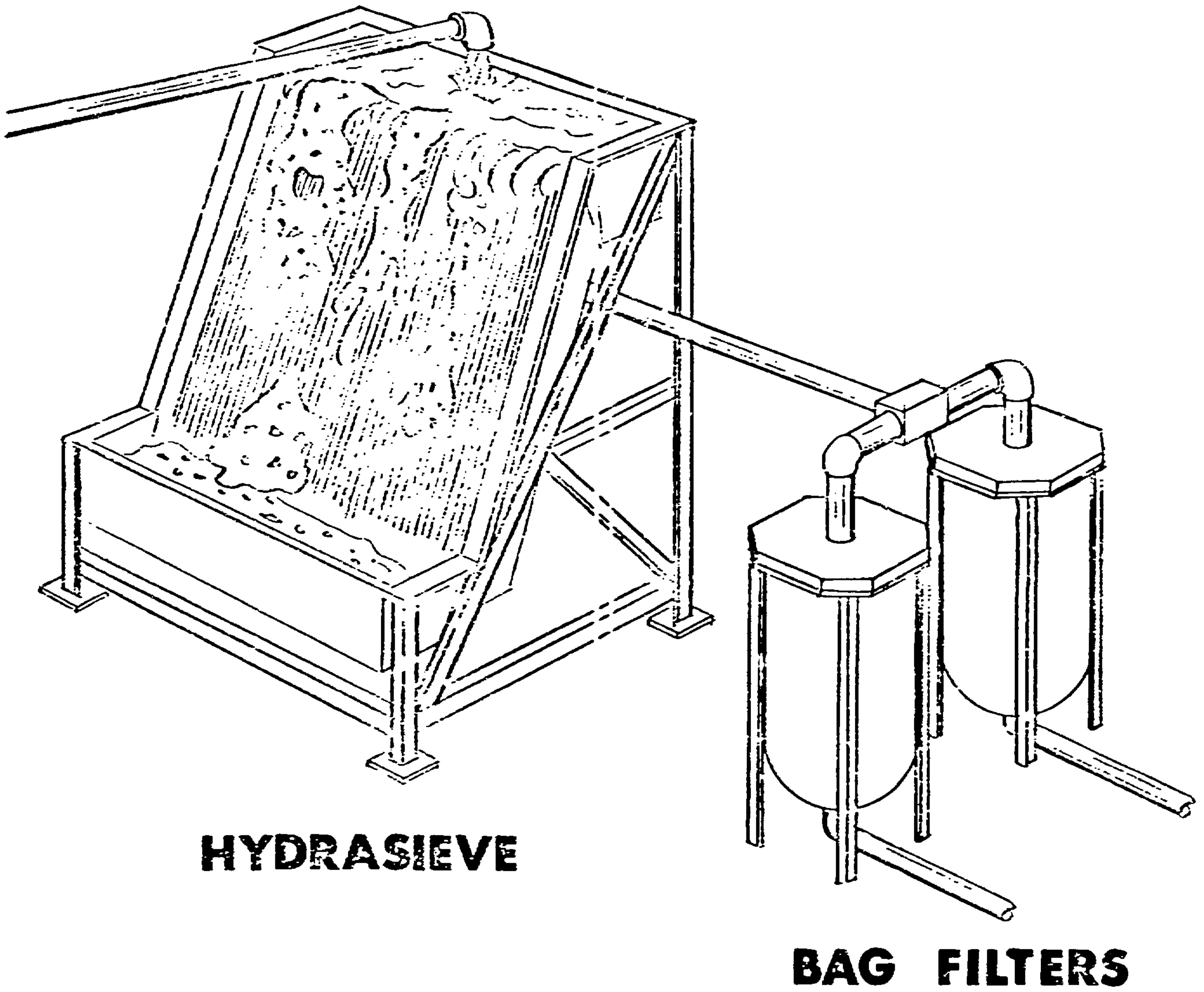

15°
.540
20°
.250
2
SLOT
.020 X.1875
2 PLCS.
$\frac{1}{4}$ NPT
$\frac{3}{8}$ DRILL – 1 $\frac{29}{32}$ DP

NOZZLE # 5



NOZZLE #6

FILTRATION SYSTEM



COMP A-3 ANALYSIS

SIEVE OPENING (mm)	% COLLECTED BY WEIGHT
4.76	64.1 %
3.36	9.1 %
2.38	7.3%
2.00	2.5%
1.68	4.2 %
collection on pan	12.8 %

EXPLOSIVE D ANALYSIS

ph	7
TOTAL DISSOLVED SOLIDS	1.56
DISSOLVED EXPLOSIVE 'D'	1.39
TOTAL SUSPENDED SOLIDS	.87

NOTE: REMAINING EXPLOSIVE 'D' SETTLED OUT

BEHAVIOUR OF NITROESTERS IN ACID SOLUTIONS

Camera E. ; Zotti B.
Dr.Ing. M. Biazzi S.A. - Vevey, Switzerland

Part of this work has been the object of Dr. B. Zotti's Thesis at the University of Padua, Italy; Supervisor Prof. G. Modena.

This study concerning the stability of Nitric esters is still at its early beginning and therefore it is not yet possible to reach a final conclusion, and it is presented here as a short paper.
However, we believe that once completed, it could be of significant importance for the increase of safety in the manufacture and storage of nitric esters.

- As it is well known,spent acids are obtained as by-products in the industrial production of nitric esters. They accumulate in large amounts and constitute a potential danger, because they may give rise to explosive reactions.
In spite of the fact that the spent acids are stored under the best conditions and with the optimal composition proposed to minimize the hazard of violent decompositions (1; 2;), now and then some reactions of this kind still occur. As the chemical reactions on which said explosive phenomena are based are not known with certainty and as this matter is of a great importance as far as safety is concerned, it was decided to reconsider the problem and to begin a complete study of the system, hoping to single out the chemical processes responsible of the explosive reactions and then to tackle in a more scientific way the problem of the control of said reactions.

In the system object of this study, i.e. in the acid solutions of nitric esters, many reactions may occur, among which one was repeatedly expressed (3; 4; 5;) and is certainly present : the hydrolysis of nitric esters.

As a matter of fact, the explosive behaviour might originate from :

a. an acceleration - perhaps, an autocatalytic one - of the hydrolysis ;
b. reactions characterized by the participation of hydrolysis products ;
c. reactions completely independent of hydrolysis.

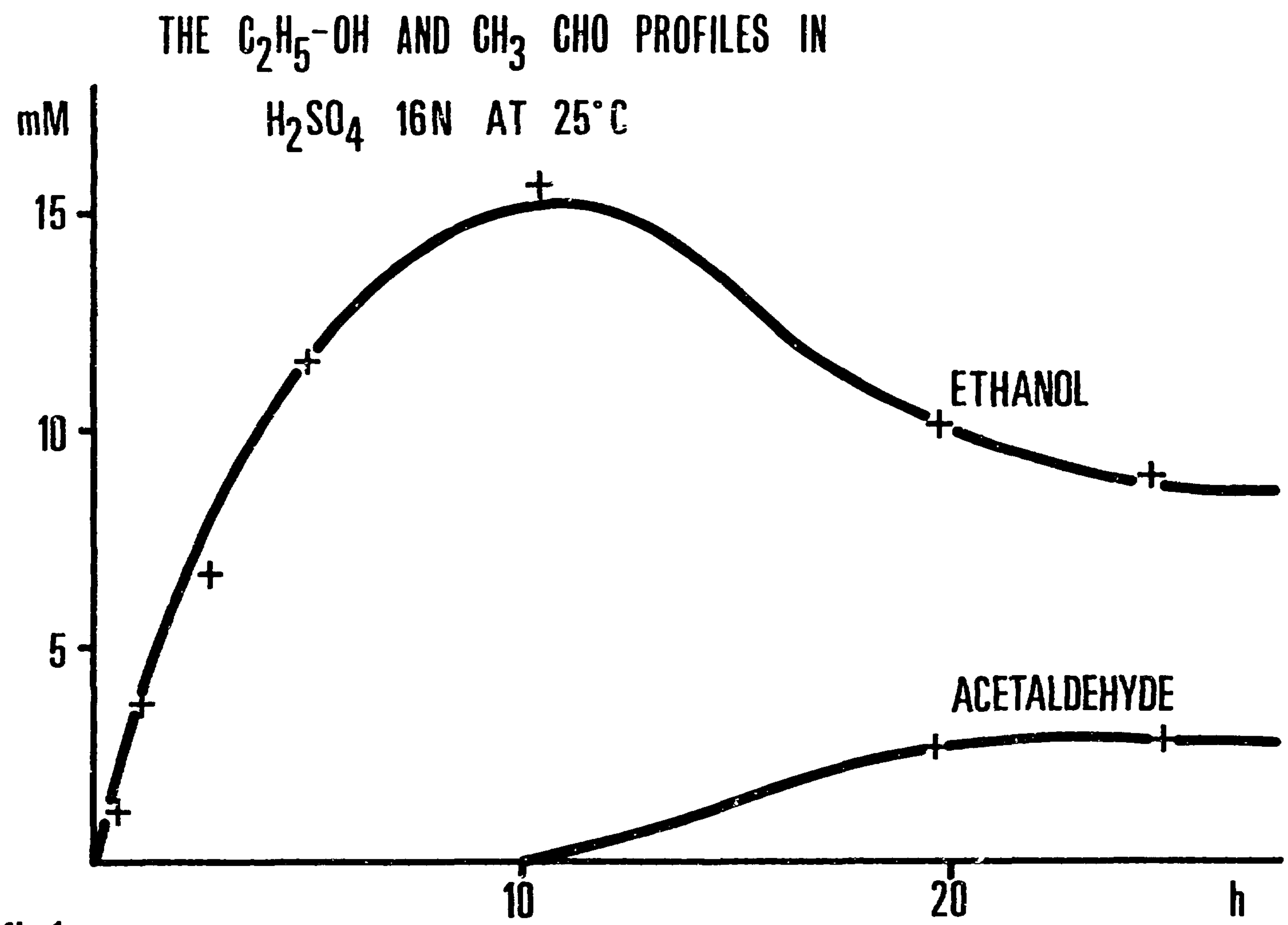
It was considered advisable to begin this study with a detailed examination of the kinetic characteristics of acid hydrolysis and to select ethyl nitrate for its simplicity in constitution. In fact, the use of more complex nitric esters, for instance glycerol trinitrate and pentaerythritol tetranitrate would have caused considerable difficulties.

The hydrolysis of the ethyl nitrate has been studied in aqueous sulfuric acid solution from 10N (38%) to 24N (72%) at 25°C.

The reaction rates have been evaluated by the disappearance of the starting material, with the aid of a gaschromatographic technique.Among the hydrolysis products,we detected ethanol, acetic aldehyde, nitric acid and carbon dioxide. Nitrous acid is also formed. However, whereas ethanol seems to be a primary product, acetic aldehyde appears in the gaschromatogram only after some progress of the reaction. Moreover, the ethanol concentration, after an initial rapid increase, reaches a maximum value and decreases at a later stage (see Fig.1).

Independent experiments showed that nitric acid in the reaction conditions oxidizes ethanol to acetic aldehyde with production of nitrous gases.

On the other hand, ethanol is not esterified by sulphuric acid to any significant extent, even at higher concentrations of sulphuric acid.



THE C_2H_5-OH AND CH_3 CHO PROFILES IN H_2SO_4 16N AT 25°C

fig.1

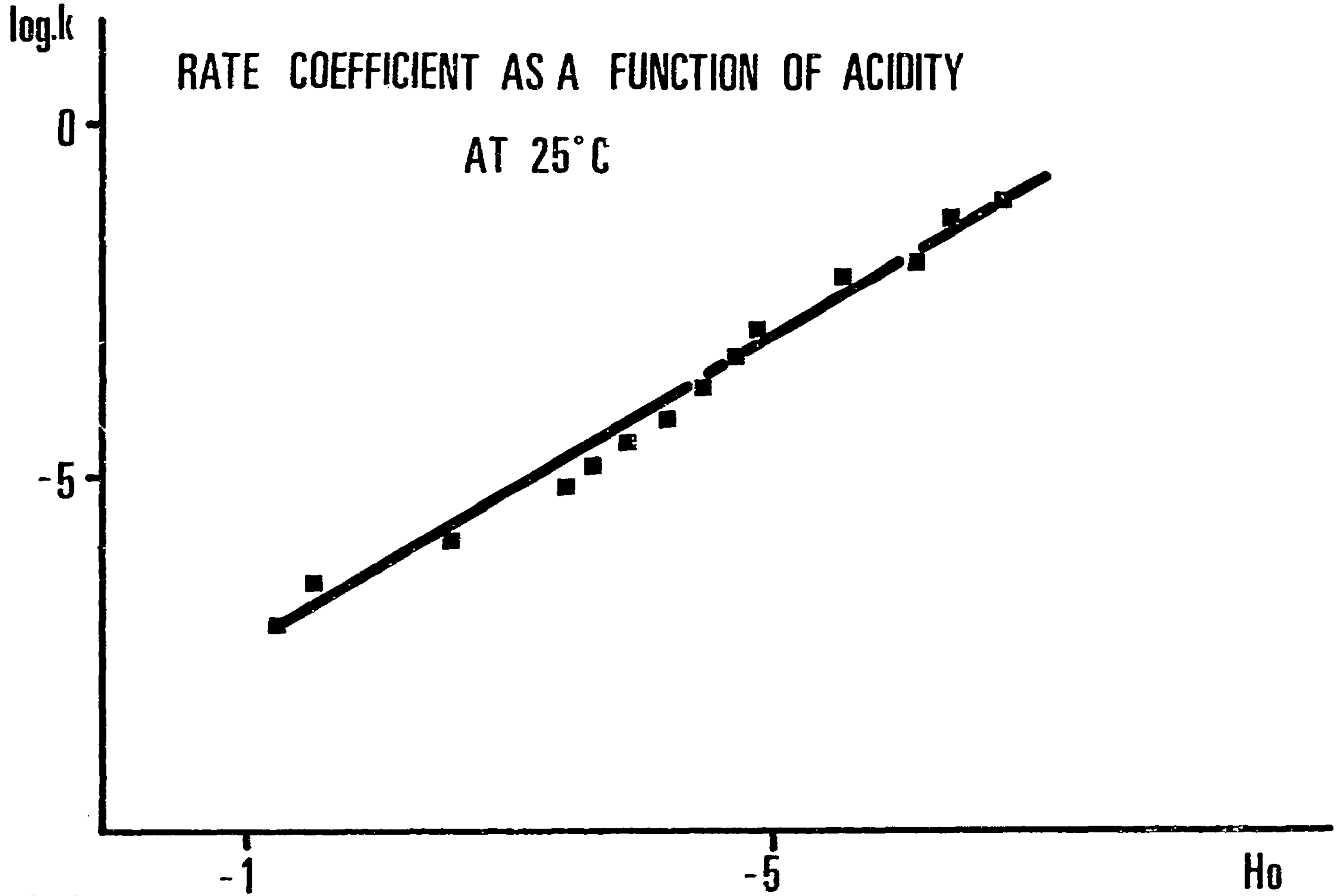

log.k
RATE COEFFICIENT AS A FUNCTION OF ACIDITY
AT 25°C
0
-5
-1
-5
Ho

fig.2

The rate of hydrolysis regularly follows a first order kinetic equation in all the range of concentrations investigated, and the rate coefficent continuously increases with acid concentration, as shown in Fig. 2.

Addition of sodium nitrite, or urea to destroy the nitrous acid spontaneously formed, does not affect the reaction rate. The overall results indicate that the hydrolysis of ethyl.nitrate (and perhaps of more complex nitric esters, too) is a simple catalized reaction giving ethanol and nitric acid.

These two primary products then react to give acetic aldehyde and nitrous acid. Further oxidative degradation of acetic aldehyde is expected to occur as well.

The above results also suggest that the hydrolysis of nitric esters at appropriate acid concentrations may be a very fast reaction, but by itself cannot be responsible of explosive reactions.
On the other hand, the rapid oxidation in these acid solutions of ethanol by nitric acid, let suggest that this is the starting point of the explosive reaction.

We hope that the studies now in progress will shed more light on this problem.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. M. Biazzi and Mr. Dal Dan for their encouragement in the execution of this work.

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ON-LINE CONTINUOUS INSPECTION OF LINKED AMMUNITION

by

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1. INTRODUCTION

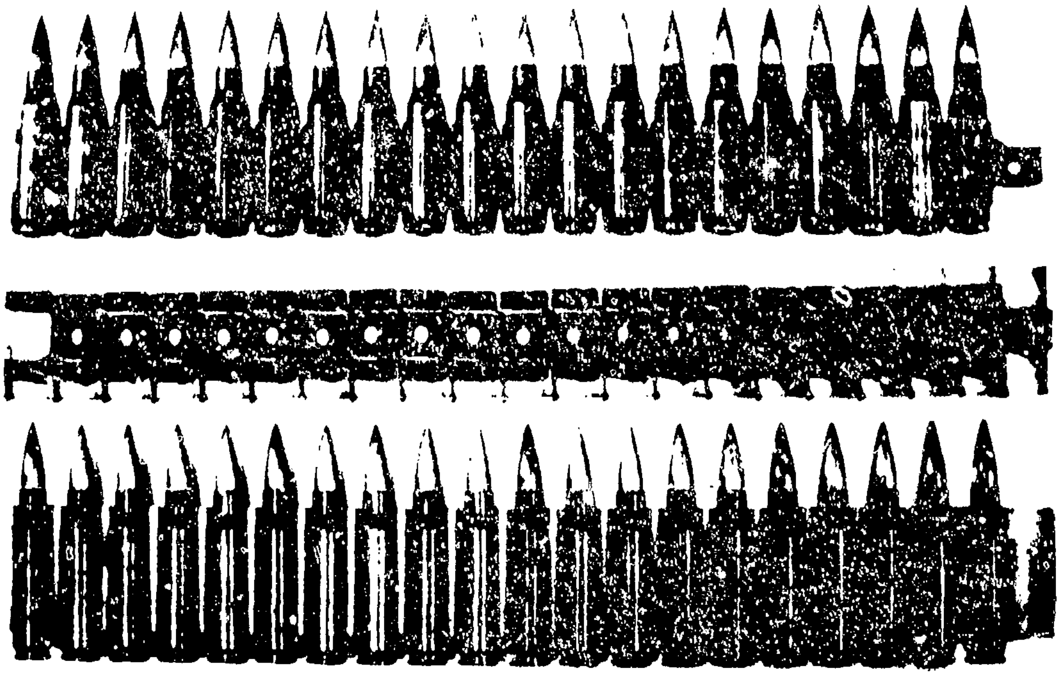
Under the SCAMP, Frankford Arsenal has sponsored two programs to develop automated linking, inspection, and packaging submodule systems for 7.62mm and 20mm small arms linked ammunition. Within each submodule are incorporated automatic on-line continuous inspection operations for procured metallic links prior to assembly with cartridges, and the completed linked belts subsequent to assembly.

2. 7.62MM M13 LINK INSPECTION

M13 links as illustrated in Exhibit I, are received from various vendors in a bulk configuration and are introduced to the Link, Feed, Orient and Inspect Subsystem by dumping fiber drum quantities into the receiving hopper. The links are subsequently distributed to eight (8) vibratory bowl feeders for orientation and feeding as illustrated in Exhibit II. Approximately sixty (60) links are stored on the output chutes of each bowl for release and merging onto one (1) of two (2) inspection conveyors. The inspection conveyors consist of a series of individual pockets into which the links are registered for inspection, as illustrated in Exhibit II. The conveyors pass each link before a diode array camera which optically measures the inside diameters of the single and double loops. This is to assure the link will not jam subsequent processing equipment. Subsequent to the dimension inspection, the link is passed beneath an eddy current probe which senses the link hardness. The hardness inspection insures belt integrity after assembly where it is subjected to a twenty-five pount tension test. Should a link fail either the dimension or hardness inspections, an air jet dislodges the link from its carrier and ejects it to a reject bin, making available only acceptable links for further processing. This inspection process operates at a rate of 1200 acceptable links per minute, using a design rate of 1500 links per minute.

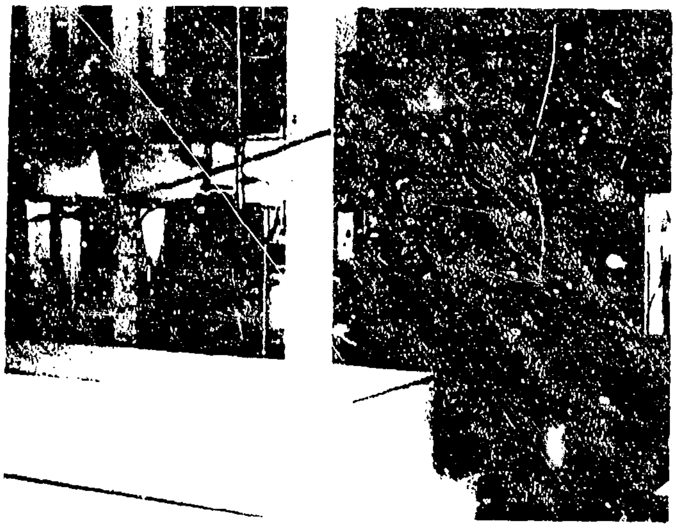
EXHIBIT I
7.62MM LINKED AMMUNITION

M13 Metallic Link

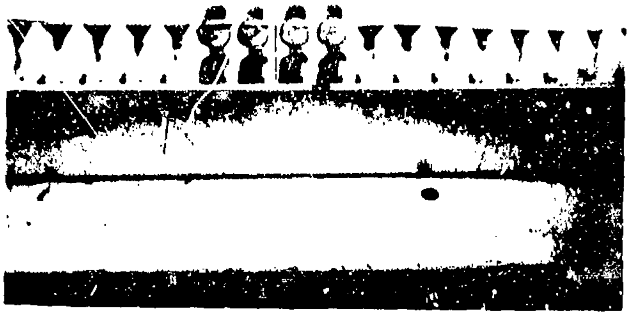


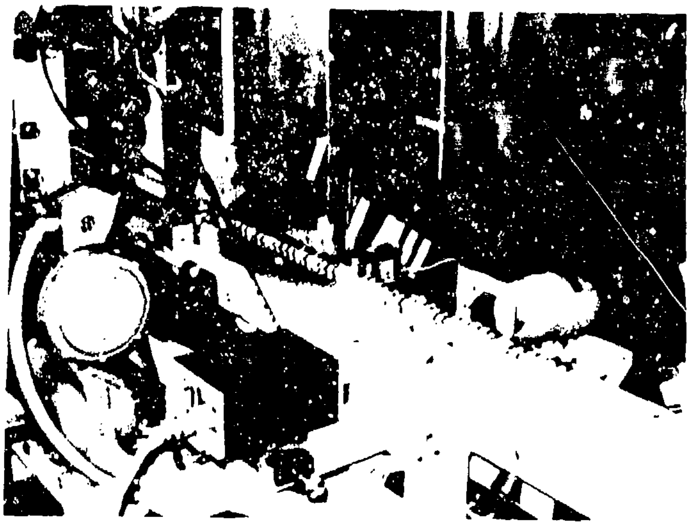
7.62MM Linking Process

EXHIBIT II
LINK FEED, ORIENT AND INSPECT SUBSYSTEM


Receiving Hopper and Vibratory Bowl Feeders

M13 Links on Inspection Conveyor




Inspection Section

3. 7.62MM LINKED BELT INSPECTION

Subsequent to linked belt assembly, the assembled belt is subjected to an inspection process to assure conformance to the criteria set forth in MIL STD 644A. These include:

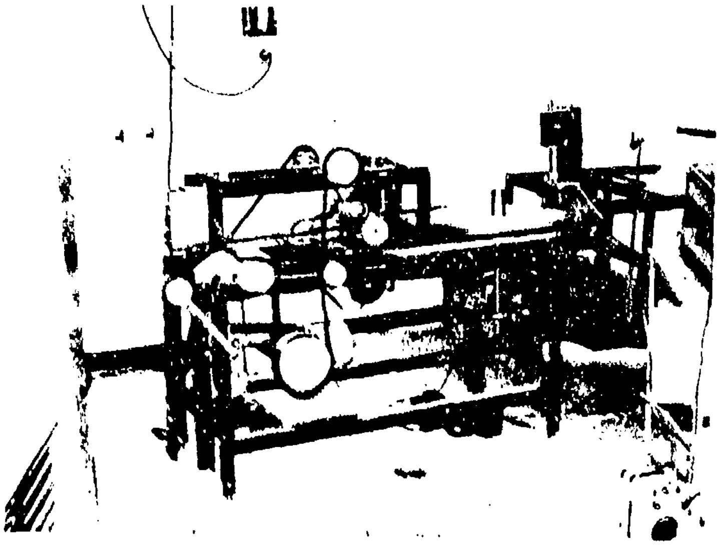
- Proper Assembly -- Full engagement of the link tab with the cartridge extractor groove.
- Tensile Strength -- Withstand a tensile load of twenty-five pounds to insure belt integrity.
- Stretched Link -- Soft links which stretched during the tensile test.
- Frozen Links -- Links whose single loops are insufficient in diameter preventing the assembled belt from hinging freely.

A test stand, as illustrated in Exhibit III, was constructed to demonstrate the feasibility of performing these inspections on a continuous basis at a rate 1200 cartridges per minute.

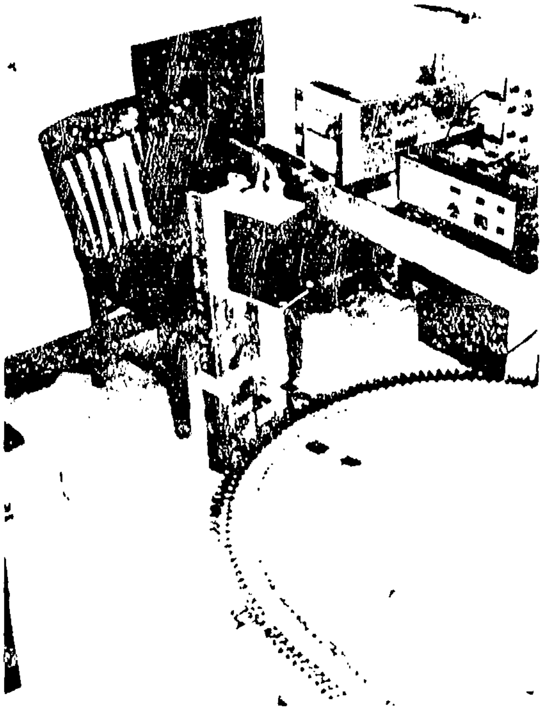
(1) Tensile Test

The tensile test is performed by the employment of a dancer roll acting on the looped belt. The roll subjects a static twenty-five pound load on the belt loop effecting the tension test requirement.

EXHIBIT III
7.62MM LINKED BELT INSPECTION
DEMONSTRATION APPARATUS



Dancer Wheel Tension Test Station



Fanning Disc Cartridge Pitch Inspection For
Stretched and Frozen Links

(2) Proper Assembly

An optical diode array scan and proximity sensor are employed to assure the link tab is fully engaged with the cartridge extractor groove.

(3) Stretched and Frozen Links

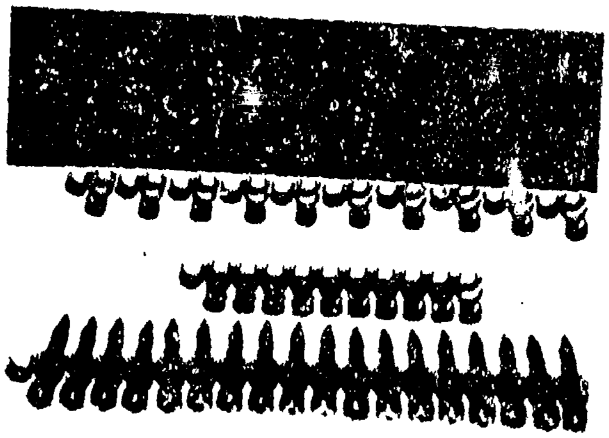
An additional diode array camera is employed to measure the pitch between cartridges as they are fanned around a disc. Excessive pitch indicates a stretched link and insufficient pitch indicates a frozen link.

Cartridge-to-link assemblies which do not meet the inspection criteria are marked with a spray gun and a signal is transmitted to the subsequent belt folding and separating operations where they are separated into either 100- or 750- round lengths and folded for subsequent packaging. Should a separated discrete belt length contain a faulty cartridge-to-link assembly, the belt is rejected for rework. The spray mark aids in identifying the location of the faulty link during the rework operation.

4. 20MM M14 LINK INSPECTION

The 20MM M14 metallic links, illustrated in Exhibit IV, are received assembled in strips of ten (10). As with the M13 links, the

EXHIBIT IV
20MM M14 METALLIC LINKS



Back Row - 10 individual M 14 links
Middle Row - 10 M14 links assembled in strip
Front Row - M14 links with cartridges inserted

M14 links shall be inspected for inside diameter and hardness. Rather than disassemble the strips of ten (10) and inspecting the individual links, the selected approach entails inspecting the ten (10) links as a unit. A go/no-go contact approach has been selected to assure the proper inside dimention of the links by sliding the strip of ten (10) down ten (10) contoured parallel rails. The strip of ten (10) is subsequently stretched with a specified tensile load to assure hardness. Should the strip yield under tension, the strip is rejected and the soft link is reworked. Likewise, should the strip not pass over the contoured go/no-go gauge rails, the strip is rejected as out of dimension, for subsequent rework. The acceptable strips of ten (10) links are subsequently automatically linked into a continuous belt and led to the linking subsystem where the cartridges are inserted. The nominal processing rate is 600 acceptable links per minute, using a design rate of 750 links per minute.

5. 20MM LINKED BELT INSPECTION

Subsequent to cartridge insertion, the 20mm assembled belt is subjected to an inspection process to assure conformance to the criteria set forth in MIL STD 644A. These include;

> Proper Cartridge Insertion -- Full engagement and proper registration of the cartridge with the links.

- Tension Test -- Withstand a tensile load of forty pounds without yielding the links.
- Flex Tests -- Flex the belt in both directions to assure a free hinge.
- Twist Test -- Twist the belt 180 degrees to assure torsional flexibility.
- Intermix Ratio Verification -- Assure the proper ratio and distribution of HE and HEI cartridges.

The selected approach is illustrated in Exhibit V and similar in design to the system currently employed at the Lake City AAP which operates at a peak of about 150 cartridges per minute. The newly designed inspection subsystem shall operate at a peak of 750 per minute.

(1) Proper Assembly

The cartridge insertion inspection is accomplished through the employment of two (2) mechanisms:

- Full Engagement -- Full engagement of the cartridge with the link is determined by gauging the overall thickness of the belt using a skid shoe and switch arrangement as illustrated in Exhibit VI.
- Proper Registration -- Proper registration of the cartridge extractor groove with the link tabs is ascertained with a photocell arrangement as illustrated in Exhibit VII.

EXHIBIT V
20MM LINKED BELT INSPECTION SUBSYSTEM SELECTED DESIGN

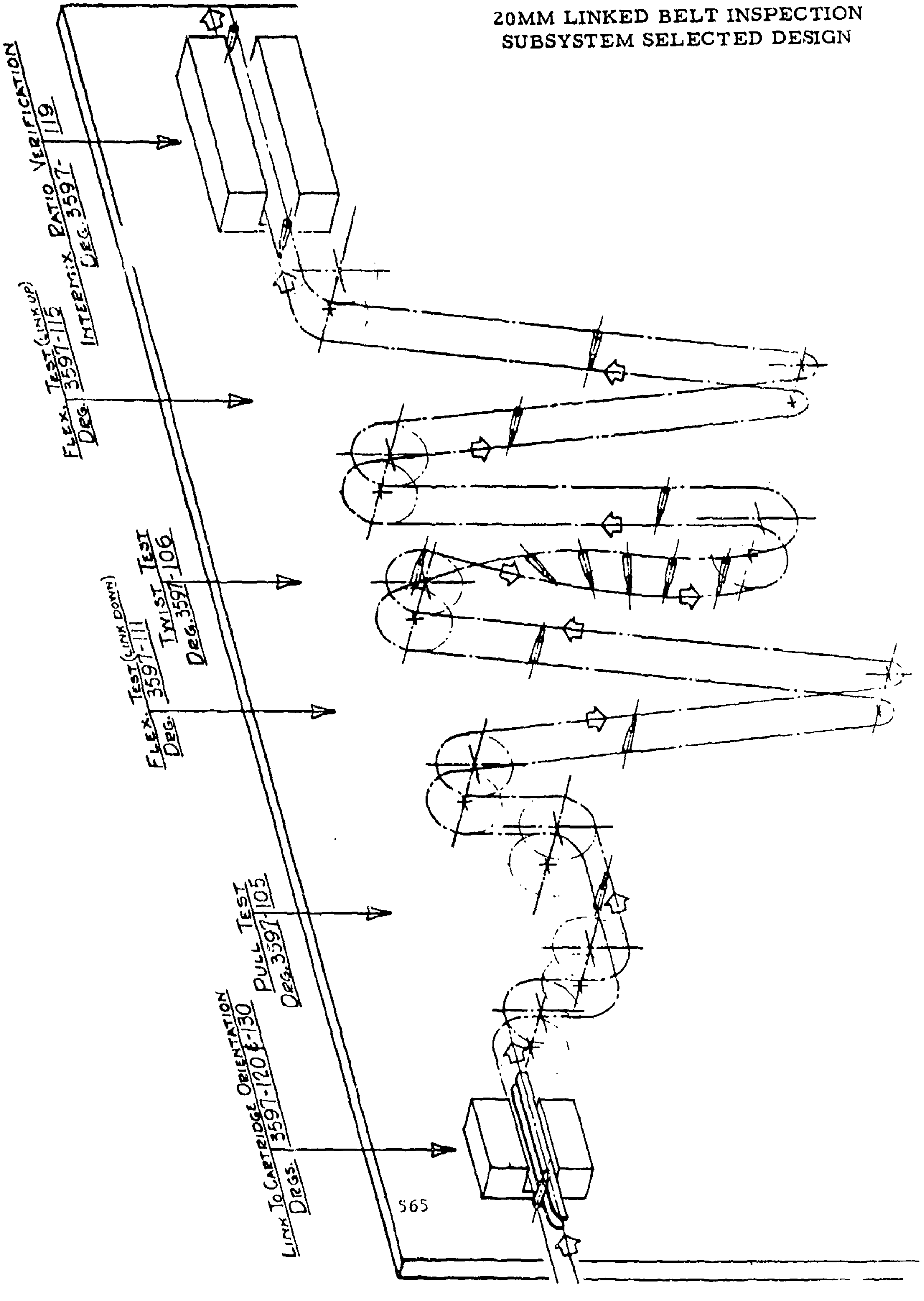


EXHIBIT VI
LINK-TO-CARTRIDGE FULL
ENGAGEMENT INSPECTION

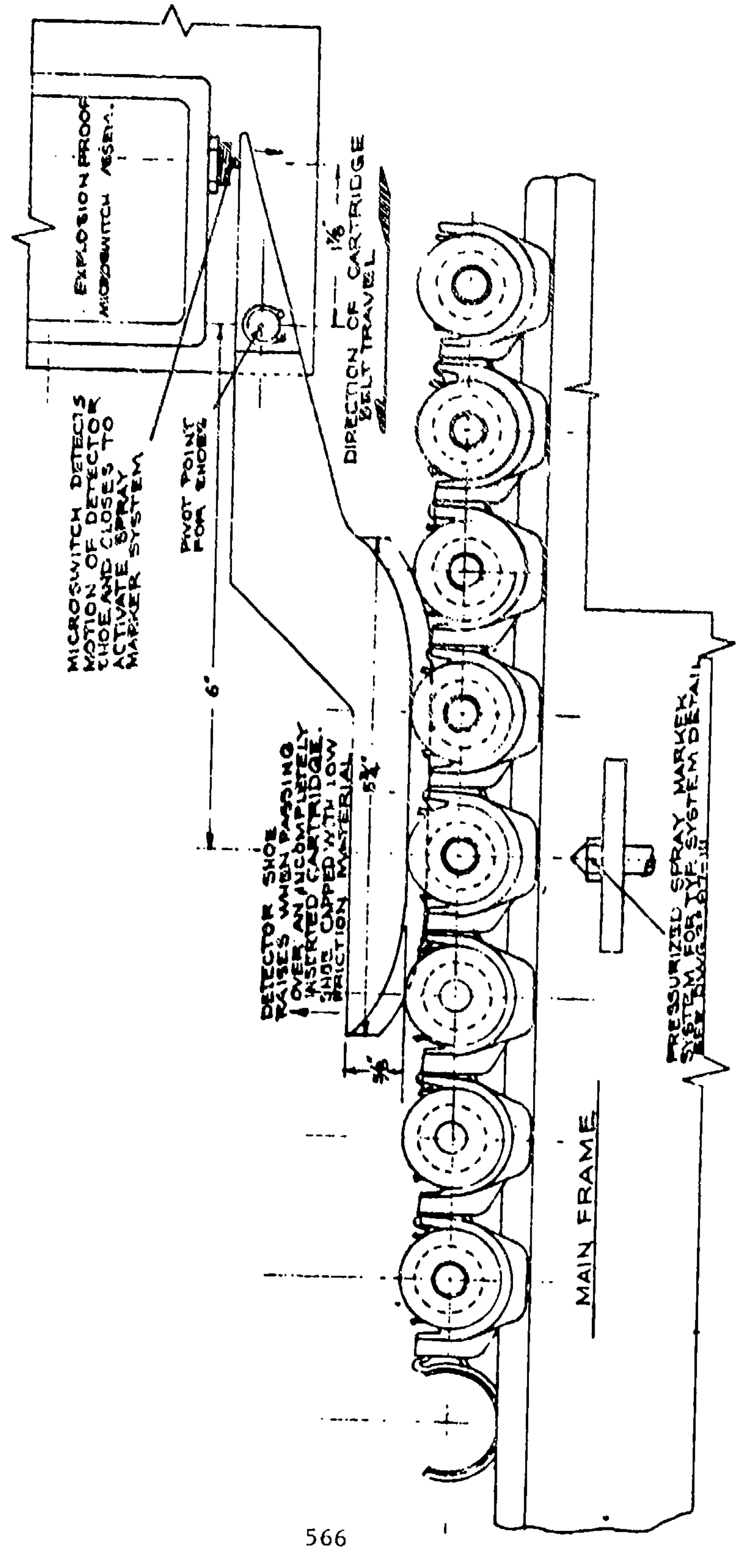
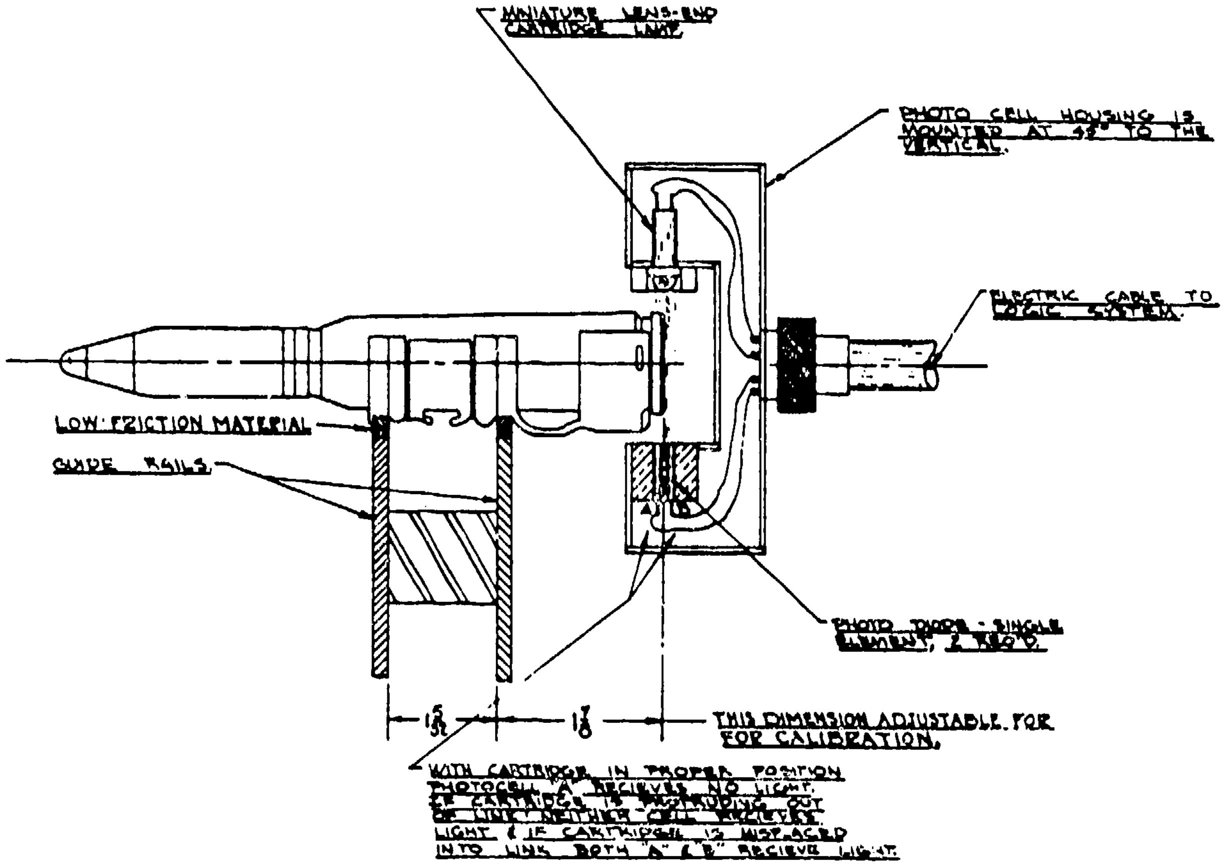


EXHIBIT VII
LINK-TO-CARTRIDGE REGISTRATION INSPECTION



(2) Tension Test

The forty pound tension test is accomplished by passing the belt over two sprockets as illustrated in Exhibit VIII. The first is run at a constant speed and the second at a constant torque, thus applying a tensile load across the section of belt spanning the two. Should a link yield, two shaft encoders sense the change in phase between the two sprockets signaling a faulty or soft link. It is assumed that a link shall yield as it comes off the first sprocket and is initially subjected to the tensile load. This permits marking the faulty link location with a spray device.

(3) Flex Tests

The flex tests are accomplished by bottom looping the belt, flexing the belt 180 degrees in each direction as illustrated in Exhibit IX. Should the link not hinge freely, it shall bridge the bottom of the loop and actuate a detector switch.

(4) Twist Test

The twist test is accomplished by twisting the belt 180 degrees over a length of twenty inches as

EXHIBIT VIII
LINKED BELT TENSION TEST

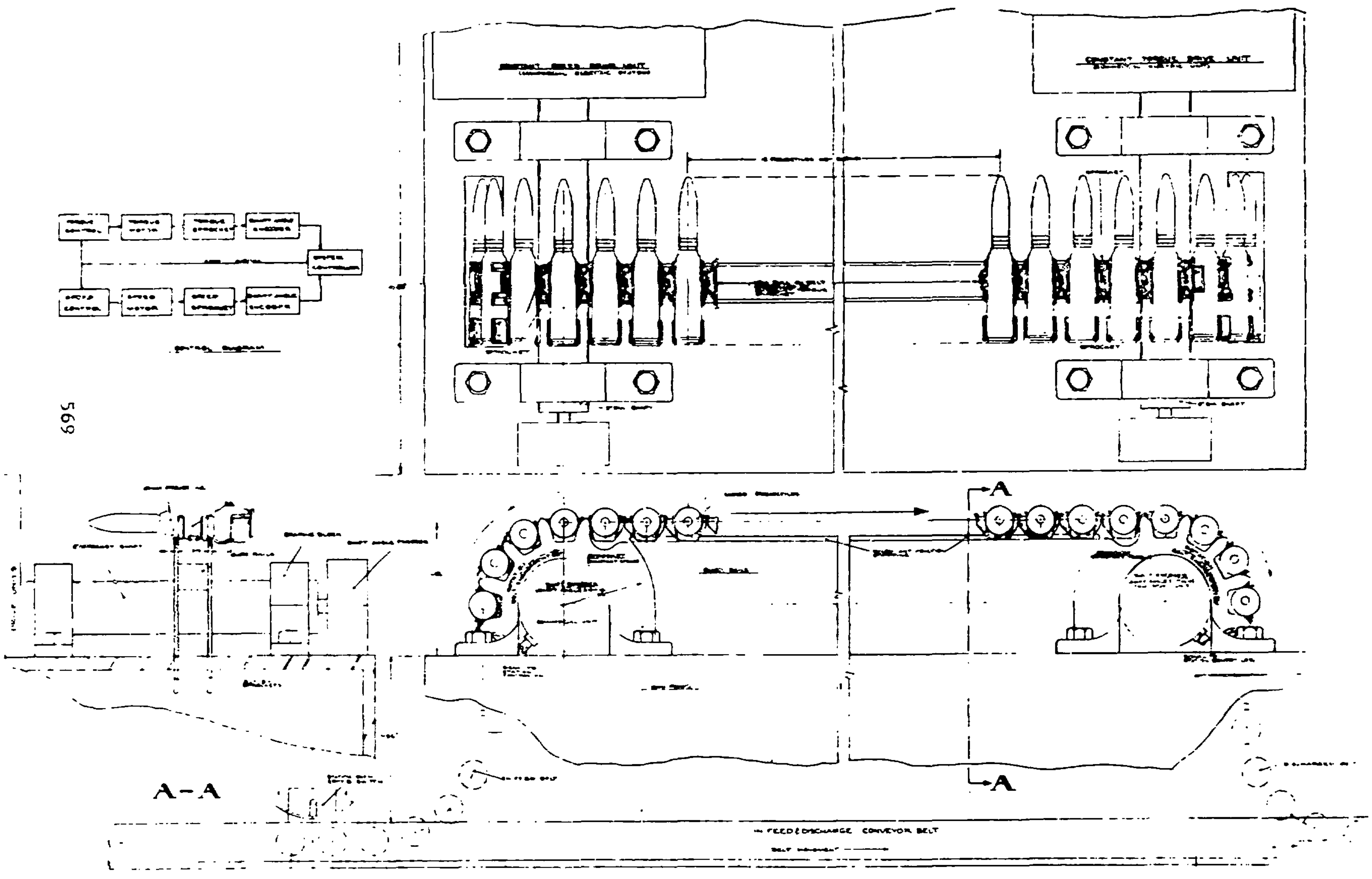
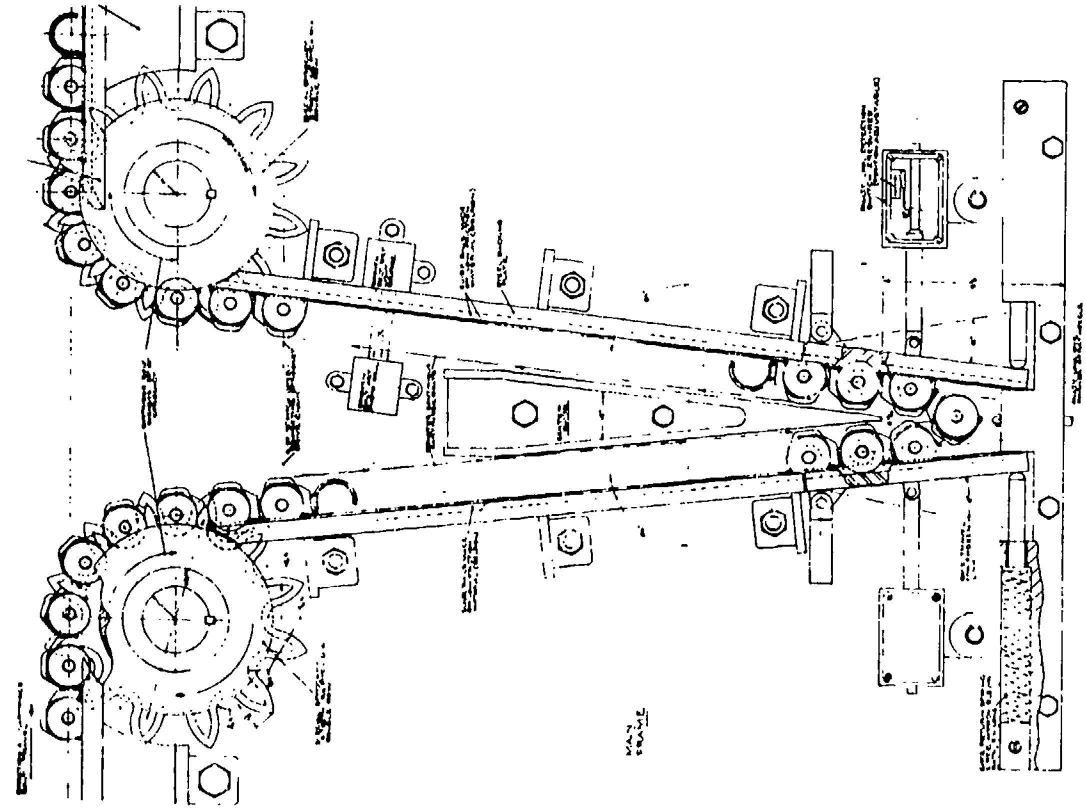
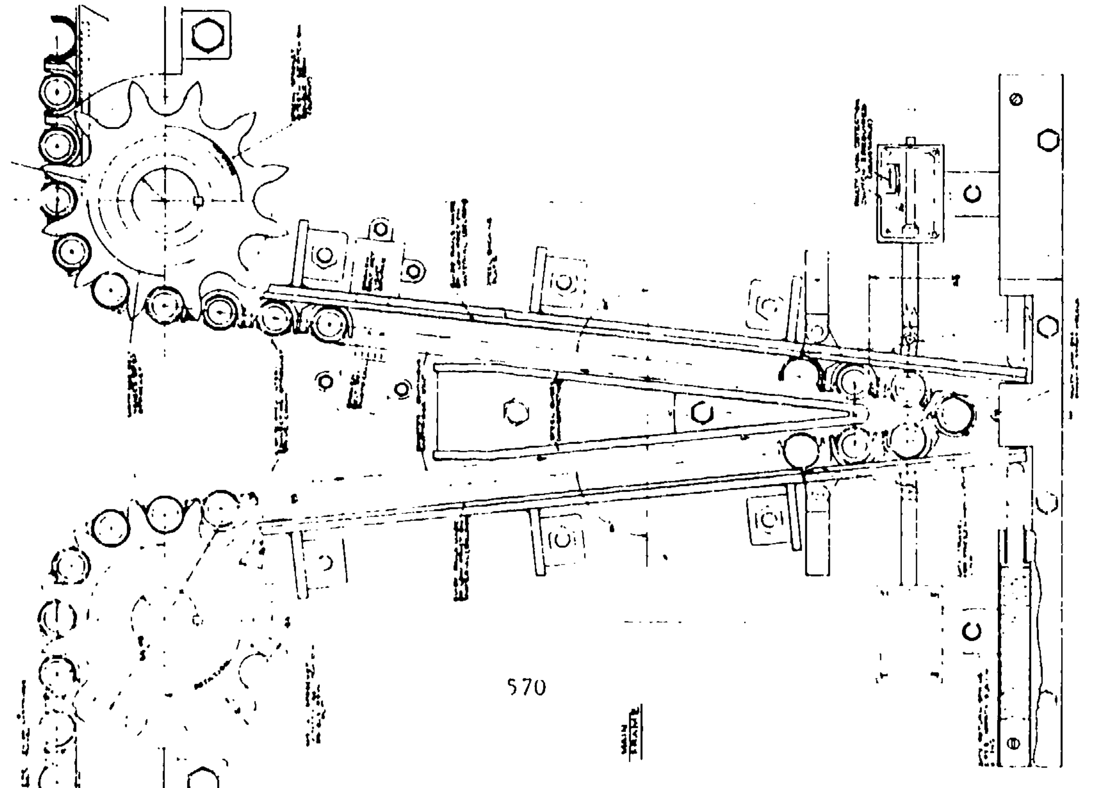


EXHIBIT IX
FLEX TESTS



Flex Test in Closed Link Direction

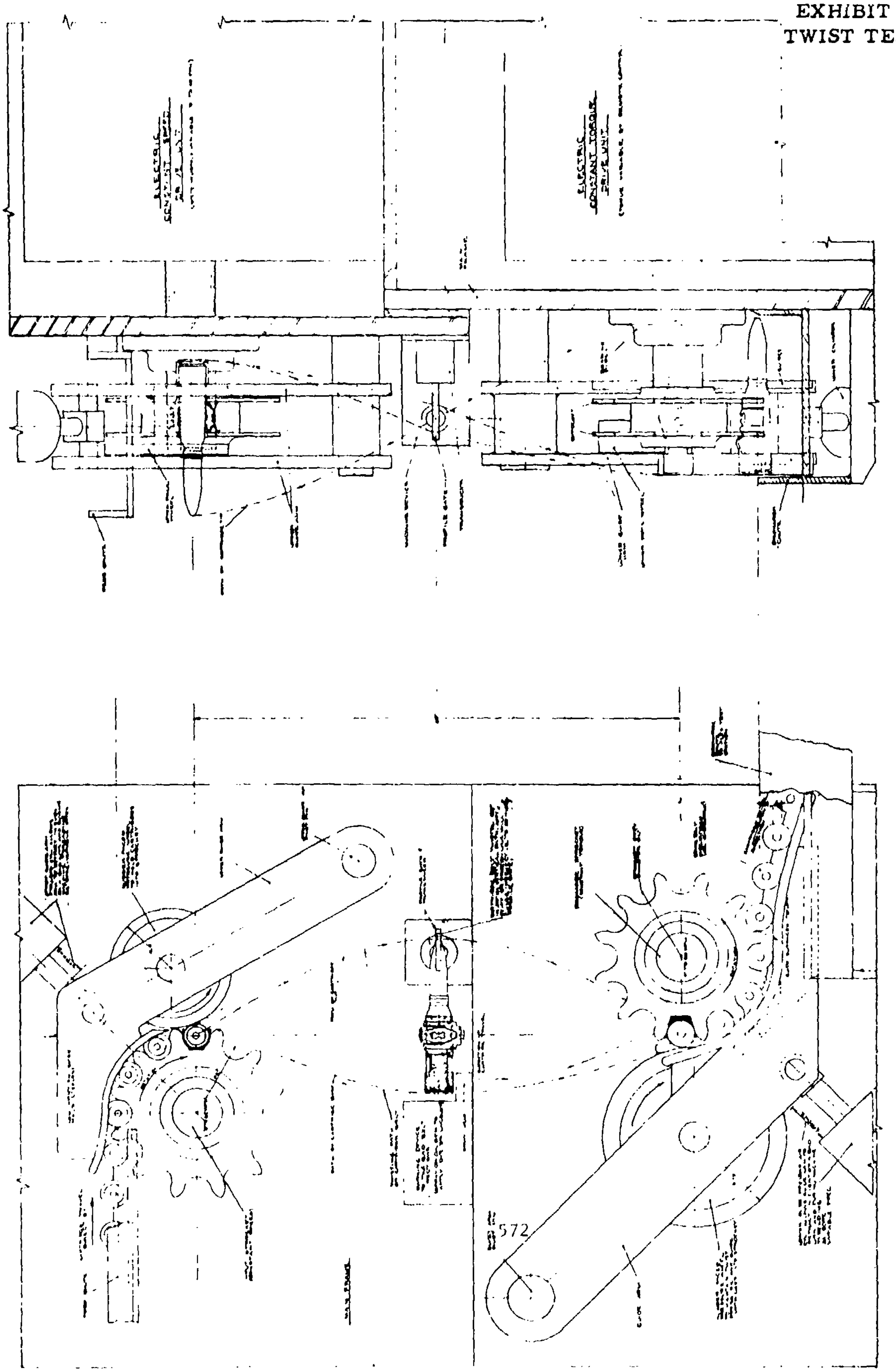


Flex Test in Open Link Direction

illustrated in Exhibit X. Midway between the input and discharge sprockets a profile gate is located for the projectile nose to pass. Should the twist be non-uniform, the nose of the projectile does not pass through the gate thus actuating a detector switch.

As with the 7.62mm belts, the cartridge-to-link assemblies which do not meet the inspection criteria are marked with a spray gun and a signal is transmitted to the subsequent belt folding and separating operations where they are separated into 100 - round lengths and folded for subsequent packaging. Should a separated discrete belt length contain a faulty cartridge-to-link assembly or faulty link, the belt is rejected for rework. The spray mark aids in identifying the location of the faulty link during the rework operation.

EXHIBIT X
TWIST TEST



ENHANCED SAFETY IN MILITARY SHIPMENTS OF HAZARDOUS MATERIALS

Mr. W. J. Burns
Office of Hazardous Materials
Department of Transportation
Washington, D. C.

Do we have any ladies in the audience? No, I don't see any. Yes, I do, too. Ladies and Gentlemen: Good afternoon. I am going to talk for just a few minutes this afternoon about the transportation of hazardous materials. Now, this is becoming a very popular subject these days, not only in Washington but throughout the United States.

We had a report issued by the General Accounting Office about two years ago, after a rather exhaustive investigation, and it was highly critical, not only of the Department of Transportation but of shippers and carriers as well.

The news media, of course, have played up this subject, in particular the air transportation of hazardous materials. The Airline Pilots Association and the unions of stewards and stewardesses have been complaining about the undue risks they have been exposed to in passenger flights where radioactive materials are involved and there has been an attempt by the Airline Pilots Association to embargo all hazardous materials on passenger-carrying aircraft.

The fact that some 5 million patients rely exclusively on radioisotopes for diagnostic and therapeutic treatments has not swayed them entirely. I think they have, however, agreed that there is a need for certain types of radioisotopes that are related exclusively to medical treatment to be allowed to be transported on passenger planes.

I have appeared before three or four Congressional committees (e.g., Mr. Staggers' House Interstate and Foreign Commerce Committee, Jack Brooks' Government Operations Committee and more recently Senator Hartke.) Now these gentlemen, and I understate purposely, have been very critical about the overall subject of hazardous materials which, of course, includes explosives although explosives transportation is not our number one problem.

Other problems we have are in the regulations area. I was just asking Erskine to run up to the room and get a copy of Title 49. I wanted to read about the section which covers military exemptions and asked him where it was. Well, he suggested two or three possible sections which were not the desired one. I finally found it in Section 173.7.

If we can't find it, how can we expect you folks to be able to find what is in the regulations? We go through this all the time. If we have five people sitting in the office to discuss a portion of the regulations, we might have five different ideas as to what they mean.

Now, one of the things we are going to try to do, after some 60 years of regulation going back to the Transportation of Explosives Act of 1908, which basically was the inception of safety regulations as we know them today, is to consolidate the regulations.

For over a period of 60 years during the tenure of the Interstate Commerce Commission, I am frank to say, not as much could have been done as should have been done in this area. When the Department of Transportation came into being in 1967, it had three different titles of the CFR. One was Title 49, basically the old ICC requirements for surface transportation. Another one, just as thick, was for water (Title 46) and the third one covered air shipments (FAR-103 from Title 14).

In Docket HM-112 we are proposing to consolidate for the first time the regulations in those three titles into one title, Title 49, thus eliminating about 800 pages of regulations. If this docket is accepted by the public (the comment period expires in about two weeks), we plan to go out with an amendment to do just that very thing -- to consolidate the three titles into one title of the Code of Federal Regulations.

In the few minutes I am up here, you are going to hear me say we have done several things for the first time. This is the first time we have attempted such a consolidation. I want to mention that about a year ago, for the first time, we came up with a proposed uniform labeling system which is consistent with the labeling system of the United Nations and we are in the process of coming up, for the first time, with a uniform placarding system.

Would you believe, for example, that the placard for a rail car is different than it is for a 40-foot trailer? If you put the 40-foot trailer on the flat car, you must remove the highway placard and put the rail placard on. When the trailer is detrained, of course, you take the rail placard off and you put the highway placard back on.

Up until last year, when we came up with another docket, we had flammable liquids defined seven different ways. Actually, we had 11 different definitions because in some Departments they had more than one definition for the same commodity.

So now we are in the process in Docket HM-102 of defining for the first time uniformly what a flammable liquid is and for the first time we are going to define a combustible liquid which hasn't been defined for transportation purposes in the past.

If and when this Docket HM-112 is approved and it becomes an amendment, we then plan to restate the regulations. The consolidation might be called a recodification. We plan to restate the regulations in simple, cohesive, understandable language.

We already have an index, for the first time, which we issued about two years ago. It rather simplifies finding information in the Title 49.

Now this is what I consider to be number one of a three-part program -- Regulations -- get those in shape so you can understand them.

The second part of the three-part program consists of training and education. The best regulations in the world, of course, are no good, if people do not understand them. We have almost a wholesale lack of understanding of the field.

Mr. John Barnum, the Under Secretary of Transportation, appeared before Mr. Hartke. Mr. Hartke asked Mr. Barnum, "How do you evaluate the effectiveness of the regulations?" He answered in one word, "poorly". He then asked Mr. Barnum in his opinion what percentage of the people who are subject to the regulations are presently in compliance. He said 75 percent -- in noncompliance -- 75 percent -- and I share that opinion.

Seventy-five percent of the people that are out there in the real world of hazardous materials, we find, are presently in noncompliance with the regulations. Now there are some, of course, who knowingly violate the regulations. You know that as well as I do. They purposely misclassify for rate reasons. There are others, however, and these are the bulk of the people, who just do not know what the regulations are because they have never heard of Title 49.

They are people who think that Tariff 6D of CAB (or IATA) is the bible for air shipments. Well, of course, it is not. You are not in compliance in toto with the DOT regulations, if you do not look at Title 49, which is where all the shipping and container specifications are found.

So in the last year we have had 17 one-day seminars to educate these people. I am sure that some of you have been to these seminars which have been held around the United States and have involved about 2,000 people -- roughly about 100-200 per seminar. We cannot handle too many people effectively at one time.

I don't have here with me samples of the 650,000 individual pieces of handout materials we have distributed. However, these labeling, placarding and shipper specification criteria, container information and so on are available free of charge, so there really is no excuse for anyone not knowing what the regulations are.

This year on October 2 and 3 in the Departmental Auditorium in Washington, we are going to hold a public conference on the air transportation of hazardous materials and we expect that there will be some 600 to 700 people in attendance. This is an important subject for those of you who are involved in air transportation, because there are attempts being made to take all hazardous materials off passenger-carrying aircraft.

Mr. Barnum, the DOT Under Secretary, and Mr. Butterfield, the Administrator of the FAA, will be the two key speakers and General Davis will be in the chair. We will have some other interesting and well-qualified members of the Department there to answer any questions you might have.

Now the third part of this program -- enforcement -- is not as complicated as it seems, if you break it down in this fashion. Enforcement is really where we are weak. In fact, we are not doing much enforcing. The Federal Highway Administration and the Federal Railroad Administration have no civil forfeiture authority today. So for the first time in a bill now pending before the Congress, and it should be in executive session today, we are seeking a uniform civil forfeiture penalty across-the-board. The Coast Guard has it and the FAA has it.

The average criminal fine today for the FHWA prosecutions is about $160 per fine. And it takes about two years to collect one. It is a very frustrating experience and it really turns you off after a while. For example, consider one situation in New England in which the company was charged with several violations, related to an incident, a fire, involving disposable cigarette lighters, which were negotiated down to four counts which resulted in the district judge fining the company a total of $10.00, this after about two years of intensive investigative and prosecutive work. This is as much as to say do not ever come back into my court with a hazardous material violation. This is the way some of the district courts are. They have, in their opinion, other more pressing and more important matters -- the criminal type of indictment.

So we are taking the civil forfeiture route. Since 1908, roughly, the maximum fine imposable has been $1,000, 1-year in jail or, if a fatality or injury is involved $10,000 and 10 years in jail.

This bill, which is in Congressional process, has a civil forfeiture penalty of $10,000 per count for each violation, with each day of a violation a separate count, so it could result in a substantial sum of money but only if the company is not complying with the regulations and only if it is done on a knowing basis.

It is not our intent to put anyone in jail. It is our intent to see that the regulations are enforced, and I can assure you that we are going to try just as hard as we possibly can to see that this is done. But first, we are going to tell you what the regulations are. We are going to answer all your questions. I think it is only fair to say that it is not asking too much that you be in compliance with the regulations. So the enforcement part of this new bill is a very important one as far as we are concerned.

This bill also has a preemptive provision for the first time and this preempts all state regulations, unless the states so certify to the Secretary of Transportation that the state's regulations are equal to or greater than the DOT regulations from the safety standpoint and that on a continuing basis the state can assure the Department that the state is in fact enforcing the regulations for intra-state commerce. There are some consumer-oriented provisions in the bill. For example, citizens have the right to petition. We do not particularly care for this, but, since it is a very popular subject, I think we will be struck with citizen petitions, citizen actions and things of that type.

However, by and large, the bill is about what we initially sought. First, it gives us civil forfeiture authority. Secondly, it removes the present restrictions on the Secretary's authority so he can delegate this function to whomsoever he chooses in the Department of Transportation. The third one gives us control of the container manufacturers which we don't have today.

We have been charged, by the Secretary, with the responsibility for enforcement of the shipper and manufacturer regulations but we never got the field staff or the resources to do the job. Notwithstanding, we have had two people in the field since 1971. And the types of violations they have found are the type you would ordinarily expect--shipping papers, for example, with no proper shipping name.

If you consider a paint, for example, Super Chem Tone, that is not the name of the item being shipped. The proper shipping name is "Paint". We have a lot of that sort of thing. People do not understand that they are supposed to use the proper shipping name and the proper classification. We find in many cases the lack of wording--e.g., no label required on shipments exempt from specification packaging marking and labeling. There are no special permit numbers on shipments moving under DOT special permits and this is a requirement. With respect to the marking of containers, we find that there is no marking in many cases on the container itself.

I was up in Kennedy airport about two months ago and inspected four air carriers with about 10 of the Kennedy FAA people. Every place we looked we found violations. There was one small carton about this size with a poison label on it, so we assumed it contained a poison material coming from overseas. We asked the man there what was in the container. Well, he did not know. I asked him "Why don't you know?" "It's not marked on the container," he said. I then asked "Where's your shipping paper?" He did not have that. My next question was, "Where is the shipping paper?" He replied, "that is with the freight forwarder." Now, here was a Class B poison shipment sitting on the floor to move inland by rail or by highway and he didn't know what it was.

Now, IATA (International Air Transport Association) does not require marking and we are in the process of changing that situation. We are just back from a meeting in Geneva on that very subject. A lot of the IATA regulations have a requirement for, shall we say, a Spec 2D container which is supposed to be analogous to one of our containers and it is not. So we have this problem.

Let me just say a few of the things, then, that we have found. In the incident reports we have a requirement that all carriers report an incident involving the leakage of a container or an injury involved in the transportation of a hazardous material. We have about 14,000 incident reports in our computer now and we can tell you just about anything that you need to know. Not everything, but a lot you need to know about a shipment or type of shipment. For example, on Class A or B explosives, the computer can tell us how many incidents took place, what caused the incident and so on and so forth.

We find a lot of improper blocking and bracing indicated on these reports. Now the railroads have had for many years the Bureau of Explosives blocking and bracing pamphlets. The American Trucking Association does not have a similar pamphlet. We find a lot of improper containers. We find the Spec 21C containers filled with various types of explosives, punctured. As you may know, the Federal Railroad Administration embargoed some of those a while back.

What are some recommendations? Well, we suggest that you carefully determine the hazard characteristics of the commodity. We suggest that you analyze the transportation environment with a view toward normal and accident conditions. We suggest that you more carefully define the individual responsibilities of your people and have a check list of operating procedures. Of course, you have many of these already in existence.

We are looking at the subject of risk analysis, having spent about $75,000 on studying its possible application as a management tool. Risk assessment does involve you too, for example, in phosgene shipments and others as well. We all need to hypothesize what an accident situation might be and what might be encountered in terms of the environment, spills and so on.

We suggest that you try to avoid classification by analogy as much as possible. This is done a lot. It is an easy way, but it is not necessarily the right way, in my opinion. I would rather see you go into it as we do at DOT -- an extensive R&D program to come up with the proper classification. Now, we have others too, but I think, and I agree with Erskine, that the real meat of any good meeting is the question and answer period and I am here now to answer any questions you may have.

If I cannot answer them and if Erskine cannot, we'll find someone who can. Are there any questions?

QUESTIC_:

One of your labels is organic peroxide. I am recalling a little accident down in Los Angeles. How come some of these materials are called organic peroxides when really they are explosives?

ANSWER BY MR. BURNS:

Well, this is a good question and I am not going to try to avoid it, but Erskine happens to be the man who is working on this particular subject at the present time and assisting "Bill" Byrd, who is my Deputy and is the Chairman of the parent committee of the U.N. working on this topic. We are deeply involved in this very subject. So let me ask Erskine if he would like to answer that for you.

ANSWER BY MR. HARTON:

I think the answer to that probably is in the degree of sensitivity as well as the actual -- I do not like to use TNT equivalency -- effect of the peroxide. I do not dispute the fact that you can have the equivalent of an explosion with certain peroxides under certain conditions and I can't really give you the full answer to that question.

COMMENT FROM THE ORIGINAL QUESTIONER:

I think what they seem to have is a sensitivity to heat. Now they were quoting over the TV at that time something like 127 to 150 degrees.

REMARKS BY MR. HARTON:

You are talking about the incident in Los Angeles? Of course, we could get out of that by saying that it was not in the transportation area -- that it was in storage. But that does not really answer the question. That was a very confusing situation. Dr. Chester McCloskey, who is President of NORAC Chemical and happens to live out in that area, tells us that he went over to look into it and as of this point they are not sure really what it was that was initiated, what actually started the thing, so I would hate to second guess what the investigation would prove.

COMMENT AGAIN BY THE ORIGINAL QUESTIONER:

I think what I was getting at is that you have such a low ignition point or a low point where the thing will start to self-heat, if you were to classify it as an explosive, you couldn't ship it.

ANSWER BY MR. HARTON:

Well, we are in the process of looking at the organic peroxide classification criteria as well as the explosive criteria and I think that those of us who have been looking into this all agree that under certain conditions so-called non-explosive materials can exhibit the equivalent impact of what an explosive material can. However, it is not quite that cut and dried, so we must not make a hasty blanket judgment. The quantity has something to do with it, the degree of confinement, of course -- a number of factors are involved. We are trying to come up with some kind of a systematic classification system for all the types of reactive hazardous materials which will make sense. Of course, the packaging and containerization will certainly be affected by this.

COMMENT BY MR. BURNS:

This is one of our most difficult areas, incidentally.

QUESTION:

Do you plan to leave the HI labels on the packages when they go out of the United States?

ANSWER BY MR. BURNS:

Yes, we do.

QUESTION:

How about the other countries, will they accept them?

ANSWER BY MR. BURNS:

Yes, they will. The HI labels are basically a counterpart of the U.N. labels, the only difference being the insertion of the HI number on the label. We do not anticipate any problems going into countries outside the U.S., nor do we anticipate any problems with shipments coming into this country with the European labels which will be basically the same as ours. We intend to accept those, too. We are striving as hard as we can to achieve to the maximum extent practicable harmonisation to use the British word, or uniformity in the labeling, placarding and classification of all hazardous materials. Are there any other questions?

Thank you very much

Packaging, Handling, Stowage, & Transportation Advances in Naval Ordnance

Messrs J. E. Kelley and J. F. Latham
Naval Weapons Handling Laboratory
Naval Ammunition Depot, Earle, NJ

I. INTRODUCTION: Accelerated Training

A. NAVSEASYSCOM/DOT-FRA SEMINARS

The film Titled: "A Special Report" shown during the General Session this morning covered the train burnings that occurred in Roseville, California and Benson, Arizona. These railroad explosions have served to emphasize the threat to public safety that shipment of explosives presents. Miraculously, no deaths resulted when the explosions occurred. During the investigation of these accidents, it was found that many railcars offered for the transport of hazardous materials did not meet the safety standards of the Federal Railroad Administration or those of the Association of American Railroads. It was also noted that both military and commercial carrier railcar inspectors were not thoroughly familiar with detailed technical railcar inspection requirements of the FRA. Many railcar defects such as breaks or defects in railcar components were not corrected prior to acceptance for loading explosives.

The results of the rail accidents at Roseville and Benson made it of paramount importance that Navy railcar inspectors perform their jobs properly. Therefore, seminars sponsored jointly by NAVSEA (Naval Sea Systems Command, formerly the Naval Ordnance Systems Command), FRA (Federal Railroad Administration), Bureau of Explosives and the Naval Weapons Handling Laboratory provided technical information for Navy and commercial railcar inspectors to better understand their responsibilities and to increase their technical expertise relative to the inspection of railcars used for hazardous materials. These seminars significantly helped improve the effectiveness of railcar inspectors to promote safer shipments of hazardous materials. The proper inspection of railcars used to transport hazardous materials should reduce the number of railroad accidents caused by defective railcars, and in turn, will provide greater protection to the public. In addition, it should reduce the accident costs both to the commercial industry and the U.S. Government.

The hazards inherent in Class A and Class B explosives make it mandatory that such material be handled, loaded and shipped in a manner that will afford optimum protection to the material and public. Similarly, because of the complex nature of applicable regulations, and in consideration of the safety and legal aspects, it is essential that all personnel performing functions involving the inspection of railcar and motor vehicle equipment used to transport explosives be thoroughly trained and knowledgeable of their areas of responsibilities.

(Roseville was L.D. 250# Bomb Mk 81 on DODX-Box Cars)
(Benson was L.D. 500# Bomb Mk 82 on Commercial Box Car palletized in accordance with A.F. requirements.)

Persons designated to conduct railcar inspections must be well qualified and able to detect evidence of the existence of defects.

The seminars also included coverage for motor vehicle inspections. The training program was targeted for those personnel physically responsible for the loading, dunnaging and the inspection of the transporting vehicles. This program also included personnel from the rail and motor carriers.

The purpose and intent of these seminars were to emphasize what to look for when inspecting a carrier's vehicle. A second purpose was to emphasize the use of available documentation in either building or inspecting the load. It was stressed that the documentation should be used to its fullest.

The attendees of the seminars were physically required to inspect railcars (DODX and commercial Box Car) and motor vehicles (usually a Navy motor vehicle and two commercial vehicles). The practical inspection included the acceptance or rejection of the transporting vehicle.

The seminars were held at the Naval Weapons Stations - Seal Beach, Yorktown, and Concord, and Naval Ammunition Depot, McAlester, Oklahoma. Attendance at those seminars was very gratifying. These seminars were detailed and gave a complete rundown on all aspects for rejection or acceptance of the carrier's equipment, blocking and bracing (dunnaging) and the paperwork involved throughout the transporting process.

The following material was presented during the seminars with adequate graphics which depicted the cause for rejection:

a. Floors
b. Braking systems
c. Wheels
d. Doors
e. Brake shoes
f. Couplings and 5th wheels
g. Spark shields
h. Emergency kits
i. Loading, blocking and bracing

The use of the following approved documents (MIL-STDs, WRs) was stressed:

MIL-STD 1320 - XXXX Truck Loading
MIL-STD 1325 - XXXX Car Loading
MIL-STDs 1322, 23, 24 - Palletizing (Fleet Issue Unit Loads, Domestic Unit Loads, Amphibious Unit Loads)

Usually after an incident the first thing done is to see if the documentation exists for the material involved and if it was complied with. The Naval Sea Systems Command has a manual OP 3681 - "Motor Vehicle and Rail Car Load Inspector's Manual for Ammunition, Explosives and Other Dangerous Articles" first published in 1969. Several changes have been published since. Another manual OP 2165 - "Navy Transportation Safety Handbook" has been with us a good many years.

B. NAVSEA's PLANS FOR FISCAL YEAR 1975.

The Naval Sea Systems Command's transportation Safety Office is currently negotiating with the Department of Transportation Safety Institute located in Oklahoma City. A formal training course is being prepared jointly by COMNAVSEASYSCOM and the Transportation Safety Institute (DOT) of Department of Transportation. The proposed course will provide Navy and Marine Corps railcar/motor vehicle inspectors with formal in-depth training in the following areas:

a. Detailed inspections of motor vehicles used for the transport of explosives.

b. Detailed inspection of rail equipment used for the transport of explosives.

c. Railcar and motor vehicle dunnaging of hazardous cargoes.

The training will provide simulated job site conditions and problem situations and applications. Emphasis will be placed on the requirements of OP 3681 and the documentation and inspections necessary for the proper shipment of hazardous materials. Further information on this special course will be forthcoming. The arrangement should be completed and classes started within the next 6 months.

C. NAD EARLE/NWHL CONTINUING TRAINING PROGRAM.

The Naval Weapons Handling Laboratory has a training program designed to keep those activities engaged in the handling and transporting of explosives informed in the current state of the art. This course (1 week) emphasizes the palletizing, blocking and bracing of explosives for railcars and motor vehicles and is given annually on the East and West Coasts. This year a third course will be given in NAD Hawthorne. The courses alert personnel to the documentation available and its mandatory nature, and the courses explain this documentation to assure that the attendees can use them properly. Discussions bring out what is actually going on in the field resulting in everyone gaining from this cross-knowledge.

II. CLASSIFICATION:

NAVSEA's Testing Program for Explosive Items.

A testing program is being initiated at the Naval Weapons Laboratory - Dahlgren, Va. to determine whether or not the packaging design for various explosive items can prevent sympathetic detonation between items in the same package or whether or not the full energy release is contained within the outside shipping container. Some of the items that will be tested first are:

ITEM	Net Expl Wt (Lbs)	Present Classification
Fuze, Time Mk 84	.0115	Class C
Fuze, Grenade M10 Series	.004	Class C
Fuze, Grenade M204 Series	.0062	Class A
Fuze, Bomb, MT	.0007	Class C
Fuze, Bomb, FMU Type	.0007	Class C
Fuze, Rocket Nose PD	.0051	Class A
Primers, Mk 34	.0043	Class C
Primers, Mk 15	.0043	Class C
Primers, Percussion	.0007	Class C
Fuze, Mk 312	.0008	Class C
Bolt, Explosive, Mk 2	.00006	Class C
Cartridge, Delay Mk 3	.0034	Class C
Cartridge, Delay M1	.0001	Class C
Detonation Simulator M80	.0066	Class B
Detonator Assembly	.00022	Class A

After determining the actual degree of hazard for these components, the current hazard classification for the item may be lowered for transportation and storage purposes, and would result in many thousands of dollars in savings. It would result in permitting greater flexibility for shipment by additional modes of transport. The tests are estimated to cost approximately $600.00 for electrically initiated items and approximately $900.00 for non-electrically initiated items.

An example of the savings by such testing, was with the Fairfield Scientific Corporation, concerning a specially designed container the Army uses to ship Mk 95 detonators. The container (Army drawing 9258182) with its special inside insulation provides adequate protection to the detonators and makes them nonpropagating. Accordingly, the hazard classification was lowered from a Class "A" explosive to a Class "C" explosive. This lower hazard classification reduced the transportation cost. For example, a small shipment of Class A detonators moving from Yorktown, Virginia to Dover, New Jersey would cost about $650.00. As a Class C explosive, it would only cost $50.00. Quite an outstanding transportation saving! There is no doubt that the cost of testing an ammunition component will result in major savings (many times more than the cost of the tests). The data shown below proves the point in question. Considering that the average shipment of fuzes weighs 800 pounds, the freight rates by various modes of transport between NAD Crane and WPNSTA Concord would be:

Item	Motor	Rail	Air	Remarks
Fuze, Class A Explosive	$546.75 (1)	$1,934.34 (2)	Prohibited $1,430.00*	(1) Rate-$21.87 cwt @ 2500 minimum (2) Rate-$32.00 cwt @ 7500 minimum
Fuze, Class C	$134.00 (1)	$964.08 (2)	$229.75**	(1) Rate-$14.24 cwt (2) Rate-$15.65 cwt 6000 minimum + 3% (3) Rate-$27.35 cwt + 5%
Fuze, Non-Regulated	$134.00	$964.08	$229.75**	Class C and non-regulated have, in this case, the same freight rate. However, Class C is usually rated a little higher.

* Approved air taxi
** Air Freight (Cargo Planes only)

Based on the above sample, it is quite evident that an unbelievable amount of money could be saved if adequate tests are made. As in the case cited above, based on the difference in freight rates - two shipments (825.50 savings) would pay for the costs of the hazard tests.

III. NAVAL SEA SYSTEMS COMMAND SAFETY DOCUMENTATION

The Fourth Revision to Volume One of Ordnance Pamphlet 5, which deals with the handling, stowing, production, renovation and shipping of ammunition and explosives in and between shore establishments, will be available in late October. This revision, in addition to promulgating the manual under the aegis of the new Naval Sea Systems Command, will offer to the user an updated, better organized compilation of safety regulations. Redundancy has been almost totally eliminated and the reorganized layout of the book will simplify its employment and understanding. Considerable effort and the expert knowledge and experience of many users of OP 5 has been put into the revised manual; however, it is recognized that even so, in an undertaking as wide sweeping as this revision is, some areas may well benefit from further suggested changes. To this end, a continuing review and evaluation by every user will be valuable. Suggestions for further changes should be submitted to the Commander, Naval Sea Systems Command (SEA-09B4).

OD 44942 (Basic) Weapons Systems Safety Guidelines Handbook

This manual has been completed, printed and distributed. Additional copies may be requisitioned through the normal Naval channels for in-house Navy activities. Copies have been made available to the Superintendent of Documents for sale and will be available shortly to the various contractors desiring copies. A synopsis of the part structure, the user and NAVSEA's intent is described below:

"SYSTEM SAFETY TECHNIQUES APPLIED TO ORDNANCE PRODUCTION"

The Naval Sea Systems Command has prepared a four part manual entitled "Weapon System Safety Guidelines Handbook" (NAVORD Ordnance Data (OD) 44942). Each part is designed for a different Navy user, but its purpose is singular - to assist each user in the application of system safety techniques as required by MIL-STD-882 and implementing Navy directives. The achievement of Weapon System Safety through design is intended to preclude catastrophic accidents and the need for costly system re-design to assure safety. The four parts of OD 44942 are as follows:

PART I	"System Manager's Guide to System Safety" - intended for Project Managers
PART II	"System Safety Management" - intended for System Safety Managers
PART III	"System Safety Engineering" - intended for System Safety Engineers
PART IV	"Hazard Control for Explosives Ordnance Production" - intended for depot Management and Engineering personnel

Parts I, II and III are an integration of the Navy's system safety "know-how" as applied to the actual weapon system. With the introduction of OSHA and Executive Order 11612, and in order to achieve greater safety at the Navy Depots and Weapon Stations, it was decided to apply system safety techniques to ordnance production areas. NAVSEA hopes to accomplish this goal with PART IV.

As in weapon system design, the design of an ordnance production line is divided into various phases. These are as follows:

Planning Phase
Design Phase
Installation Phase
Pilot Production Phase
Full Production Phase

A typical safety milestone chart which keys system safety tasks to the various production phases is shown in Figure 3-1 of the manual (PART IV). These milestones are shown for the most part in chronological order.

During each phase, a system safety analysis and corrective action loop is used to resolve safety problems. Verification of the analysis - and its attendant corrective action - may be accomplished by testing or independent technical assessment. In general, each phase can be broken down into an analysis of (a) support functions (facilities and utilities) for the depot, (b) process line hazardous material, and (c) the analysis of equipment and personnel.

For example, during the planning phase an Architectural and Engineering (A&E) firm may be hired to design a facility for bomb loading. During this stage either the A&E or a Navy safety committee will "define the System" and conduct the PHA. From the PHA will come the system-oriented safety requirements to be incorporated in the facility and equipment specifications. These requirements plus the requirements of NAVSEA OP-5, OSHA, EPA, DOT, DOD and NAVSEA regulations are combined to establish the overall facility, i.e., "system requirements."

During the conduct of the PHA, all areas of the system are subjected to scrutiny to insure all hazards are identified; especially those that interface with or cross over the responsibility lines of different depot support functions. High risk areas are also earmarked for more detailed study in subsequent phases.

During the Design and Installation Phase, Sub-System Hazard Analyses (SSHA) are to be required on each area or equipment found to be a high risk by the PHA.

Typically hazardous areas would include the handling of bare explosives, volatile and toxic materials, or where an interface between personnel and heavy equipment exists. In general, the target industries for OSHA are often the same high risk areas which the PHA singles out for detailed analysis.

Sub-System Hazard Analyses are to be prepared by the equipment or facilities contractor. The SSHA may be an elaborate Fault Tree Analysis (FTA) or a Fault Hazards Analysis (FHA).

When the facility and equipment drawing, the SSHA, and an updated PHA are available, a System Hazard Analysis is conducted. At this time, the Standard Operating Procedures (SOP) must exist. The SOP writers perform the System Hazard Analysis. The SHA may be in a narrative, columnar or Fault Tree format. It may also be in the form of a detailed updating of the original PHA.

An independent SHA is also performed by the Naval Ammunition Production Engineering Center. With the completion of these analyses a safety inspection of the line is conducted during a dry run using inert materials where possible.

During pilot line production, an Operating Hazards Analysis (OHA) is conducted, with specific emphasis placed on experience gained from observing the man-machine interface. Results of the OHA are utilized to improve equipment and procedure safety through design or SOP changes.

Before start-up of full production, a safety inspection by independent safety observers is conducted. These safety observers are obtained from the Naval Sea Systems Support Offices and NAPEC. Upon satisfactory completion of this inspection, the full production start-up is approved.

During line operation, updates of the OHA are required whenever any changes are made to the production process.

Through environmental studies and improved techniques, the Navy is attempting to protect the worker and the environment. The Naval Sea Systems Command is presently reviewing OSHA standards to insure that we comply with or exceed the standards. In some instances, our standards already exceed those of OSHA. For example, OSHA has adopted the American Table of Distances for explosives safe separation. The Navy abides by the more restrictive DOD Explosives Safety Quantity-Distance requirements.

Utilizing the Systems Approach, in PART IV we are attempting to resolve the conflicts by adopting the method which best contributes to the safety of the production worker and the public.

TRANSPORTATION OF MILITARY AMMUNITION AND EXPLOSIVES

James H. Edgerton*

ABSTRACT

Transportation of military ammunition and explosives involves the packaging, storage, movement, and transport of these materials by all modes throughout the United States and the world. The general public and the people who live and work near the airways, highways, railroads, and waterways must be given confidence in the safety during transport of military ammunition and explosives. To implement the Department of Transportation (DOT) regulations the Department of Defense (DOD) issues military directives in the form of regulations, circulars, notices, manuals, and other publications. The Military Traffic Management Command (MTMC) has responsibility for the DOD freight loss and damage prevention program and utilizes the Discrepancies in Shipment Report (DISREP Form 361) as an essential tool in the prevention program. However, DOD still experiences shipment discrepancies resulting from inadequate blocking, bracing, and tiedown; rough handling; omissions or incorrect descriptions on bills of lading; improper labeling and placarding; and other causes. Loss and damage statistics on ammunition and explosives are presented in this paper. An accident involving 750-pound bombs in railcars at Tobar, Nevada, is described. The DOD efforts to improve safety during transportation of ammunition and explosives are discussed. To identify transportation environmental effects, the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) has monitored shipments of various ammunition, explosives, and other hazardous materials. Two containers were monitored for shock and vibration during the initial DOD test shipment of ammunition in Sea-Land shipping containers from Doyline, Louisiana, to the Republic of Vietnam (RVN). A transportation system analysis was made at the Naval Ammunition Depot, Earle, Colts Neck, New Jersey. Also, a transportation engineering study was conducted at the Military Ocean Terminal, Sunny Point, Southport, North Carolina. These are discussed. The monitorings and studies have provided significant data to resolve transportation problems encountered during the movement of ammunition and explosives. MTMCTEA develops transportability criteria and guidance to aid shippers of military ammunition and explosives. However, there are areas requiring additional research, as pointed up in this report.

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INTRODUCTION

The transportation of military ammunition and explosives throughout the United States and the world is presenting many technical problems because of the large amounts transported and the hazards associated with their movement. The provisions that are made to protect the public health and safety during the transport of these hazardous materials are of particular concern to all. It is essential that criteria, guidance, and performance standards be verified for packaging, handling, and transportation to improve safety during the movement of these materials by all modes. It is necessary that military, Federal, state, and local regulatory agencies work together to understand the many associative problems of safety during transportation. The interchange of information in this area on an international basis is also important to the development of regulations for the safe transport of these materials worldwide. Carriers must know and understand the risks involved in transporting ammunition and explosives. Package designers or shippers must know pertinent requirements; frequently, they must be informed several years in advance of a proposed shipment. Insurance companies must ascertain that their policyholders are not taking unnecessary risks. The general public and the people who live and work near the airways, highways, railroads, and waterways must also be given confidence in the safety during transport of military ammunition and explosives.

In recent years fatal and sometimes catastrophic accidents have occurred during the movement of commercial and military hazardous materials. The result has been renewed program emphasis on eliminating unsafe practices and correcting regulations that permit them to exist. In the Hazardous Material Transportation Control Act of 1970 (Public Law 91-458), Congress reiterated that Department of Transportation (DOT) has primary responsibility for insuring that the hazards and dangers associated with the transport of dangerous commodities are reduced to the lowest level possible. The Department of Defense (DOD) is a shipper of hazardous materials. There is, therefore, a necessity for coordinate action among Federal agencies to improve safety during handling and transportation of these hazardous materials.

REGULATIONS FOR TRANSPORTATION OF AMMUNITION AND EXPLOSIVES

DOD implements Public Law 91-458 by issuing pertinent military directives in the form of service regulations, circulars, notices, manuals, and other publications shown in Table 1. For example, the Joint Military Traffic Management Regulation AR 55-355, is the "Bible" with which all transportation elements of the DOD must comply. The Joint Services Manual, AFM 71-4/TM 38-250, of which the Air Force is the proponent agency, prescribes specific details essential for adequate packaging, handling, and transport of ammunition and explosives by military aircraft. The Navy Transportation Safety Handbook, NAVORD OP 2165, provides essential guidance to Navy shippers of these materials. The other regulations listed in Table 1 provide the basis for many implementing military publications related to proper packaging and transportation of hazardous materials.

Table 1. Regulations for Transportation of Ammunition and Explosives

Department of Defense (DOD)	MTMR AR 55-355
	AFM 71-4, TM 38-250
	NAVORD OP 2165
	AR 55-55
	AR 55-228
	AR 70-44 and AR 70-47
Atomic Energy Commission (AEC)	10 CFR 71
International Atomic Energy Agency (IAEA)	SAFETY SERIES NO. 6
Department of Transportation (DOT)	14 CFR 103
	46 CFR 146
	49 CFR 170-179
	49 CFR 397
STATES	STATES REGULATIONS ARE SIMILAR TO AEC AND DOT REQUIREMENTS

Additional DOD documents used to improve safety during transportation include DD Forms 626, 836, 836-1, and 1387-2. DD Form 626, Motor Vehicle Inspection, provides additional assurance for safe transport by requiring inspection of transport equipment, load securement, placarding, and other safety checks at both origin and destination, thus eliminating the need for the receiving agency to complete a new DD Form 626. DD Form 836, Special Instructions for Motor Vehicle Drivers, and DD 836-1, Briefing for Aircraft Commanders Transporting Explosives and Other Dangerous Articles, provide pertinent information regarding the commodity, general precautions, and actions to be taken in the event of an accident or emergency. DD Form 1387-2, Special Handling Data/Certification for Military Air Shipments of Ammunition and Explosives, is used to provide information on nomenclature of the item, net explosive weight, gross weight, handling instructions, shipper certification, labeling, and shipment within passenger or cargo limitations. Proper preparation of DD Form 1387-2 will help prevent frustrated freight at air terminals. This form must accompany all shipments.

The recent change to part 397, Motor Carrier Safety Regulations Governing Driving and Parking Rules for Vehicles Containing Ammunition and Explosives, is another area of significant interest to the military and commercial carriers. The vehicle must not enter congested areas, must be inspected, and cannot be left unattended.

Although I have mentioned quite a few DOD and DOT regulations, there are more that many of you are aware of, particularly those implemented by the various services. Because of the rapid change in regulations governing the transportation of ammunition and explosives, it is essential that all personnel concerned be apprised, especially the operations element responsible for documentation, packing, loading, blocking, bracing, tiedown, labeling, placarding, dispatching, and driving of vehicles. Personnel must not be involved in shipment of ammunition and explosives until they are trained to insure safe transportation by all modes. Training in this specialized area is available to industry, civilian, and military personnel through enrollment in the resident 2-week courses offered by AMC Ammunition Center, Savanna, Illinois, and the courses on Transportation of Hazardous Materials given by the Office of Hazardous Materials, DOT.

LOSS AND DAMAGE PROBLEMS

The Military Traffic Management Command (MTMC) has responsibility for the DOD freight loss and damage program in accordance with the provisions of Joint Regulation AR 55-38, Reporting of Transportation Discrepancies in Shipment, and utilizes DISREP Standard Form 361 as an essential tool in damage prevention. Many shipment discrepancies are erroneously being reported on DD Form 6, Packaging Improvement Report, instead of the Standard Form 361, Discrepancy in Shipment Report. Since MTMC is not involved in the DD 6 program, and does not receive copies of DD Form 6, they are not aware of the complete picture of shipment discrepancies that are reported on this form. Strict compliance with the provisions of the Joint DISREP Regulation, AR 55-38, will insure proper preparation and distribution of the required information relative to loss and damage. Consideration should be given to combining DD Form 6 and SF Form 361.

Considering the vast volume of ammunition and explosives shipped over the past few years, the actual loss and damage record is good. However, DOD still experiences shipment discrepancies, resulting from inadequate blocking, bracing, and tiedown; rough handling; inadequate transport equipment; omissions or incorrect description on bills of lading; improper labeling and placarding; and other discrepancies. These discrepancies create potential hazardous conditions that endanger the health and safety of the general public and transportation personnel involved in air, highway, rail, and water modes of transport including potential loss and damage to public and private property. Close communition and coordination between shippers and carriers cannot be overemphasized.

Other areas of utmost concern to the military are the expedient resupply and transportation actions required to replace ammunition and explosives when damaged during transit, particularly when such material is urgently required at destination for combat or emergency operational readiness. Even if no loss of life or property other than the cargo is involved, the upset to manufacturing and movement schedules may have impact in other logistics areas not involved with ammunition or explosives.

Now, when we speak of damage involving ammunition and explosives, we must not overlook the fact that this encompasses materials not only visibly damaged, but also those that may have incurred concealed damage because of severe impact, jostling, tumbling, and falling, that items experience during an abnormal transportation incident. A single item, a couple of items, or an entire carload or truckload of items may require destruction for reason that the items are declared to be unsafe by explosive ordnance experts.

Some items, when damaged, are considered unserviceable and may not require destruction, but must be sent to a military facility that has the unique capability of reworking the items to serviceable condition. The appropriate rework facility may be a considerable distance away. It is apparent that the extra preparation and transportation costs involved in these operations may be considerable.

The DOD implementation of the loss and damage prevention program is accomplished through various means, including but not limited to the following: transportability analysis and testing; development of military specifications and standards for shipping containers, palletization, and containerization; and the development of loading, blocking, bracing, and tiedown procedures for the various methods and modes of transportation. Implementation is further reflected in corrective actions taken on discrepancy in shipment reports (DISREP), Standard Form 361, and related loss and damage statistics derived from these reports.

Statistics on the total number of DOD loss and damage claims for ammunition and explosives and those caused by fire or wrecks are shown in Table 2. Please note the relative low number of claims, 41 for Fiscal Year 1970 and 30 for Fiscal Year 1971, resulting from fire and accidents during transport. However, they make up 82 percent of the total dollar value of claims for Fiscal Year 1970 and 83 percent of the value of claims for Fiscal Year 1971. These are the types of accidents that the DOT, carrier industry, and the military must reduce in order to achieve the lowest possible level of accidents and curtail the need for emergency resupply and additional transportation actions.

DOD loss and damage claims entered against commercial CONUS carriers for Fiscal Year 1972 and Fiscal Year 1973 with causes, number, and value of claims and transfer mode (except LOGAIR and QUICKTRANS) are given in Table 3. The statistics in this table are for all freight shipments including hazardous materials.

Table 2. DOD Loss and Damage Claims for Accidents Involving Ammunition, Fiscal Year 1970 Through Fiscal Year 1973

AMMUNITION/EXPLOSIVES		CAUSE (FIRE/WRECK)		PERCENT OF TOTAL DOLLAR VALUE OF CLAIMS
		FY 1970		
Total Claims	276	Total Claims	41	82
Total Value	$1,416,790	Total Value	$1,166,468	
		FY 1971		
Total Claims	231	Total Claims	30	83
Total Value	$ 604,037	Total Value	$ 485,207	
		FY 1972		
Total Claims	191	Total Claims	NOT AVAILABLE	
Total Value	$1,185,872	Total Value	NOT AVAILABLE	
		FY 1973		
Total Claims	108	Total Claims	NOT AVAILABLE	
Total Value	$ 143,253	Total Value	NOT AVAILABLE	

Table 3. DOD Freight Loss and Damage Claims Entered Against CONUS Commercial Carriers by Cause and Mode, Fiscal Year 1972 and Fiscal Year 1973*

Causes	Number Claims	Claims Values	Modes	Number Claims	Claims Values
		FY 1972			
Fire/Wreck	82	$1,532,447	Rail, Cl/LCL	1,542	$1,684,573
Shortages	3,744	1,245,178	LTL	3,102	1,289,171
Rough Handling	2,109	950,537	Tl	907	817,237
Spoilage	138	91,345	Surface Frt Fwdr	254	155,946
Concealed Loss and Damage	251	64,755	REA Express	488	38,487
Theft	113	38,493	Air	250	34,324
Improper Load and Block	35	16,883	Other Modes	103	29,409
Other	174	109,589			
Total	6,646	$4,049,227		6,646	$4,049,227
		FY 1973			
Shortages	2,992	$1,166,123	LTL	2,441	$ 924,977
Rough Handling	1,386	770,132	Rail	988	851,282
Fire/Wreck	277	708,616	Tl	886	833,716
Spoilage	114	95,855	Surface Frt Fwdr	293	131,823
Other	154	59,011	Other Modes	80	53,847
Improper Load and Block	29	24,432	REA Express	393	34,944
Concealed Loss and Damage	293	20,388	Air	230	25,532
Theft	66	11,564			
Total	5,311	$2,856,121		5,311	$2,856,121

*SOURCE: MTMTS Freight Loss and Damage Claim Report, RCS MTMTS-10(R-1). Includes all freight shipments via all modes except LOGAIR/QUICKTRANS.

DOD freight loss and damage claims for ammunition and explosives amounted to 191 claims for a value of $1,185,872 of the total 6,646 claims in the amount of $4,049,227 entered against commercial CONUS carriers for all commodities during Fiscal Year 1972. These claims for ammunition and explosives loss and damage during this period amounted to 29 percent of the total value of all claims. Damage reported as caused by inadequate blocking and bracing for Fiscal Year 1972 ammunition and explosives shipments amounted to 30.3 percent, while 14.7 percent were attributed to rough handling and 5 percent were caused by improper loading or stowing.

DOD freight loss and damage claims for ammunition and explosives amounted to 108 claims for a value of $143,253 of the total of 5,311 claims in the amount of $2,856,121 entered against commercial CONUS carriers for all commodities during Fiscal Year 1973. These claims for ammunition and explosives loss and damage amounted to 5.0 percent of the total value of all claims. Damage reported as caused by inadequate blocking and bracing for Fiscal Year 1973 ammunition and explosives shipments amounted to 10.6 percent, while 8.4 percent were attributed to rough handling and 10.3 percent were caused by improper loading or stowing.

These figures show an encouraging decline in the number of incidents but, from the data available, it is not possible to determine whether this is the result of improved safety procedures or whether it is directly related to a decline in the total number of shipments of such materials.

The total number of rail accidents (national) involving hazardous materials in CONUS from 1958 to 1969 for commercial and military movements is given in Table 4.

Table 4. Rail Accidents (National) Involving Hazardous Materials in CONUS (Commercial and Military)

CY	Instances	Fires	Explosions	Persons Killed	Persons Injured	Property Loss
1969	598	43	2	10	147	$6,527,758
1968	517	21	0	0	3	1,376,027
1967	457	32	2	0	10	2,248,268
1966	450	31	2	0	1	2,602,714
1965	466	36	3	0	22	1,305,687
1964	516	20	0	0	18	1,103,726
1963	538	25	0	0	56	617,932
1962	359	25	1	0	11	275,413
1961	349	25	1	0	11	380,548
1960	364	36	0	1	9	2,449,956
1959	346	35	0	10	52	950,323
1958	322	40	3	0	6	2,329,112

Figure 1 illustrates an accident that occurred on 29 June 1969, involving 750-pound bombs in railcars, which exploded at Tobar, Nevada. The flagman heard a loud explosion and saw a large ball of flame, followed by black smoke, erupt from the upper portion of the 61st car. He immediately opened the air brake valve in the caboose, applying the brakes in emergency, and stopped the train within 4,200 feet. While the train was coming to a stop another explosion occurred in the 61st car. In addition to the damage shown, the series of explosions that occurred after the train stopped disintegrated four cars of unfused demolition bombs and injuries occurred to two train employees and to two unauthorized

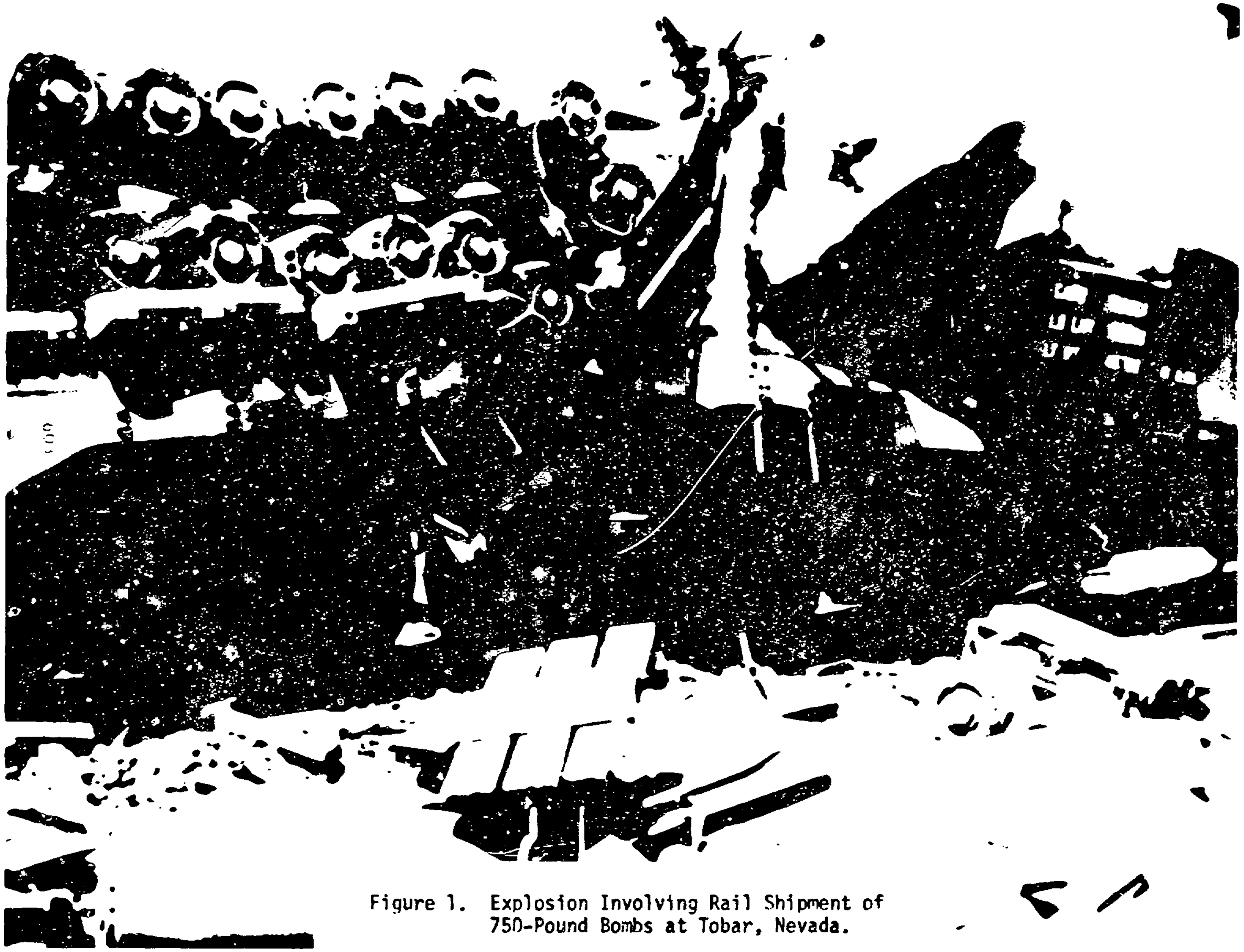

Figure 1. Explosion Involving Rail Shipment of 750-Pound Bombs at Tobar, Nevada.

transients riding the train. Four craters about 30 feet long, 20 feet wide, and 8 feet deep were blown into the track structure and ground at the locations where the four cars stopped. The cause of the explosions could not be determined. It was postulated that there was a possibility that the floor at one end of the 61st car collapsed because of a floor-stringer failure, permitting a bomb pallet to drop in such a manner that a bomb rested against a rotating axle and/or wheel, and subsequently exploded as a result of being subjected to friction heating in excess of 350° F., causing the bomb to deflagrate and the resulting fire to trigger off the subsequent explosions.

DEPARTMENT OF DEFENSE EFFORTS TO IMPROVE SAFETY DURING TRANSPORTATION

In order to reduce the risk and probability of potential hazards during transport of ammunition, explosives, and other hazardous materials, the basic factors listed in Table 5 must be considered.

Table 5. Basic Factors to be Considered to Reduce the Risk and Probability of Accidents

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1. Relative Hazard Potential of the Item or Material.
2. Packaging Performance Standards.
3. Adequacy of Transportation Equipment and Restraint Systems.
4. Consideration of the Effects of Transportation Environments.

In light of these considerations, safety during transportation of ammunition, explosives, and other hazardous materials is provided in part by insuring that packages are constructed of adequate materials;

meet structural and containment requirements; have adequate lifting devices and slinging and tiedown attachments; and that adequate blocking, bracing, and tiedown devices have been provided to insure proper restraint of the cargo.

The Joint DOD Engineering for Transportability regulation identified as Army Regulation 70-44, Navy OPNAV Instruction 4600.22, Air Force Regulation 80-18, Marine Corps Order 4610.14A, and Defense Supply Agency Regulation 4500.25, gives actions to be taken to achieve compatibility of military material with existing and foreseen transportation systems through transportability. Each of the services has designated a transportability agent to implement the DOD program. Transportability is defined as follows:

TRANSPORTABILITY is the capability of efficiently and effectively transporting an end item of military equipment, or component thereof, over railways, highways, waterways, oceans, and airways, either by carrier, towed, or by self-propulsion.

There are three major elements of responsibility involved in this effort, as listed in Table 6. The Army carries out these responsibilities as they apply to land transportation, inland waterway, Army air, and ocean terminals; the Navy acts in the field of ocean transportation; and the Air Force performs the responsibilities as they apply to commercial and Air Force air transportation.

Table 6. Major Responsibilities of Appropriate Military Departments

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1. Issue Transportability Criteria.
2. Insure the Conduct of Transportability Field Tests.
3. Issue Transportability Guidance With Emphasis on Safety During Transportation.

The Joint Engineering for Transportability Regulation (AR 70-44) contains the three major policy statements given in Table 7.

Table 7. Three Major Policy Statements of Joint Regulation

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1. Blocking, bracing, slinging, and tiedown procedures will be developed to insure safe delivery of materials concurrently with development and test of the item.
2. Transportability includes the adequate accommodation of materials that have fragile, sensitive, and/or dangerous characteristics either of themselves or to other items during transportation.
3. Safety will be a primary transportability objective. The general well-being of communities will receive primary consideration in this area of concern.

A transportability evaluation is required by Joint AR 70-44 for all transportability problem items when designing new items of material, or when modifying existing items of material including commercially adopted material. A transportability problem item is an item of equipment that when in its proposed shipping configuration may be denied movement because of its size, weight, or fragile or dangerous characteristics. Transportability problem items require special equipment or handling, or are delayed when moving within existing or newly designed transportation systems, or may be unaccepted for transport. The criteria for identification of a transportability problem item are contained in paragraph 12, Appendix A, Joint AR 70-44. A transportability report (request for a transportability evaluation) is prepared by any military activity responsible for design, development, procurement, or modification of material, or by their contractor on those items identified as a transportability problem item. The report will be submitted to the transportability agent (MTMC for the Army; Naval Supply Systems Command for the Navy; AFSC for the Air Force; Commandant, Marine Corps; or DSA), for evaluation and appropriate guidance. Information required is given in paragraph 13, Appendix A, Joint AR 70-44. The report will identify the problem items' transportability characteristics. MTMCTEA, Newport News, Virginia, as the transportability operating agent for MTMC, will make these transportability evaluations for the Army. Request should be submitted as soon as the pertinent transportability characteristics are known but not less than 3 months prior to a movement to provide sufficient time for analysis.

Ammunition and explosives are classified according to definition and results of test procedures specified in DOD and DOT regulations. They are categorized in three different degrees of hazard: Class A is a detonation hazard; Class B is a fire hazard; and Class C is a minimum hazard. Compatibility of ammunition, explosives, and other hazardous materials by all modes of transportation is most important. The provisions of the Loading and Storage Charts in the DOT and US Coast Guard regulations must be complied with to insure safe transport of these materials.

Highway shipments of Class A and Class B explosives must be tendered only to those motor carriers authorized by MTMC. Additionally, these authorized carriers must comply with the provisions specified in a written agreement between the carrier and MTMC, which contains clauses specified in AR 55-355 MTMR. When shipments of Class A and B explosives are prepared for highway movement only, it is most essential that the applicable Bill of Lading be annotated "Substitute Service Not to be Used." This is a preventive measure to preclude the possibility of the shipment being placed in trailer or flatcar (TOFC-Piggyback) rail service, an environment where blocking, bracing, and tiedown procedures used for highway modes would be inadequate. Chapter 216 of AR 55-355 MTMR outlines such requirements in this area.

The military utilizes air taxi service for small shipments of explosives and only those air carriers authorized by MTMC will be used by military shippers. There is considerable concern by Congress and the DOT with regard to transport of hazardous materials by commercial air.

For more than 25 years, the Bureau of Explosives, an element of the Association of American Railroads (AAR), has worked with both the Army and Navy in the development of blocking, bracing, and tiedown restraint procedures for ammunition and explosives. Certain principles and standards have been developed that may be applied to many given items, but it is still necessary to conduct actual transportation tests on many containers. For the most part, and to insure safety during transportation, the military issues loading drawings for individual ammunition and explosive items, including missiles. Both the Army and Navy develop outloading drawings for the Air Force, as per their request. Military outloading drawings are developed at the AMC Ammunition Center, Savanna Army Depot; and the Naval Weapons Handling Laboratory, Naval Ammunition Depot (NAD), Earle, New Jersey. When these drawings are officially approved, they are issued to the field where the transportation officer becomes involved. Here again is another area that requires strict compliance. The same requirements apply to the following illustrations and rules contained in the applicable Bureau of Explosives pamphlets.

Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) provides the DOD representative to the Association of American Railroads for the rules governing the loading of DOD materials on open top railcars. Shippers of DOD hazardous materials desiring to deviate from the AAR loading rules or desiring new rules or revisions of or additions to the present rules, figures, or specifications, must submit such proposals to the Military Traffic Management Command Transportation Engineering Agency, Newport News, Virginia 23606, through appropriate command channels. Proposals are reviewed for adequacy and conformance with established procedures, coordinated, and processed for approval by the AAR. When required, MTMCTEA provides DOD interface for closed railcar shipments.

For an effective military transportability program, coordination is not only essential among the responsible elements of the DOD, but also with the transportation industry, particularly in the mutual interest of utilizing advanced transportation developments. MTMC maintains liaison with the DOD Explosives Safety Board (DODESB) on problems related to accidents with explosives involving commercial carriers. Accordingly, liaison is also maintained with the American Trucking Association and the terminal industry.

Packaging and transportation of hazardous materials are the outgrowth of many years of experience in shipment of ammunition and explosives and exhausting research and tests. In the interest of safety, packaging and transportation of hazardous materials must not only be fully capable of protection to contents, but also be practical from the standpoint of cost, cube, and gross weight. These are only a few of the prime areas of consideration in the current containerization of ammunition for transportation studies being conducted by the military.

MTMCTEA is actively engaged in a program to develop transportability criteria and guidance for hazardous, oversize, overweight, fragile, and sensitive materials for movement by highway, rail, Army air, inland waterway, and logistical amphibious and for terminal handling. Some recent projects affecting military ammunition and explosives transport are described in the following paragraphs.

MTMCTEA participated in the development of shipping procedures for eight different types of ammunition that were used in the initial DOD test shipment in Sea-Land shipping containers to the Republic of Vietnam

(RVN).[1] Two containers were instrumented to measure shock and vibration environments during the entire move. The movement originated at Doyline, Louisiana, and encompassed highway transport to Port Chicago, California; terminal handling at Port Chicago; ocean voyage to Cam Ranh Bay, RVN; handling at Cam Ranh Bay; barge movement to Qui Nhon; unloading at Qui Nhon; and, finally, highway movement by military convoy to a forward ammunition supply point at Pleiku. Good shock and vibration information was obtained during the entire movement. Maximum g values were: vertical 10+, lateral 1.3, and longitudinal 5.0. These maximum values occurred during the highway movement to Pleiku over asphalt and gravel-surfaced roads.

A transportation systems analysis was made by MTMCTEA of the Naval Ammunition Depot, Earle, Colts Neck, New Jersey,[2] to determine problems and recommend solutions concerning materials handling equipment, motor freight, and rail systems; cargo processing and temporary storage procedures; inspection of transportation equipment and cargo; depot roadways; and repair parts availability.

A transportation engineering study was made by MTMCTEA of the Military Ocean Terminal, Sunny Point (MOTSU), Southport, North Carolina,[3] to determine the throughput capability of the terminal under various operating conditions. The purpose of the analysis was to reveal constraints that could be reduced or removed to increase the terminal capability. This report was published in July of this year.

Latest Army explosives stowage techniques for marine transport were documented by MTMTS Pamphlet 55-6, entitled <u>Loading and Securing of</u>

Military Explosives Aboard Merchant-Type Ships. The pamphlet specifies techniques for the safe and economical securement of military explosives on conventional break-bulk ships. Presently, procedures defined therein are being applied to contract negotiations and in the instruction of personnel at the Army's major explosives shipping activity, the Military Ocean Terminal, Sunny Point (MOTSU), North Carolina.

MTMCTEA served as a contributing member of a working group to prepare a joint service publication specifying uniform procedures for securing explosives aboard ships. This joint publication will consolidate and replace MTMTS Pamphlet 55-6 and NAVORD OP 3221. The draft report is nearing completion and should be available for coordination by 15 August 1974.

AREAS REQUIRING ADDITIONAL RESEARCH

Although much has been done to improve safety during transportation of ammunition and explosives, additional research is needed to assure that requirements are realistic and adequate. Areas requiring additional research are given in Table 8.

Table 8. Areas Requiring Additional Research

1. Shock and Vibration.
2. Test Standards.
3. Temperatures, Pressures, and Humidities Encountered in Transportation.
4. Types of Accidents and Incidents Creating Critical Impacts Occurring in Transportation.
5. Risk Analysis Related To Transportation Accidents.

MTMCTEA and other military research workers have developed environmental criteria for shock and vibration by air, highway, rail, and sea modes of transportation. The following data, based upon transportation engineering tests and analyses of maximum accelerations during instrumented shipments, representing the most severe shock and vibration environment to be expected in the mode indicated, are recommended as interim criteria pending the development of more refined values.

a. Air shock. 12g's at 0.1 second (vertical).

b. Air vibration. From 5g's at 5 cps to 9g's at 1,000 cps (vertical, lateral, and longitudinal).

c. Highway shock. 10g's at 0.083 second (vertical and lateral).

d. Highway vibration. From 2g's at 2 cps, to 9g's at 7 cps, to 2-1/2g's at 50 cps (vertical).

e. Rail shock. 50g's at 0.011 second; 30g's at 0.064 second (vertical and longitudinal).

f. Rail vibration. From 4.8g's at 5 cps to 3.5g's at 350 cps (vertical and lateral).

g. Sea shock. 1.5g's at 0.044 second (vertical and lateral).

h. Sea vibration. 0.8g at 0.8 cps to 14 cps (vertical and lateral).

The ranges of shock and vibration in the different modes are, of course, subject to change as technology progresses. Consequently, it is necessary to survey these environments continually to detect trends that may affect packaging and cargo securement requirements. The criteria may require change as a consequence of new research.

Test standards have been written by MTMCTEA for Army air, highway, rail, and terminal modes of transport. A transportability criteria Military Standardization Handbook with test standards included is being written by MTMCTEA and should be published during Fiscal Year 1975.

MTMCTEA has monitored shipments from the MH-1A Sturgis floating nuclear power plant for the environmental effects of temperature, pressure, and humidities encountered in transportation of radioactive materials by highway and sea modes of transport. Other shipments of radioactive, ammunition, and explosives, and other hazardous materials have been monitored by Army air and other modes of transport. Information obtained during the monitoring of these shipments has enabled refinement of criteria. However, further research and development in this area are required.

A joint study was conducted by the Atomic Energy Commission and Department of the Army on the transportation of fissile and radioactive materials to determine scientifically the effects of a serious transportation accident on the cargo, vehicle restraint, and total transport system. Tests were made in which two tractor-semitrailer combinations loaded with containers for radioactive materials, AEC birdcage container assemblies, and irradiated spent fuel casks were crashed into a barrier. During these tests, information and experience were obtained to provide criteria and guidance in future tests for evaluating the dynamics of a system. Further research and development should be conducted to determine the effects of rear-end crashes and overturns and right-angle collisions of vehicles loaded with inert ammunition and inert explosive containers.

The National Transportation Safety Board considers that the development of methods for quantifying the risk levels created by the movement of dangerous goods in transportation systems appears to be technically feasible. The US Coast Guard within the DOT has produced a noteworthy study of a model containing approaches to development of an analytical framework and methods that bear on this problem. This work is contained in an unpublished study entitled "Estimating the Damages Presented to Ports and Waterways From the Marine Transportation of Hazardous Cargoes: An Analytical Model," 12 December 1969. Similar studies should be made for the other modes of transportation. Use of technology and approaches utilized in system safety should be used in solving problems associated with transportation. Considerable research and development are needed in this area.

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CHANGES TO 46 CFR 146.29 (CG-108)

Ensign D. A. Riikonen, USCG
HQ, U. S. Coast Guard
Washington, D. C.

GOOD AFTERNOON, MY NAME IS DAVID A. RIIKONEN. I AM AN ENSIGN IN THE UNITED STATES COAST GUARD, PRESENTLY ASSIGNED TO THE CARGO AND HAZARDOUS MATERIALS DIVISION AT COAST GUARD HEADQUARTERS IN WASHINGTON, D. C. WHERE MUCH OF MY TIME IS SPENT WITH THE COAST GUARD'S EXPLOSIVES REGULATIONS.

THE COAST GUARD HAS HAD AN ACTIVE ROLE IN THE SAFE TRANSPORTATION OF MILITARY EXPOLSIVES SINCE OCTOBER 1942, WHEN THE FIRST SET OF RULES AND REGULATIONS FOR MILITARY EXPLOSIVES AND HAZARDOUS MUNITIONS WERE ISSUED. THESE REGULATIONS, MORE COMMONLY REFERRED TO BY THE COAST GUARD PUBLICATION NUMBER: CG-108, HAVE BEEN AMENDED AND REVISED MANY TIMES SINCE 1942, HOWEVER THE ORIGINAL FORMAT IS STILL INTACT. IN CG-108, MILITARY EXPLOSIVES ARE DIVIDED INTO 28 CLASSES FOR THE PURPOSES OF COMPATIBILITY AND SEGREGATION ON BOARD VESSELS. IN ADDITION, TWO OF THE 28 CLASSES, CLASS XIC AND CLASS XID, ARE SUBDIVIDED INTO 27 SPECIAL CLASSES WHERE ADDITIONAL SEGREGATION IS REQUIRED.

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THE COAST GUARD, THROUGH ITS INVOLVEMENT IN THE DEVELOPMENT OF INTERNATIONAL EXPLOSIVES REGULATIONS HAS RECOGNIZED THE COMPLEXITY OF THE COMPATIBILITY TABLES IN CG-108 AND HAS EMBARKED ON A MAJOR REVISION OF THESE REGULATIONS IN ORDER TO CORRECT THIS AND OTHER PROBLEM AREAS. IN REVISING THE MILITARY EXPLOSIVES REGULATIONS IT IS PLANNED TO ADOPT THE UNITED NATIONS RECOMMENDATIONS FOR EXPLOSIVES COMPATIBILITY. THIS WILL SIMPLIFY THE COMPATIBILITY TO 12 GROUPS AND PROVIDE STANDARD DEFINITIONS FOR EACH COMPATIBILITY GROUP, THUS

ELIMINATING THOSE ITEMS WHICH SHOULD BE HANDLED AS OTHER REGULATED CARGO. THE ITEMS PRESENTLY IN CLASSES XIC AND XID, AS WELL AS CERTAIN ITEMS IN THE OTHER CLASSES, ARE NOT EXPLOSIVE AND SHOULD CORRECTLY BE REGULATED ACCORDING TO THE ACTUAL HAZARD OF THE COMMODITY. IN CONJUNCTION WITH THE ADOPTION OF THE U.N. COMPATIBILITY GROUPS IT IS ALSO PLANNED TO ADOPT THE SEGREGATION CRITERIA RECOMMENDED BY U.N. THIS CHANGE PARELLELS SIMILAR CHANGES BEING PROPOSED FOR ALL OTHER CLASSES OF REGULATED CARGOES. TOGETHER THESE TWO CHANGES WILL PROVIDE A CONSISTENT APPROACH TO THE STOWAGE, SEGREGATION AND COMPATIBILITY OF ALL DANGEROUS CARGOES ON AN INTERNATIONAL SCALE, WITH ONE EXCEPTION.

AS YOU PROBABLY KNOW THE COAST GUARD'S DANGEROUS CARGO REGULATIONS CONTAIN TWO SETS OF EXPLOSIVES REGULATIONS - THE COMMERCIAL EXPLOSIVES REGULATIONS AND THE MILITARY EXPLOSIVES REGULATIONS CONTAINED IN SUBPARTS 146.20 AND 146.29 RESPECTIVELY. AS YET THE U.N. COMPATIBILITY RECOMMENDATIONS HAVE NOT BEEN PROPOSED FOR THE COMMERCIAL EXPLOSIVES REGULATIONS. THIS IS DUE, IN PART, TO THE INTERFACE OF COAST GUARD REGULATIONS WITH OTHER REGULATIONS IN TITLE 49, AND THE NATURE OF THESE TWO TYPES OF EXPLOSIVES. IN GENERAL COMMERICAL EXPLOSIVES PRESENT A MASS EXPLOSIVE RISK WHILE MILITARY EXPLOSIVES PRESENT A PROJECTILE OR MISSILE HAZARD. ONCE THE PROBLEM CREATED BY THESE DIFFERENCES IS RESOLVED, THE U.N. COMPATIBILITY WILL BE APPLIED TO THE COMMERICAL EXPLOSIVES REGULATIONS, AND IDEALLY, THE VARIOUS EXPLOSIVES REGULATIONS WOULD BE COMBINED TO PROVIDE ONE SET OF REGULATIONS FOR ALL EXPLOSIVE CARGOES TRANSPORTED BY VESSEL.

THE IMPACT ON SAFETY BY THIS REGULATORY ACTION IS OBVIOUS. SHIPMENTS OF EXPLOSIVES BY WATER ARE PREDEMINATELY INTERNATIONAL VOYAGES AND, AS OF JANUARY 1974, 21 COUNTRIES HAVE ADOPTED THESE SAME RECOMMENDATIONS FOR THEIR NATIONAL SHIPPING REGULATIONS. THEREFORE, IT BEHOOVES THE UNITED STATES TO HAVE AN INTERNATIONAL COMPATIBLE SYSTEM FOR THE MARKING, LABELING PACKAGING AND STOWING OF EXPLOSIVES.

THE WORK ON REDRAFTING THE MILITARY EXPLOSIVES REGULATIONS IS BEING DONE WITH GUIDANCE FROM THE DOD ESB. I HAVE AVAILABLE SEVERAL COPIES OF THE EXISTING REGULATIONS IF ANYONE IS INTERESTED IN THEM. BOTH MYSELF AND THE BOARD, WOULD APPRECIATE ANY CONSTRUCTIVE COMMENTS YOU COULD MAKE TO HELP US IN THIS ENDEAVOR. THANK YOU.

THE IMPACT OF HAZARD IDENTIFICATION NUMBERS ON EXPLOSIVES SAFETY IN TRANSPORTATION

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Recent efforts by the Department of Transportation to bring the Hazardous Materials Regulations into conformity with international regulations have resulted in a series of dockets which if accepted in their proposed form will have a considerable impact on present methods of marking, packaging, and labeling hazardous materials.

One such proposed change is Docket No. HM-103; Notice No. 73-10, titled Hazard Information System and Miscellaneous Proposals; Notice of Proposed Rule Making, dated 24 January 1974, in the Federal Register.

Addressing itself to specific deficiencies in documentation, the Hazardous Materials Regulations Board stated in its preamble: "...[T]he communications requirements of the regulations (1) generally are not addressed to more than one hazard; (2) do not in all instances require disclosure of the prescence of hazardous materials in transport vehicles; (3) are not addressed to the different hazard characteristics of a mixed load of hazardous materials; (4) do not provide sufficient information whereby fire fighting and other emergency response personnel can acquire adequate immediate information to handle emergency situations; and (5) are inconsistent in their application to the different modes of transport."

The Hazard Information System is two-fold; first, hazardous materials will be amended to include a Hazard Identification Number: 01 for Dangerous, 05 for Irritant, 15 for Explosive C, 17 for Explosive B, 19 for Explosive A, through 85 for Corrosive. The format of the present labels will be changed to permit a "Hazard Information Number Block" which appears directly below the printing of the hazard class. Placards will follow the format of the labels to include the hazard identification numbers. Secondly, a pamphlet containing the fire prevention, spill or leak, and first aid measures to be employed in case of accidents during transportation will be made available to each person involved in the transportation of hazardous material. This pamphlet will be keyed to each Hazard Identification Number by label type for quick identification.

The Board was asked to consider incorporation of "A Recommended System for the Identification of the Fire Hazard of Materials," also referred to as the NFPA 704M System into regulations. This was rejected as the 704M System is oriented toward storage and handling. Furthermore, the Board rejected the contention of the International Association of Fire Chiefs (IAFC) that the 704M System identifies the nature of the hazard or the potential degree of severity. It is the position of the Board that the Hazard Information System satisfies these requirements.

The intent of this measure is clear: hazardous material labels in their present form do not provide the information necessary to cope with specific hazards connected with a class of hazardous material. To correct this, specific hazard identification numbers will identify specific hazards. For example, the proposed change calls for seven numbers to identify flammable liquids, nine numbers to identify flammable solids, five for poisons, etc. To again quote the Board: "...[T]he use of the hazard information numbers would serve to tie together and authenticate communications of the hazards of materials on shipping papers, labels, placards, the hazard information cards, and verbal communications to [assist] personnel who may or may not go to the site of an incident." A proposed commodities list which assigns a hazard identification number to each article is contained in Docket No. HM-112; Notice No. 73-9, titled Consolidation of Hazardous Materials Regulations and Miscellaneous Proposals, dated 24 January 1974. It is assumed that Dockets HM-103 and HM-112 will become effective simultaneously thus easing the transition to the new system. It should be noted that proposed Section 172.401 exempts labels applied to a package in conformance with any United Nations Recommendation (including the entry of the class number below the hazard information number block) or the Inter-Government Maritime Consultative Organization (IMCO) requirements. This is especially applicable to import/export shipments to/from Europe. The consolidation of the hazardous materials regulations into Title 49 of the Code of Federal Regulations will introduce the hazard identification numbers into motor, rail (railway express), air, and water transportation. Thus, the impact of this system will be felt by all three modes. This uniformity in effect is the Docket's greatest strength for it simplifies the documentation required in inter-modal shipments.

The main drawback of this system will be its complexity. As the effect of these changes will be felt by firefighters, police, and other emergency personnel, in addition to transportation personnel, a massive re-education campaign will be required if the system is to be effective.

Since Docket HM-8 introduced the UN system of labeling in 1968, the Department of Transportation has slowly abandoned a national system of labeling in favor of an international system. By 1 January 1975, all hazardous materials labels will follow the UN system. But the hazard information system is not recognized by the UN Recommendations. Inclusion of the class/division compatability code is still recommended. Thus, relabeling of commodities, which HM-8 is supposed to alleviate, is still a possibility. The prospect exists for the abandonment, by the Coast Guard, of CG 108 in favor of the IMCO requirements. This is a great step toward international conformity of hazardous materials regulations. The adoption of Dockets 103 and 112, and especially the adoption of the provisions of proposed section 172.401, will be equally important in permitting the freer flow of materials around the world.

INFLUENCE OF BURST POSITION ON AIRBLAST, GROUND SHOCK AND CRATERING IN SANDSTONE

by

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Summary

Seven 1,000-lb nitromethane spheres were detonated at different height/depths of burst with respect to the surface of a sandstone rock mass near Grand Junction, Colorado. The purpose of the tests was to study the effects of burst position on airblast, ground shock and cratering phenomena. Primary interest was in ground shock.

Ground motions were measured directly beneath the charges to maximum depths of 60 feet and at several locations near the ground surface within 100 feet. Airblast pressure-time histories were measured along the rock surface at five stations extending to the 10 psi level. Postshot surveys were made to determine apparent and true crater dimensions. Results showed a strong dependence of burst position on crater dimensions, horizontal motions near the surface and peak airblast pressure. The most influential range of charge elevations was from two charge radii above the surface to two charge radii below the surface. Airblast, crater and ground motion parameters were normalized and plotted as functions of normalized charge elevation to provide a direct and simple assessment of charge position effects.

Introduction

Effects of ground shock, cratering and airblast are very sensitive to charge position for near-surface bursts. Results of previous high explosive tests indicate large increases in motion magnitudes and crater dimensions as the height of burst is varied from slightly elevated to buried configurations. This strong dependence is caused partly by the increase in contact area between the explosive and the ground.

Project CENSE (Coupling Efficiency of Near Surface Explosions) is a high explosive test program sponsored by the Office, Chief of Engineers to study systematically the effects of burst position on ground shock, cratering and airblast in varying geologies. Primary interest is the ground motion directly beneath the charge and the strong surface motions near the explosion. The first phase of a series of tests was conducted in a nearly homogeneous sandstone in the autumn of 1973 near Grand Junction, Colorado. This series consisted of detonations of seven 1000-lb nitromethane spheres. Burst positions relative to the center of the charge were $-4R_c$, $-R_c$, $-0.5R_c$, 0, $+0.5R_c$, $+R_c$, $+7R_c$ depths (heights) in units of charge radii ($R_c = 1.5$ feet). Figure 1 shows the experimental geometry and event number designations for the various tests. Vertical motion gages were located on-axis directly beneath each charge. A radial array of two-component (vertical and horizontal) motion sensors were placed near the ground surface at fixed ranges from ground zero. These ranges were determined by expected surface airblast overpressures of 150, 70, 30, 15 and 10 psi for the elevated bursts. Airblast gages were placed along the rock surface directly over the near surface motion instruments on all but the deeply buried configuration (where airblast levels were trivial).

This paper presents an analysis of the results of the CENSE I experiments in terms of the relative enhancement (or suppression) of the primary explosion effects resulting from the degree of explosive containment. Coupling factors, defined as the ratio of an effect magnitude to that for a standard containment condition, are introduced as a measure of this

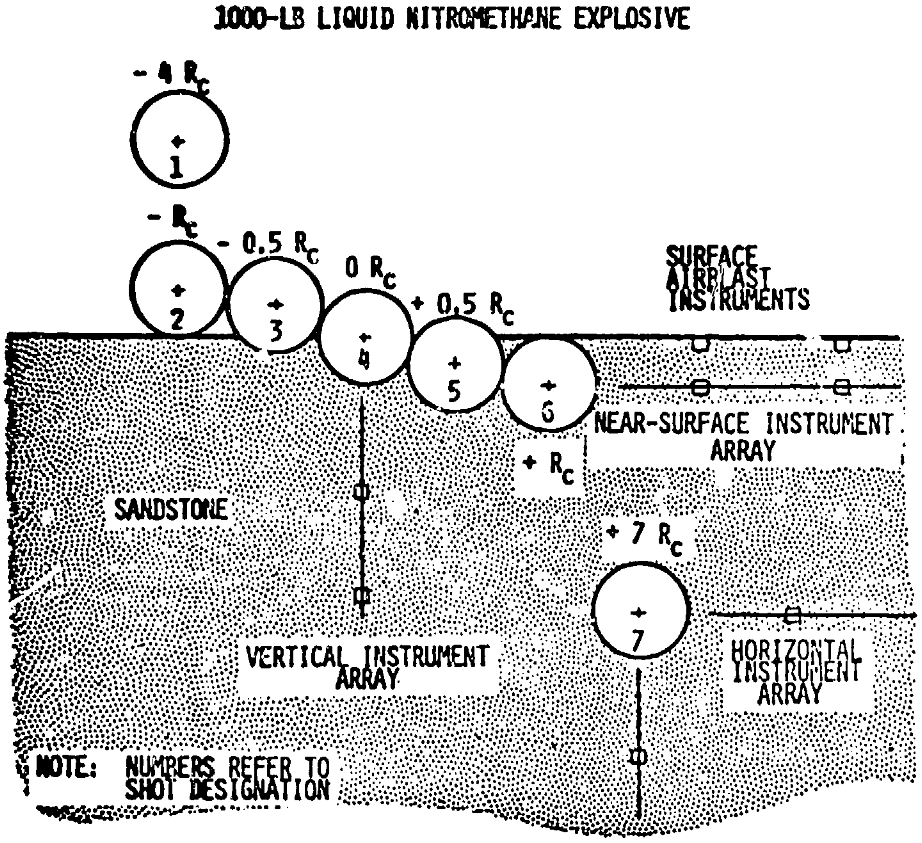

Figure 1. CENSE-I Experimental Plan.

enhancement and to simplify the data presentation. Specific coupling factors for the various effects are defined as:

Airblast factor, F_a

$$F_a = \frac{\text{Surface overpressure}}{\text{Standard free-air pressure}}$$

Ground shock factor, F_u

$$F_u = \frac{\text{Peak horizontal particle velocity}}{\text{Peak radial velocity for full containment (DoB} = 7R_c)}$$

Cratering factors

$$F_r, F_d, F_v = \frac{\text{True crater dimensions}}{\text{True crater dimension for full containment (DoB} = 7R_c)}$$

Near-Surface Ground Motion

Particle velocities were measured with vertical and horizontal sensors near the rock surface at fixed ranges from ground zero (36, 48, 65, 85 and 100 feet) for all tests. The gages were two feet deep for all tests except the fully-contained burst (Shot 7); for this test they were located at shot depth.

The most consistent motion parameter which best illustrated containment effects was the horizontal particle velocity. A composite plot of the horizontal particle velocity waveforms at the 48 foot range for all burst positions is shown in Figure 2. These normalized waveforms, which

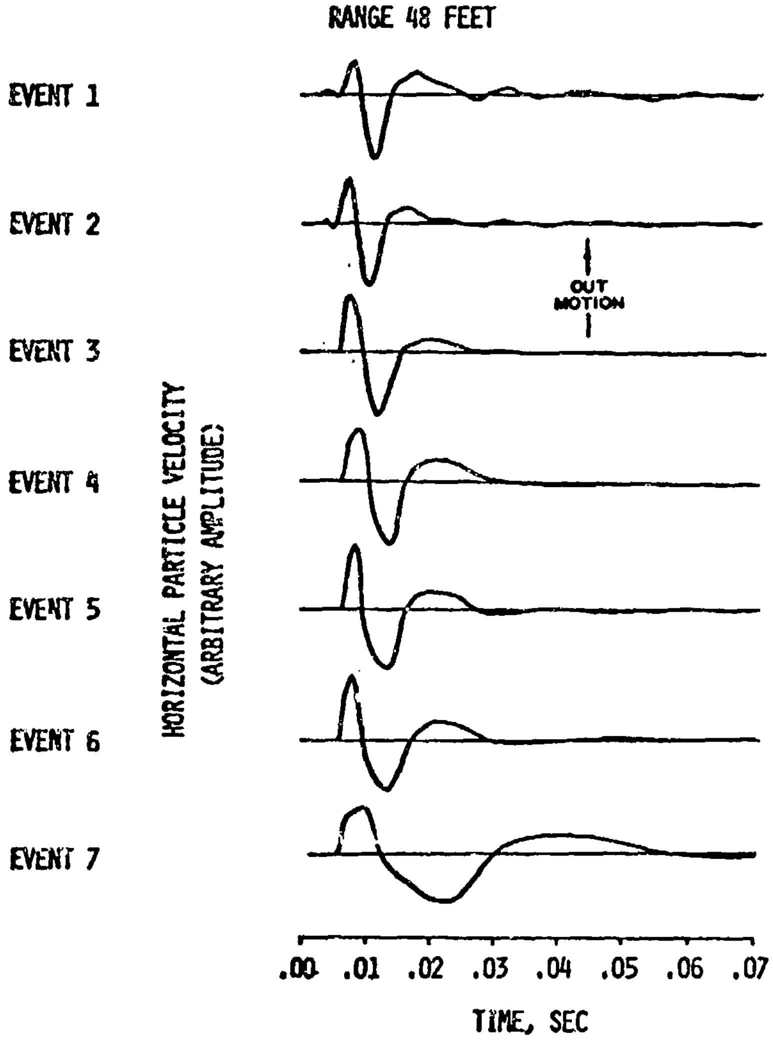

Figure 2. Near-Surface Horizontal Particle Velocity Waveforms at 48 ft Range.

are typical of those at other ranges, show a slight increase in the characteristic pulse width (duration) with increased containment. The most dramatic increase occurred when the blast was fully contained. This figure clearly demonstrates that burst position does not change the characteristic horizontal particle velocity waveform; however, large increases in peak amplitude were noted with increasing containment.

A parametric plot of peak horizontal particle velocity versus scaled range for the various charge containments is shown in Figure 3. Scaled range is defined as the actual range divided by the cube root of the charge weight and expressed in units of $ft/lb^{1/3}$. This scaling law allows for data correlation and extrapolation for different explosive weights.

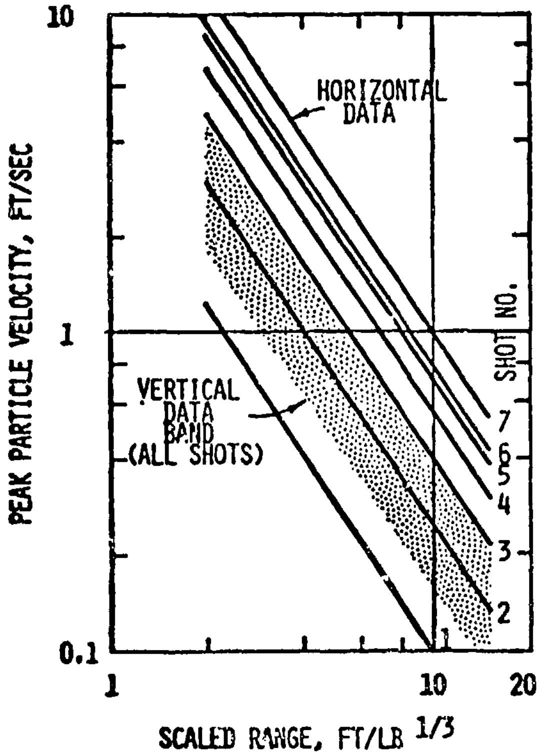

Figure 3. Peak Particle Velocity Versus Scaled Range as a Function of Charge Containment.

Data trends, shown as lines of approximately equal slope, show a tenfold increase in peak horizontal velocity when the charge containment was varied from slightly elevated (-4R_c) to full buried (+7R_c). This marked increase is best described by the ground motion coupling factor F_u as shown in Figure 4. This plot shows that the greatest sensitivity of coupling occurs for the near-surface charge positions, that is, slightly elevated to slightly buried (-2R_c to +2R_c). In this region, F_u is proportional to the containment parameter. The coupling factor becomes asymptotic to its maximum value of unity for greater containment and approaches a lower limit of about 0.1 for the elevated burst positions.

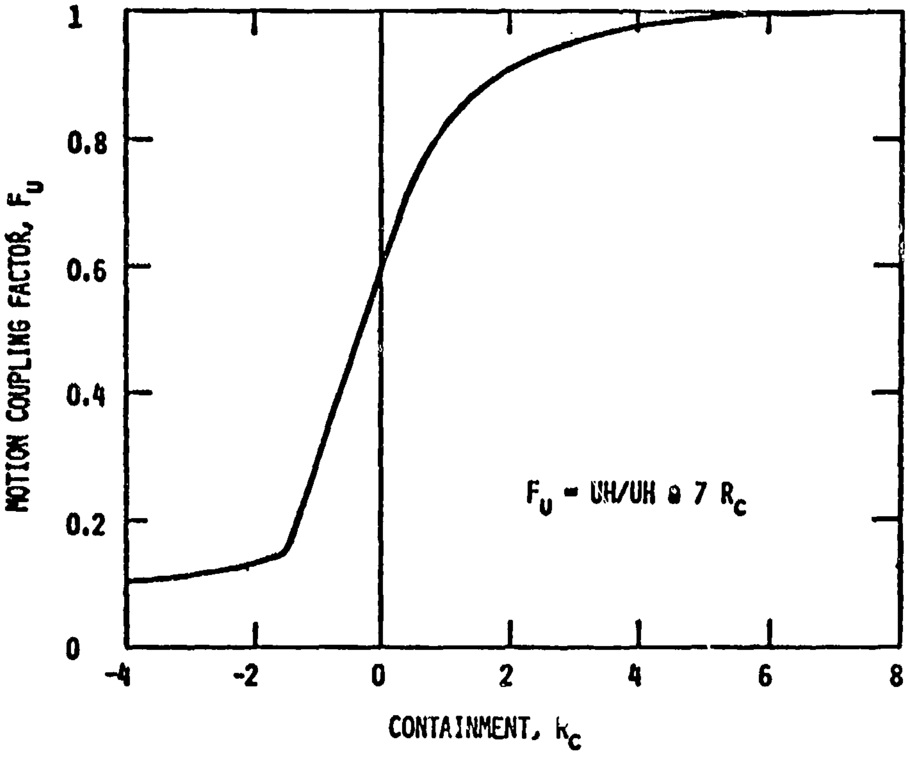

Figure 4. Motion Coupling Factor F_u, as a Function of Charge Containment.

In contrast to the strong sensitivity of the horizontal peak motions to burst position, the peak vertical particle velocities were found to be virtually independent of the degree of containment. Data spread (shown as hatched area in Figure 3) was on the order of ±50 percent of the mean with no pronounced trend associated with explosion containment. Phasing of the local airblast loading, which dominated the vertical motions, and the surface wave is believed to be the principle source of scatter in the vertical velocity data.

Surface Airblast

Surface airblast measurements were made at five ranges (36, 48, 65, 85 and 100 feet) from ground zero, corresponding to a general overpressure range of 150 to 10 psi. Airblast gages were flush-mounted in a concrete pad to minimize effects of surface roughness on the measurements. An average coupling factor for each shot was determined from the mean of the coupling factors as determined by the five measurements on each shot. In all cases the overpressure was reduced to standard temperature and pressure before comparison to the standard free air curve.

Average airblast coupling factors F_a as a function of charge containment are shown in Figure 5. Similar to the effects noted for ground motion, the airblast suppression (enhancement) was strongly influenced by the burst position in the containment region from $-2R_c$ to $+R_c$. For bursts higher than $-2R_c$ the enhancement asymptotically approached a maximum value of twice the free air condition. Suppression was substantial for burst positions within the rock where containment was greater than unity. F_a was about 1.3 for the surface burst (containment equal to zero).

The airblast coupling factor was independent of range for the relatively small spread of above-surface positions investigated; however, as the containment increased F_a became more dependent upon the specific range. Increasing containment caused a progressive flattening of the peak pressure attenuation with range. This effect limits the conclusion about airblast suppression to shallow buried bursts (containment about 1) or less. Extrapolation to greater depths of burst and ranges is not warranted with this data base.

Crater Parameters

The true crater formed by an explosion is defined as the boundary of the crater representing the limit of dissociation of the medium by the explosion (the crater prior to debris fallback). True radius, true depth and true volume are parameters used to define the true crater. As with

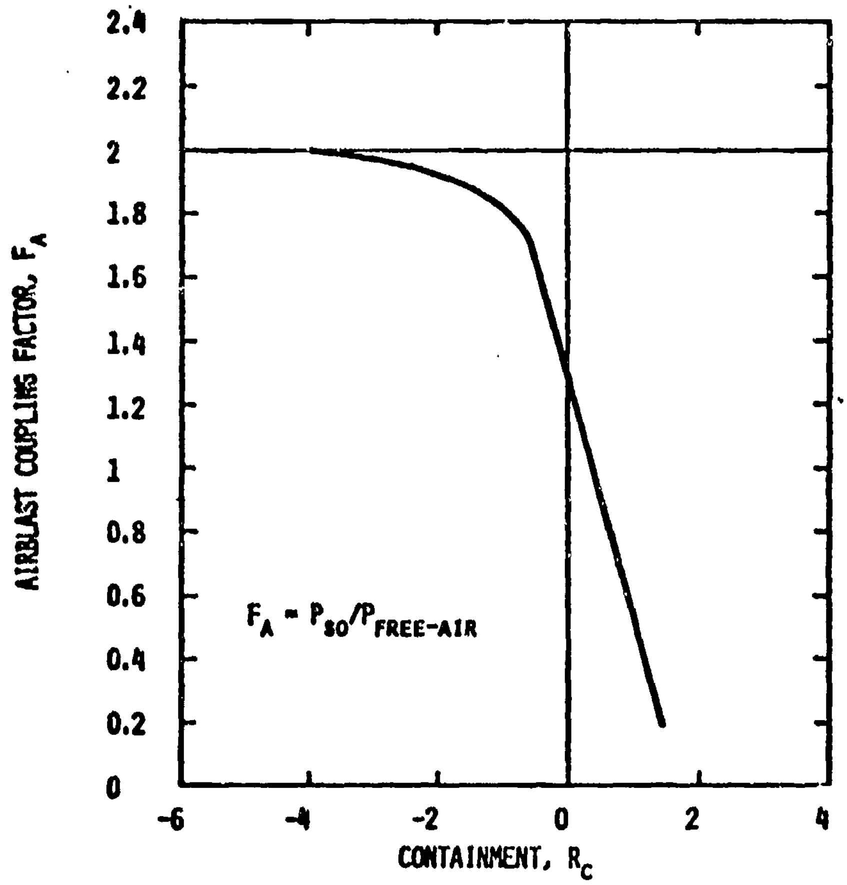

Figure 5. Airblast Coupling Factor, F_a, as a Function of Charge Containment.

motion and airblast, coupling factors best illustrate influence of burst position on crater formation. Crater parameter coupling factors as a function of charge containment are shown in Figure 6. Simple ratios were used to derive coupling factors for radius, F_r, and depth, F_d; however, a cube root ratio was used for volume, $F_v^{1/3}$, to allow convenient plotting and to show more clearly the relationship between volume and radius. As seen in Figure 6, the region of greatest crater parameter sensitivity to charge containment (burst position) was within the same bounds as that of both airblast suppression and ground motion enhancement, i.e., $-2R_c$ to $+2R_c$. The depth coupling factor was somewhat of a surprising exception to this observation. The depth factor followed the F_r and $F_v^{1/3}$ response for charge containments less than $-0.5R_c$, but was relatively independent of containment between $-0.5R_c$ and $+1.5R_c$. For containment greater than $+1.5R_c$ the crater depth factor followed a similar, but lower-valued curve. This result can perhaps be re-stated as follows: the true crater depth remained essentially constant for charge burials from $-0.5R_c$ to $+1.5R_c$; the increase in true crater volume resulted from increasing crater radius with depth of burst.

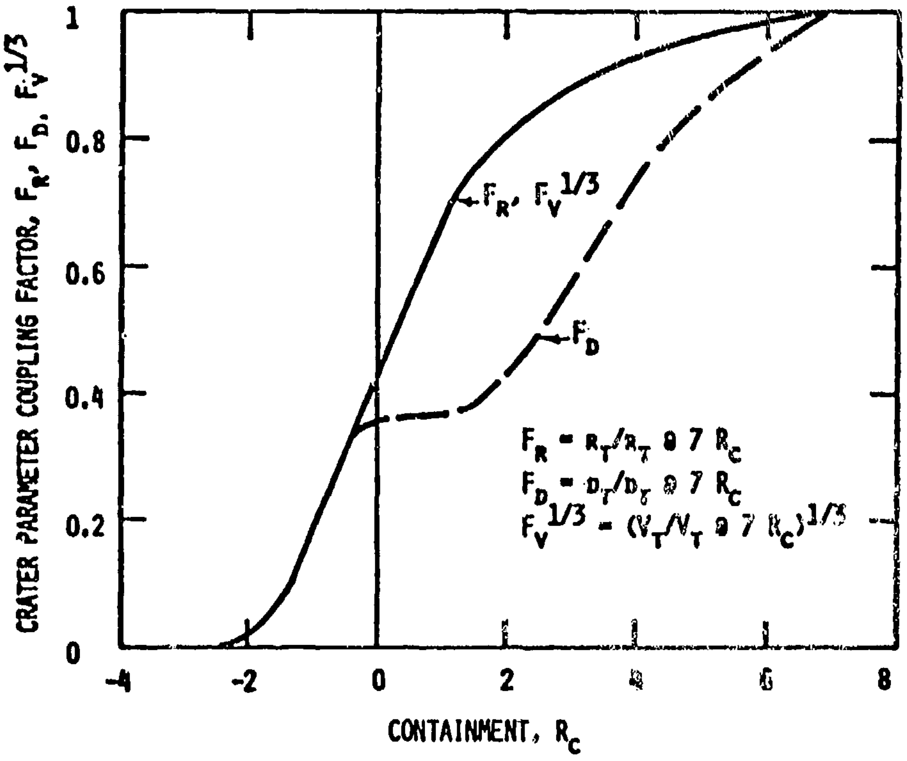

Figure 6. Crater Parameter Coupling Factor, $F_r, F_d, F_v^{1/3}$, as a Function of Charge Containment.

Conclusions

The CENSE I experiments clearly demonstrated a strong dependence of burst position on horizontal ground motion, airblast pressures and crater dimensions for near-surface explosions over sandstone. The strongest influence was observed for burst positions ranging from two charge radii above the surface to two charge radii below the surface ($-2R_c$ to $+2R_c$). Within this interval, tenfold changes were noted in the horizontal particle motion amplitudes, airblast suppression and in the true crater radius. True crater volumes increased on the order of one-hundred fold in this range. Outside this containment interval coupling factors (as defined herein) slowly approached their respective asymptotic limits.

Two explosion effects were not as strongly dependent on the near-surface burst position; namely, the peak vertical particle velocity and the true crater depth. Peak vertical particle velocities were determined to be independent of burst containment over the broad range of burst positions tested. True crater depth was found to be essentially constant for the containment interval $-0.5R_c$ to $1.5R_c$.

Future Plans

A test series using similar charge weights and experimental procedures is being conducted in soil. Effects of geologic layering will be studied later.

DAMAGE POTENTIAL FROM REAL EXPLOSIONS: TOTAL HEAD AND PROMPT ENERGY

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INTRODUCTION

Damage to targets is virtually the whole point in explosive safety and in military applications. To diagnose the blast variables that control damage and be able to predict them quantitatively thus becomes the focal point for explosions research. Peak pressure, impulse, dynamic pressures, positive durations and all the familiar quantities we usually measure and talk about are only a means to the end product: target damage.

Damage potential signifies that an explosion is only a capacity for damage, damage depends just as strongly on the target and full damage can be achieved only against weakest targets. "Potential" also implies a capacity for work, like voltage or height, which depends only on the end state and is independent of the path (or shape of the integrand) in getting there. Here, the hypothesis is that neither the damage capacity of the explosion nor the response of most military targets will depend on the specific pulse shape in loading, but mostly on an integral of the pulse, like impulse or energy.

Real means simply non-ideal. The classical point-source models of an explosion as a smooth, expanding ball of pressurized gas do not work even for nuclear explosions because of real effects like radiative transport, non-ideal equation-of-state and mass of the bomb and its surrounds (LA 1664). Nearly any photograph, nuclear or HE, does not show a transparent ball of gas, but dramatizes instead a host of effects like smoke and particulate debris, jetting, afterburning, dust-loading and turbulence. Table 1-2 of NOLTR 72-209 lists nearly three dozen effects which may be necessary to describe real explosion.

Total head and prompt energy are proposed in this paper as two most meaningful properties of real explosions which primarily control the damage from it. Total head refers to the shock front (or near it) and here means the sum of peak side-on overpressure plus the total kinetic energy, not just of the air itself but including the explosion debris, smoke, case fragments and all other particulate matter swept outward by the shock and helping to drive it ahead. Total head is normally defined as an absolute pressure, but here it is defined as an overpressure. It resembles a stagnation pressure but differes algebraically.

Prompt energy is a concept introduced in the unified theory of explosions (UTE) (NOLTR 72-209) which refers to the blast wave as a whole and in effect is the capacity of the wave to do mechanical work rapidly enough to damage targets. Prompt energy comprises the total kinetic energy and the prompt work in the wave, is integrated over the shock volume, and includes the effect of the added mass due to explosive debris. Prompt work is that part of the internal energy which can do work quickly -- either on the surrounding air or on an exposed target -- by compressing, deforming or accelerating the surrounding material; it does so by virtue of its own pressure and subsequent expansion along the real thermodynamic path it follows back to ambient pressure not necessarily an adiabat. It is a fact of nature that not all the energy delivered to the material by the shock is released quickly enough to support the shock; a fraction remains in the material which we think of as "waste heat". The prompt energy is gradually depleted as the shock grows. It turns out in the unified theory of explosions that this remaining prompt energy fraction controls the growth of the subsequent shock wave and makes it possible to relate all kinds of explosions in many different media and configurations - explosions which could never be scaled by the familiar $W^{1/3}$ scaling laws. Most useful for pioneering research, for explosive safety and for military applications, UTE then provides a simple, uniform way to make quantitative predictions from first principles for virtually any kind of explosion without specifying pulse shapes.

We turn now to some brief reasons why total head and prompt energy are suggested as damage criteria, to some predictions of these quantities with UTE, and to some comparisons with experimental results. Finally, we will summarize these speculations with their implications, applications, and discussion of appropriate on-going studies. A main import: damage does not appear to depend on pulse shape either, but only on the prompt energy in the wave.

TOTAL HEAD

Peak overpressure P is probably the most familiar criterion for damage that is used for diffraction targets on nuclear explosions. The dynamic pressure $\frac{1}{2}\rho u^2$ is used for drag targets. Here we propose that their sum, loosely

$$H = P + \frac{1}{2}\rho u^2$$

is a more realistic measure for damage. More precisely, the density of air in this expression is weighted to include the mass M of debris in the wave relative to the mass of air $\frac{4\pi}{3}\rho_0 R^3$ engulfed by the shock, that is

$$H = P + \frac{1}{2}\rho u^2 \left[1 + \frac{M}{\frac{4\pi}{3}\rho_0 R^3} \right] .$$

The compelling reason for using total head instead of static or dynamic pressure is because that is what the target "sees and all it cares about". The force on the target is due to the impact of molecules; the separation of their velocities into a purely random divergent fraction which we call pressure, manifest as a force per unit area, and a directed component we call kinetic energy is a human artifice, highly useful, but a distinction of which the head-on target is blissfully unaware. Nor does the target know the name of the impacting particle -- whether air molecule, smoke, debris or fragment; all that counts in initially stressing the target is the velocity of the particle and its mass.

Figures 1 and 2 will show the mass effect, a controlling effect of simply adding inert mass to an explosive, mass which is itself neither an energy source nor sink except for what energy it absorbs and stores as internal energy (heat) or kinetic energy. The curves were calculated for 1 megacalorie yield, roughly 1 kilogram of high explosive, using UTE with spherical symmetry and varying the mass for representative values of yield/mass ratio. The yield/mass ratio Y/M is the effective heat of explosion, i.e., energy/total mass of explosive. Yield itself is the blast energy actually delivered to the surrounding air (and other targets). The units for Y/M are the classic 1000 cal/gm that was used to define the nuclear kiloton: 10^3 cal/gm = 10^6 cal/kg = 10^9 cal/ton = 10^{12} cal/KT. The representative values for Y/M shown on the figures correspond to physical cases:

Y/M
- >>1, nuclear explosion, nearly a point source of energy, near zero mass
- = 1, typical high explosive, like H-6. (TNT yields only 720 cal/gm)
- = 0.1, heavily cased bomb or warhead
- = 0.01, heavily covered explosion, 100 kg surrounding 1 kg HE, also a pressurized tank, or very low energy explosive.

Because the curves were calculated for Y = 1 megacalorie exactly, they correspond to 1 kg nuclear. Familiar cube root scaling applies so the same curves apply to kilotons if the distances are read in meters instead of centimeters.

Figure 1 shows the peak overpressures (bars on the left, psi on the right) versus distance (cm scale at the bottom, feet at the top). Nuclear explosions, of course, produce by far the highest pressures close-in. Note the systematic reduction in close-in pressure due to diluting the energy density by adding inert mass. Note also the corresponding increase in far field pressures for massive explosions. This is because the dissipation of shock energy into waste heat is a strong function of pressure; due to the lower pressures close-in, the massive explosions dissipate relatively less energy at early times and leave more prompt energy to drive the shock wave at late times.

Figure 2 shows the corresponding curves for total head. The outstanding result here is that the total head for the massive explosions ($Y/M \leq 1$) is much higher close-in, everywhere exceeds that from a point source, or a nuclear explosion. The gain in efficiency, seen only in the far field for side-on pressure, is also manifest close-in for total head. The reason for the increase: the addition of massive debris, which reduces peak pressure and material velocity, makes a corresponding increase in overall density. The addition of inert mass is, in fact, hydrodynamically a more efficient means to drive the shock energy outward.

We caution, however, that these curves apply only to the addition of inert mass. They do not include the energy losses due to unrecovered heat and kinetic energy, to endothermic phase changes, to rupture energies and similar energy sinks which would reduce the prompt energy available at late times.

The author is not aware, but would appreciate learning, of any direct measurements of total head which are suitable for comparison with the predictions of Figure 2. But we can do almost as well by comparisons with measured values of normally reflected pressure, where the dynamic pressure is stagnated by the shock reflection and becomes manifest as static pressure.

Figure 3 is adapted from a report by Wenzel and Esparza showing the normally reflected peak pressure close to HE charges. It provides a convenient set of measurements to test the overall validity of three UTE ideas -- calculation of the shock front from first principles, effect of mass in enhancing the total head and a simple rule-of-thumb for relating reflected pressure P_R with total head H namely: $P_R = 2$ H. The squares, circles, spreads, and full lines show experimental results from spherical and pancake pentolite charges (SwRI Project 02-3132), along with measurements reported by Ballistic Research Laboratory (BRL 1499). The lower dashed curve is Granstrom's well-known data for TNT (Granstrom). The upper dashed curve is taken directly from Figure 2, for Y/M = 1, simply doubling the total head to estimate the reflected overpressure. Considering the uncertainties of both theory and measurements at these enormously high pressures (10^5 psi), the agreement is very reassuring and virtually within experimental variations.

More than that, the differences found here are in the expected directions and are of the right magnitude. First, all curves here have been scaled to a common basis, one pound mass, on this figure; except for minor differences in explosive efficiency, they should reasonably agree at long distances and they do. But TNT has a yield about .85 that of pentolite, so its close-in pressures should lie about 15% below the pentolite pressures; they do. The theoretical explosive Y/M = 1 is about 20% more energetic than pentolite and pressures should start about 20% higher. They are higher, but what we see here is more interesting yet: the effects of afterburning and/or the explosion not being fully developed. Calculations with UTE show that if TNT and pentolite were balanced explosives and released their full yields instantaneously, as presumed in the theoretical explosive, then the cross-overs noted in Figure 1 would already have occurred by one foot or so from the charge. But about 25% of the energy of TNT and pentolite comes from afterburning of explosive debris in atmospheric oxygen; the detonation releases only about 75% of their eventual blast yield. At one foot or so from a one pound charge, far too little atmospheric oxygen (a few percent) is available to burn the excess carbon in the debris; both TNT and pentolite should lie about 25% or so below the theoretical curve on that account. When the shock has grown to several feet, enough atmospheric oxygen is available to realize most of the afterburning; the curves should come together around that distance, and they do. This extra pulse of afterburning energy is also manifest as a second brightening of the TNT pulse.

Here we see good agreement of measurements with predictions from UTE, in a range where the mass effect makes a difference of a hundred fold in the total head. Yet, close-in predictions for this explosion were good enough to show the effect of afterburning. In these days of short budgets, we also note that all the UTE calculations shown here cost less than $10.00 machine time, included a detailed print-out of the results.

PROMPT ENERGY

The compelling reason for suggesting prompt energy to characterize damage is by definition: it is the capacity of the explosion to do mechanical work on either the surrounding air, or on a target. Among contender criteria, pressure alone cannot specify damage; pressure can be enormously high, yet applied for too short a time to drive the target beyond its elastic limits. Impulse alone cannot specify damage; the duration can be infinitely long (such as in a pressure vessel) and still no damage be done. Damage, permanent changes, always seem to be characterized by work or energy; they require a force and a displacement large enough to exceed elastic limits; in other words they are characterized by $\int F\,dx$ or a deformation energy.

The very existence of stress-strain curves is a definitive case in point. They are an elemental portrayal of damage, showing deformation x (strain) versus loading P (stress). The failure of the material is described by the integral under the curve as a deformation energy $\int P\,dx$. Time does not even appear except in a higher stage of sophistication where the curve itself may depend on time. But even then, the failure depends on an energy, $\int P(x,t)dx$, not an impulse, $\int P dt$.

An intrinsic part of UTE is that the prompt energy Y(R), and thus the capacity of the wave for doing damage, is gradually converted to delayed energy. The fraction Y/Y_0 of the original yield, Y_0, remaining in the wave at distance R is shown in Figure 4 for various Y/M ratios. The uppermost ordinate is the initial yield, that is $Y/Y_0 = 1$; the center ordinate is $Y/Y_0 = .1$, and the bottom ordinate is $Y/Y_0 = .01$. We see that only a few percent of the original blast energy is still available near the right side of the figure, which corresponds to a few psi overpressure. The lowest curve here is the nuclear case; it starts with a behavior like $Y \sim R^{-1/2}$ close-in, and Y decreases as R^{-1} in the weak shock regime. The upper lines, for yield/mass ratios of 1, .1 and .01, show directly the increase in blast efficiency due to adding inert mass or surrounds to the explosive. Again the caution, losses in the surrounds can more than offset this inherent increase in hydrodynamic efficiency. The well-established fact that nuclear explosions are less efficient than HE is shown here by the factor of 3 displacement of the nuclear curve (lowest) below the curve for Y/M = 1.

The question: "Which characterizes damage best, prompt energy Y(R) or impulse I(R)?" turns out to have a highly convenient answer. The two quantities can be shown to be closely related by a nearly constant factor K, that is

$$\frac{Y(R)}{4\pi R^2 U I(R)} = K$$

where U is the shock velocity. In other words, if the impulse $\int P dt$ results in a change in momentum in the wave, and it does, this energy can be regarded as a momentum flux, and U is the phase velocity.

Figure 5 is a test of this relation, to test whether the dimensionless ratio K is in fact a constant as expected theoretically, and to establish the value of the constant empirically. Here again, there are no direct measurements available for total loading. However, Granstrom does give positive and negative reflected impulses, for which the dynamic pressure is stagnated and appears as reflected pressure. By the same rule-of-thumb used to relate the peak reflected pressure with the peak total head, the net reflected impulse was divided by 2 as an estimate for the net-incident impulse I(R). The lower full line is the value $Y(R)/4\pi R^2 U$ calculated with UTE; the dashed line is the same value multiplied by a numerical factor 2.4. The circles are representative points from Granstrom's data. The figure shows that the two quantities are in fact closely related by a nearly constant factor; if damage is characterized by one quantity, it will be equally well characterized by the other, using K, U, and R as indicated.

It also follows that if damage is characterized by the prompt energy, as found here, then damage predictions do not require the detailed shape of the pressure-time history: damage will depend only on an integral value such as energy or impulse.

Direct measurement of target damage with distance and yield would provide a definitive test of the prompt energy criterion. But such data are sparse and somewhat ambiguous. However, long accumulation of experience in the blast trade does come close to a corroboration that for high explosives at least, damage is characterized better by energy than by peak pressure or impulse. First note:

1) If damage were characterized by peak pressure, then similar pressures occur at distance $R \sim Y_0^{1/3}$; hence similar damage would occur at distances $R \sim Y_0^{1/3}$, or wherever $Y_0^{1/3}/R$ = constant.
2) If damage were characterized by impulse, the extra dimension of time implies that similar impulse occurs at distance $R \sim Y_0^{2/3}$, and damage distance would increase as $R \sim Y_0^{2/3}$.
3) If damage were characterized by prompt energy, then as we will show later, the damage radius would behave as

$$R \sim Y_0^n \;, \qquad \frac{1}{3} \leq n \leq \frac{1}{2} \;,$$

depending on how $Y(R)$ decays with R.

Two sources of experience on blast damage suggest that the energy criterion is more nearly correct. In evaluating underwater explosion damage against ships, and on a purely empirical basis, a "keel factor" $Y_0^{1/2}/R$ is used; similar damage is said to occur at the same values of keel factor, in other words, where $R \sim Y_0^{1/2}$, this is essentially an energy criterion.

Perhaps the most comprehensive compilation of damage data was made by O. T. Johnson (BRL 1389). He considered a number of basically different generic types of targets such as

Simple structures	Complex structures
Wire drag gauges	Dish radar antenna
Aluminum beams	B-29 fuselage section
Aluminum cylinders	2 1/2 ton trucks

On a purely empirical basis, Johnson found a blast damage relationship which requires, in our terminology, $R \sim Y^{.435}$ as an average for all classes. I take this to be sensible agreement with $R \sim Y^n$, at least as a first approximation for soft targets. Also, the individual classes of targets appear to spread over the range $\frac{1}{3} \leq n \leq \frac{1}{2}$.

Here is the argument for damage distance with the prompt energy criterion. Suppose that the prompt energy decays with distance R as

$$\frac{Y(R)}{Y_0} = \left(\frac{R_0}{R}\right)^n \text{; from Figure 4, } 0 < n < 1$$

Y(R) is the prompt energy in the wave; the damage will depend on the flux density or $Y(R) / 4\pi R^2$. It follows that

$$\frac{Y}{R^2} \sim \frac{Y_0}{R^{n+2}}$$

Thus similar values of flux density Y/R^2 will be found wherever $R \sim Y_0^{1/(n+2)}$. That is, damage distance will vary as $R \sim Y_0^{1/2}$ when $n = 0$ and will vary as $R \sim Y_0^{1/3}$ when $n = 1$. This is the spread I find in examining Johnson's data.

The qualification "potential" is particularly appropriate for prompt energy because potential has also come to mean an integral quantity -- work, potential energy of height, voltage -- which is independent of the path that was followed in arriving at that state. Here, "potential" implies that the integral of the total head for loading the target, not the shape of the total head vs time curve, characterizes the damage.

In 1970, Youngdahl described a calculational technique for characterizing transient loads required to cause given levels of of plastic deformation to structures (JAM, 1970). He found a number pair representing the effective impulse and the "effective load" which could be used to provide a very good measure of damage potential, which applied to four typical modes of failure, and which was independent of the shape of the time history of loading.

Cummings and Schumacker extended the work of Youngdahl, and found it consistent with earlier work by Sperrazza, Baker, and O. T. Johnson.

The connection with the prompt energy criterion is partly because Youngdahl's correlation parameters seem to be energy criteria. Beyond that, for the softest targets, the critical values of loading will be the ambient pressure and thus the time of loading will extend into the positive and negative phases of the wave. In that case the "effective impulse" becomes the net impulse of the wave, which as we have related to the prompt energy in the wave.

SUMMARY

The familiar stress-strain curves are the simplest, least ambiguous kinds of damage curves and do not contain time. While some time-dependent effects are known, this is direct relevant evidence that to a first approximation at least, the stress-strain curves, adiabats etc., are essentially independent of the time history of the loading. The strain or deformation are uniquely related to a deformation energy and are virtually independent of impulse.

Damage appears then to behave like a great many other similar physical effects that depend on an overall energy, or an integral quantity and not upon the shape of the integrand. These effects are characterized by threshold energies, which must be exceeded before permanent changes occur. Among such threshold quantities are:

1) all latent heats: vaporization, freezing, sublimation
2) ionization potentials
3) phase changes
4) energies of activation.

These facts certainly seem relevant to damage criteria, and if so, great simplification can ensue for damage measurements. There will be no strong requirement to simulate the shape or duration of the blast wave directly for damage studies. We require mainly that some threshold loading be exceeded by the total head and that the prompt energy, the excess prompt energy perhaps, be determined for the simulator, for which UTE methods are readily available.

Based on the results of Figures 1 and 2, as well as the above arguments for insensitivity to time effects, it does not appear likely that explosions can significantly be optimized or that blast effectiveness be much improved by tailoring the pressure-time curves. By the same token, damage predictions for safety purposes can be all the more reliable because the damage will not depend on timing or other details of the energy release, but depend almost entirely upon the blast energy released.

Among other applications of these damage criteria are:

1) With reasonable estimates for the energy loss in casings, earth covers and other surrounds, damage from many explosion configurations can be predicted cheaply, quickly, and reliably using UTE.

2) So in many cases, precise blast simulators are not really required. Many types of blast simulators will be adequate to establish damage vs load curves, provided the total head and prompt energy they deliver is determined and used as the input variable.

3) Direct tools are now available with UTE techniques for measuring the energy loss in casings, earth covers, blast shields, and in many other surrounds, by evaluating the prompt energy for the explosive with and without the surrounds.

Among the on-going work which needs to be done are:

1) Extend the predictions made here to include losses in the explosive surrounds.

2) Compile tables and graphs which are convenient for

engineering applications to safety problems. Among such tables are:

- a. Total head as a function of incident angle
- b. Total head height of burst curves
- c. Total head vs time for typical energy inputs.

3) Compile and catalog the total head and prompt energy required to achieve damage for a comprehensive list of targets for military and safety purposes.

4) Devise meaningful experiments to measure damage directly.

On the basis of the studies reported in this paper, we conclude:

1) Total head is a more meaningful criteria for threshold loading than peak pressure or dynamic pressure taken separately, or by ignoring loading due to debris.

2) The prompt energy appears to correlate well with degree of damage.

3) The rule-of-thumb; reflected pressure $\approx 2 \times$ total head, appears a useful, reliable means to estimate the reflected pressure in debris laden explosions.

A most useful insight gained in this study and an aid to understanding damage mechanisms: energy and momentum are not independent quantities, energy is simply momentum flux. A main import: pulse shapes are not necessary to predict damage for a wide range of responsive targets. Both the pressure-distance curves and the damage from an explosion are specified by the prompt energy Y(R).

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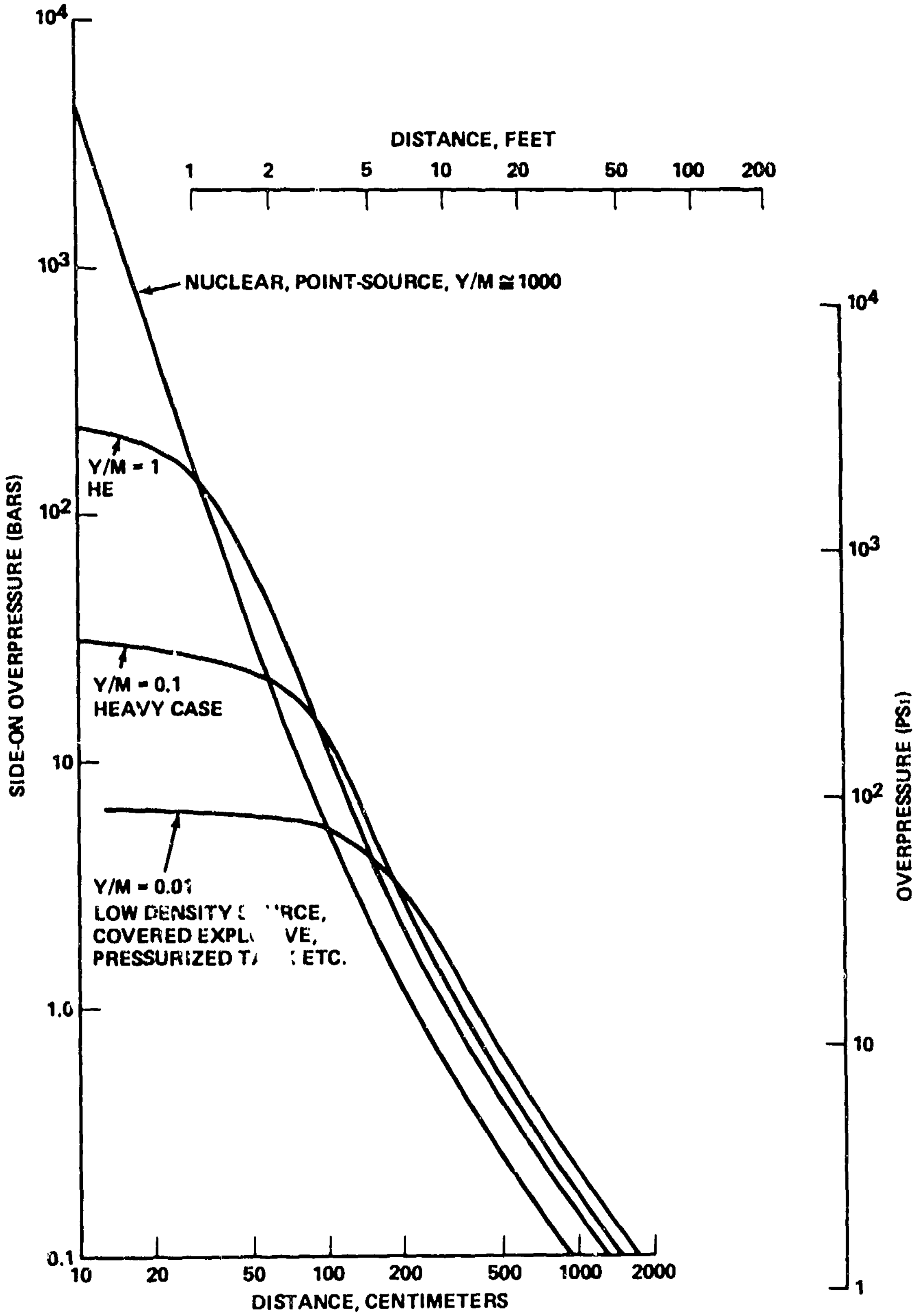

FIG. 1 SIDE-ON OVERPRESSURE VS. DISTANCE FOR REPRESENTATIVE YIELD/MASS RATIOS. (Calculated with unified theory of explosions for 1 megacalorie released in inert masses of 0.001, 1, 10 and 100 kilograms (Y/M = 1000, 1, 0.1, 0.01 respectively.)

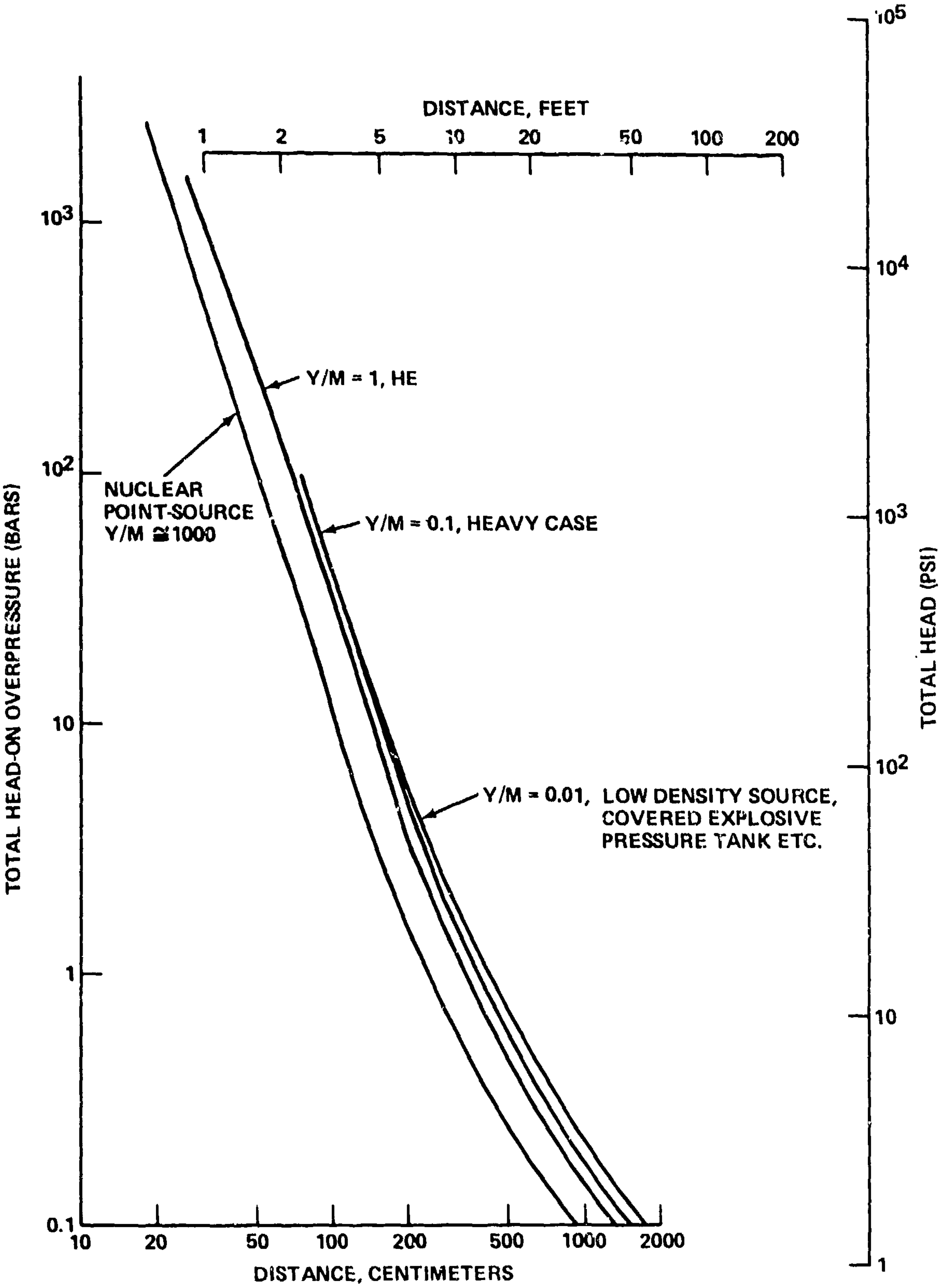

FIG. 2 TOTAL HEAD VS. DISTANCE FOR REPRESENTATIVE YIELD/MASS RATIOS. (Total head here means side-on overpressure plus total dynamic pressure. Calculations were made with unified theory of explosions for 1 megacalorie instantaneously released in inert masses of 0.001, 1, 10 and 100 kilograms.

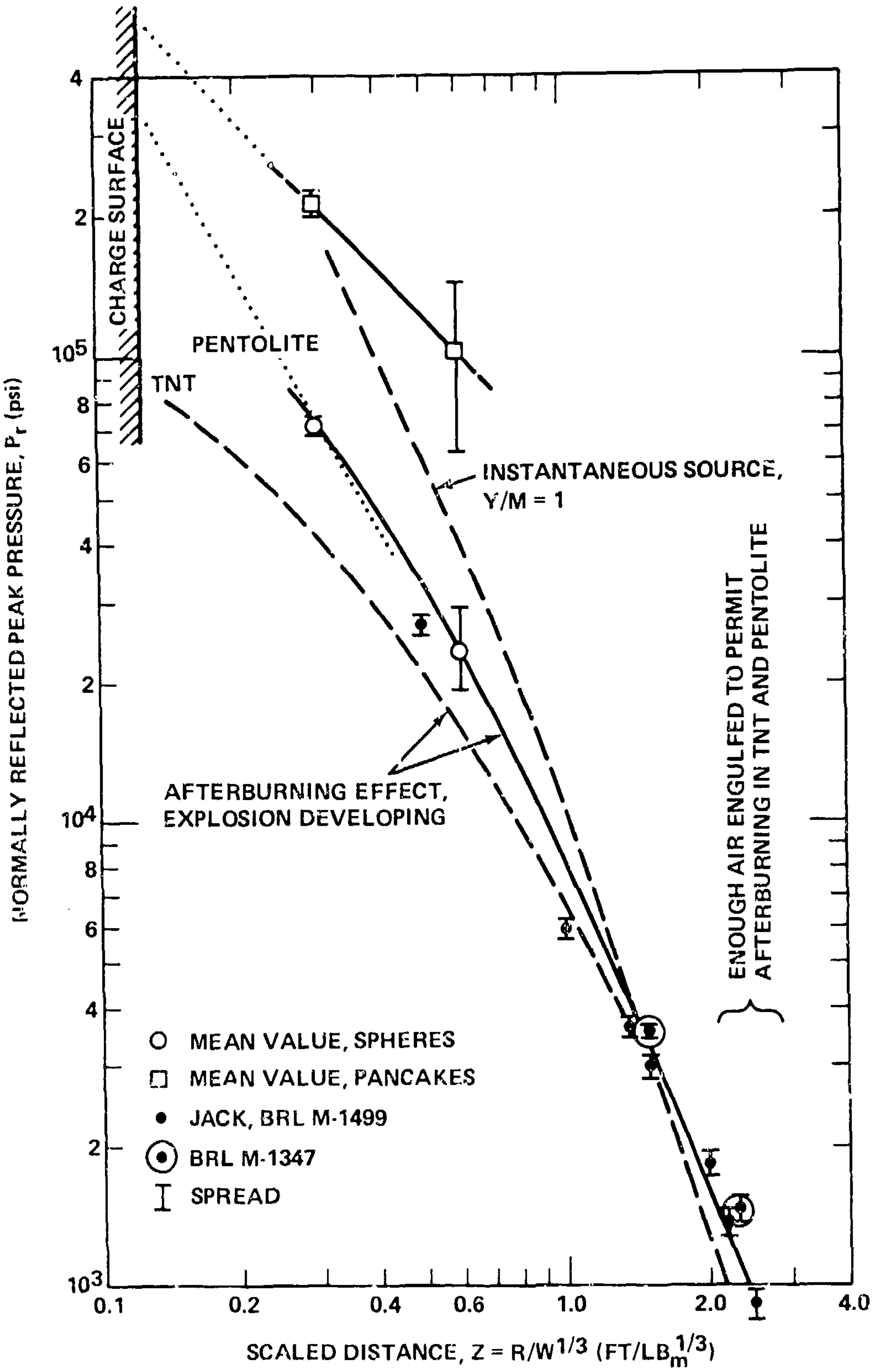

FIG. 3 COMPARISON OF PEAK REFLECTED PRESSURE FOR 1 LB PENTOLITE TNT, AND 1000 cal/gm INSTANTANEOUS SOURCE.
(The lower initial pressure for TNT and Pentolite are attributed to lower yield/mass ratios, to afterburning and/or explosion being formed.)

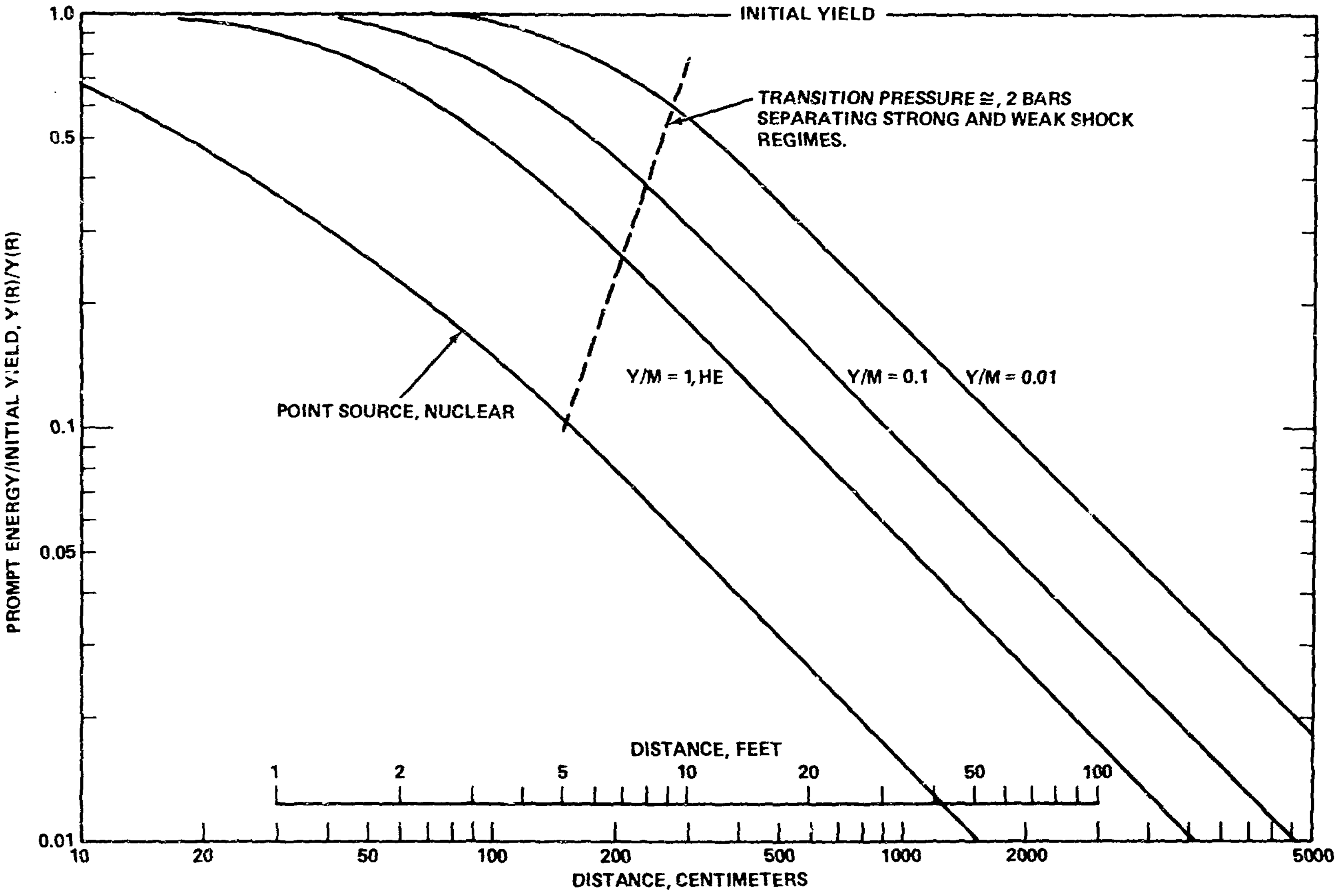

FIG. 4 PROMPT ENERGY FRACTION VS. DISTANCE FOR REPRESENTATIVE YIELD/MASS RATIOS. (Calculated with UTE (NOLTR 72-209) for yield of 1 *megacalorie in inert masses* of 0.001, 1, 10 and 100 kilograms. No allowance for energy source or sink in the surrounds.

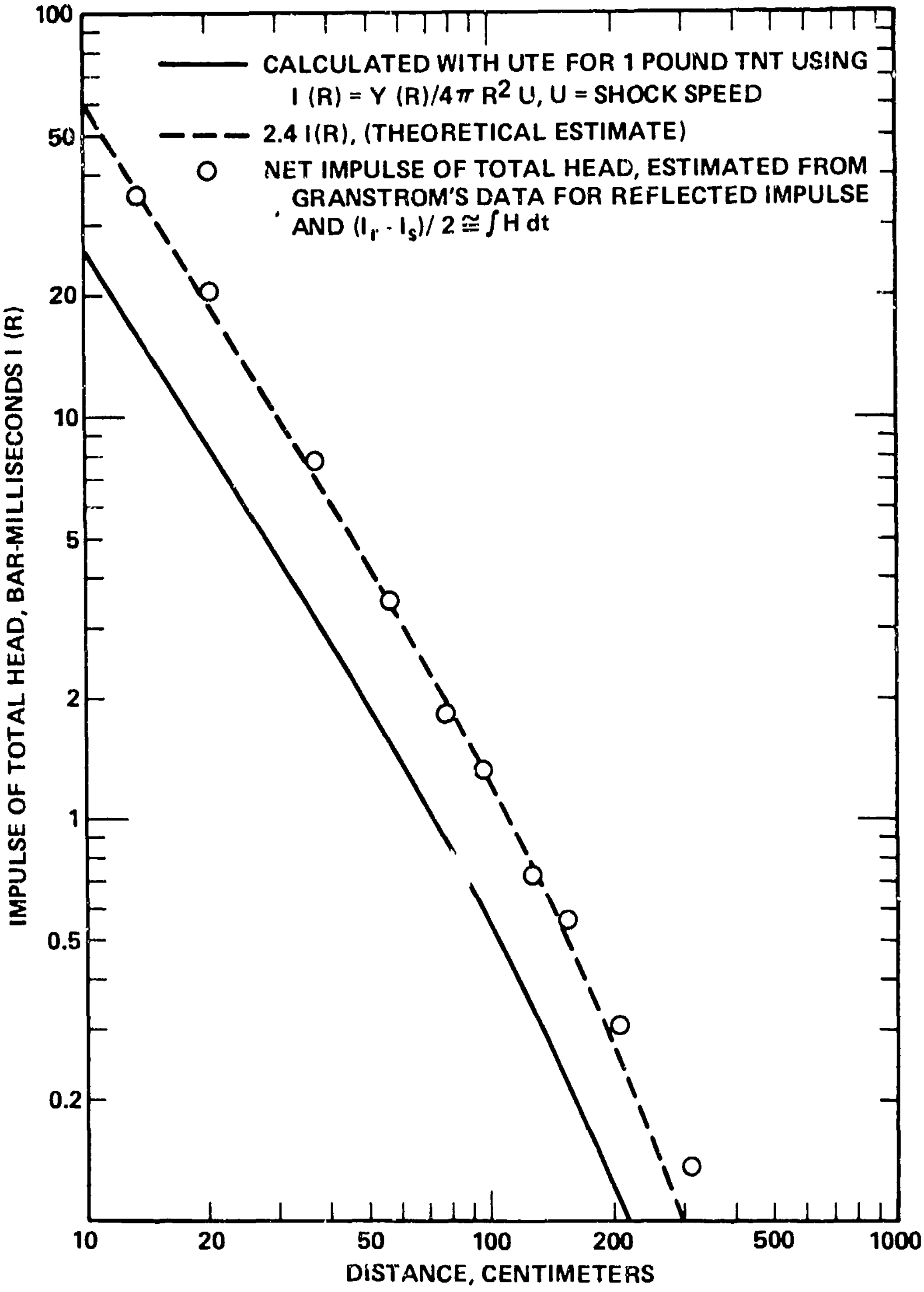

FIG. 5 COMPARISON OF TOTAL IMPULSE, MEASURED VS. UTE CALCULATION. (The dashed line is a test of the theoretical relation $\frac{Y(R)}{4\pi R^2 U I(R)}$ = CONSTANT

for a strong short and an ideal air, K = 2.4 is the theoretical estimate, and is found consistent with Granstroms data.

CRITERIA FOR SAFETY AND ENVIRONMENTAL HAZARDS IN FIELD TESTING

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In the past, plans for the field testing of explosives, or for any activity involving the manufacture, transportation, or storage of explosives, required consideration of the possible damaging effects of an explosion and the safety of personnel. Explosion effects that were not damaging were often ignored unless they led to complaints from nearby residents.

However, since the passage of the National Environmental Policy Act of 1969, and subsequent laws and directives, we are also required to consider the effects of explosive operations on both the environment and on the ecology of a region prior to the initiation of the work. When we prepare an environmental impact assessment we must not only evaluate health and safety but a variety of other aspects, including such intangibles as effects on the quality of life. The net result will be to raise the standards considerably and to make certain procedures unacceptable in the future.

These environmental laws have forced us to take a more comprehensive view of explosion phenomena and to examine some effects that have been neglected in military studies. In this effort, we have encountered problems of definition and of establishing criteria, and often have no guide-lines that apply to our unique circumstances. To begin, I have listed four general categories of explosion phenomena on the first <u>SLIDE</u> (1).

My own experience has been mainly in underwater testing, and the next <u>SLIDE</u> (2) lists some of the damaging effects of military importance. Tests on land have a similar phenomenology.

It is not always easy to distinguish between safety aspects and environmental effects, and the next SLIDE (3) provides some guide lines. In both cases, the effects may be difficult to define and to quantify.

In regard to safety, the criteria for a possible accidental explosion differ from those for controlled detonations in a test program. Military damage data are helpful here, but we are concerned with much lower levels of damage. Some of the phenomena of interest are listed in the next SLIDE (4).

The following are what I consider to be environmental effects (SLIDE (5)). (You will note that some items appear on almost every list).

What I have called nuisance effects (SLIDE 6) might be termed environmental effects by others, but I'm referring mainly to occasional transient events that do not harm, but could be offensive to the public. They may result in complaints if they occur repeatedly. In this case, they affect the quality of life and move into the environmental category.

In my discussion, I will be concerned only with safe distances and not with procedures. In the case of safety from accidental explosions, quantity-distance tables and other guide-lines are available, but no handbook has been written for field tests. We rely heavily on experience and predictions of the phenomenology.

The shock wave in air falls in all four effects categories, ranging from damaging high pressures at close-in positions to low noise levels at long ranges. Noise is a common problem in all testing, though it doubtless is of greater concern with explosions on land. The next SLIDE (7) lists some low-pressure-level shock wave phenomena at typical pressure levels. A decibel scale is shown for comparison.

The decibel scale is used for sound waves and the decibel criteria developed for exposure to industrial and environmental noise are based on repetitive or continuous events. In the case of shock waves, there are variations in effects, depending on the rise time and duration of the pulse. With explosives, this varies with the charge weight and range.

Exposed personnel can stand relatively high shock wave pressures without harm, although ears are relatively sensitive. For protection from secondary effects such as breaking glass, a level of 0.01 psi should provide adequate safety. When the public is exposed to levels above 0.001 psi, individuals could be startled by the unexpected sound, just as in the case of a sonic boom or a nearby lightning strike. Pressure levels below 0.001 psi are in the nuisance category and could be viewed as affecting the quality of life. Therefore, from environmental considerations, a minimum distance equivalent to 0.001 psi from occasional tests should be considered. If explosion tests are frequently conducted in the same location, 0.0001 psi might be a more appropriate criterion.

The next SLIDE (8) gives an indication of the distances involved for surface bursts. The curves for inhabited buildings located in the vicinity of magazines are based on published quantity — distance tables. In the case of magazines, these distances provide a high degree of protection from structural damage and from death or serious injury, but they do not provide protection from glass breakage. They are considerably less than those based on consideration of safety or noise from controlled explosions.

Noise is not a problem in underwater testing unless the explosions are relatively shallow. The SLIDE (9) shows that the noise level drops off rapidly with increasing depth. For the 1000-lb weight shown, distant noise should become negligible at depths exceeding 50 feet, or a reduced depth of 5.0 $ft/lb^{1/3}$ (depth/charge weight $^{1/3}$).

I should emphasize that the calculated ranges are based on the absence of any refraction or focussing effects in the atmosphere. If possible, tests should not be conducted when these conditions are present.

In addition to air blast effects, damage can be done at a distance by fragments of weapon cases when explosions take place on the surface or at relatively shallow depths in water or soil, and by ejecta over a wider range of conditions. Data on both effects are limited and show considerable scatter. The SLIDE (10) shows a curve published by Jarrett (1968) for safety from fragments, based on the assumption that only one fragment would exceed this range. This should hold for water surface as well as land surface bursts of cased charges. The few data points on fragment distances from underwater tests are consistent with this result. The range of ejecta from bottom explosions is less than the distance reached by fragments, and both hazards should be absent if the reduced depth exceeds about 3.0 ft/lb$^{1/3}$.

The effects of explosions on the seabed ecology should be limited to the crater and a surrounding area of disturbed sediment and heavy ejecta deposit. The slide includes estimates of these ranges for shallow water explosions on sand or clay. In general, it appears that safe distances exceed the range of ecological effects in this case. However, these cannot be ignored, and the best procedure is to utilize regions that are relatively barren of marine life.

When we discuss chemical pollution of the air and water environment by explosions we run into difficulties because of the nature of the phenomena and the absence of standards developed specifically for this case. Criteria established by the Occupational Safety and Health Administration are applicable mainly to continued exposure of industrial employees to hazardous gases and other materials. However, the Threshold Limit Values published by OSHA and other organizations are useful criteria for explosions that eject products into the air because the TLV represents a concentration to which nearly all workers may be repeatedly exposed during an 8-hour day without adverse effects. As any possible exposure to the cloud of products formed by an explosion would be very brief, concentrations higher than the TLV would be acceptable if they could not be avoided. When explosion products are deposited in water, we are guided by criteria developed by the Water Quality Office. These vary with the usage of the body of water, but those published for recreation or fisheries are the most appropriate here, as we do not do our testing in the public water supply.

As the actual percentages of explosion products in air and water have not been measured, we make use of theoretical values and data obtained in calorimeters. For underwater test planning we simplify the approach by examining two extreme conditions, each of which constitutes a probable "worst case". For example, if an explosion is relatively shallow, almost all of the products are ejected to the atmosphere to form a roughly spherical smoke crown (SLIDE 11) — this cloud is carried downwind and is diluted by atmospheric turbulence.

When an explosion is relatively deep, virtually all of the products are deposited in a surface pool that moves with the current and is diluted by turbulence in the sea. The SLIDE (12) shows such a pool, colored by a dye tracer.

A safe distance, therefore, would be a distance at which the maximum concentrations in the cloud or pool reach safe levels. The SLIDE (13) lists the gaseous explosion products of TNT and the estimated initial concentrations in the smoke crown. The concentrations are independent of charge weight, but the radius of the crown is proportional to the cube root.

The products of TNT are in general not hazardous after they are diluted by the initial rapid expansion of the crown. In the table, only carbon monoxide is potentially harmful, but the concentration should be reduced to the TLV of 50 ppm after the cloud has traveled downwind a relatively short distance as shown in the SLIDE (14). Even if we employ the EPA Ambient Air Quality Standard of a maximum 8-hour concentration of 9 ppm, the range is not excessive. For these shallow explosions, other safety and environmental considerations greatly outweigh the hazard from chemical pollution of the atmosphere.

A similar situation holds if all of the products are deposited in the water, as shown in the next SLIDE (15). I have no information on carbon monoxide, but the standards listed indicate the absence of a hazard to marine life, even at this early stage, which occurs within minutes of an explosion. In this case, the drifting pool might possibly have a nuisance effect if it transports carbon or bottom sediment toward a region used by the public. I should stress, however, that some new explosive compositions have products that are less innocuous than those of TNT.

The killing of fish by underwater explosions is an environmental effect that we can often avoid by careful selection of the place and time of firing. When this is not possible, we make use of theories developed on the assumption that the swimbladder is relatively vulnerable, even at long distances from an explosion. The SLIDE (16) shows an estimated range of kill by the crushing effect of the direct shock wave, on the basis that pressures above 200 psi are lethal. It also includes a region near the surface where the direct shock is overtaken by a tension wave, and the sudden drop in pressure may cause an overexpansion and rupture of the swimbladder. A comprehensive fish-mortality theory is now under development at NOL.

In addition, it is known that fish without swimbladders, and crabs and oysters, can withstand high pressures without physiological damage.

For relatively deep explosions, such as the one on the slide, the underwater shock wave is of primary concern for establishing the safe distance of a ship. In this case, the safe distance for ships is less than the safe range for fish, but this will not always hold true. The next SLIDE (17) is a sketch showing the relationship we use for determining a safe standoff for ships engaged in experimental work. Combat ships are designed for higher shock factors.

An example of the type of situation in which the Navy is now getting involved is the current controversy over the proposed construction of a new ammunition pier on the Island of Guam. The SLIDE (18) shows some of the problems associated with the existing pier, which is located in the only deep water harbor in Guam. It seems obvious that this is about the worst place to handle explosives; nevertheless, when the Navy proposed the construction of a new pier in an almost uninhabited bay, there was considerable opposition.

Most of this came from the Guam Legislature and from environmental groups. The next SLIDE (19) lists some of the objections. The reason for the relatively large land area (almost 6 square miles) is the requirement for a quantity — distance radius of 10,400 feet, based on shiploads with a total of nine million pounds of explosive per month.

The objections are not all justified. For example, a land swap has been proposed, and the historical artifacts would be protected. The real reasons for blocking this project are probably political, nevertheless, environmental arguments can be used very effectively in cases such as this.

An environmental impact statement is required if (SLIDE 20): a significant adverse impact is expected; or the impact is controversial. In the case of construction, or tests involving the use of large quantities of explosive, we can assume that the proposal will always be controversial. It is important to treat all aspects of the project in detail, not just those related to the use of explosives. An environmental impact statement is subject to review by Federal and State Agencies and is open to public scrutiny. Environmentalists can use the E.I.S. procedures to voice objections and to raise questions, and the originator is obligated to attempt to answer. The net result is a long, sometimes frustrating process, and an awareness of these problems in advance is essential.

We should also remember that the actual response of the public and local government is difficult to predict and is not always negative. For example, the Navy conducted underwater explosion tests against two target vessels, a cruiser and a destroyer, near Key West during May 1972. The Navy had planned to sink the ships in deep water to reduce the environmental impact, but moved to a shallow site near shore at the request of the Mayor of Key West, the President of the Greater Key West Chamber of Commerce, and the Governor and Cabinet of the State of Florida. They had no objection to the tests, they just wanted the ships sunk in shallow water to provide artificial fishing reefs for the benefit of local fishermen.

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EXPLOSION PHENOMENA CATEGORIES

NOL

MILITARY DAMAGE

SAFETY ASPECTS

ENVIRONMENTAL EFFECTS

NUISANCE EFFECTS

Slide 1

NOL

DAMAGING EFFECTS
OF
UNDERWATER EXPLOSIONS

UNDERWATER SHOCK

AIR BLAST

CRATER

PLUMES

FRAGMENTS

EJECTA

NOL

SAFETY	ENVIRONMENTAL
IMMEDIATE	LONG TIME PERIOD
CLOSE IN	LONG RANGE
PEOPLE	ALL FORMS OF LIFE
PHYSICAL INJURY	DISTURBANCE
EXPERIENCE	LITTLE DATA

NOL

SAFETY ASPECTS

UNDERWATER SHOCK

GROUND SHOCK

AIR BLAST

PLUMES

FRAGMENTS

EJECTA

Slide 4

ENVIRONMENTAL EFFECTS

NOL

- CRATER
- EJECTA
- EXTENSIVE FISH-KILL
- KILL OF BIRDS OR ANIMALS
- BOTTOM DISTURBANCE
- BOTTOM DEPOSIT OF EXPLOSION PRODUCTS
- EXPLOSION PRODUCTS IN AIR
- EXPLOSION PRODUCTS IN WATER
- LOUD NOISE

NUISANCE EFFECTS

NOL

MUDDY WATER

HARMLESS CHEMICALS

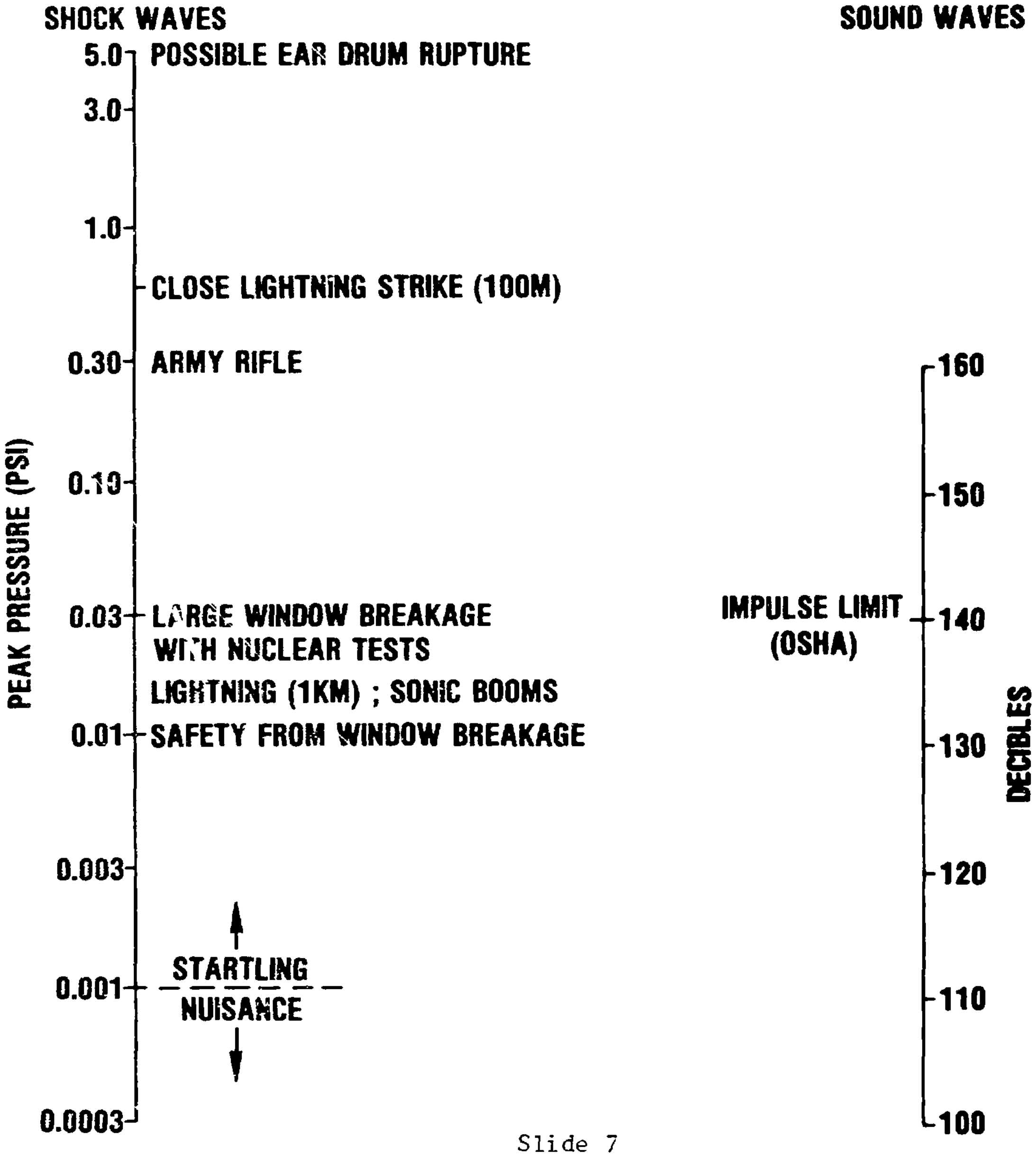
FEW DEAD FISH

ODORS

SMOKE

MODERATE NOISE

Slide 6



SHOCK WAVES

SOUND WAVES

NOL

PEAK PRESSURE (PSI)

5.0 POSSIBLE EAR DRUM RUPTURE

3.0

1.0

CLOSE LIGHTNING STRIKE (100M)

0.30 ARMY RIFLE

0.10

0.03 LARGE WINDOW BREAKAGE WITH NUCLEAR TESTS

LIGHTNING (1KM) ; SONIC BOOMS

0.01 SAFETY FROM WINDOW BREAKAGE

0.003

0.001 STARTLING / NUISANCE

0.0003

160

150

IMPULSE LIMIT (OSHA) 140

130

120

110

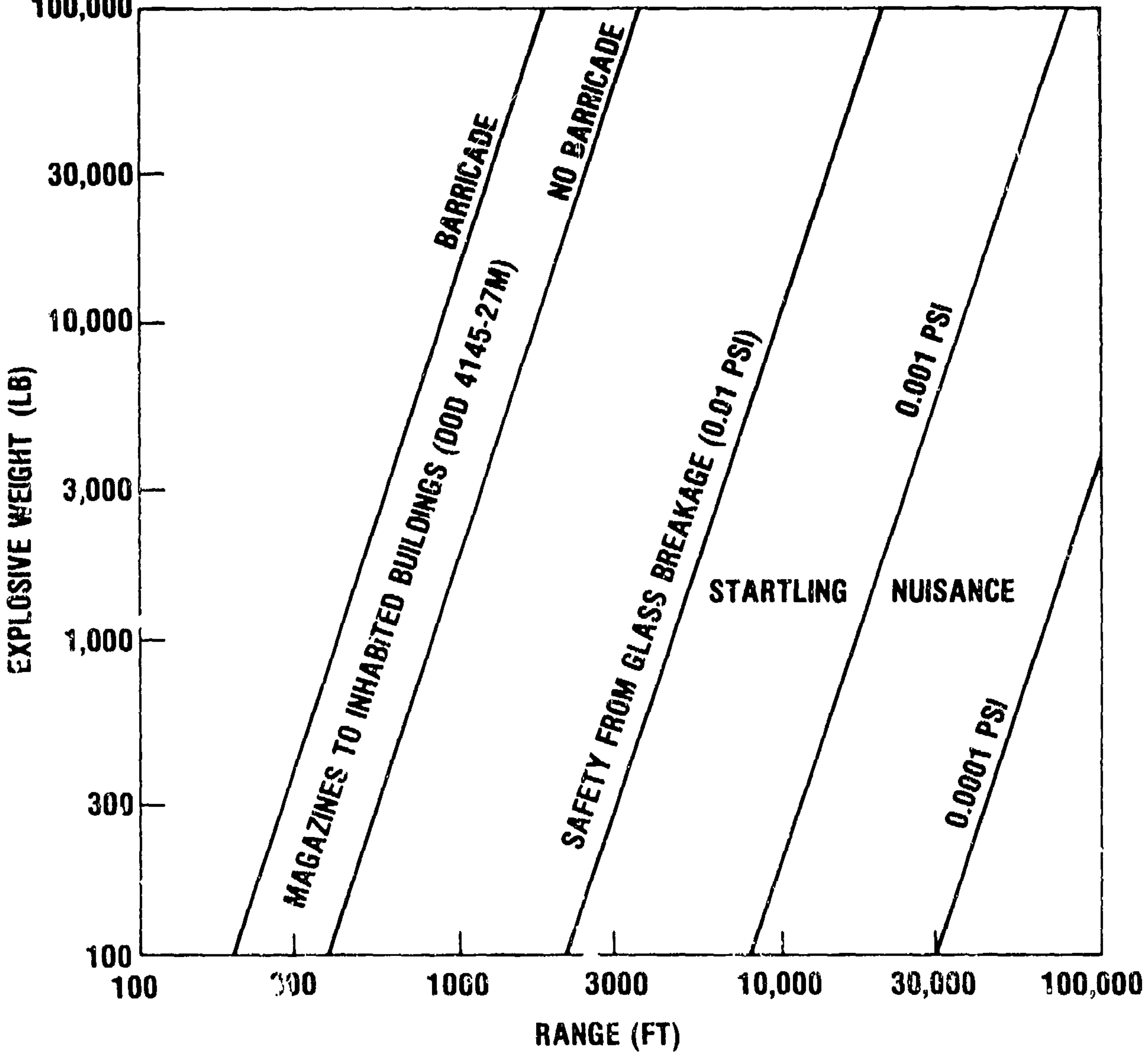
100

DECIBLES

Slide 7

RANGES FOR SURFACE BURSTS

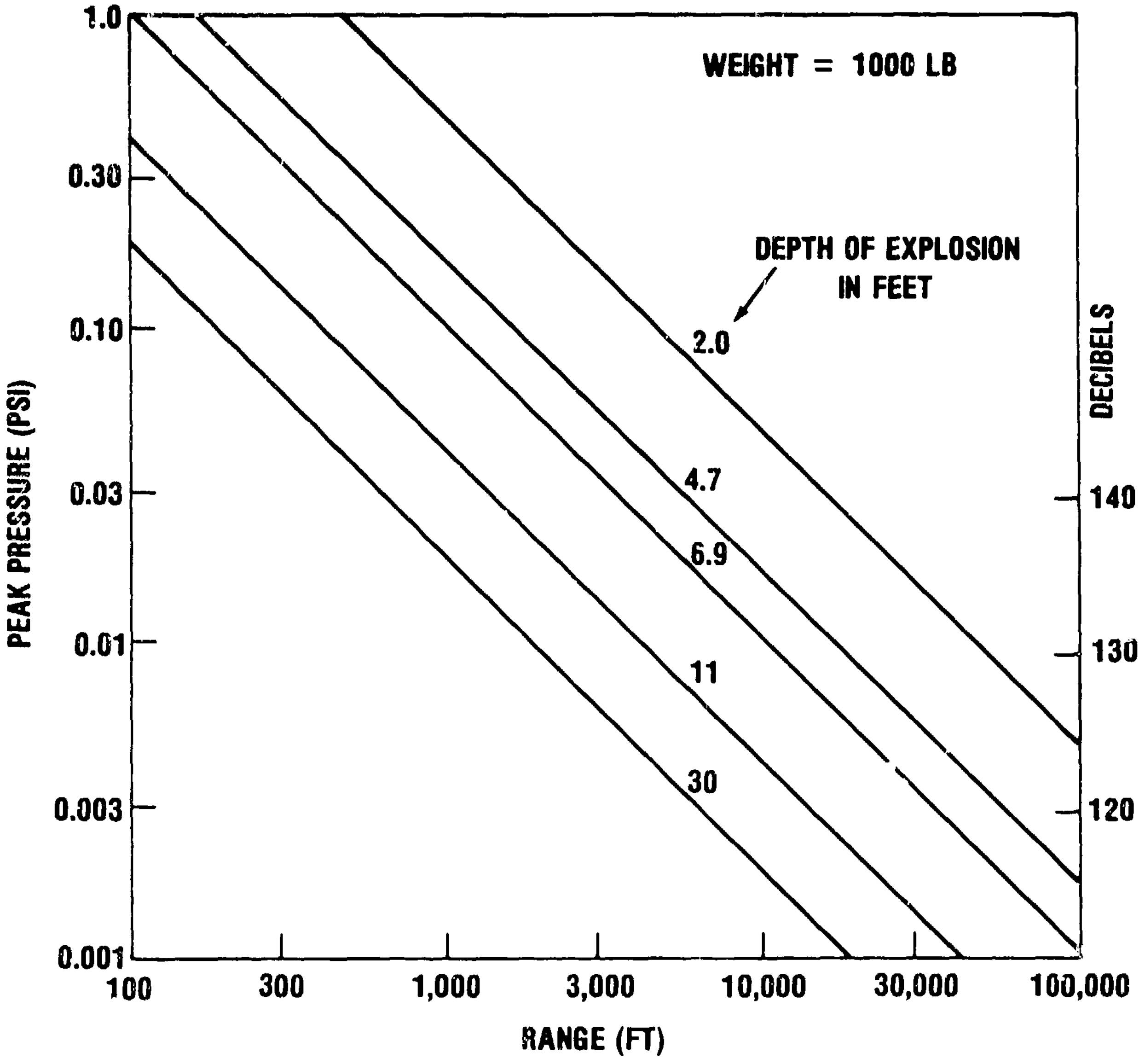
NOL



Slide 8

NOL

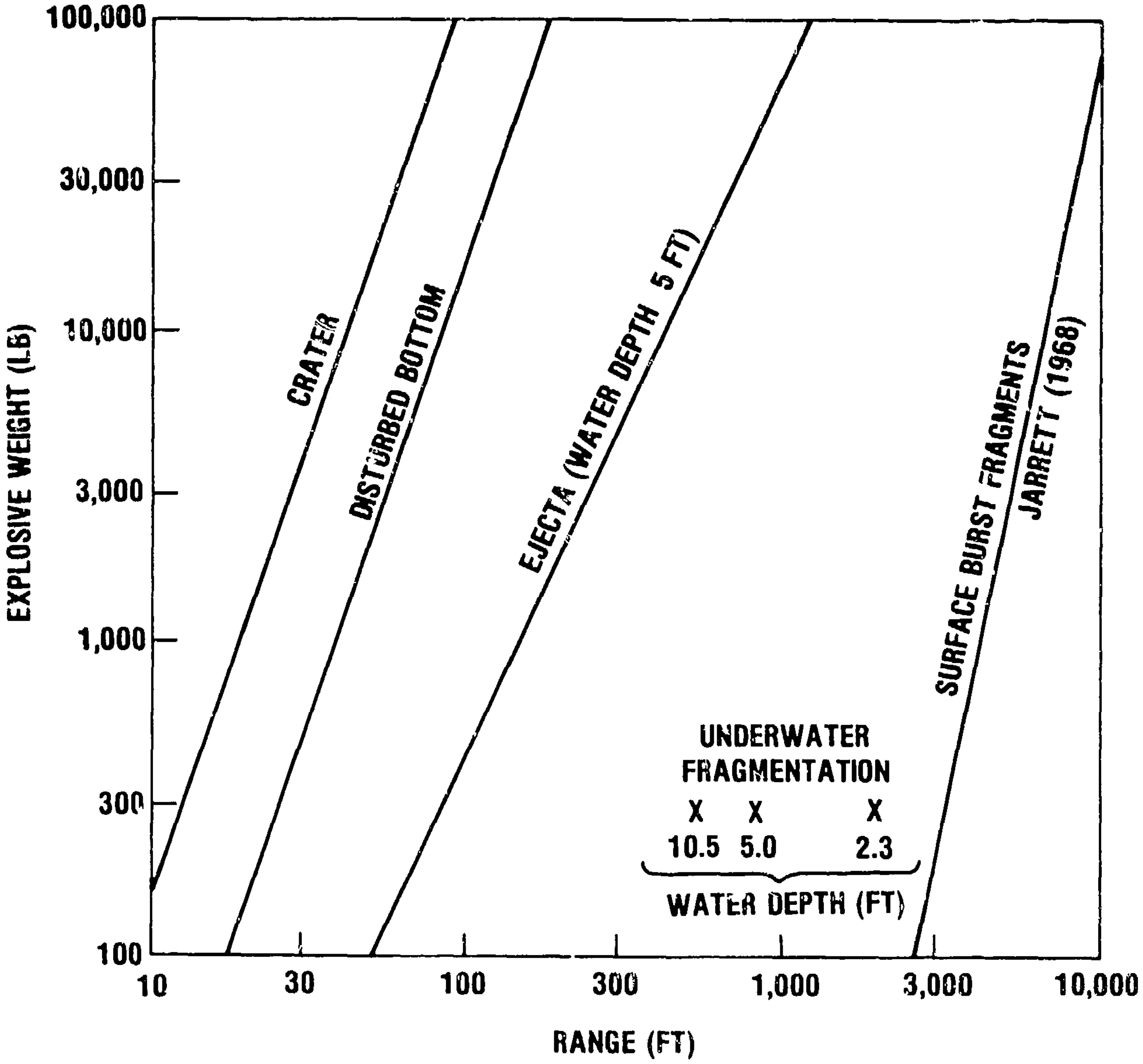
NOISE FROM SHALLOW UNDERWATER EXPLOSIONS



Slide 9

NOL

RANGES FOR SHALLOW UNDERWATER EXPLOSIONS



Slide 10

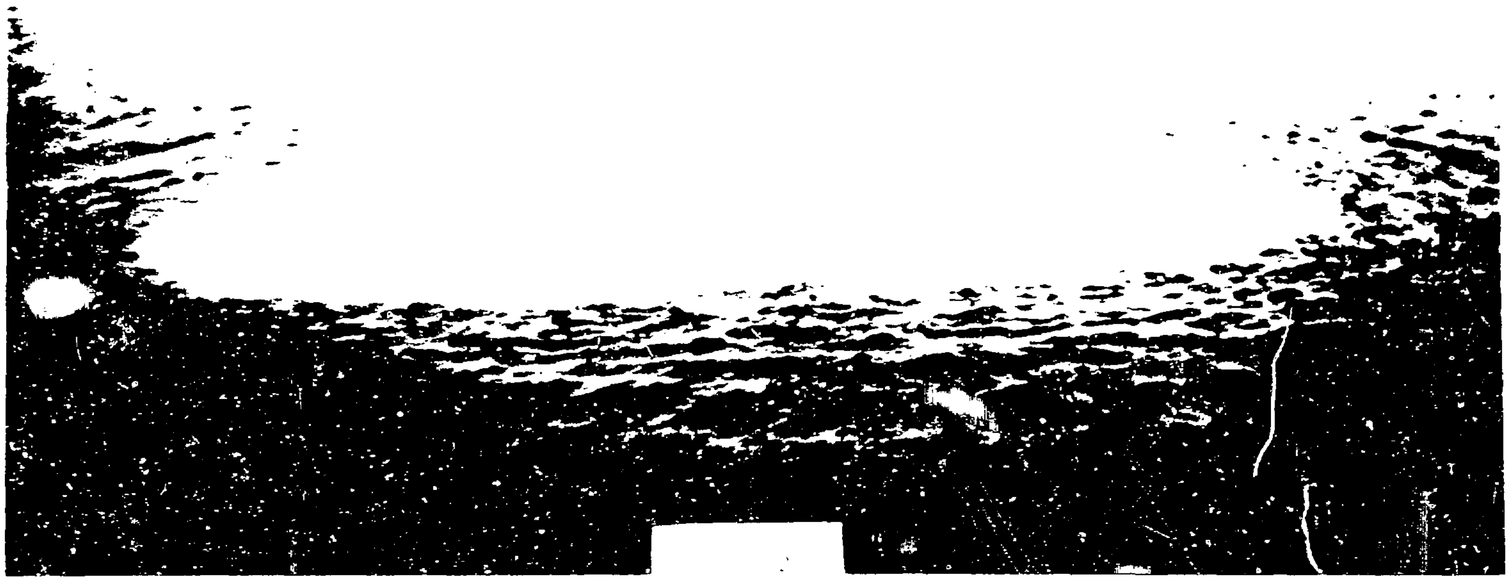
SHALLOW UNDERWATER EXPLOSION

NOL

Slide 11

VERY DEEP UNDERWATER EXPLOSION

NOL



CONCENTRATIONS OF EXPLOSION GASES IN AIR

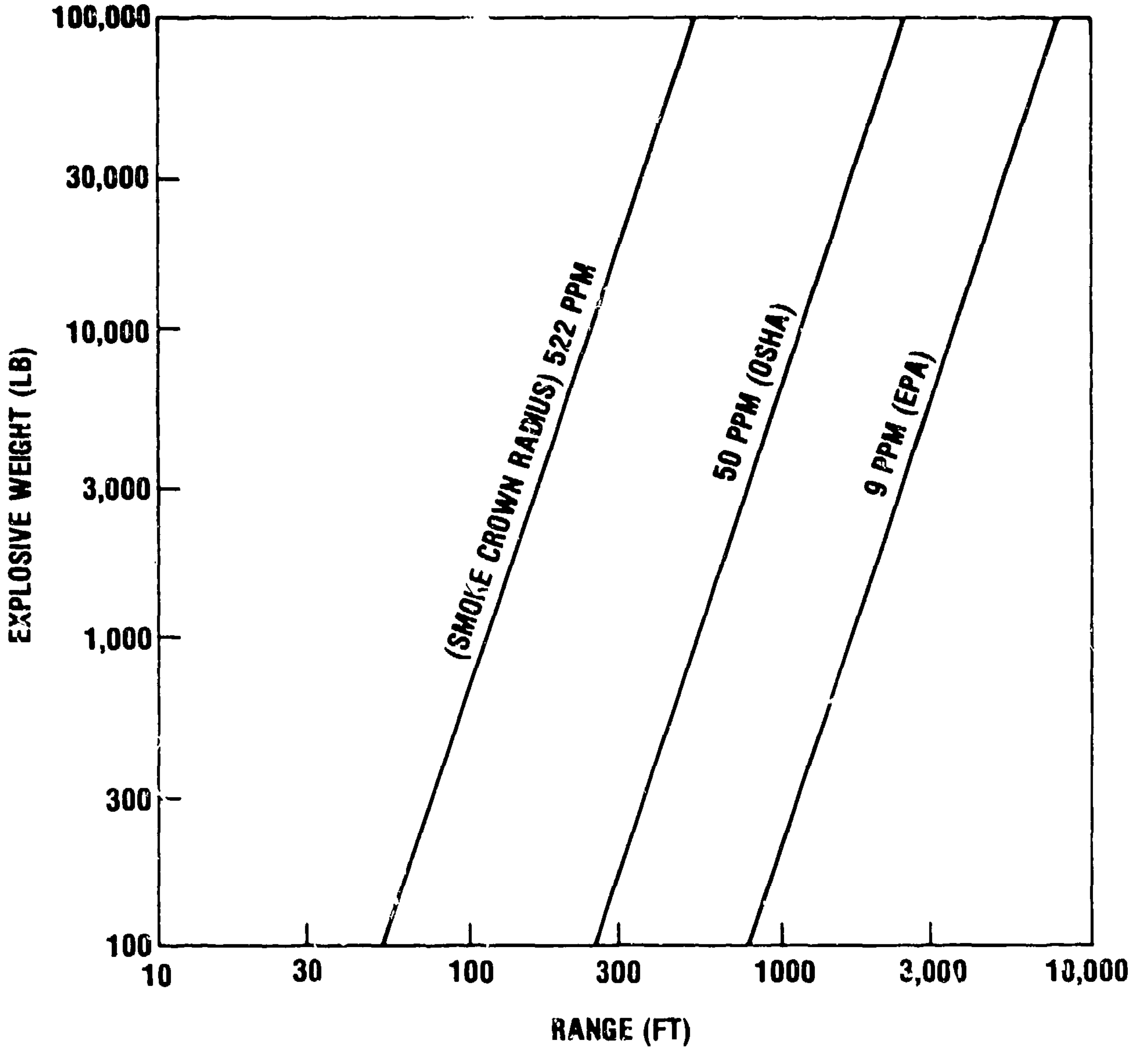
(SHALLOW UNDERWATER TNT EXPLOSIONS)

NOL

PRODUCT	CONCENTRATION (ppm)	THRESHOLD LIMIT VALUE (ppm)
CO_2	329	5,000
CO	522	50
N_2	348	—
H_2O	405	—
H_2	122	—
NH_3	42.5	50
CH_4	26.2	—
HCN	5.30	10
C_2H_6	0.98	—

NOL

CARBON MONOXIDE CONCENTRATIONS IN AIR FOR SHALLOW UNDERWATER EXPLOSIONS OF TNT



Slide 14

CONCENTRATIONS OF EXPLOSION PRODUCTS IN SURFACE POOL

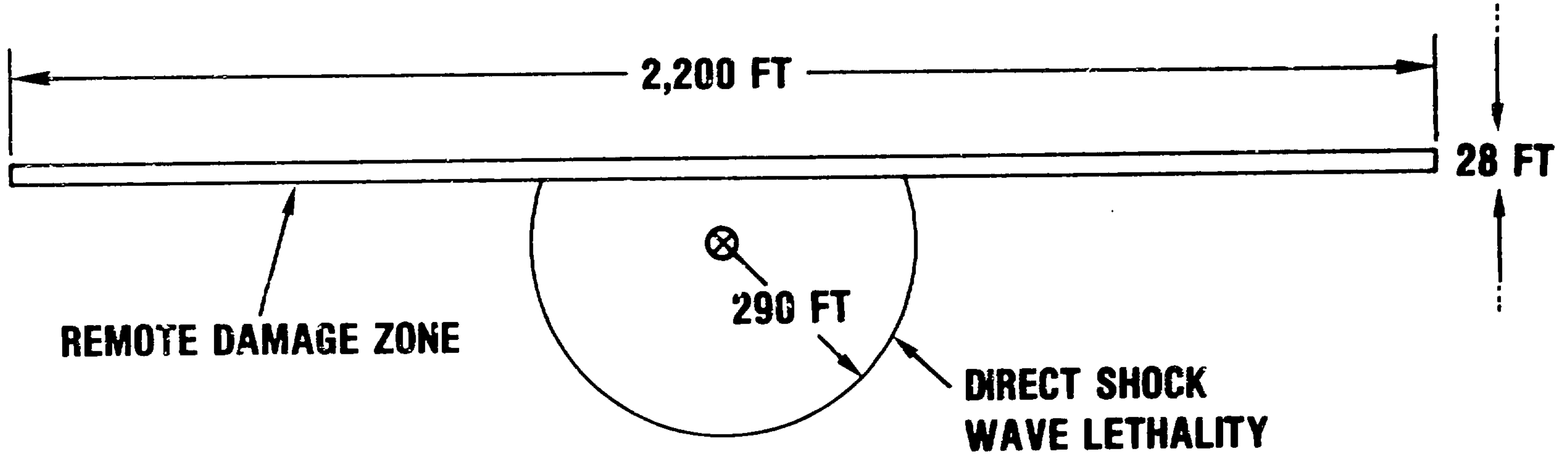
(VERY DEEP TNT EXPLOSIONS)

PRODUCT	CONCENTRATION (mg/l)	CRITERIA FOR FISHERIES (mg/l)
CO_2	0.215	25 (MAXIMUM)
CO	0.217	—
C	0.172	—
N_2	0.145	—
H_2O	0.113	—
H_2	3.64×10^{-3}	—
NH_3	1.08×10^{-2}	1.0 (TOXIC)
CH_4	6.22×10^{-3}	—
HCN	2.13×10^{-3}	0.3 (UNDESIRABLE) 1.0 (TOXIC)
C_2H_6	4.44×10^{-4}	—

Slide 15

ESTIMATED FISH-KILL REGIONS

NOL



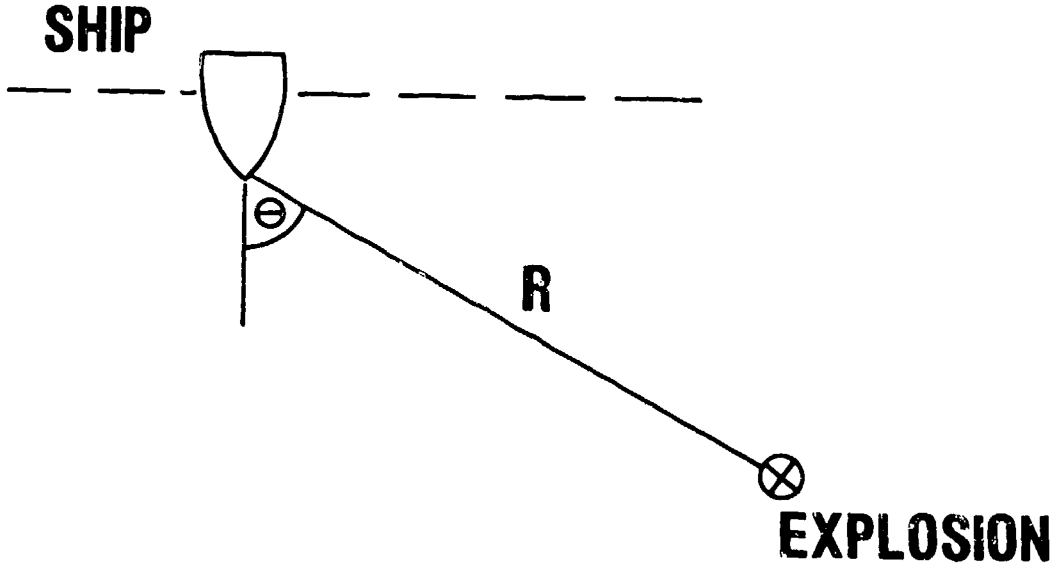
EXPLOSIVE WEIGHT = 100 LB

EXPLOSIVE DEPTH = 100 FT

Slide 16

KEEL SHOCK FACTOR

NOL



$$Q_k = \frac{\sqrt{W}}{R}\left(\frac{1+\cos\theta}{2}\right)$$

FOR SAFETY $Q_k = 0.01$

Slide 17

GUAM AMMUNITION PIER

NOL

LOCATED IN COMMERCIAL HARBOR (APRA)

LIMITED EXPLOSIVE HANDLING CAPABILITY

WAIVER OF QUANTITY—DISTANCE REQUIREMENT

LIMITS DEVELOPMENT OF THE PORT

EXPLOSION COULD CAUSE 4400 CASUALITIES

Slide 18

OBJECTIONS TO NEW PIER AT SELLA BAY

NOL

LAND SHORTAGE — 33.7% OF GUAM HELD BY MILITARY
2.6% OF GUAM REQUIRED FOR PIER SAFETY ZONE

SCENIC AREA

POTENTIAL SITE FOR TOURIST AND RECREATIONAL DEVELOPMENT

DEGRADATION OF UNDAMAGED CORAL REEF

DISTURBANCE TO MARINE LIFE

HISTORICAL ARTIFACTS

INCREASED COST OF HIGHWAY MAINTENANCE

AN ENVIRONMENTAL IMPACT STATEMENT IS REQUIRED IF:

NOL

(1) A SIGNIFICANT ADVERSE IMPACT IS EXPECTED, OR

(2) THE IMPACT IS CONTROVERSIAL.

DESIGN OF A FACILITY FOR THE GAMMA IRRADIATION OF PROPELLANT AND EXPLOSIVES

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ABSTRACT

An experimental and theoretical program was conducted to design a facility for exposing explosives and solid rocket motors to a 1000 Ci Co-60 gamma-ray source. The facility had to provide adequate personnel protection from both the radiation and explosives and at the same time prevent any accidental initiation of the explosives or propellants from spreading any Co-60 contamination throughout the area. It was calculated that it was convenient to adapt an existing solid propellant processing cell by adding the required radiation shielding.

For protection of the irradiator it was assumed that either detonation or explosion is a possible failure mode and the design formulae were derived for each of the cases. These formulae were tested experimentally at Edward Test Station of the Jet Propulsion Laboratory for their validity.

The results showed that an aluminum shield could be designed which is adequate for both detonation and explosion. However, since it was not possible to bring the propellant to detonation, the first shield is designed to protect against explosion only.

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I. Introduction

The objective was to design a Co-60 gamma-ray irradiation facility which could be used for exposing explosives and solid rocket motors. The facility had to meet the radiation safety requirements for ordinary radiation exposures plus those for handling explosives and/or propellants. Finally it had to be assured that any detonation or explosion that might accidentally occur would in no way damage the irradiator or disrupt its mechanism. The first part of the paper will discuss how the general facility requirements were met, followed by a discussion of the effort required to insure that there would be no spread of radioactive contamination.

Fortunately, a similar type of facility satisfies both the radiation and explosive requirements in that both are often constructed with thick concrete walls and ceilings. The explosive requirements also requires special lighting and electrical fixtures. An obvious first choice is then to convert an existing cell for explosive use into the irradiation facility. Such a cell was available in the facilities of the Solid Propellant Engineering Section at the Jet Propulsion Laboratory, and an investigation of the required modifications for irradiation use was begun.

II. Radiation Shielding Design and Construction

A plan view of the building is shown in Figure 1 with the proposed cell indicated. Two basic problems presented themselves. The first concern was whether the 3 ft thick concrete walls and ceiling were adequate to reduce the radiation to safe levels in the adjoining cell and the corridors of the building, one of which would also contain the control console for the irradiation. The second concern was the thin blow-out wall at the back of the cell. Although a steep embankment a short distance behind the wall served as a limiting boundary, the driveway in between the building and the embankment would allow personnel access to this area.

The solutions to these problems are of course a function of the gamma-ray source strength and geometry and must be mentioned briefly first. To obtain the widest range of exposure dose rates a beam type irradiation was chosen with a 120° horizontal aperture and a 30° vertical aperture (Fig. 2). The source strength chosen was 1000 Ci which gives a dose rate of about 1000 Rem/hour at one meter. To put this in perspective, if one stood at this distance for 15 sec he would receive his allowable yearly whole body dose. The desired dose levels exterior to room are 0.2mRem/hour in the hallway and adjoining rooms but 2.0mRem/hr was allowed in the driveway area since it is a normally unoccupied area.

Let us consider first the attenuation of the direct gamma ray beam. The dose rate will of course fall off with distance according to the inverse square law from essentially a point source. In addition to this there will be the reduction by the concrete walls. This attenuation of the incident beam is directly calculable by knowing the probability of interaction with the atoms in the cement; however, the dose rate depends not only on the reduced incident beam but also on the many lower energy gamma-rays generated by scattering of the incident beam. This additional dose rate is generally called radiation build-up. The calculation of the build-up is extremely complicated and requires the use of digital computers to carry out the computations in 6 dimensional phase space - 3 for position, 2 for direction and one for energy. However several useful approximations are available and were used for this study.

The expression for the total attenuation is given by:

$$\phi = B(E,\mu r) S \frac{e^{-\mu r}}{4\pi r^2}$$

where

r = distance from "point" source

$\frac{1}{4\pi r^2}$ = inverse square law attenuation

$e^{-\mu r}$ = exponential attenuation in cement, having an attenuation coefficient, μ

S = source strength

$B(E,\mu r)$ = build-up factor

E = energy of gamma ray

Two approximate expressions were used for the build-up factor. A linear expression was used where

$$B(E,\mu r) \simeq 1+\alpha(E)\mu r \tag{1}$$

and this was compared to results from the exponential expression

$$B(E,\mu r) \simeq A(E)e^{-\alpha_1(E)\mu r}+[1-A(E)]e^{-\alpha_2(E)\mu r} \tag{2}$$

Values for $\alpha(E)$ used in equation (1) have been tabulated by Trubey (Ref. 1) and values for $\alpha_1(E)$ and $\alpha_2(E)$ for equation (2) by Taylor (Ref. 2). For the work done here values from the two expressions agreed with one another to within a few percent.

Calculations of the shielding provided by the existing cement wall indicated a dose rate of 3mRem/hr in adjacent halls and rooms with the source placed as far from the walls as possible. This is over a factor of 10 higher than the 0.2mRem/hr limit specified by JPL in an uncontrollable area. This required additional shielding in the path of the direct beam. Some " heavy" concrete blocks were available at reasonable cost and this was stacked to a height of 6 ft. and a thickness of 16 inches along the forward side walls in the path of the direct beam. Transite 1/4" thick with a metal frame were used to secure the blocks in position (Fig. 3). Calculations with this thickness indicated the dose rate level to be below 0.2mRem/hr.

This was borne out after construction with measurement of <0.1 mRem/hr.

At the feed throughs at the eight foot level the dose rate was ≈1.5 mRem/hr. but this was located high enough to prevent personnel exposure.

The more difficult problem came with the scattered radiation. The cement roof was quite adequate to reduce the scattered dose rate to essentially zero except in the vicinity of some airconditioning ducts. Rather than shielding for this, since the roof is not normally occupied, the two access ladders are locked during any irradiation. This left the back blowout wall as the remaining problem. It was obvious that the existing wall would not be adequate although it was still considered desirable to maintain the advantage of at least a partial blowout wall. The decision was to erect a block wall about six feet high to prevent direct line of sight personnel exposure and have the blow-out wall extend the remainder of the way to the ceiling. The wall was planned in maze form to allow minimum radiation exposure through the door. (Fig. 4). It was felt that with this approach gates would still be needed across the driveway druing irradiations.

Accurate calculation of this wall would involve Monte Carlo methods to treat the statistical nature of the multiple scattering and energy of the resulting gamma-rays. Instead some back-scatter dose rate measurements were made on a similar lower strength cobalt irradiation in a somewhat similar geometry. These were pessimistically assumed to be all caused by gamma rays single scattered through an average angle to reach the back wall and an appropriate concrete block wall thickness calculated. After this was constructed (Fig. 5), dose rate measurements were made along the exclusion gates and were found to be high by a factor of ∼40 where one could see the access door and a factor of from 3 to 10 elsewhere. By using a dose rate meter with preferentially located 2" thick lead shielding it was possible to determine that the major problem was downward scattering in the air from radiation passing through the blow-out portion of the wall above the maze and through the door. Lead sheet 1/4" thick was then added to the door and double sheets of plywood each with 1/8" thick lead sheet attached were added to the blow-out wall. With this the dose rates at the gates were reduced to 1.0mRem/hr or less.

The safety of operation of the facility rests both on limited and controlled key distribution and on interlocks. The initiating sequence for an exposure consists of verification that:

1) Roof access ladders are locked. (because of design this automatically insures that no persons are present on roof).
2) No persons are present in the irradiation cell.
3) Door and gates are closed.

Next upon operation of a key switch:

1) A horn blows for 10 seconds.
2) A pneumatic mechanism raises the radioactive isotope out of the lead shielded container shown in Fig. 2.
3) A standard flashing red light is operated continuously as long as the radioactive isotope is not at the bottom of the container.

An automatic timer and a "scram" button are also provided in the control console. Any one of four interlocks causes immediate return of the radioactive source to the container upon occurrence of any of the following:

A) West gate not closed.
B) East gate not closed.
C) Door not closed.
D) Door bolt not in locking position.

Panic box on door and emergency ingress key in a strike box complement the safeguards.

Finally an independent area radiation monitoring system with read-outs both in the cell and at the console is connected with an automatic alarm system which is actuated upon occurrence of both:

A) High radiation field.

B) Unlocked cell door

III. Blast shield considerations

In case of accidental rocket motor initiation, two possibilities are assumed to exist: detonation and explosion. Explosion is a rupture of the rocket motor due to the slow build-up of pressure inside chamber which becomes larger than the structural strength limit at some point and bursts the motor open. In this case, a portion of the propellant inside the motor could still remain unburnt at the time of explosion. In detonation, the propellant is burnt so fast that the failure occurs at the motor pressure far above the structural strength limit. In this case, the total amount of propellant is consumed before rupture.

Several mechanisms contribute to potential damage to the irradiator from accidental initiation: blast wave generated by the explosion or detonation, shrapnels from motor case, heat radiation and heat convection. The last is negligible for the conditions of this facility.

In calculating the damage effect of blast wave and shrapnels, the explosion can be treated as a detonation if an effective mass of detonation, W, is known. In the following sections, this effective mass of detonation is calculated, and then shield design formulae are derived accordingly.

The effect of heat radiation will be mentioned later.

IV Effective Mass of Detonation, W

If there is a detonation, W is the total propellant mass. On the other hand, if there is an explosion, W can be calculated as follows. First, it is assumed that the effective explosion energy, E_α, is linearly related to internal energy of gas, E_1, at the time of explosion, which in turn is proportional to the product of the container volume, V, and the rupture pressure of the container, P_o.

$$We_\alpha = E_\alpha \sim E_i \propto VP_o. \qquad (3)$$

The above expressions represent a minor generalization from Ref. 3. Here, the proportionality constant is unknown, and this can be indirectly derived as follows.

Now consider a motor case of the shape of a spherical shell with volume, V, radius, r, thickness, δ, and density, ρ_m. The mass will be

$$M \propto 4\pi r^2 \delta \rho_m$$

The force acting on a hemisphere by the inner pressure, P_o, is expressed

$$F_1 = \pi P_o r^2$$

The ultimate force of this container with yield strength, Y, is

$$F_2 = 2\pi Y r \delta$$

At the rupture point these two forces should match.

$$F_1=\pi r^2 P_o=F_2=2\pi Y r\delta$$

Thus:

$$P_o=2Y\delta/r$$

Substituting this in Eq. (3):

$$We_\alpha \sim VP_o \propto r^3 P_o=2r^3 Y\frac{\delta}{r}=2Yr^2\delta \tag{4}$$

$$W/M \sim Y/(\rho_m e_\alpha)$$

This means that W/M depends only on the material properties of the container, but not on its dimensions.

The initial shrapnel velocity from the detonation of the motor depends only on the heat of explosion of the propellant and the W/M of the motor, as shown by the following empirical formula (Ref. 4):

$$v_o=\sqrt{2e_\alpha}\sqrt{\frac{W/M}{1+W/2M}} \tag{5}$$

Because of Eq. (4) the initial fragment velocity depends only on the heat of explosion and Y/ρ_m. In Eq. (5) v_o is the initial fragment velocity and e_α is the specific heat of explosion.

Solving Eq. (5) for the ratio W/M and substituting into Eq. (4) one obtains:

$$(2e_{\alpha,x}/v^2_{o,x} - 1/2)^{-1} = (2e_\alpha/v^2_o - 1/2)^{-1} \frac{Y_x/(\rho_{m,x} e_{\alpha,x})}{Y/(\rho_m e_\alpha)} \tag{6}$$

where the subscript x denotes parameters for the case under consideration. Eq. (6) permits the calculation of the fragment velocity $v_{o,x}$ for any case, provided the velocity v_o is known for one set of propellant and case parameters Y, ρ_m, e_α. Suitable correction coefficients should be introduced for motor shapes other than spherical and nonhomogeneous compositions.

Pittman (Ref. 3) measured fragment velocities from bursting pressure tanks with Titanium- 6 Aluminum - 4 Vanadium alloys with several different sizes and shapes. The results show that for the variety of tank shapes and sizes, the initial fragment velocities were in the narrow range of 1215-1470 fps or 920-1200 fps depending on the measuring systems. Considering the inhomogeneity and the nonspherical shape of the casing, these values can be regarded as very much uniform. The average value can be taken safely to be 2000 fps. Thus, one can use this result with Eq. (6) to calculate the equivalent TNT charge amount of any given motor.

Pittman's result is:

$$W/M = (v_o^2/2e_\alpha)/(1 - v_o^2/4e_\alpha) = 0.0877 \quad \text{for Ti-6Al-4Va}$$

where

$$\sqrt{2e_\alpha} = 6900 \text{ ft/sec} \quad \text{for TNT}$$

One can, therefore, get

$$(W/M)_{steel} = 0.0877 \times \left(\frac{\rho_m e_\alpha}{Y}\right)_{Ti-6Ae-4Va} \times \left(\frac{Y}{\rho_m e_\alpha}\right)_{steel}$$

Finally,

$$(W)_{steel} = (W/M)_{steel} \times M$$

Since most propellants have similar values for e_α.

V. Blast Wave Effect

The pressure wave impulse which hits the protective shield is obtained from a semi-empirical chart (Fig. 6) as a function of r, the distance between explosion source and the shield and of W, the effective detonation mass expressed in equivalent amount of TNT (Ref. 5).

First one calculates the effective distance

$$Z = r(\mathrm{ft})/W^{1/3}(\mathrm{lbs})$$

Then read $I_r/W^{1/3}$, and correspondingly I_r, from Fig. 5.

Next the critical shield thickness, δ_c, which can barely withstand the given pressure wave impulse, I_r, is given by an empirical formula (Ref. 6).

$$\delta_c = \frac{I_r \cdot c_o}{\sigma_y}$$

where c_o is sonic speed in the shield material and σ_y, its dynamic yield strength. This thickness δ_c will be used in the next section to obtain the design thickness of the shield.

VI. Shrapnel Effects

The damage caused by a shrapnel is quantified by the maximum thickness d_p which can be perforated by it. According to an empirical formula provided by Sewell (Ref. 5), Kornhauser (Ref. 8), for aluminum:

$$d_p(\text{inches}) = d'_p\,(1.5) = \frac{2.3 \times 10^{-7} \times \text{mass of fragment (grains)} \times v_s\ (\text{fps})}{\text{Impact area of fragment (in}^2)} \times 1.5$$

Where d'_p, is given by Sewell is the depth of penetration in a thick shield and v_s is the striking shrapnel velocity.

In our situation, the striking fragment velocity is practically identical to the initial fragment velocity which is given in Eq. (5) because the flying distance is too short for the drag force to slow down the fragments.

For thin shrapnels, if one assumes an average hitting angle of shrapnels on the shield, the mass to area ratio is independent of the size of the shrapnels but dependent only on their density and thickness.

The effective impact area of the shrapnels is considered to be a portion of the projected area of the shrapnels, that is,

Effective area $= \alpha \times$ flat surface area where

$\alpha =$ cos (average angle of impact presentation).

In this paper α is taken to be 1/2.

To account for the possible summing of effects due to certain sequence of events, the thickness of the shield which can barely withstand the blast is computed as

$$d = \delta_c + d_p$$

For the actual shield design, a safety factor of $\beta = 3 \sim 4$ should be applied to give a design thickness,

$$D = \beta d.$$

VII. Experimental verification

Four tests were performed at Edward Test Station of Jet Propulsion Laboratory. The shield was designed without any safety factor to be just marginal and therefore allow verification of the formulas. Propellant or explosive was placed inside vertical tubes (OD:3.5", thickness: 65 mils, height: 10", Fig. 7) and ignited after an Aluminum Shroud (thickness: 1/4", OD: 2.5', height: 1.5') with a top plate (Fig. 8) was placed surrounding the tube. Damage on the shroud for each case was observed and is described in Table 1.

Typical results of the experiement are shown in Figs. 9 - 12.

Figs. 9 and 10 show the ruptured tube and the damage on the shroud for Test B. Figs. 11 and 12 show the same for Test D.

The results show that only in Test 4 (where explosive was used), detonation conditions were achieved.

Furthermore, in Test 1 and Test 3, the pressure wave impulse and the shrapnel velocity were reduced by a weakening of the container case due to heat concentration on a certain region before the rupture.

The experimental results matched the calculations very satisfactorily. In the case of no detonation the computed thickness was d=0.16", and the 0.25" Aluminum shroud withstood the first 3 tests with only one hole. This hole was probably made by a shrapnel hitting the shroud with a sharp angle.

For the detonation case the calculated thickness of 0.28" was very close to the actual thickness of the Aluminum shroud, and, as expected, the blast produced many perforated holes as well as many unperforated indentations. Again, when these were closely examined, it was known that the perforated holes were mainly made by the shrapnels hitting the shroud sharply and the others by the shrapnels hitting the shroud more or less flat.

VIII. Heat radiation

The temperature increase of the shield was calculated as:

$$\Delta T = \frac{Q}{c_{ps} \cdot \rho_s \cdot D}$$

where $Q=\sigma T_c^4 \cdot (\frac{r_o}{r})^2 \cdot t_c$.

C_{ps} is the specific heat of the shield, ρ_s, its density, D, its thickness, σ, Stephan-Boltzmann constant, T_c, propellant combustion temperature, r_o, propellant radius and t_c, propellant combustion temperature.

For the given conditions,ΔT of the shield is calculated to be of order of 100°C. Therefore, the temperature increase of the irradiator itself should be negligible.

IX. Conclusion

A facility for the gamma irradiation of propellants and explosives was constructed. A proper protection against the radiation source was built and design formulae were assembled for a shield against any accidental motor initiation. These formulae were tested experimentally and proved to be satisfactory.

Furthermore, the calculated aluminum shield thickness for the given conditions (approximately 1 cm) reduces the radiation intensity by only approximately 10%.

The author gratefully acknowledges many instructive discussions with Mr. V. Menichelli as well as his invaluable contributions in the design of the tube, design of the explosive train, and in the experimental runs.

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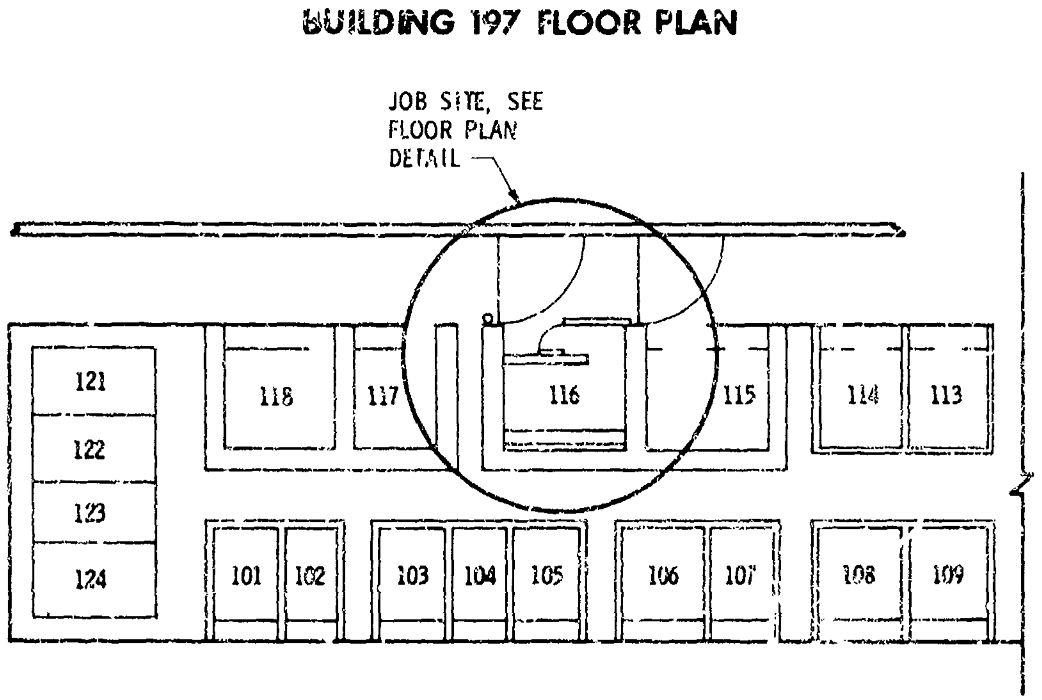

Fig. 1 Floor Plan

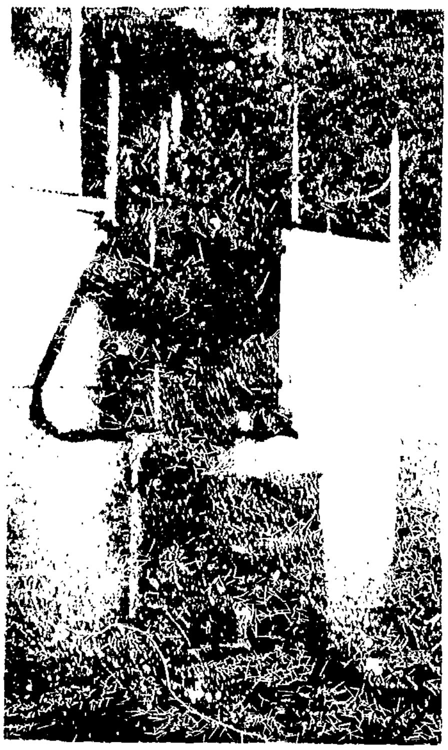

Fig.2 Co^{60} GAMMA IRRADIATOR

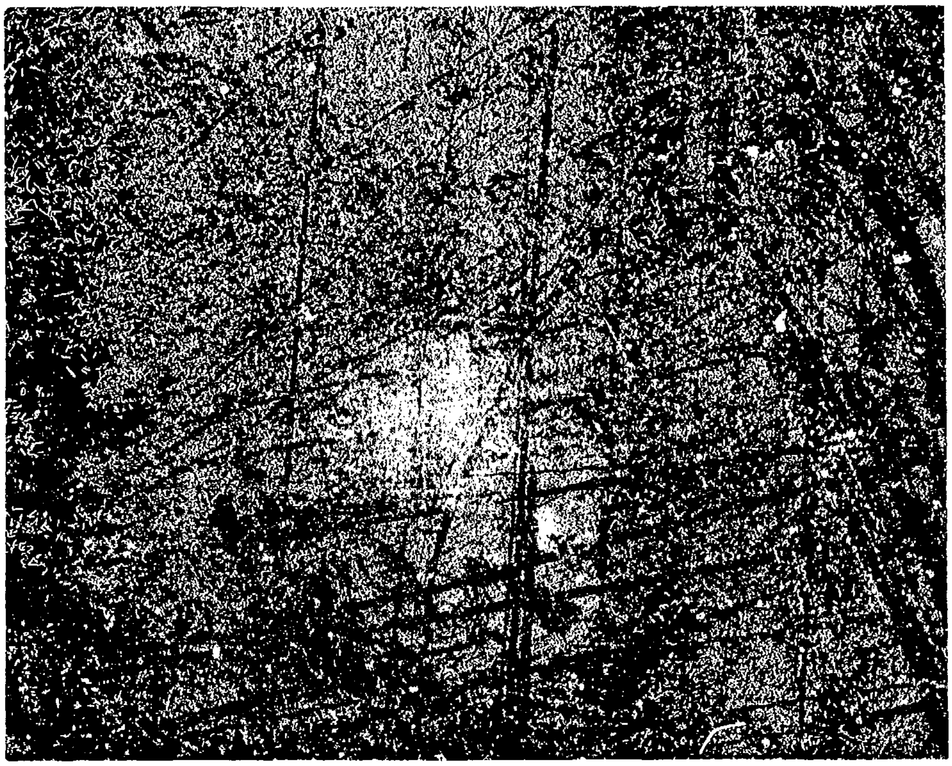

Fig.3 **RADIATION FACILITY**

FLOOR PLAN DETAIL

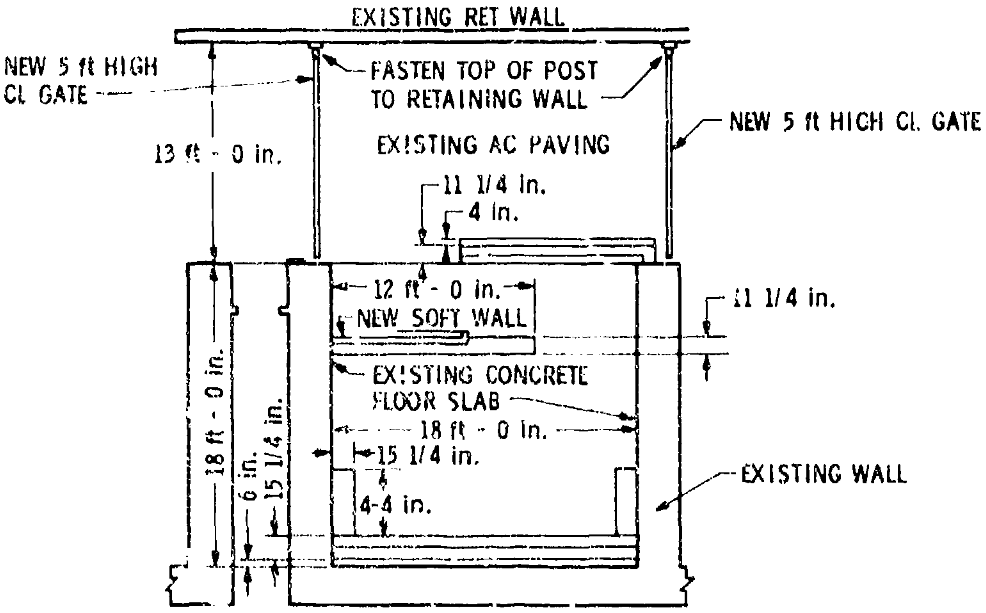

Fig. 4 Floor Plan Detail

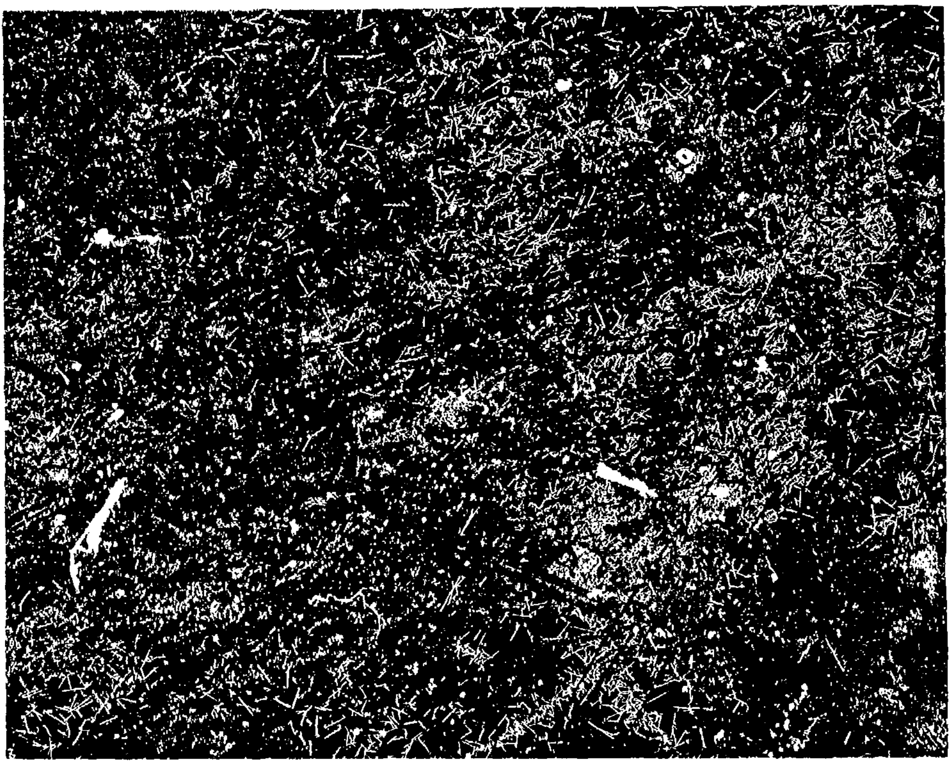

Fig. 5 **ENTRANCE TO RADIATION ROOM**

REFLECTED POSITIVE PHASE IMPULSE

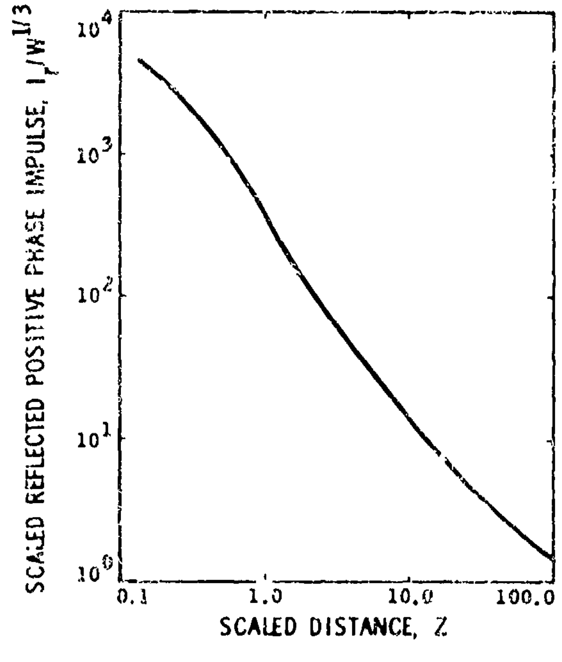

Fig. 6 Reflected Impulse

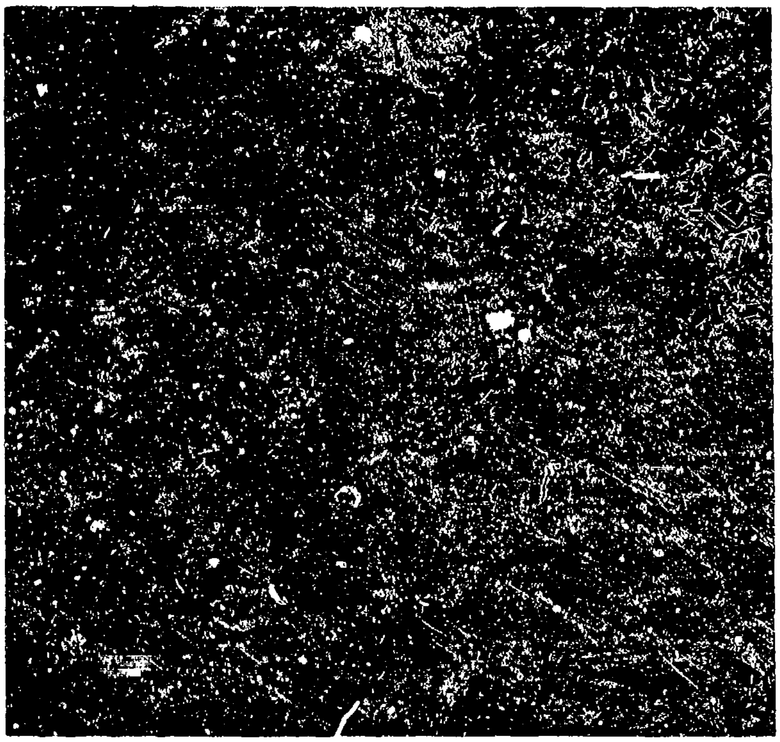

Fig.7 **TUBE SETUP**

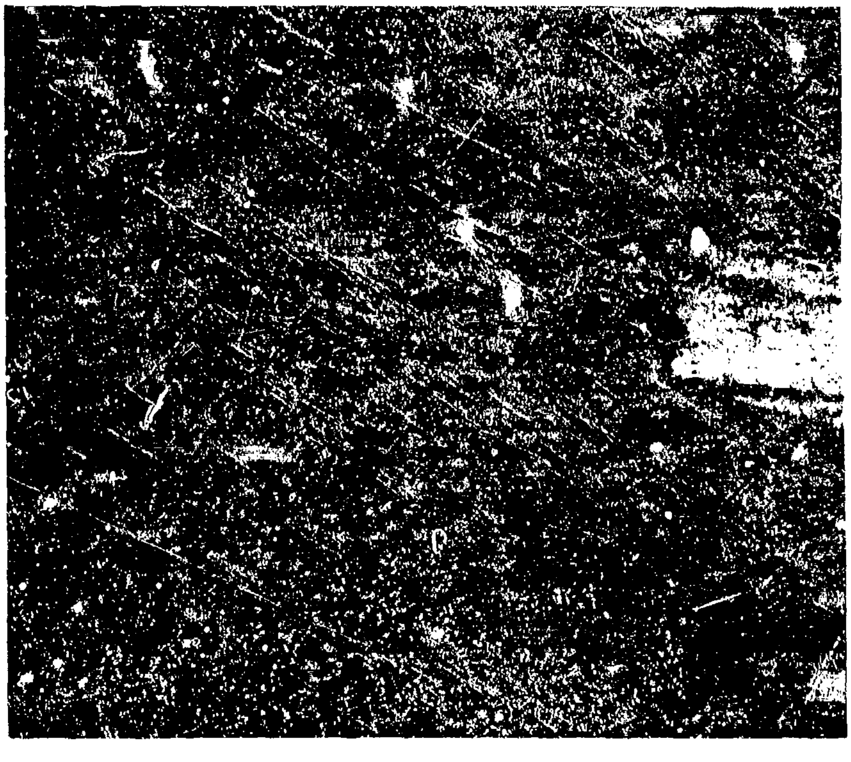

Fig.8 **SHROUD**

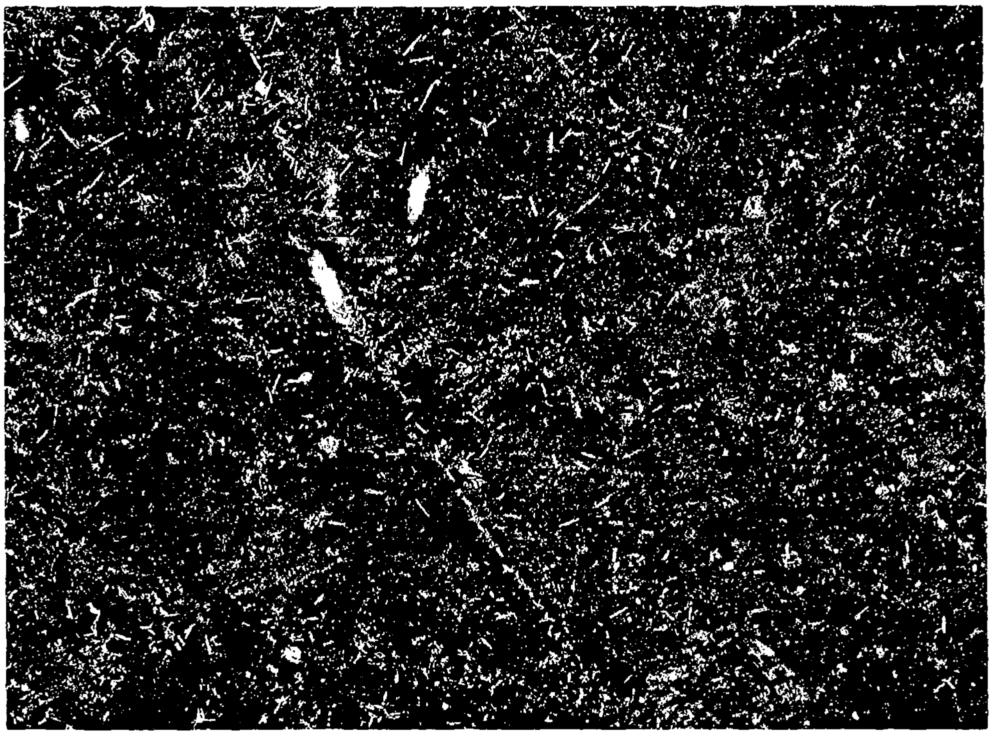

Fig.9 **RUPTURED TUBE, TEST B**

Fig.10 **SHROUD DAMAGE, TEST B**

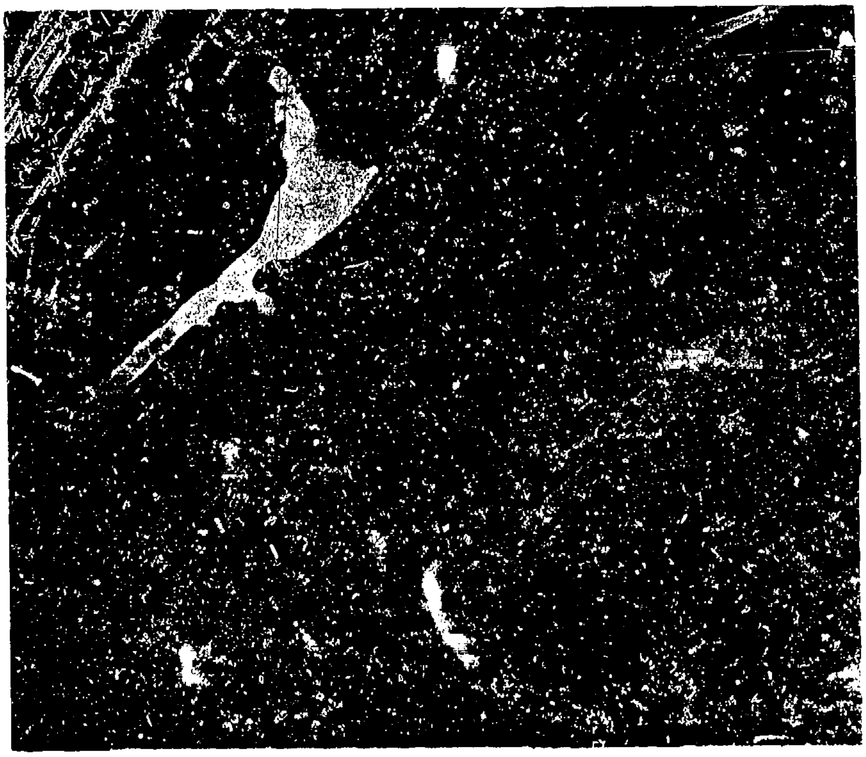

Fig.11 **RUPTURED TUBE, TEST D**

Fig. 12 **SHROUD DAMAGE, TEST D**

DESIGN FORMULA TEST

TEST	COMPOSITE PROPELLANT	IGNITION METHOD	INSULATION INSIDE TUBE	TYPE OF BLAST	CALCULATED SHROUD THICKNESS	ACTUAL SHROUD THICKNESS	TUBE DAMAGE	SHROUD DAMAGE	COMMENT
A	[illegible] 120 g	SQUIBS WITH BORON PELLETS	NONE	EXPLOSION	0.16 in.	1/4 in.	LARGE HOLE AT BOTTOM	NO APPRECIABLE DAMAGE	HEAT CONCENTRATION ON BOTTOM PART BEFORE RUPTURE
B	JPL 540 2% CuO_2O_2 694 g	SQUIBS WITH BORON PELLETS	PL-30K 1/4 in.	EXPLOSION	0.16 in.	1/4 in.	SEVERAL LARGE PIECES	6 DENTS 1 HOLE	EXPLOSION
C	JPL 540 2% CuO_2O_2 1860 g	SQUIBS WITH BORON PELLETS	PL-30K 1/4 in.	EXPLOSION	0.16 in.	1/4 in.	TOP PART OPEN	NO FURTHER DAMAGE	HEAT CONCENTRATION ON TOP PART BEFORE RUPTURE
D	DETASHEET 91 g	No. 8 BLASTING CAP	NONE	DETONATION	0.25 in.	1/4 in.	NUMEROUS SMALL PIECES	20-30 SMALL DENTS ~10 HOLES	DETONATION

Table I. Design Test

ENVIRONMENTAL BLAST EFFECTS DUE TO ACCIDENTAL DETONATION OF A MONOPROPELLANT FUEL

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ABSTRACT

In a detailed safety study of the Experimental Propulsion Testing Facilities at the Naval Underwater Systems Center (NUSC), Newport, Rhode Island, estimates were made of the environmental blast effects of an accidental detonation of a monopropellant fuel tank during captive torpedo powerplant testing. The study revealed a potentially serious problem with testing operations: The facility test control center was found to be at a critical location and of questionable construction for testing present-day state-of-the-art torpedo propulsion systems.

This paper describes the testing facilities, discusses the estimated blast effects on the facilities, and outlines the steps taken by NUSC to improve the safety of propulsion testing.

INTRODUCTION

The Naval Underwater Systems Center (NUSC) is the Navy's principal RDT&E center for underwater combat systems. NUSC was formed in 1970 by the merger of two independent laboratories of the Naval Material Command: The Naval Underwater Weapons Research and Engineering Station, Newport, Rhode Island, and the Naval Underwater Sound Laboratory, New London, Connecticut. These two R&D laboratories now form the two principal laboratory complexes of NUSC, headquartered in Newport. Field facilities, detachments, and test ranges at geographic locations other than Newport and New London are shown in figure 1.

Torpedo propulsion system research, development, test and evaluation programs are conducted at the Newport Laboratory's Experimental Propulsion Test Facilities shown in figure 2. These facilities consist of the following:

- Deep Depth Torpedo Propulsion Test Facility.
- Propulsion System Component Test Facility.
- DC Power Generating Facility.
- On-Site Engineering Offices, Assembly Machine Shop, and Instrumentation Support Area.
- Explosive Test Facility.
- Fuel Storage Area.
- Special Engine Assembly Area.

DEEP DEPTH TORPEDO PROPULSION TEST FACILITY

Torpedo propulsion systems are tested in NUSC's Deep Depth Torpedo Propulsion Test Facility under controllable conditions that closely duplicate those encountered by a sea-launched torpedo. This facility, shown in figure 3, can test both thermal and electric torpedoes and can simulate sea-water depths to 5600 feet and depth transients to 60 feet per second. Power outputs up to 1000 horsepower can be absorbed on the variable water brake dynamometer. High-pressure large-volume liquid propellant tanks are available to supplant or supplement torpedo tankage for extended duration tests.

This torpedo test facility has two unique features: (1) Torpedoes can be launched, and shut down, at any simulated depth; (2) The sea-water reservoir is temperature-controlled to allow testing at temperatures from 30°F to 130°F.

The test facility is housed in a specially constructed, T-shaped building. The building has a control room, a dynamometer room, a main test cell, an engine test cell, a combustion test cell, a fuel tank cell, and a high pressure air cell. The "cell" part of the building is constructed of 18-inch reinforced concrete walls and ceilings; the center walls of the test cells and tankage cells are designed for rapid and unidirectional release of gases in the event of an explosion. Each test cell and room is protected by the centralized carbon dioxide fire fighting system shown in figure 4. Additionally, deluge sprays (figure 5) are directed at fuel storage tanks to control their temperature in the event of fire. Vehicle and pedestrian traffic in the vicinity of the test site is strictly controlled by road guards during test operations (figure 6).

PROBLEM DEFINITION

ESKIMO I test series presentations and discussions at the 14th Explosive Safety Seminar sponsored by the Department of Defense Explosives Safety Board prompted a detailed and critical safety review of blast effects on the propulsion facilities at NUSC. This study revealed a potentially serious problem with testing operations. Facility improvements and development had not kept pace with the technology being tested.

The propulsion test facility, constructed in 1960, was designed for propulsion tests that used remote oxidizer, fuel, and diluent water facility tankage, or bulkhead-separated torpedo tankage. Potential detonations were most probable only in the combustion chamber, where fuel and oxidizer were joined and where only small quantities (5 to 10 pounds) would be involved. These considerations, coupled with the containment concept of thick-walled test cells using pre-1960 construction techniques, allowed the control room to be built of cement block with a reinforced concrete slab roof.

During the ensuing time span, rapid developments were made in underwater propulsion technology -- the case in point being the development of families of torpedo monopropellant fuels containing both fuel and oxidizer mixed in the same liquid.

Tests presently conducted at the NUSC facility use quantities of monopropellants in excess of 800 pounds, pressurized above 1000 psia in temperature environments from 30°F to 130°F. With a TNT-equivalent rating of 1.0, the monopropellants now used represent a major increase in potential hazard as compared to the type of propellant systems for which the facility was initially designed.

Awareness of these factors led to consultations with the staff of the Naval Sea Systems Command Safety Office regarding the following aspects of present-day propulsion testing:

- The use of monopropellants in which fuel and oxidizer are mixed at the molecular level.
- The large quantities of fuel involved.
- The environment of the propellant during testing (confinement, pressurization, elevated temperature, close proximity of fuel tank to combustor).
- Safety test data on propellants.

It was determined that monopropellants in an environment of systems test on a liquid propellant static test stand comprised a Category IV hazard as defined in reference 1. Application of quantity distance requirements as required by Naval regulations for this category hazard revealed that the location of the control room was critical. Thus, an investigation of the control room's structural suitability was begun.

CONTROL ROOM INVESTIGATION

BLAST EFFECTS STUDY

Using the structure geometry of NUSC's propulsion test facility (figure 7), a study was undertaken to estimate the blast effects of an accidental detonation of a monopropellant fuel tank during captive torpedo powerplant testing. A generalized monopropellant fuel having a TNT-equivalent rating of 1.0 was selected as the donar system in the amount of 1000 pounds.

The safety design manual entitled "Structures to Resist the Effects of Accidental Explosions" (reference 3), developed under the technical direction of Picatinny Arsenal and the sponsorship of the DOD Explosives Safety Board, was used as the primary guide for this study. This regulatory tri-service safety design manual contains procedures, tables, and charts required to establish the output of an explosion in its environment and the damaging effects on that environment in terms of blast and fragmentation. This manual has established, through analytical studies supported by testing, realistic design criteria to prevent explosion propagation, damage to material, and, most importantly, injury to personnel.

BLAST PHENOMENA

The intensity of the pressures associated with monopropellant detonation decays as a function of time and distance as the shock expands outward from the center of the explosion. Structures hit by the shock wave experience blast loads whose magnitude and distribution depend on: (1) the weight and type of explosive, (2) the position of the explosion relative to the structure, and (3) the magnitude and reinforcement of the pressure by its interaction with the ground or structure.

In the case of explosions involving liquids, the explosion is in many cases incomplete with only a portion of the charge weight detonating. The remaining charge generally undergoes deflagration, which may cause fires. However, confinement, high pressure, or elevated temperature conditions would tend to accelerate the reaction kinetics. The pressure-time history at any point away from the detonation is shown in figure 8. Time t_A indicates the time the shock front arrives. After rising to the peak value P_{so}, the incident pressure decays to ambient during time period t_o^-, which is of longer duration than the positive phase and which has a pressure level lower than the predetonation ambient pressure. The incident impulse density (or unit incident impulse, as it is sometimes called) associated with the blast wave is the integrated area under the pressure time curve, denoted by i_s for the positive phase and i_s^- for the negative phase. The positive phase wavelength L_w is the length from the detonation site to a point that is experiencing positive pressures.

WALL LOADING

In order to accurately determine the side wall loading on a surface where the span direction is perpendicular to the shock front, a simultaneous, complex dynamic analysis of the stresses in the span as a function of time is required. However, to simplify this procedure, an approximate method has been developed using an equivalent uniform loading technique, which is presented in detail in reference 2.

An equivalent load factor C_E and blast wave location ratio D/L are obtained from figure 9 as a function of wavelength-to-span ratio L_{wb}/L.

The peak value of the pressure on the side wall P_o is the sum of the contributions of the equivalent incident pressure $C_E P_{sob}$ and the drag pressure $C_D q_{ob}$:

$$P_o = C_E P_{sob} + C_D q_{ob}$$

In this equation, P_{sob} is the peak overpressure occurring at point b; and q_{ob} is the peak dynamic pressure corresponding to the value of $C_E P_{sob}$. The drag coefficient C_D for roofs and side walls is a function of the peak dynamic pressure. For conditions of peak dynamic pressure <25 psi, an accepted value of the drag coefficient is -0.40.

The scaled ground distances Z_G to points b and f are given by:

$$Z_{Gb} = \frac{R_b}{W^{1/3}} \qquad Z_{Gf} = \frac{R_f}{W^{1/3}}$$

$$= \frac{74}{(1000)^{1/3}} \qquad = \frac{44}{(1000)^{1/3}}$$

$$= 7.4 \text{ ft}/(\text{lb})^{1/3} \qquad = 4.4 \text{ ft}/(\text{lb})^{1/3}$$

Figure 10 presents preliminary data from the Naval Civil Engineering Laboratory, Port Hueneme, on pressure leakage from a three-walled, roofed cubicle as a function of scaled ground distance.

The peak incident pressure P_{so} at points b and f due to leakage is: $P_{sob} = 5.5$ psi and $P_{sof} = 7.2$ psi. The following tabulation presents shock parameters corresponding to these levels of peak incident pressure as taken from figure 11.

Shock Parameter	Value
P_{sob}	5.5 psi
$\frac{L_{wb}}{W^{1/3}}$	3.1 ft/(lb)$^{1/3}$
U	1.3 ft/ms
$\frac{t_{Ab}}{W^{1/3}}$	7.0 ms/(lb)$^{1/3}$
$\frac{i_{sb}}{W^{1/3}}$	7.2 psi ms/(lb)$^{1/3}$
P_{sof}	7.2 psi
$\frac{L_{wf}}{W^{1/3}}$	2.8 ft/(lb)$^{1/3}$
U	1.37 ft/ms
$\frac{t_{Af}}{W^{1/3}}$	5.4 ms/(lb)$^{1/3}$
t_{Ab}	70 ms
t_{Af}	54 ms

From the foregoing tabulation, the scaled wavelength at point b is

$$\frac{L_{wb}}{W^{1/3}} = 3.1,$$

whence $L_{wb} = 3.1\ (10) = 31$ feet. The wavelength-to-span ratio becomes

$$\frac{L_{wb}}{L} = \frac{31}{30} = 1.03$$

for a control room span length L of 30 feet.

From figure 9, it can be determined that for $L_{wb}/L = 1.03$, the equivalent load factor C_E is 0.73 and the blast wave location ratio D/L is 0.38. The equivalent uniform load corresponding to a peak positive incident pressure P_{so} of 5.5 psi at point b is

$$C_E P_{sob} = (0.73)\ (5.5) = 4.02 \text{ psi}.$$

For P_{sob} of 5.5 psi, the peak dynamic pressure at point b from figure 12 is $q_{ob} = 0.7$ psi. Thus, the pressure on the side wall is

$$P_b = C_E P_{sob} + C_D q_{ob}$$

$$= (4.02) + (-0.40)\ (0.7) = 3.74 \text{ psi}.$$

The arrival times of the shock wave at points f and b of the span are determined for $\frac{t_A}{W^{1/3}}$:

$$t_{Af} = 54 \text{ ms}$$

$$t_{Ab} = 70 \text{ ms}.$$

The rise time t_d is the time at which the shock reaches point d and is given by

$$t_d = \frac{D}{U}.$$

The distance D at which the shock exerts the maximum load is

$$D = \left(\frac{D}{L}\right) L$$

$$= (0.68)\ (30) = 20.4 \text{ feet}.$$

Hence, the rise time is

$$t_d = \frac{20.4}{1.3} = 15.7 \text{ ms},$$

where U = 1.3 ft/ms at point b.

The duration of the fictitious positive phase is

$$t_{of} = \frac{2i_s}{P_{so}}$$

$$= \frac{2\ (72)}{5.5} = 26.2 \text{ ms}$$

FINDINGS

CONTROL ROOM CONSTRUCTION

A plot of the pressure-time history of the loading on the side wall is presented in figure 13. This plot shows that the control room of the propulsion test facility will experience an equivalent side wall pressure loading of 3.74 psi for a duration of 26.2 milliseconds. This loading corresponds to a peak positive incident pressure of 5.5 psi at the end point of the side wall span.

As concrete block walls and glass areas cannot withstand peak incident pressures above 2.0 and 0.5 psi, respectively, the control room's construction was obviously unsuitable for present-day propulsion testing. The leakage pressure generated by the blast would either push the side walls inward during the positive pressure phase or force them outward during the negative phase, with the ensuing collapse of the pre-stressed slab concrete roof into the interior of the control room.

These findings were confirmed by recent data presented by the URS Research Company (reference 4), which revealed that concrete block walls will fail when subjected to peak incident pressures above 2.0 psi.

CONTROL ROOM LOCATION

Quantity distance requirements as stated in reference 1 are shown in figure 14. The blast area extends outward a distance of 800 feet in a 60° inclusive arc. The intraline distance encompasses an area of 300° of arc and a radius of 95 feet. The inhabited building distance is 400 feet. Figure 15 shows incident pressure isobars of 100, 5, and 1 psi superimposed on the quantity distance requirements for comparison of the blast effects with these regulatory distances. Based on these considerations, the location of the control room was found to be improper.

CORRECTIVE ACTION

When alerted to the magnitude and scope of this potential hazard, Center management immediately took the following course of action:

1. Initiated a project to relocate the control room into Building 127, which is of suitable construction and meets quantity distance requirements (see figure 16).
2. Imposed a per-test limitation of 200 pounds on the use of sensitive monopropellant pending completion of the relocation project.
3. Obtained a waiver from the NAVSEASYSCOM Safety Office for continuation of programs vital to the National Defense under conditions 1 and 2.

Relocation efforts are in progress, with completion expected in the near future. The NAVSEASYSCOM Safety Office is presently reviewing torpedo monopropellant certification criteria and safety tests as well as testing facilites in the Navy and the private sector.

ACKNOWLEDGEMENTS

The author wishes to thank the staff of the NAVSEASYSCOM Safety Office under Mr. Herb Roylance for its continuing guidance. The contribution of Mr. Richard Rindner of the Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey, including his technical review of the initial study on which this paper is based, as well as his concerned professional cooperation, is gratefully acknowledged. The author also thanks the Department of Defense Explosive Safety Board under CAPT P. F. Kleir for providing the impetus for discovery and correction of this major potential hazard.

The value of the Annual DOD Explosive Safety Board Seminar to government and industry alike has once again been demonstrated.

REFERENCES

1. "Ammunition and Explosives Ashore," Dept. of the Navy, NAVORD OP 5, Vol. 1, Part 1, Third Revision.

2. John Miguel, "Blast Effects Due to Accidental Detonation of Monopropellant Fuels,' Naval Underwater Systems Center Technical Memorandum 4354-73, 24 July 1973.

3. "Structures to Resist the Effects of Accidental Explosions," Dept. of the Army, TM 5-1300; Dept. of the Navy, NAVFAC P-397; Dept. of the Air Force, AFM 88-22, June 1969; revised 17 March 1971.

4. C. Wilton, B. L. Gabrielson, and K. Kaplan, "Failure Strength of Wall Panels Under Explosive Loading," U. R. S. Research Company, San Mateo, Calif., presented at D. O. D. E. S. B 15th Explosives Safety Seminar.

LIST OF ILLUSTRATIONS

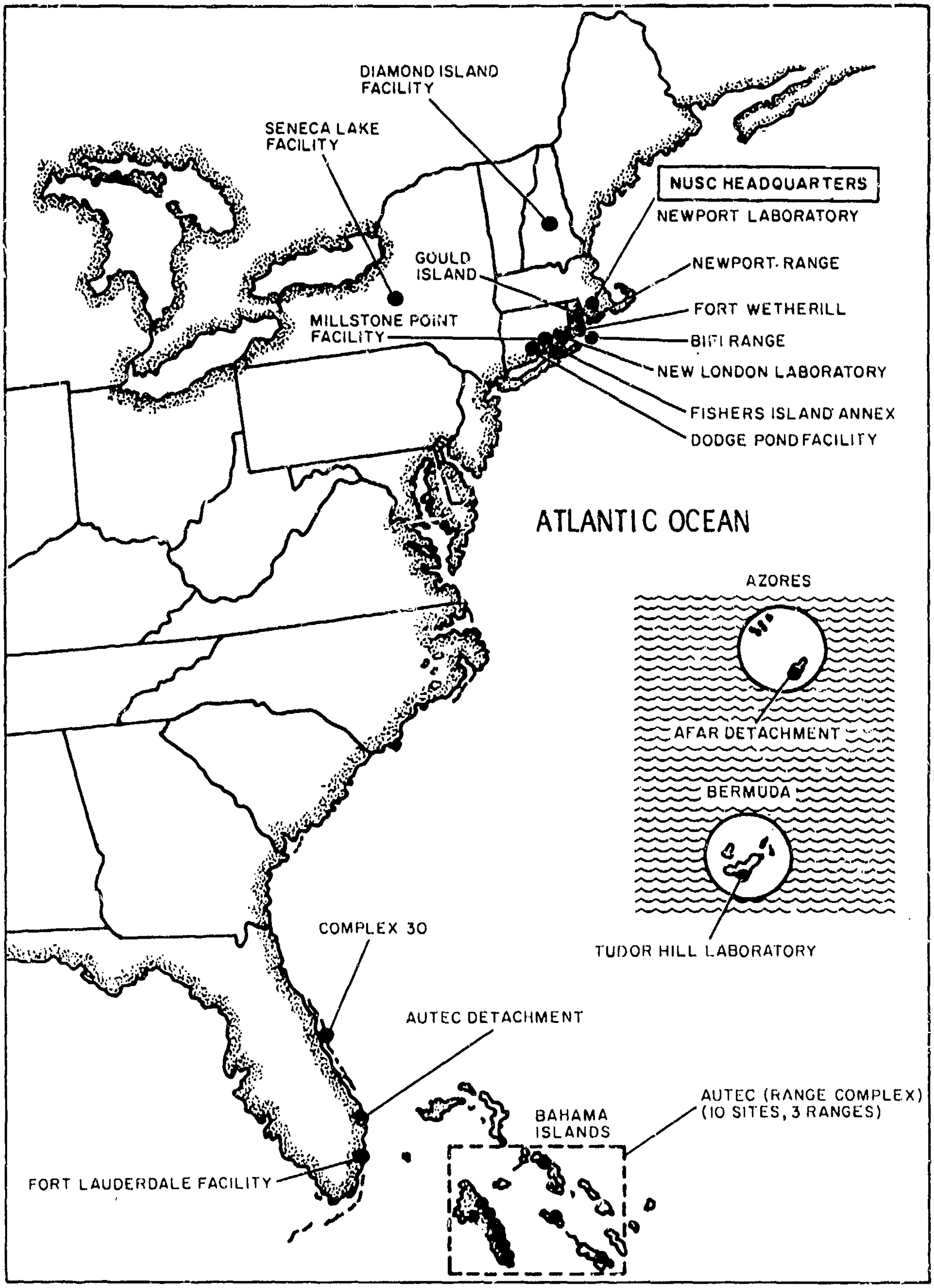

DIAMOND ISLAND FACILITY
SENECA LAKE FACILITY
NUSC HEADQUARTERS
NEWPORT LABORATORY
GOULD ISLAND
NEWPORT RANGE
FORT WETHERILL
MILLSTONE POINT FACILITY
BIFI RANGE
NEW LONDON LABORATORY
FISHERS ISLAND ANNEX
DODGE POND FACILITY
ATLANTIC OCEAN
AZORES
AFAR DETACHMENT
BERMUDA
TUDOR HILL LABORATORY
COMPLEX 30
AUTEC DETACHMENT
AUTEC (RANGE COMPLEX)
(10 SITES, 3 RANGES)
BAHAMA ISLANDS
FORT LAUDERDALE FACILITY

FIGURE 1

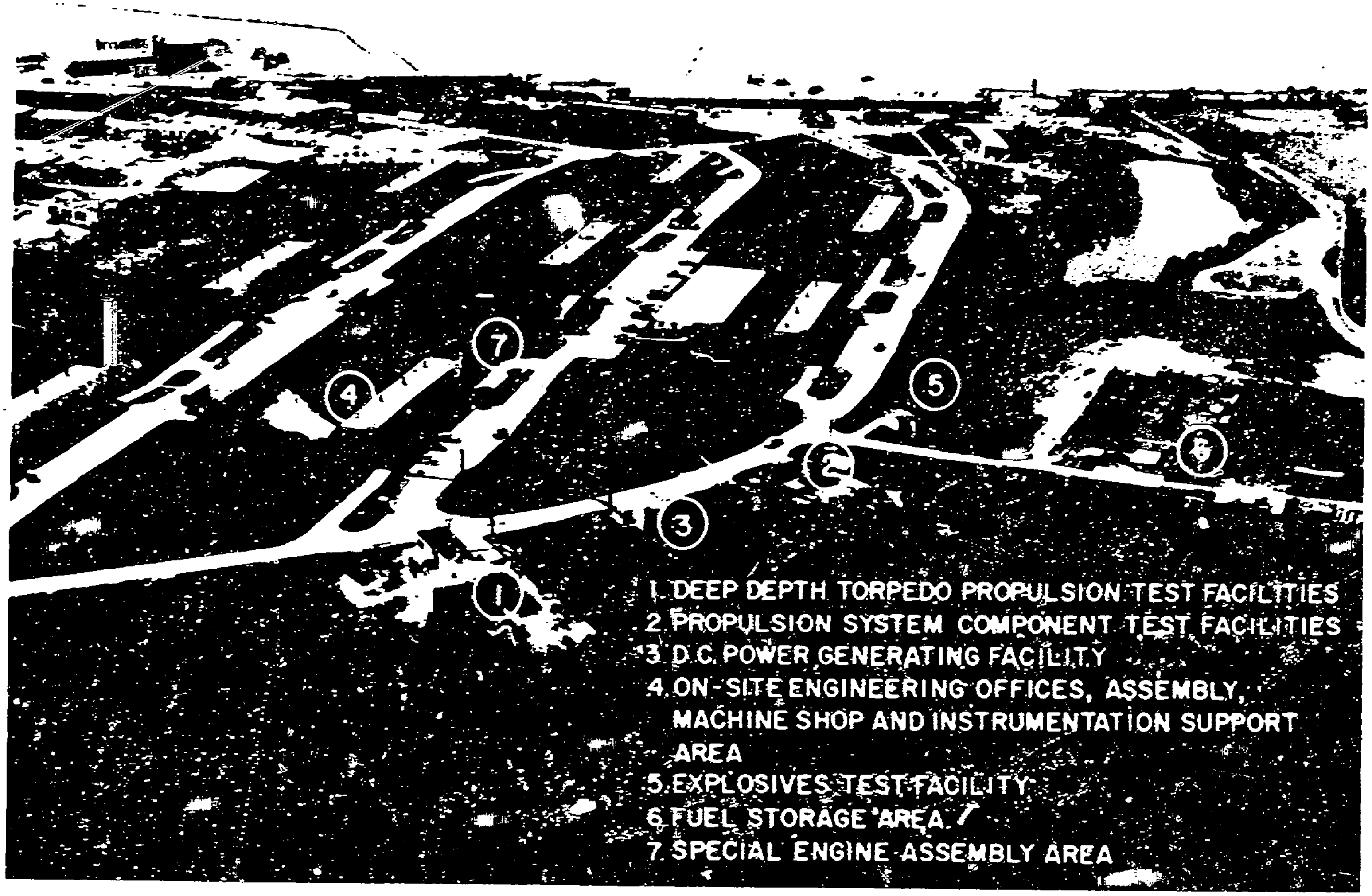

1
2
3
4
5
6
7
1. DEEP DEPTH TORPEDO PROPULSION TEST FACILITIES
2. PROPULSION SYSTEM COMPONENT TEST FACILITIES
3. D.C. POWER GENERATING FACILITY
4. ON-SITE ENGINEERING OFFICES, ASSEMBLY, MACHINE SHOP AND INSTRUMENTATION SUPPORT AREA
5. EXPLOSIVES TEST FACILITY
6. FUEL STORAGE AREA
7. SPECIAL ENGINE ASSEMBLY AREA

FIGURE 2

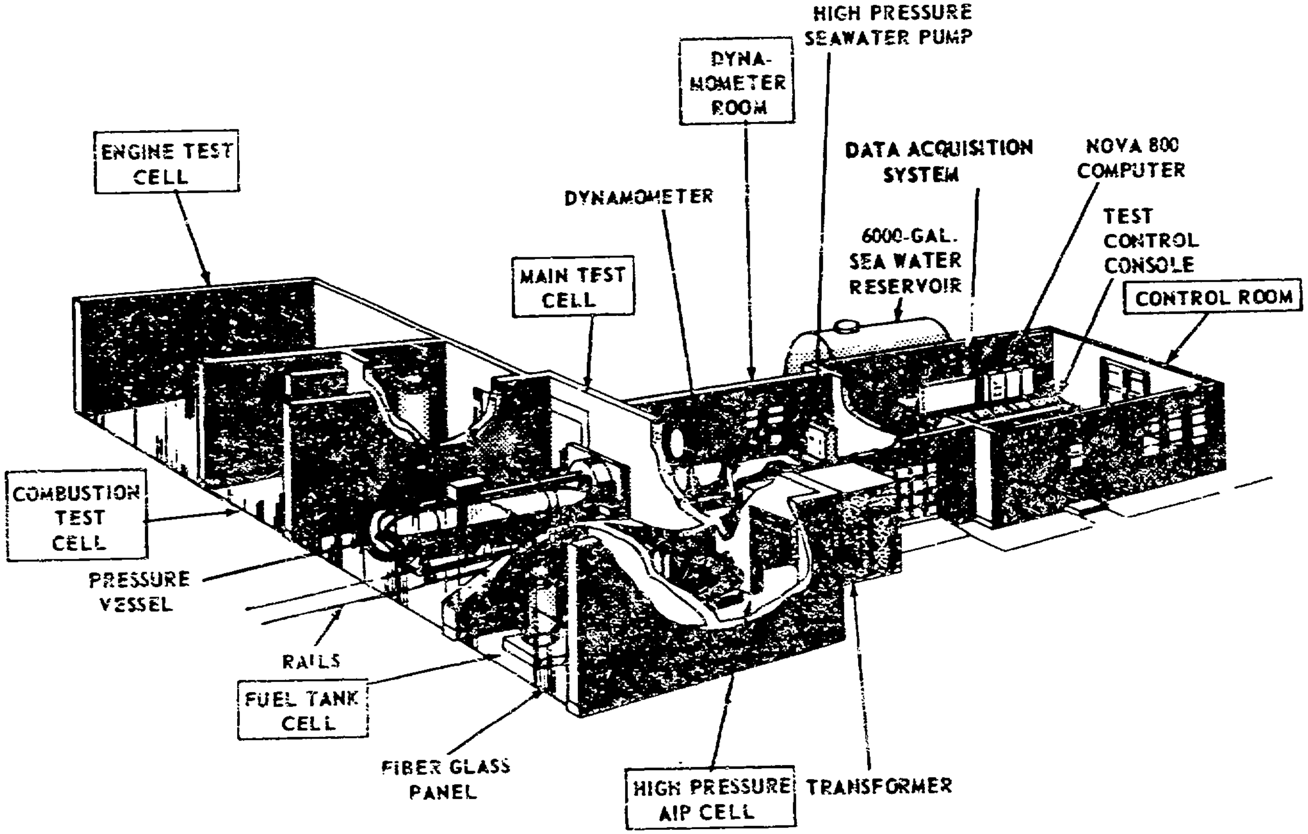

HIGH PRESSURE SEAWATER PUMP
DYNA-MOMETER ROOM
ENGINE TEST CELL
DATA ACQUISITION SYSTEM
NOVA 800 COMPUTER
DYNAMOMETER
TEST CONTROL CONSOLE
6000-GAL. SEA WATER RESERVOIR
MAIN TEST CELL
CONTROL ROOM
COMBUSTION TEST CELL
PRESSURE VESSEL
RAILS
FUEL TANK CELL
FIBER GLASS PANEL
HIGH PRESSURE AIR CELL
TRANSFORMER

FIGURE 3

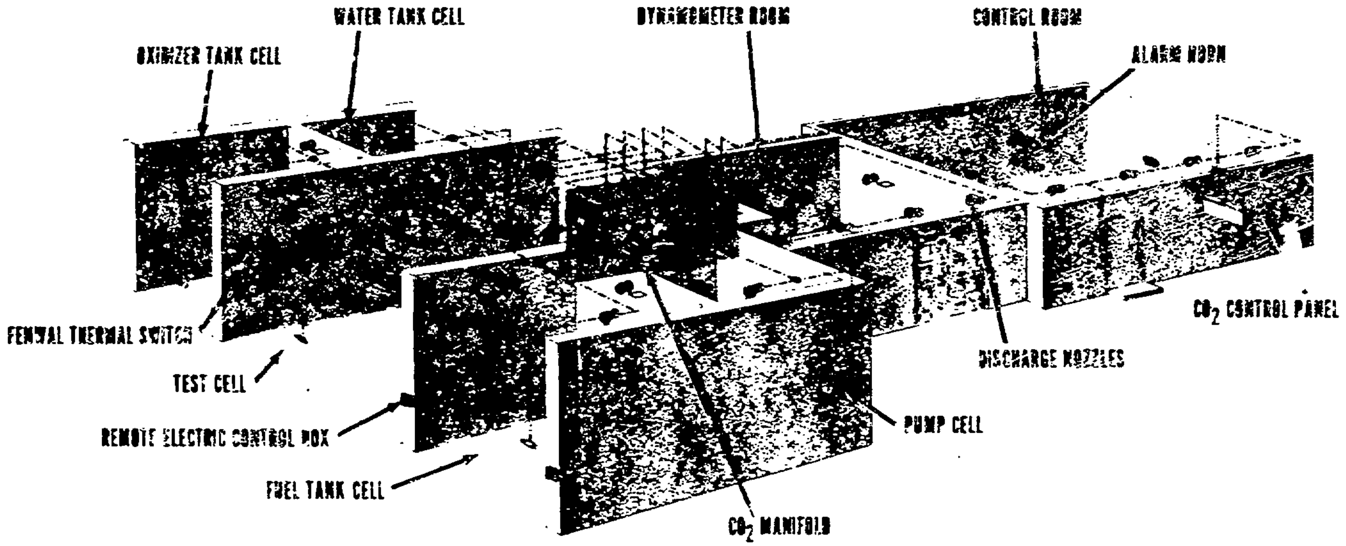

OXIDIZER TANK CELL
WATER TANK CELL
DYNAMOMETER ROOM
CONTROL ROOM
ALARM HORN
FENWAL THERMAL SWITCH
TEST CELL
REMOTE ELECTRIC CONTROL BOX
FUEL TANK CELL
CO_2 MANIFOLD
PUMP CELL
DISCHARGE NOZZLES
CO_2 CONTROL PANEL

FIGURE 4

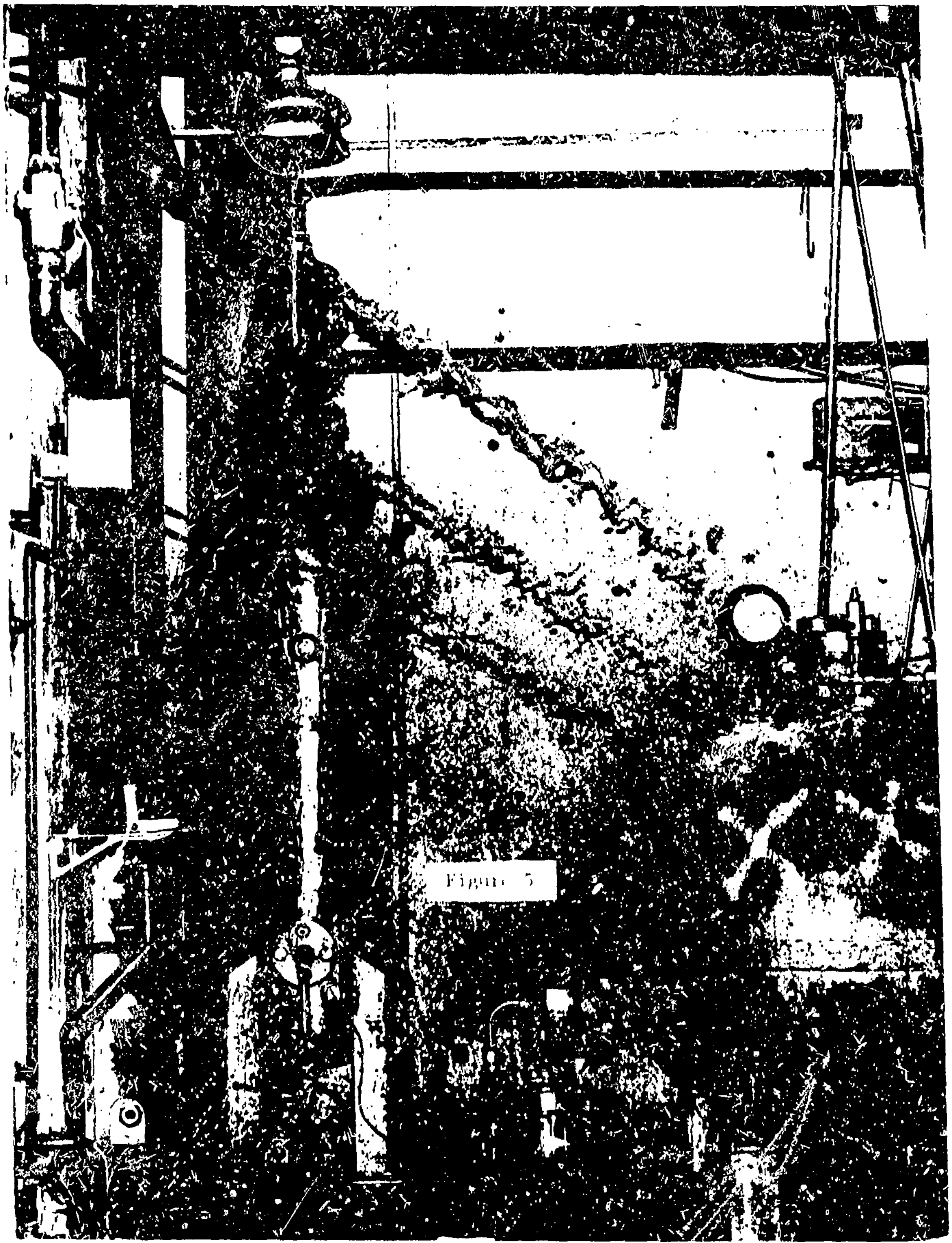


Figure 5

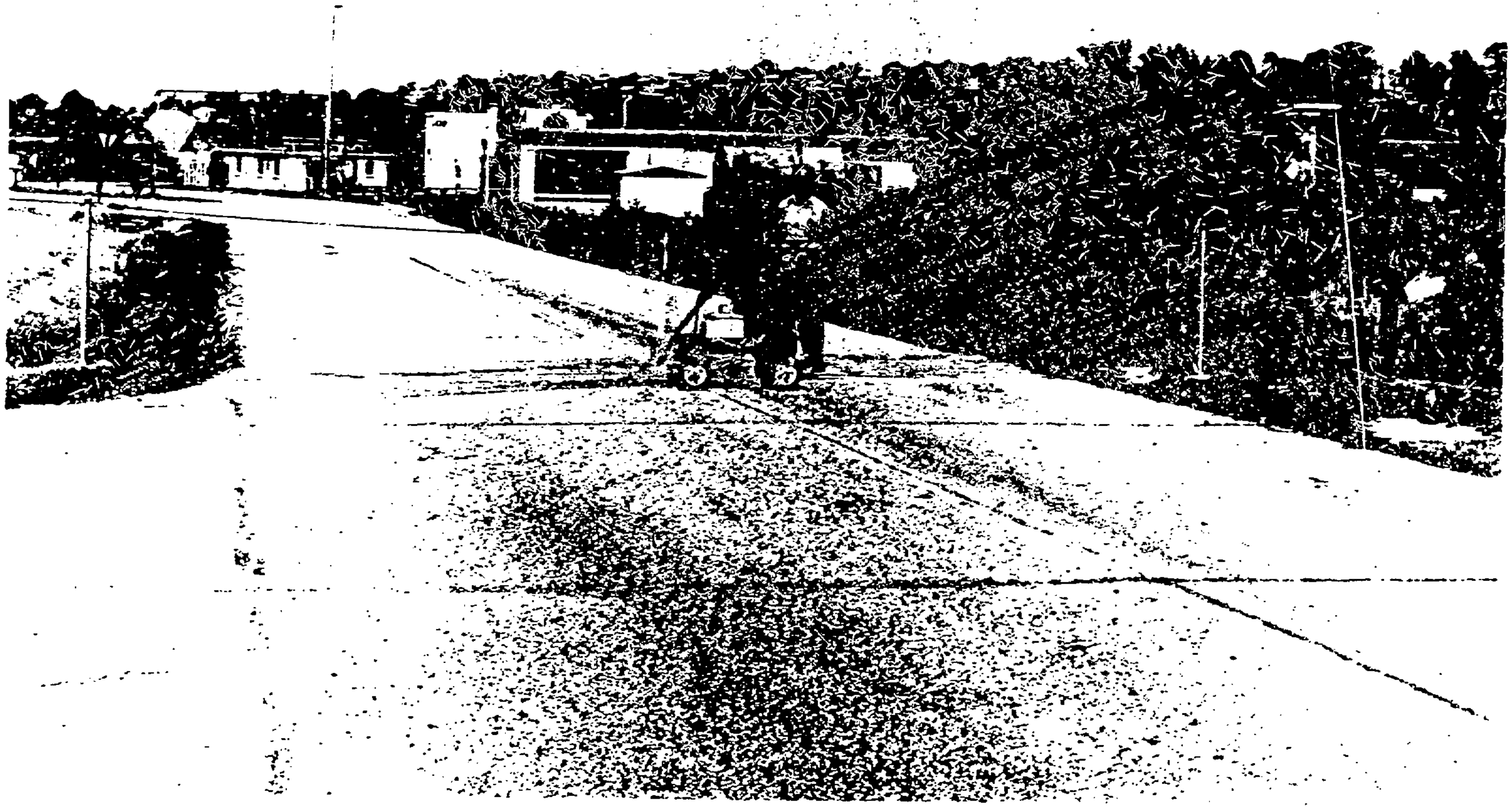
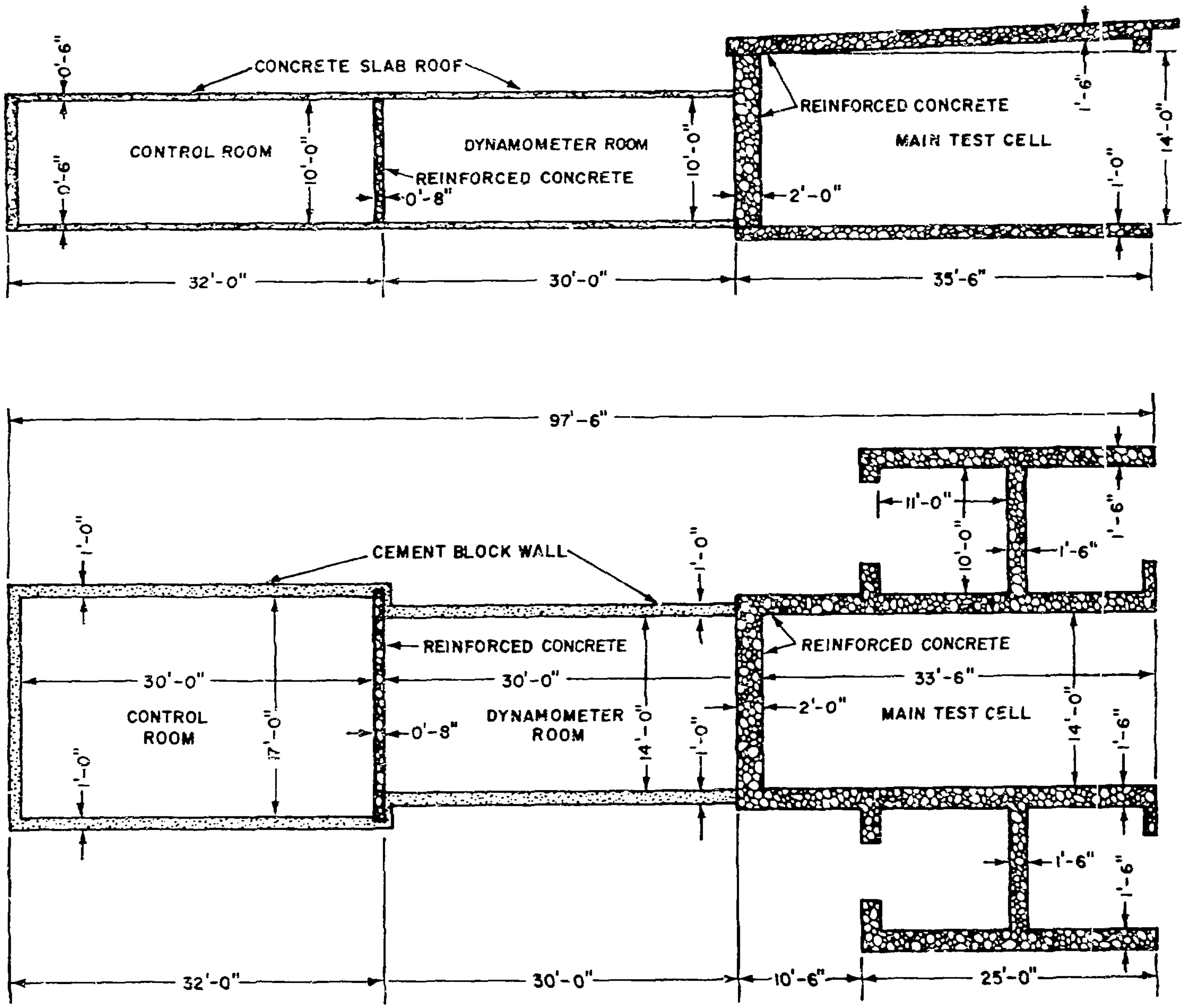


FIGURE 6



CONCRETE SLAB ROOF
0'-6"
CONTROL ROOM
10'-0"
REINFORCED CONCRETE
0'-8"
DYNAMOMETER ROOM
10'-0"
2'-0"
REINFORCED CONCRETE
MAIN TEST CELL
1'-6"
1'-0"
14'-0"
32'-0"
30'-0"
35'-6"
97'-6"
CEMENT BLOCK WALL
1'-0"
REINFORCED CONCRETE
30'-0"
CONTROL ROOM
17'-0"
0'-8"
30'-0"
DYNAMOMETER ROOM
14'-0"
REINFORCED CONCRETE
33'-6"
2'-0"
MAIN TEST CELL
14'-0"
11'-0"
10'-0"
1'-6"
32'-0"
30'-0"
10'-6"
25'-0"

FIGURE 7

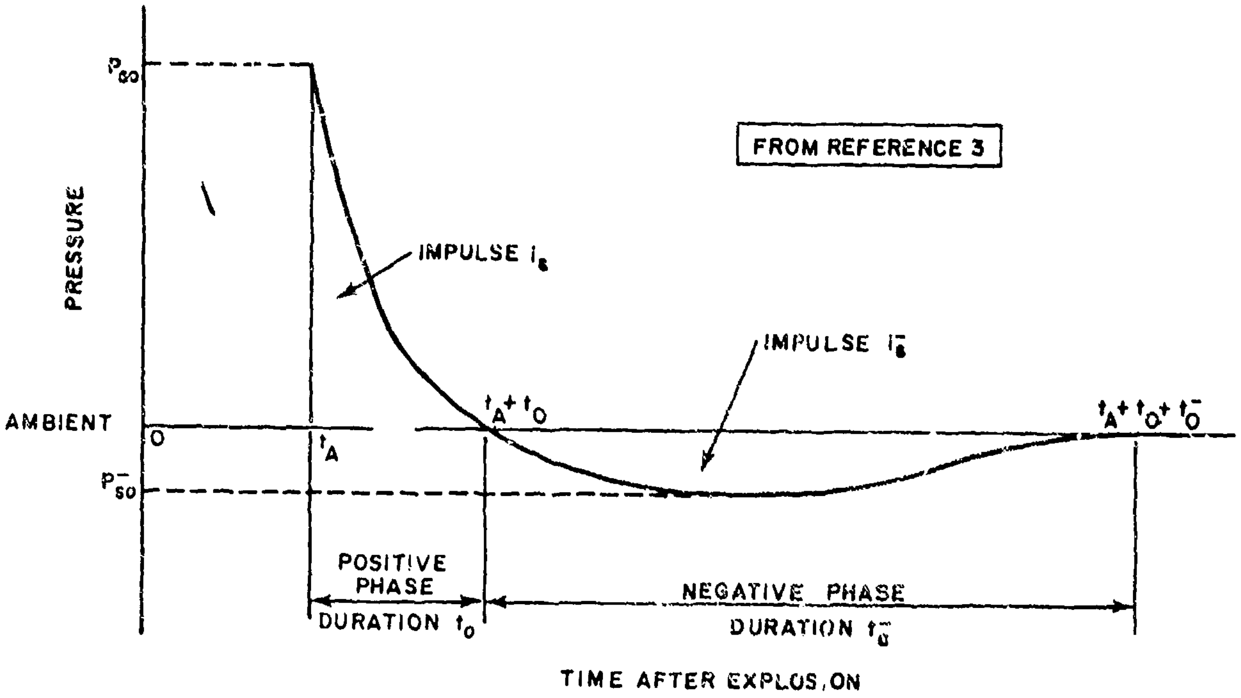
FROM REFERENCE 3
PRESSURE
P_{so}
IMPULSE i_s
IMPULSE i_s^-
AMBIENT
O
t_A
$t_A + t_O$
$t_A + t_O + t_O^-$
P_{so}^-
POSITIVE PHASE
DURATION t_o
NEGATIVE PHASE
DURATION t_o^-
TIME AFTER EXPLOSION

FIGURE 8

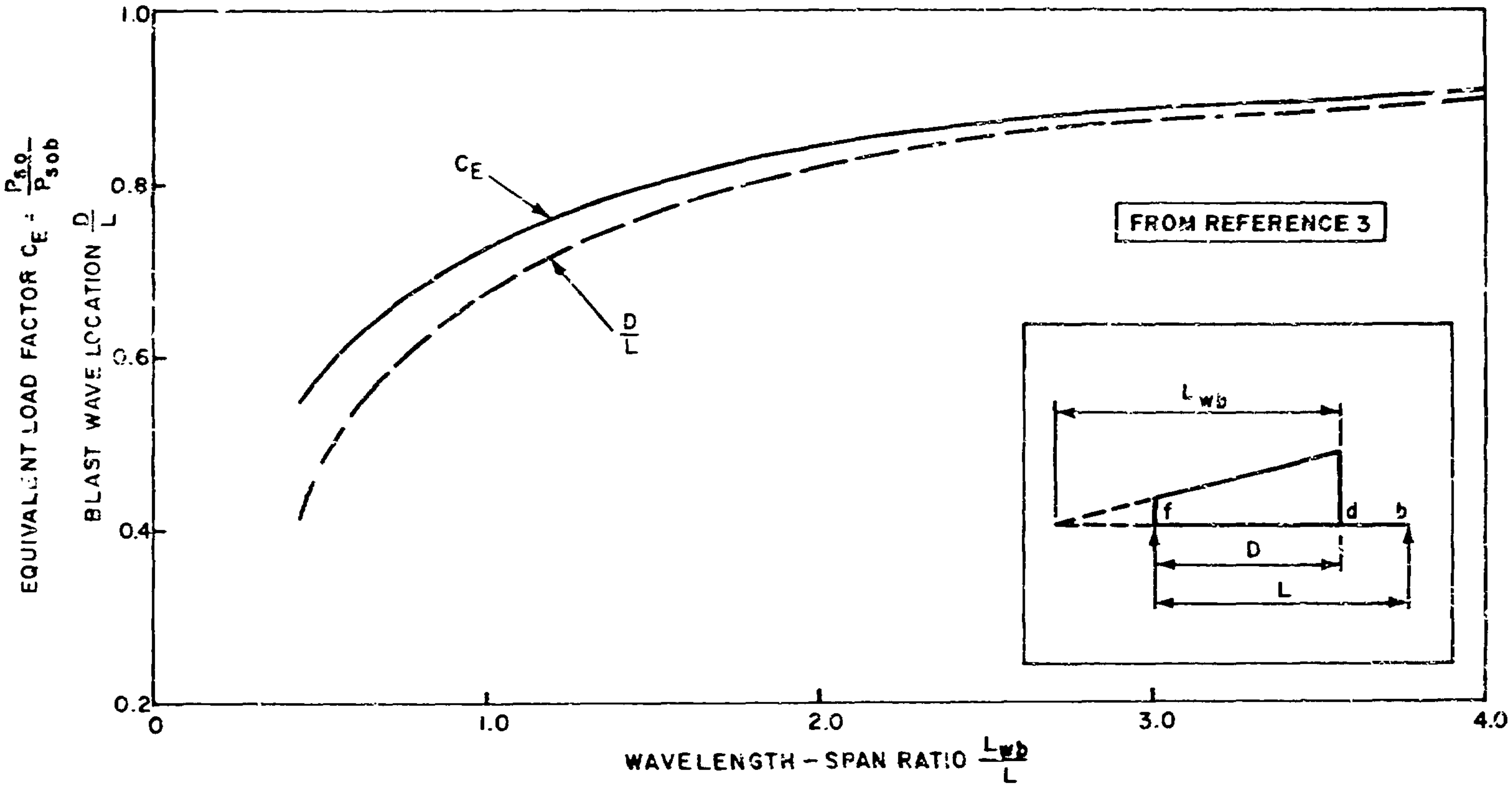

EQUIVALENT LOAD FACTOR $C_E = \frac{P_{so}}{P_{sob}}$
BLAST WAVE LOCATION $\frac{D}{L}$
1.0
0.8
0.6
0.4
0.2
0
1.0
2.0
3.0
4.0
WAVELENGTH – SPAN RATIO $\frac{L_{wb}}{L}$
C_E
$\frac{D}{L}$
FROM REFERENCE 3
L_{wb}
f
d
b
D
L

FIGURE 9

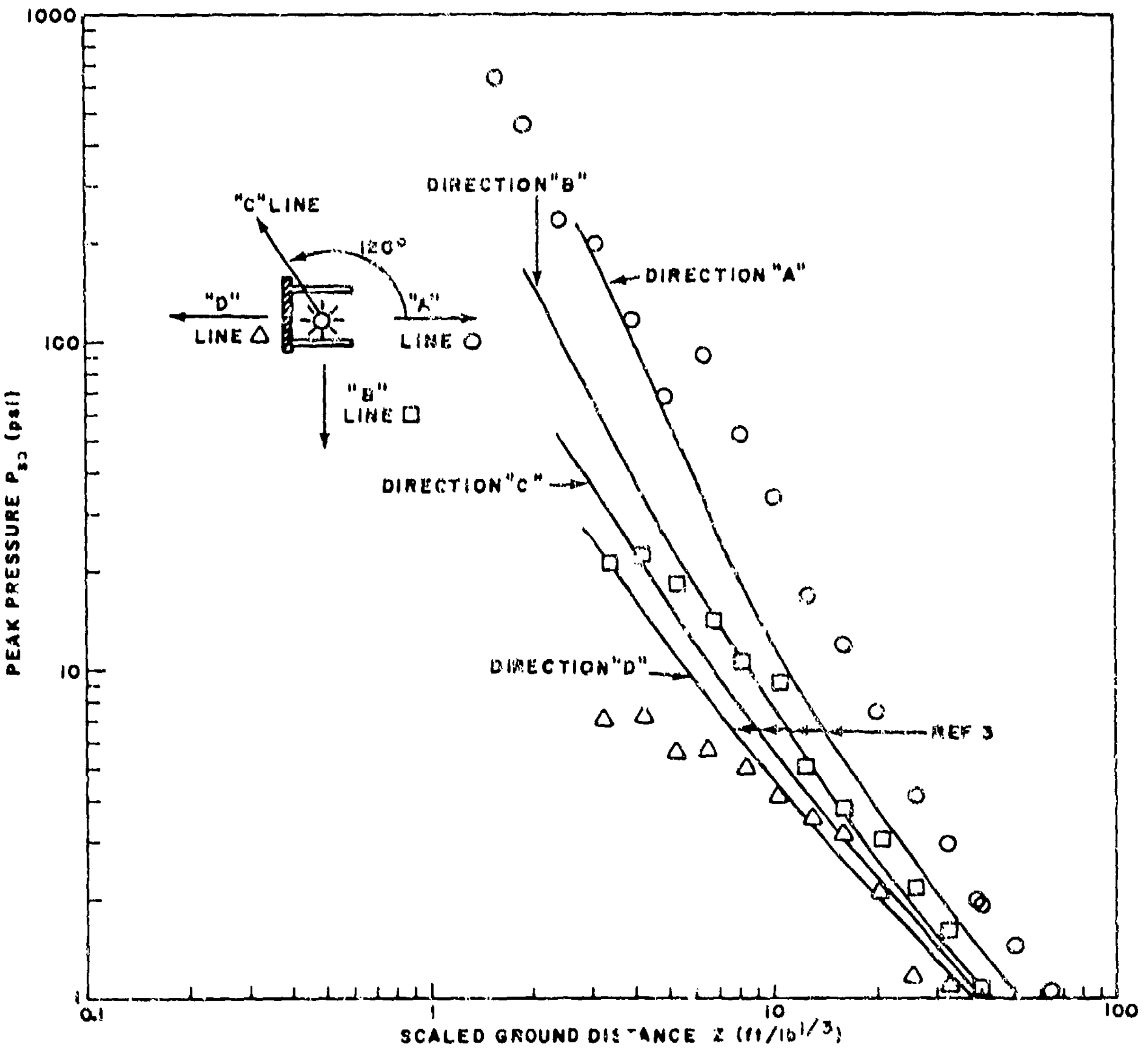
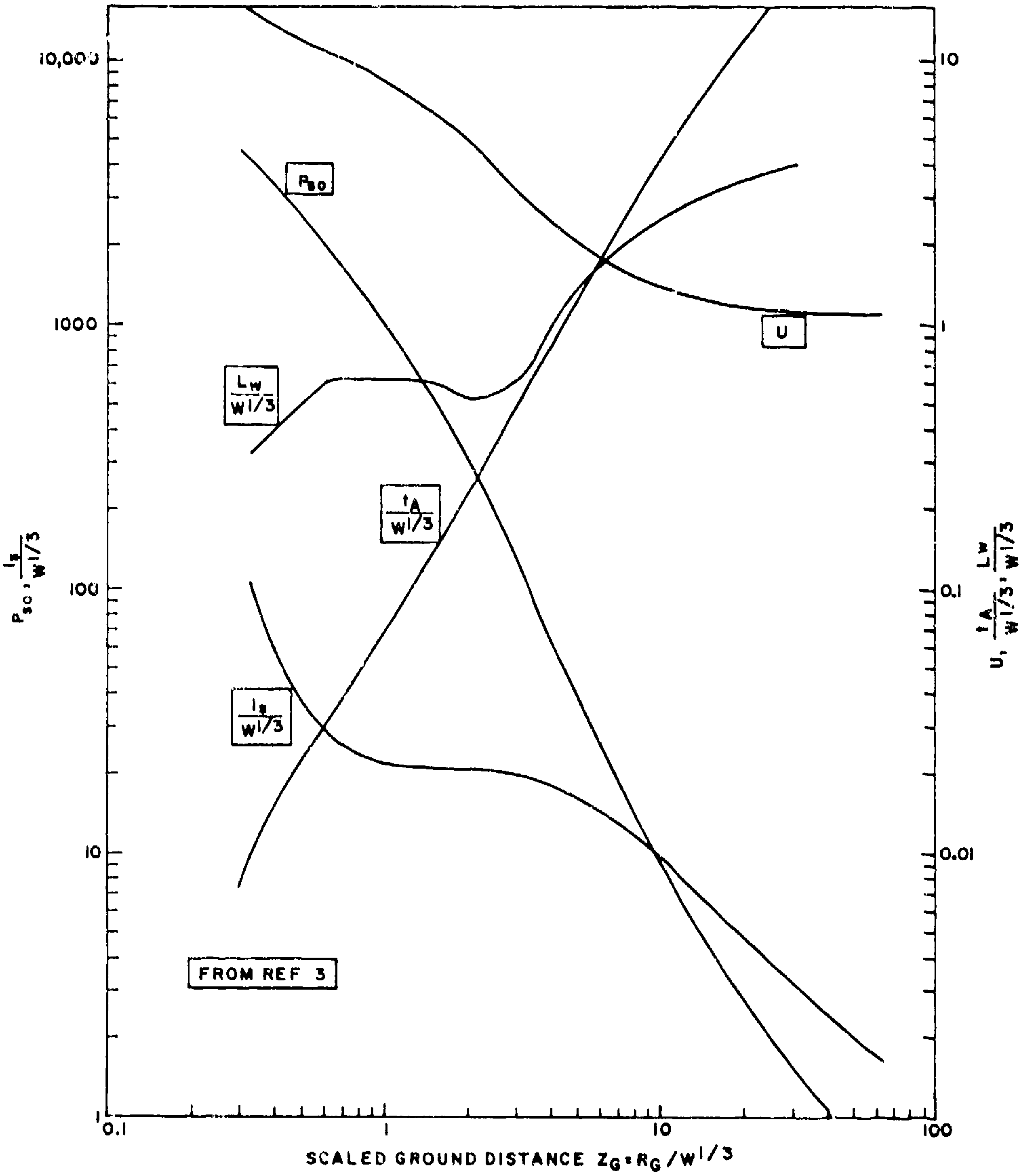

1000
100
10
1
0.1
1
10
100
PEAK PRESSURE P_{so} (psi)
SCALED GROUND DISTANCE Z (ft/lb$^{1/3}$)
"C" LINE
120°
"D"
LINE △
"A"
LINE ○
"B"
LINE □
DIRECTION "B"
DIRECTION "A"
DIRECTION "C"
DIRECTION "D"
REF 3

FIGURE 10



10,000
1000
100
10
1
P_{so}, $\frac{I_s}{W^{1/3}}$
10
1
0.1
0.01
U, $\frac{t_A}{W^{1/3}}$, $\frac{L_W}{W^{1/3}}$
0.1
1
10
100
SCALED GROUND DISTANCE $Z_G = R_G / W^{1/3}$
P_{so}
U
$\frac{L_W}{W^{1/3}}$
$\frac{t_A}{W^{1/3}}$
$\frac{I_s}{W^{1/3}}$
FROM REF 3

FIGURE 11

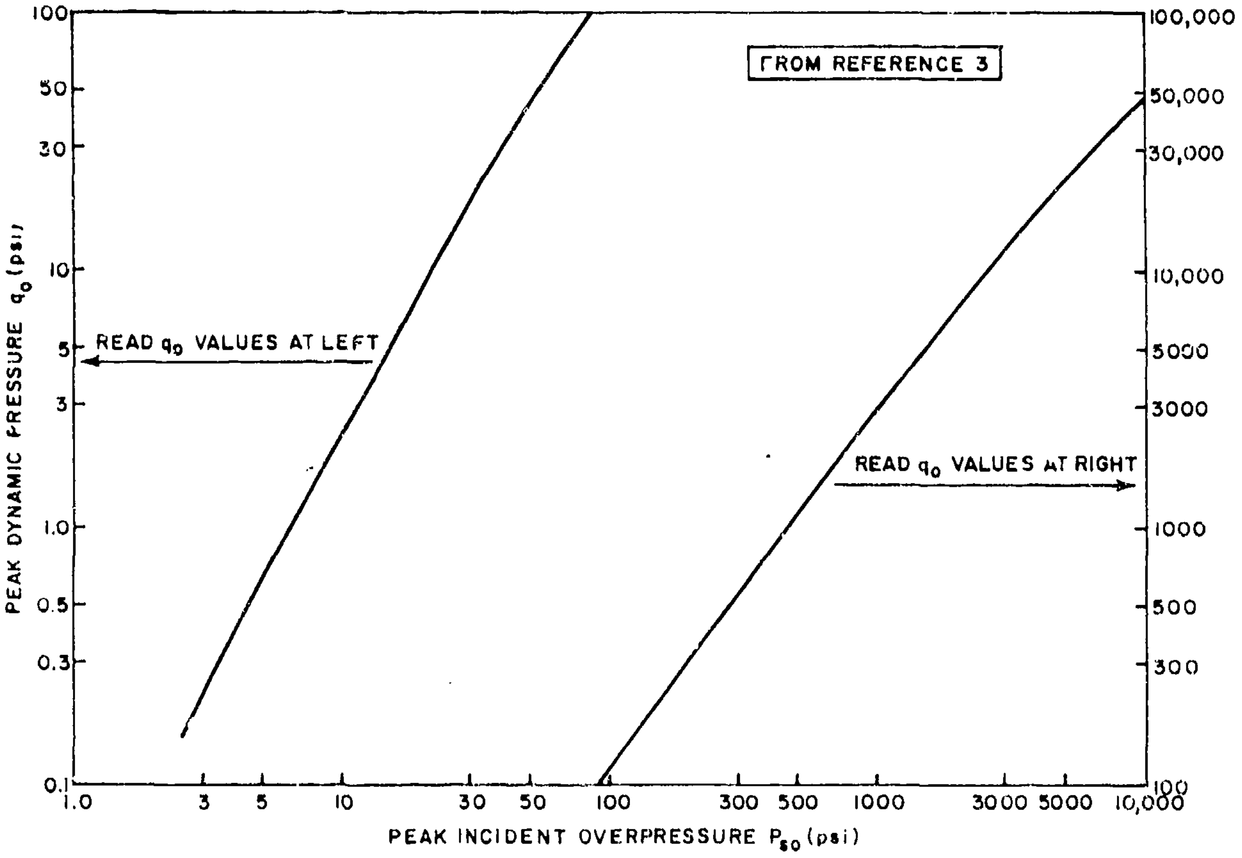

FROM REFERENCE 3
READ q_0 VALUES AT LEFT
READ q_0 VALUES AT RIGHT
PEAK DYNAMIC PRESSURE q_0 (psi)
PEAK INCIDENT OVERPRESSURE P_{so} (psi)
100
50
30
10
5
3
1.0
0.5
0.3
0.1
100,000
50,000
30,000
10,000
5000
3000
1000
500
300
100
1.0
3
5
10
30
50
100
300
500
1000
3000
5000
10,000

FIGURE 12

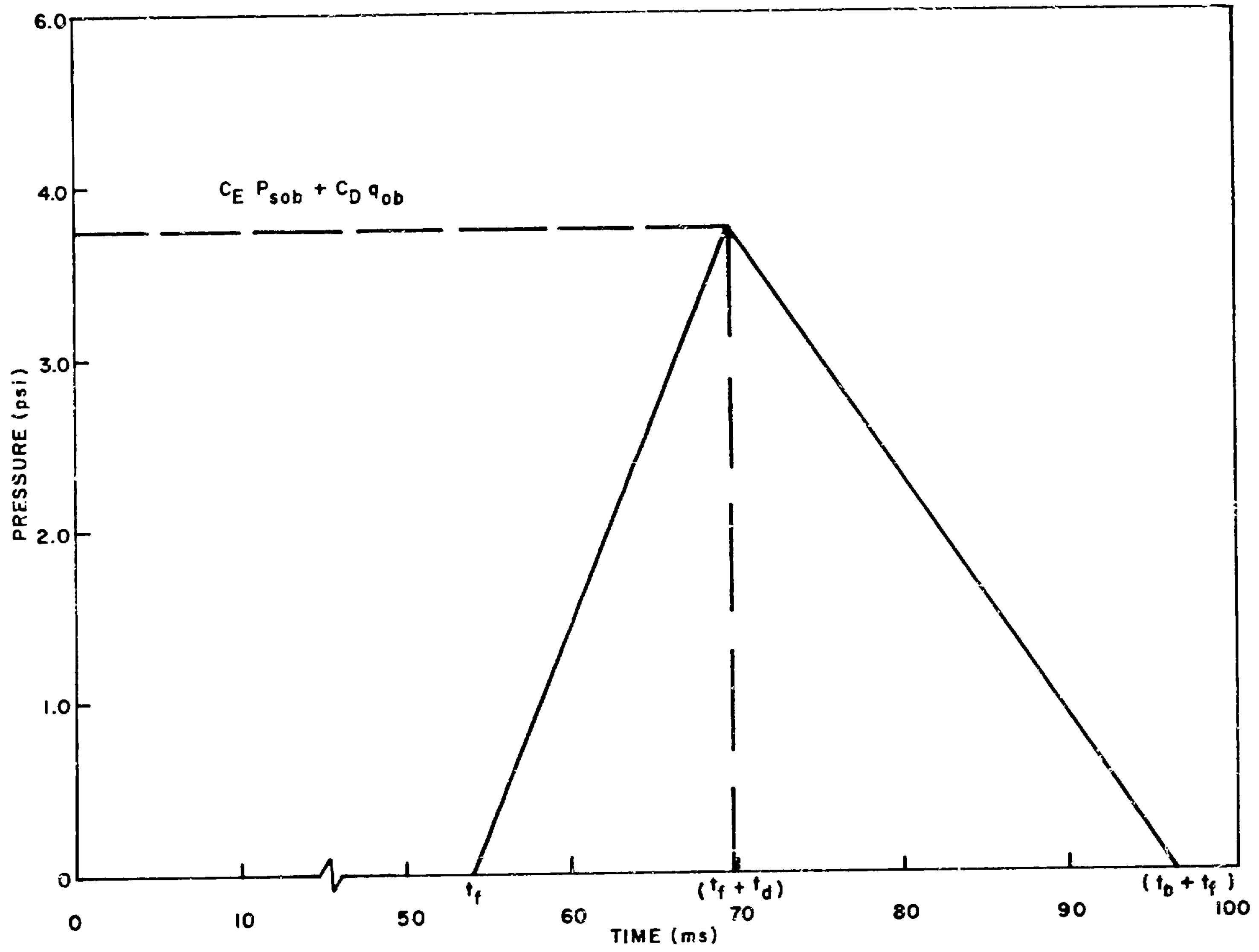

$C_E\ P_{sob} + C_D\ q_{ob}$
6.0
4.0
3.0
2.0
1.0
0
PRESSURE (psi)
0
10
50
60
70
80
90
100
t_f
$(t_f + t_d)$
$(t_D + t_f)$
TIME (ms)

FIGURE 13

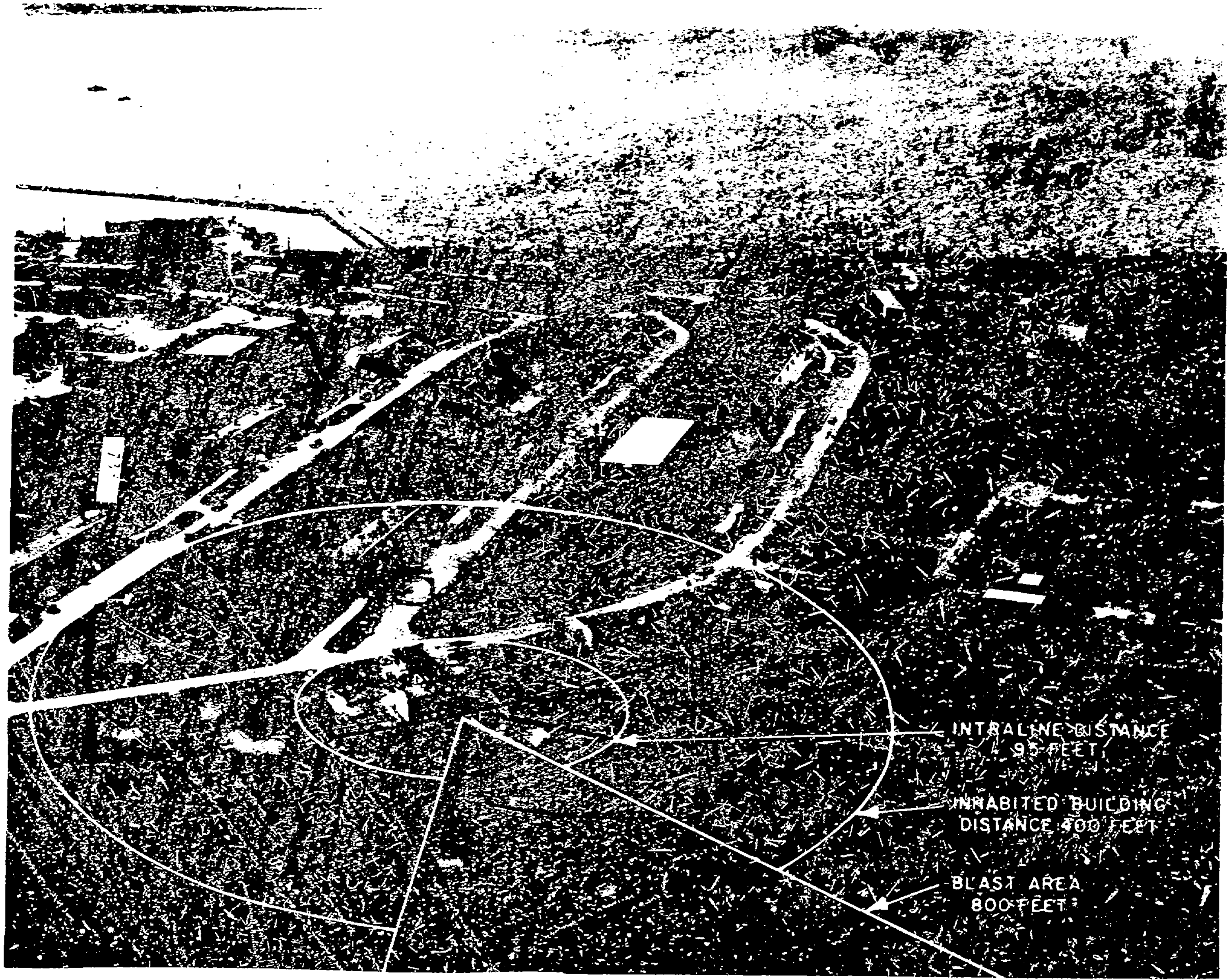

INTRALINE DISTANCE
95 FEET
INHABITED BUILDING
DISTANCE 400 FEET
BLAST AREA
800 FEET

FIGURE 14

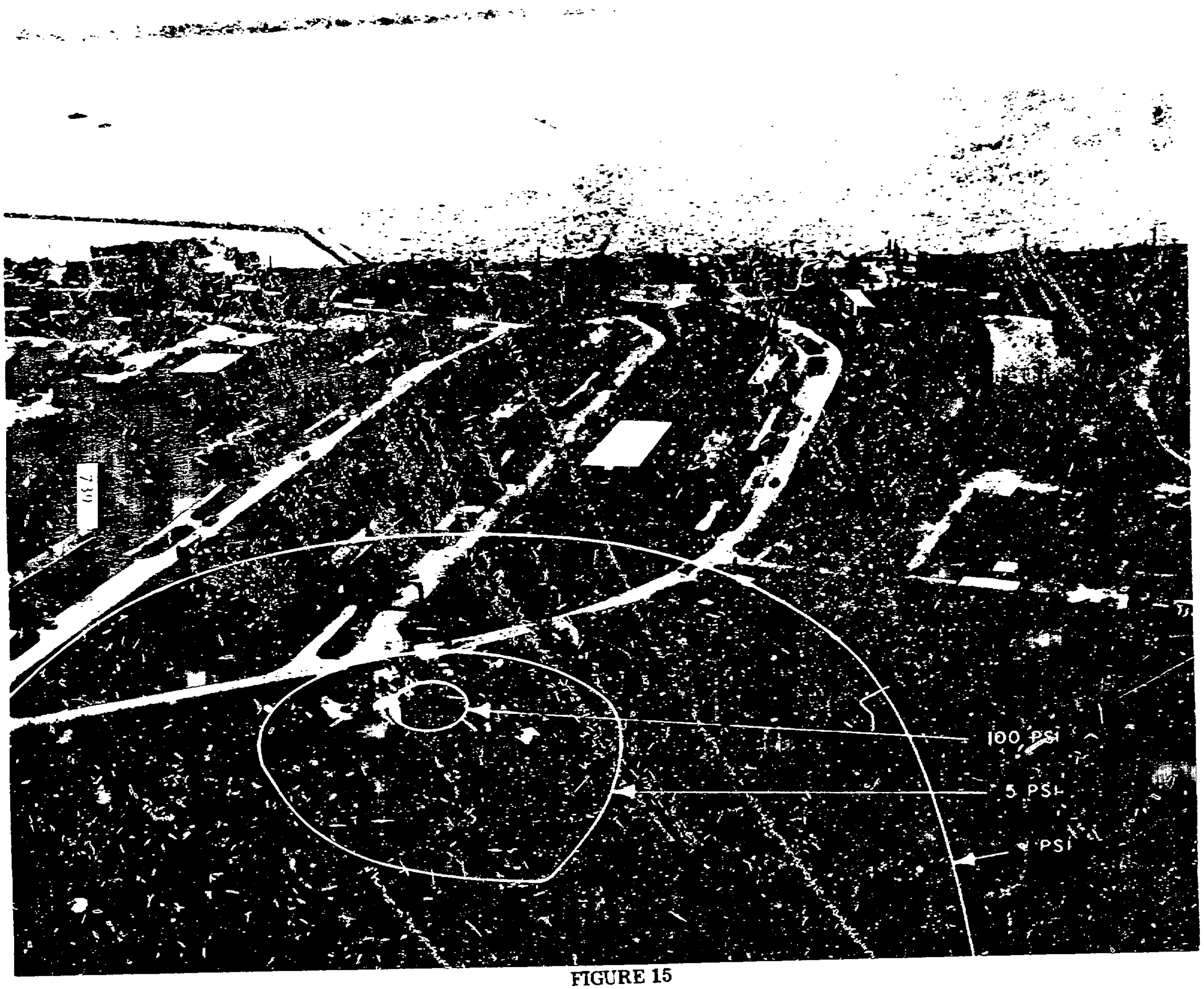


FIGURE 15

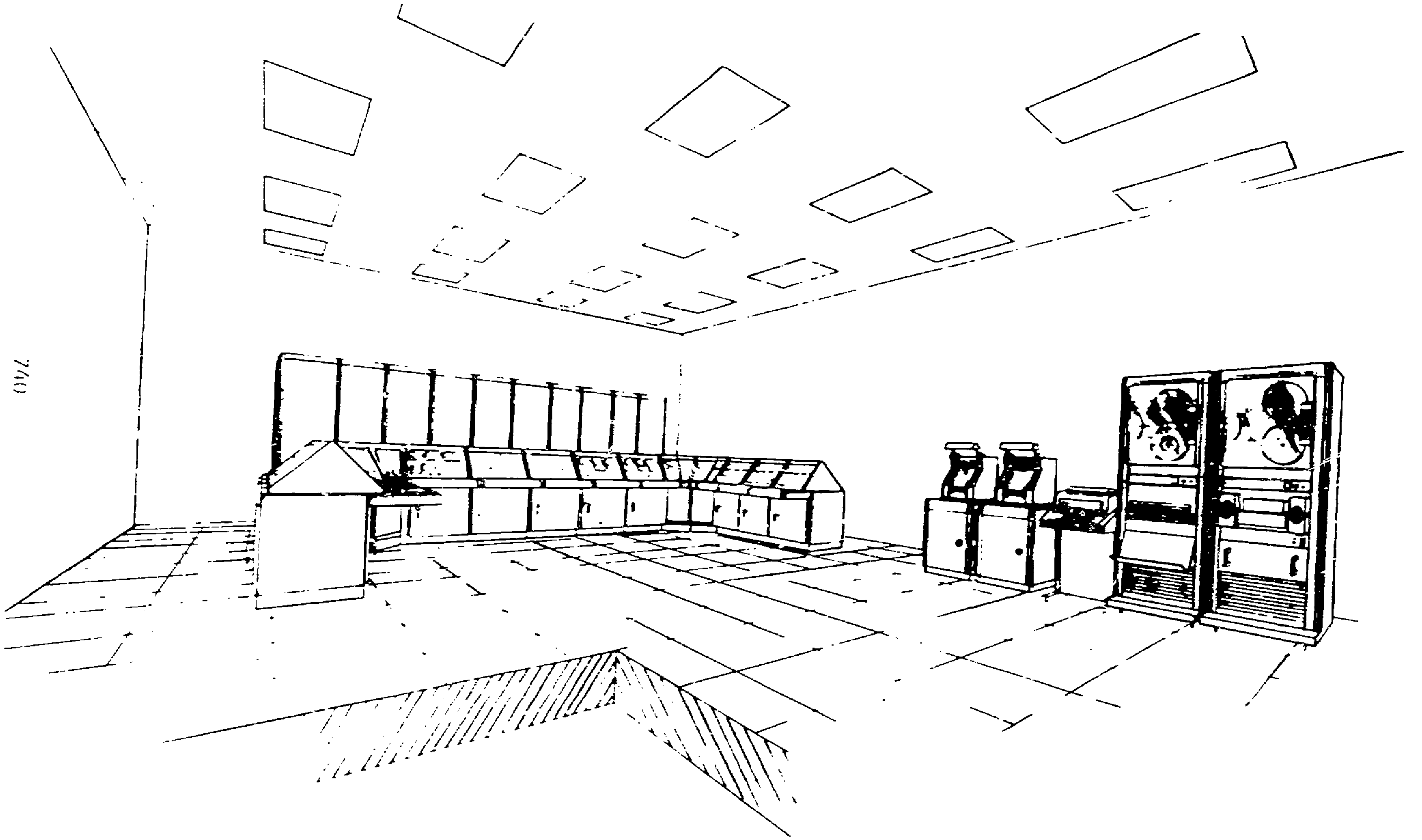


FIGURE 16

SIMPLIFIED BLAST NUISANCE PREDICTIONS FOR SMALL EXPLOSIONS*

Jack W. Reed
Sandia Laboratories
Albuquerque, New Mexico

Introduction

Demolition of obsolete or defective munitions has caused complaints about the noise from neighbors of a number of military installations. Airblast propagation, nuisance, and complaints from these relatively small explosions are often strongly dependent on atmospheric conditions. In this paper a simple calculation procedure is described for predicting and limiting this nuisance at Tooele Army Depot, Utah.

Their normal operation is limited to demolition of 5000 lbs of chemical explosives, under 10 ft of earth cover. On occasion however, this does cause blast annoyance at Tooele, 9 miles east, and at Grantsville, 7 miles north of the firing site. Some complaints have charged broken windows or plaster cracks which may or may not be valid. These are often difficult to disprove. Certain weather conditions cause most of these scattered troubles. Sandia Laboratories' experience, in predicting airblast from nuclear explosion tests, has been used to develop a method to estimate weather conditions when these firings should be delayed until better circumstances prevail.

The 10-ft dirt cover normally used on 5000-lb high explosives (HE) at Tooele does little to reduce these relatively distant blast effects. Such cover may partially confine the HE and cause a more efficient explosion burn, comparable to a shaped-charge effect. At large distances this yield enhancement may largely overcome the blast attenuation found close-in from this depth of cover. It would take about 20 ft of dirt cover to reduce distant blast pressures by 80%. A 10-ft cover would effectively (80%) attenuate a 1000-lb HE charge.

Atmospheric Effects

The atmosphere may act like an acoustic lens, depending on air temperatures and winds, both along the ground and aloft. Blast propagation to the 5 to 10 mile distances to communities near Tooele Army Depot depends on atmospheric conditions up to about 3000 ft above ground. At that height, above the ground friction boundary layer and Salt Lake sea breezes, winds and temperatures do not change as much as they do near the ground. Balloon measurements made twice daily at Salt Lake City airport, 30 miles away, can be used to estimate upper air conditions over Tooele.

Blast waves travel at about the speed of sound, and that depends on air temperature. Sound travels faster in warm air than it does in cold air. Sounds may also be speeded or retarded by winds. If the temperature and sound speed increases with height (see Figure 1-B), as it may early in the morning,

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*This study was supported jointly by the U. S. Atomic Energy Commission and the U. S. Army.

a blast wave travels faster above the ground than it does at ground level. The wave front is turned by refraction toward the ground, causing loud noise at relatively long distances. An increase in temperature with altitude is called an inversion, because temperature is usually lower at higher elevations.

During sunny afternoons, with little wind, temperature is highest at the ground. This turns or refracts the blast wave front upward and into the sky (see Figure 1-A). Along the ground, blast pressures are then relatively small and may not even be heard.

Explosions in early afternoon, near the warmest time of day, usually cause the least disturbance. On the other hand, winds (at the surface as well as above ground) may cause strong propagations in spite of good temperature conditions. Surface winds stronger than about 5 knots may also cause strong propagations in the downwind quadrant, independent of refraction.

The following calculation is used to determine whether sound velocity (sound speed plus wind) increases (strong propagation) or decreases (weak propagation) with altitude. Calculations are made for directions of concern, toward Grantsville, and Tooele.

Upper Air

Salt Lake upper air weather reports are obtained daily by calling the National Weather Services Office at Salt Lake City Airport. Temperature and wind at 6000 ft MSL (mean sea level altitude) are required. Their balloon observation system, called a rawinsonde, is released daily at 1200Z (Greenwich Time) or 0600 MDT (Mountain Daylight Time) and results are available by about 0800 MDT. These upper air reports are assumed to remain valid throughout the day, unless a storm passes through the area. At Tooele, a cold front passage causes more northerly winds and better conditions for reduced airblast propagation. Such abrupt changes there do not lead to unpleasant surprises, as they might at other locations.

Upper air temperatures are reported in degrees Centigrade and a conversion table is provided to obtain sound speed, in feet per second, from either Fahrenheit or Centigrade air temperatures.

Wind is reported as the direction from which the wind is blowing, in degrees clockwise from True North. A wind from the east would be 090°, from the south 180°, and from northwest 315°. Wind speeds are reported in knots (nautical miles per hour) by National Weather Services for the convenience of aviation navigators. Local surface measurements in statute miles per hour need conversion to knots for use in the following calculations.

Wind vectors (direction and speeds) must be resolved into components toward targets of concern, toward Tooele and Grantsville. Wind components are calculated from a polar coordinate graph, as shown in Figure 2, by following out on the radial line marked with the wind direction to the radius circle that is marked by the wind speed (in knots). Larger scale, cardboard graphs in two colors have been furnished for field use. The component toward Tooele, T_6, in ft/sec, is read from the straight line grid (red overlay on working graphs) superimposed on the polar chart. The component toward Grantsville, G_8, is read from a similar chart with an appropriately rotated grid. The algebraic sign (±) must be correct.

Instructions

A blank form for daily calculations is shown in Table I. Sound speed at 6000 ft MSL, S_6, is obtained from the temperature chart, depending on the Centigrade temperature. When the temperature is $0^\circ C$ (freezing, 32° Fahrenheit) the sound speed is 1088 ft/sec. When the temperature is $20^\circ C$ ($68^\circ F$) the sound speed is 1128 ft/sec.

The sum of $S_6 + T_8$ would give the sound velocity toward Tooele at 6000 ft MSL, but is not recorded. Similarly, $S_3 + G_8$ is the sound velocity toward Grantsville.

Surface Conditions

Surface temperature and wind are obtained from a thermometer and anemometer near the firing site. Sound speed, S_0, is obtained as before, from a conversion table. Wind components T_0 and G_0, are likewise calculated from polar coordinate charts. These are entered in appropriate blanks on the form, as well as the difference, D, between sound speeds at altitude and ground level. Note that values below -6 (for example, -8) would be entered as -6. Larger temperature decreases with this particular altitude difference cause very unstable, turbulent air that could not be depended upon to limit propagation. Also if T_0 or G_0 exceed about +5, downwind propagation could cause nuisance noises.

Sound velocity differences, between 6000 ft MSL and ground, are calculated as shown on the blank form. Values of V_G (toward Grantsville), or V_T toward Tooele) may be positive (+) or negative (-), depending on whether wave velocities increase or decrease with height. A decrease of temperature and sound speed with height is called a gradient. Strong propagations would result from large positive (+) values; weak propagations result from large negative (-) values, or gradients, as shown by Figure 3.

Strong propagations could occur with velocity differences greater than +5. These could break windows and crack plaster walls. Tooele is more distant than Grantsville, but has the larger population. The net disturbance or damage would, coincidentally, be similar in those two towns.

Intermediate propagation strength, with velocity differences between -5 and +5, could give a loud bang or rumble, but would not be strong enough to break windows or crack plaster. If such waves occurred very often, however, the noise could irritate people to make claims for some damages not really caused by the blast waves.

Best firing conditions come with velocity differences even more negative than -5. With -15 differences the blast would hardly be heard.

Strong propagations calculated in morning hours would usually be reduced considerably by afternoon. If wind effects could be ignored, then the best firing time would be at the warmest time of day, between about 1300 MDT and 1500 MDT.

Note that numerical values in Figure 3 were determined for a particular yield, burst environment, distances to and populations of neighboring towns for Tooele Army Depot operations. Different criteria would apply for other demolition locations and parameters.

Test Procedure

If propagation is calculated to be strong in the morning, extra blanks are provided in the blank form for calculations at later hours with revised surface weather observations. The morning upper air data from Salt Lake City is used during the whole day. It is not expected to change very much and there is no later balloon run until evening. Check calculations from surface observations about once each hour should show whether there is a trend toward improving or worsening conditions.

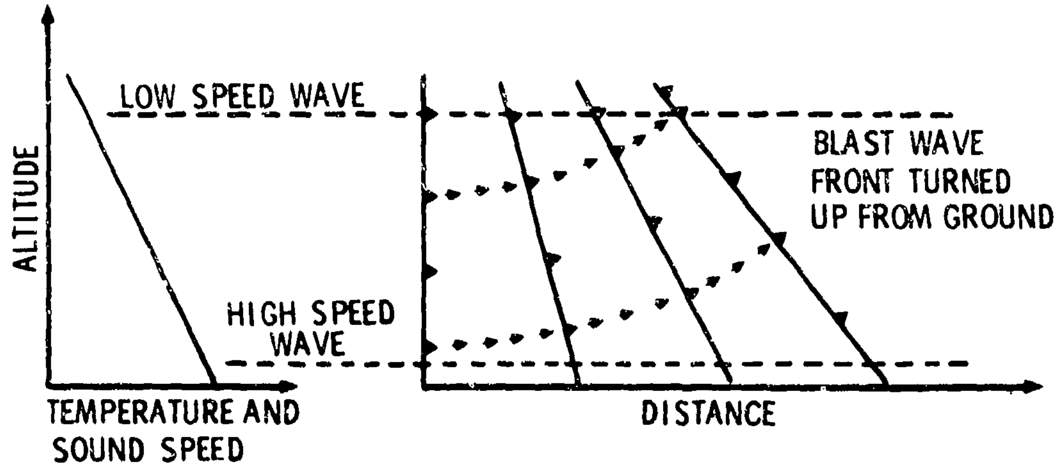
One caution here: Both surface temperatures and winds should be averaged readings. Small perturbations or changes in temperature, or wind gusts should be ignored, because they are not representative of atmospheric conditions along the total propagation paths of 5 to 10 miles.

In general, for Tooele Army Depot activities, cold northerly winds would protect both Grantsville and Tooele from strong blast waves. Warm southerly winds of even 5 to 10 knots would increase the probability of nuisance noise and damage at either town. After some experience has been gathered there will be a better feeling for the effect of local lake and mountain-valley winds as they change during the daylight hours. Usually, near the mountains the surface wind flows downhill at night and blows uphill during the day. Firing conditions should be best during early afternoon because of high surface temperatures, as well as the local north wind blowing toward the mountains to the south, and away from communities to the north and east.

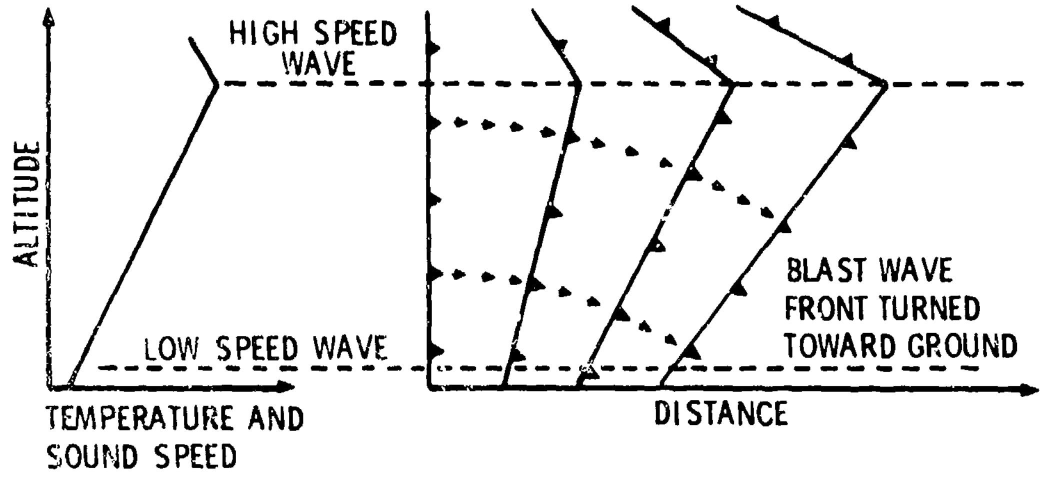
Generalizations

A similar procedure could be developed for other demolition sites. The most important parameters are the yield and the distance and population of nearby communities. Proper consideration of the local climatology of temperatures and winds, both at the surface and above the boundary layer, can possibly lead to an optimized site selection and certainly to a reasonable yield limitation.

Propagation of 1-mb recorded peak-to-peak wave amplitude correlates fairly well with the lower threshold of complaints. Ranges of this amplitude, for various yield and atmospheric conditions are shown in Table II. Although a 1-lb HE surface burst may, in strong propagation conditions under an early morning temperature inversion, give noise to nearly 2 miles, a 5000 lb HE burst may have its noise restricted to only 3 miles under optimized weather conditons.



A. TEMPERATURE DECREASING WITH ALTITUDE (GRADIENT)



B. TEMPERATURE INCREASING WITH ALTITUDE (INVERSION)

FIGURE I. BLAST WAVE DISTORTIONS CAUSED BY ATMOSPHERIC CONDITIONS

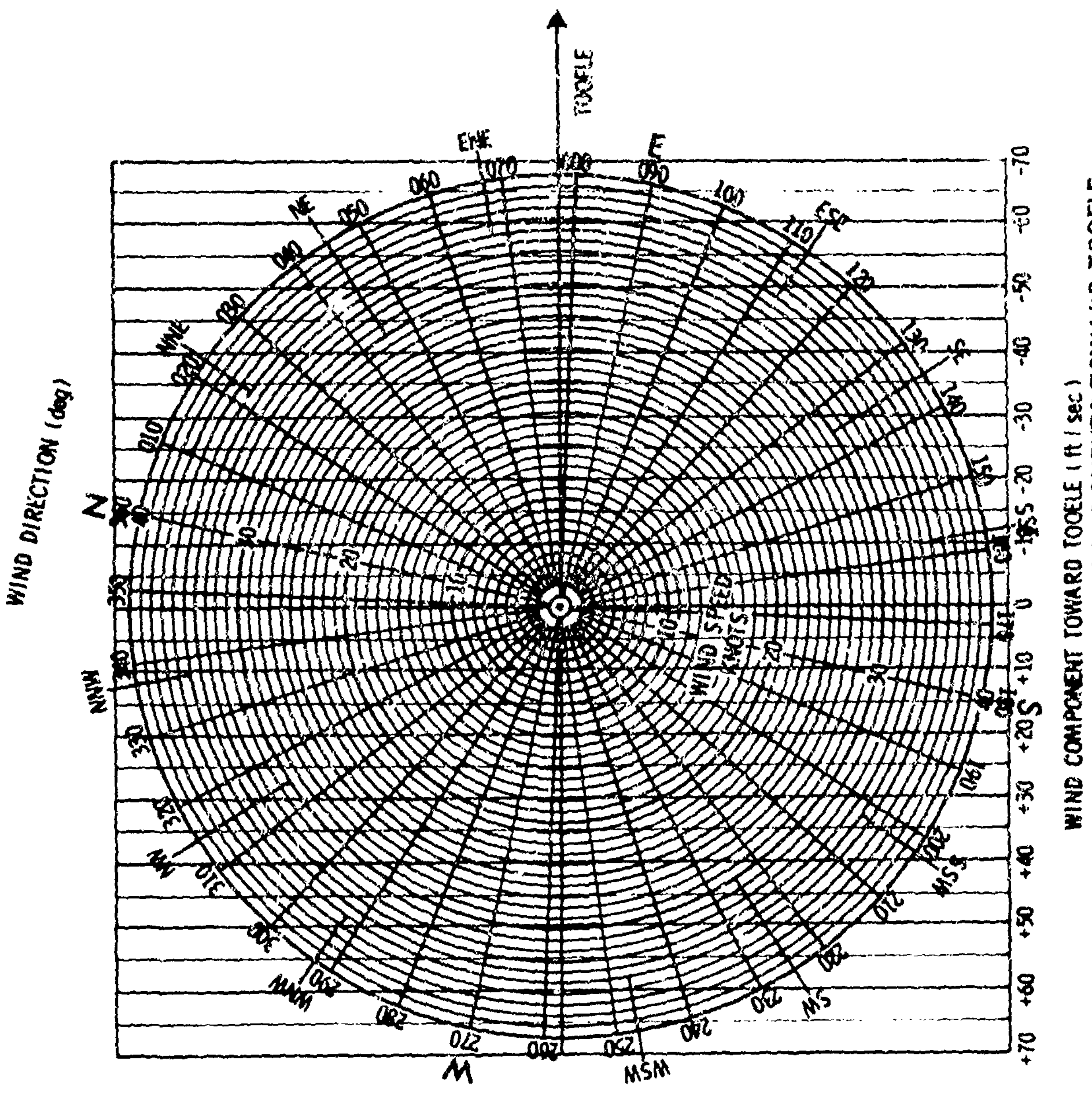


FIGURE 2. COMPUTER FOR WIND COMPONENTS TOWARD TOOELE

TABLE I. CALCULATIONS FOR BLAST PREDICTIONS

DATE: ____

I. SALT LAKE CITY UPPER AIR WEATHER REPORT

TIME: ____

6000FT MSL TEMPERATURE: ____ °C WIND: ____ °/ ____ KNOTS

S_6= ____ G_6= ____ T_6= ____

II. TOOELE SURFACE WEATHER REPORTS

A. TIME: ____ TEMPERATURE: ____ °F WIND: ____ °/ ____ KNOTS

S_o= ____ G_o= ____ T_o= ____

$D = S_6 - S_o$ ____ (-6 limit)

SOUND VELOCITIES:

GRANTSVILLE: $V_G = G_6 - G_o + D =$ ____

TOOELE : $V_T = T_6 - T_o + D =$ ____

B. TIME: ____ TEMPERATURE: ____ °F WIND: ____ °/ ____ KNOTS

S_o= ____ G_o= ____ T_o= ____

$D = S_6 - S_o$ ____ (-6 limit)

SOUND VELOCITIES:

GRANTSVILLE: $V_G = G_6 - G_o + D =$ ____

TOOELE : $V_T = T_6 - T_o + D =$ ____

C. TIME: ____ TEMPERATURE: ____ °F WIND: ____ °/ ____ KNOTS

S_o= ____ G_o= ____ T_o= ____

$D = S_6 - S_o$ ____ (-6 limit)

SOUND VELOCITIES:

GRANTSVILLE: $V_G = G_6 - G_o + D =$ ____

TOOELE : $V_T = T_6 - T_o + D =$ ____

D. TIME: ____ TEMPERATURE: ____ °F WIND: ____ °/ ____ KNOTS

S_o= ____ G_o= ____ T_o= ____

$D = S_6 - S_o$ ____ (-6 limit)

SOUND VELOCITIES:

GRANTSVILLE: $V_G = G_6 - G_o + D =$ ____

TOOELE : $V_T = T_6 - T_o + D =$ ____

If V_G or V_T is greater than +5 : Strong propagation; delay firing.

If V_G or V_T is between -5 and +5: Medium propagation; delay preferable.

If V_G and V_T are both below -5: : Weak propagation; Okay to fire.

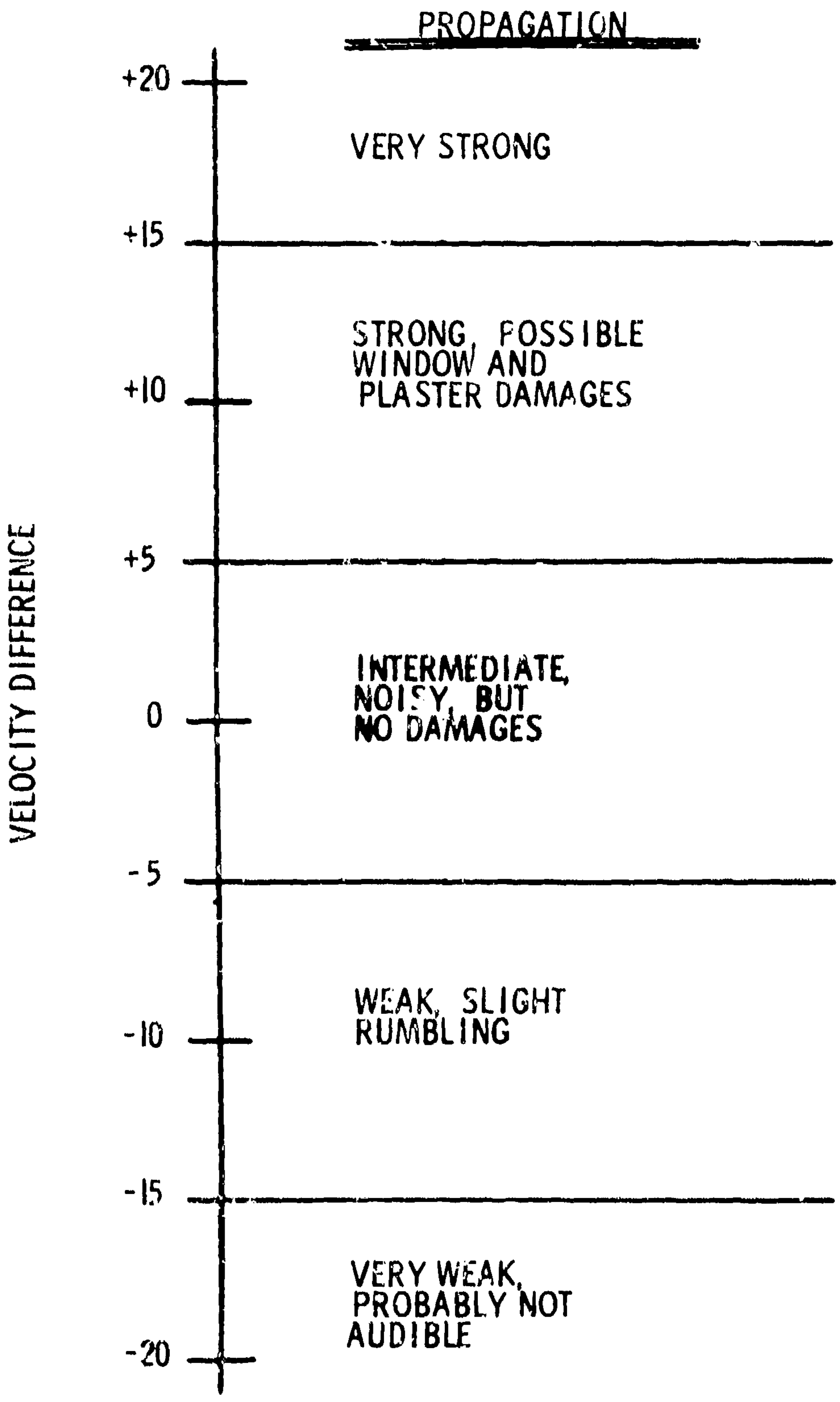


FIGURE 3. BLAST EFFECTS VERSUS SOUND VELOCITY DIFFERENCES

TABLE II

PROPAGATION RANGES FOR I-MB RECORDED AMPLITUDE

EXPLOSIVE WEIGHT (lb)	PROPAGATION RANGE (miles) DOWNWIND OR INVERSION	STANDARD	GRADIENT
1	1.8	0.7	0.2
50	7	2.7	0.7
2000	23	9	2.4
5000	31	12	3.2

EXPLOSIVE INCIDENT IN THE CONTINUOUS TNT PROCESS

Mr. E. P. Moran, Jr.
ARMCOM Safety Office
Rock Island, IL

Members and guests of the DoD Explosive Safety Board. It is a pleasure to address you this afternoon. My name is Paul Moran, Jr., of the ARMCOM Safety Office. The purpose of our discussion today is to present a brief analysis of the accidental explosion at Radford on 31 May this year. This analysis will be presented in four segments:

First, the process will be described by Mr. Raymond Goldstein, of Picatinny Arsenal. Mr. Goldstein, is a chemical engineer working with the Manufacturing Technology Group who has some years of experience with the complexities of nitrating toluene by the continuous method.

My part of the discussion involves the accident itself, some probable causes, the aftermath.

The third part of our discussion will be addressed by LTC Richard Stephans, Plant Commander, of Volunteer AAP. LTC Stephans, a chemical engineer by educational background, was appointed as Chairman of the Board of Investigation which convened at Radford due to the explosion. He will point out some rather serious problems which confront such an investigative body.

Mr. Edward Lindler, a safety engineer at the AMC . eld Safety Agency will provide a fault tree analysis of the continuous TNT nitration process in an attempt to identify the causal factors associated with the explosion and to provide guidance for future hazard analyses.

At approximately 1555 hours, 31 May 1974 the Chief Operato. on the 2nd shift relieved the day operator in Building 9502, the nitration and purification (N&P) building of A-Line in the TNT area at Radford Army Ammunition Plant (RAAP). According to the testimony of these men and strip chart recording of nitrator temperatures, the process at this moment appeared normal.

However, a few minutes later the operator noted "flooding" in Separator 2. This condition is caused by reduced process flow, normally resulting from a build-up of white compound (an oxidation by-product) inside the transfer line between Separator 2 and Nitrator 3A. Operating personnel indicate that line blockage due to white compound build-up is a normal periodic occurrence in the nitration process.

In order to regain normal flow, the operator, who was alone in the N&P building, proceeded to "rod out" the material blocking the transfer line with a six foot length of black rubber hose. (The hose was composed of a combination of natural rubber and various synthetic rubbers

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and contained a braiding of polyester knit yarn.) The Standing Operating Procedure addresses the unplugging of process lines due to white compound build-up and requires that cleaning be accomplished during operation with two men present by running either a steel fish or teflon rod through the lines to dislodge this material. Although the SOP neither allowed nor disallowed the use of a hose for this purpose, testimony indicates that it was common practice for one man to employ a rubber hose in this fashion. This hose had not been analyzed for compatibility with the nitration mixture of Nitrator 3A.

Tests show that this type of rubber hose reacts with a rapid temperature rise soon after immersion in acid-nitrobody mixture simulating the operating condition of Nitrator 3A.

The operator stated that as he applied this procedure, the hose was jerked from his hand. (This action was presumably caused by the hose wrapping around the nitrator shaft inside the draft tube of Nitrator 3A). At this point, his testimony becomes unclear and it is not possible to establish all of his actions. However, he had no clear procedure for coping with this type of emergency.

There was a period of time (as long as five minutes) between entry of the hose into Nitrator 3A and the fire during which the operator remained in the N&P building, probably attempting to take corrective action. This was determined by examination of the strip chart from the 12-point temperature recorder located in the A-line utility building which was recovered. It indicates the existence of a period of approximately 5 minutes prior to the explosion during which Nitrators 1A, 1B, 2, 3A, and 3B were cooling.

The sensing devices for the 12-point recorder as well as sensors for automatic high temperature dump and for cooling water control are located at the bottom of the nitrators. A fourth sensing device for the high temperature alarm is in the top of the nitrators.

The operator stated that upon seeing a fire in Nitrator 3A, he evacuated Building 9502. He also stated that he did not have sufficient time in which to either dump the charge in 3A or activate the building sprinkler system.

A high order detonation completely destroyed Building 9502 at approximately 1621 hours, EDT.

The introduction of the hose in the draft tube of Nitrator 3A resulted in a fire in that vessel. The most plausible sequence of events is as follows:

> After an induction period, the hose underwent rapid oxidation with the mixed acid. The heat generated by this reaction caused a local acceleration of the nitration reactions which occur in 3A until a critical temperature was reached. At this point the oxidation of DNT/TNT proceeded as a runaway reaction, igniting the material present in the vessel.

A possible but less likely initiation mechanism would not depend on chemical decomposition of the hose, but upon loss of agitation due to entanglement of the hose in the draft tube. This could allow localized heating within the draft tube to cause a runaway reaction.

The fire in Nitrator 3A transitioned to detonation which involved the other nitration vessels sympathetically.

Due to the nature of the continuous process, the exact amount of in-process material at any given time was unknown.

High order detonation occurred in all vessels between and including Separator 2 and the acid washer. The total amount of Class 7 material contained in these vessels is estimated at 12,000 pounds. A study recently completed by Livermore Labs indicated an effective yield of 8,000 pounds TNT.

There was no propagation of explosion to other buildings.

Blast damage to adjacent structures although severe was that expected at barricaded intraline distance. Damage to unbarricaded buildings in the TNT area ranged from substantial to total.

Damage to the administrative barracks area at 900-1200 feet from Building 9502 included complete destruction of windows, partial destruction of doors, some rafter breakage (2 x 12's) and interior partition displacement.

Approximately 90 percent of all missiles were found within 2200 feet. The acid mix tank (empty weight of 5000 pounds), located on the roof of Building 9502, was blown a distance of approximately 2400 feet and landed in the Solvent Recovery Building (1601).

Total plant damage is estimated at $10.5 million.

There were 16 disabling and approximately 100 non-disabling injuries. Three of the disabling injuries occurred in the TNT area. The large number of injuries was due to flying glass and other missiles outside the TNT area. The injuries sustained by the operator are primarily the result of acid burns. He was the only injured person who sustained burns of any kind.

All TNT area personnel were accounted for within 30 minutes after the detonation and the injured were evacuated to the plant hospital and other nearby hospitals for medical treatment.

Based on equipment volume calculations, there was approximately 19,000 pounds of Class 7 material in Building 9502 at the time of the detonation, including approximately 1,000 pounds in the drowning tanks. There was no Class 7 material in the remelt area.

No large fragments of A-line nitration equipment located between and including Separator 2 and the acid washer were identified during a field survey of missiles conducted after the explosion.

Some 32 recommendations were generated by the Board of Investigation to improve the system and to prevent future incidents. These recommendations are being staffed by higher commands at this time.

In addition 79 other recommendations to improve the continuous TNT process were written by Hercules employees and the Board membership.

MAJOR EXPLOSION INVESTIGATION MANAGEMENT

LTC R. A. Stephans, USA
Volunteer Army Ammunition Plant
Chattanooga, TN

Ladies and Gentlemen, you have heard Mr. Moran discuss the details of the Radford explosion from the report aspect. I would like to address the management aspects to include:

Administrative
Technical
Legal
After Action

Having had the dubious honor of being the President of the Investigation Board at Radford, I think I'm qualified by experience to make this short talk. This discussion is particularly important to the DOD since the TNT line that blew at Radford was a "sort-of" prototype to the modernized method of TNT production to which the DOD is committed to the tune of approximately two dozen 50 ton per day production lines (either in operation, being constructed or planned).

(VG 1)

Since our time is very limited, I will cover only the highlights of the areas hown; interject what I feel were the important aspects, and give some advice and axioms.

(VG 2)

ADMINISTRATIVE CONSIDERATIONS

(1) During that first day of the investigation, less than 48 hours after the explosion, there was a briefing and discussion by me, a tour of the

explosion area, and a briefing by Radford personnel giving everyone a better understanding of the facility and the TNT process there. This was extremely important in getting everyone off on the right foot with a good appreciation of what it was about. My briefing covered what had to be done during the investigation, stressed divorcing the members from their home station jobs, and asked for full, free and frank discussions.

(2) Of the ten who served on the Board, two were Safety Engineers, four were practicing Chemical Engineers, two were Legal representatives, one was a Quality Control Specialist and me, the Commander of another TNT Plant. All were Department of the Army civilian employees except myself and an Army Captain who was an Attorney.

(3) Regulatory guidance was somewhat lacking but it presented relatively few problems. Formal appointment orders to the Board listing the regulations to be followed were not published until 17 days after the incident. Basically and logically, we were charged with finding out what happened and making recommendations for corrective action. Because of the importance of this type of TNT process as a forerunner to future TNT production, an added element of "Lessons Learned" was tacked on to the investigation.

(4) Basically, the investigation phases consisted of data gathering and report write-up. Data gathering took approximately 80 plus percent of the nearly 2000 manhours expended by the Board. It was a major task to collect, classify and ferret out that which was not needed. The interrogation of 29 witnesses started two days after initial convening and lasted until about two weeks prior to Board adjournment, nearly 1 1/2 months later. Initial phases of write-up were farmed-out to a sub-committee consisting of four members while others

carried on added chores, such as classifying gathered data, claims responsibilities, summarizing testimony, etc. Even after sub-committee presentation, it sometimes took in excess of several hours to agree on the wording of perhaps one key sentence.

(5) The Board was offered and received the full support of several outside agencies in the pursuit of the investigation. We received help from:

(a) The Army Corps of Engineers, Crater Research Group at Lawrence Laboratories, Livermore, California.

(b) Norfolk Engineer District - for aerial photos and construction information.

(c) Canadian Industries Limited - Operators of the first continuous TNT lines upon which the Radford lines were based.

(d) DOD Explosives Safety Board.

(e) Army Material Command for blast attenuation expertise from their Systems Analysis Agency.

The vast majority of information was gathered directly from the Radford Plant (without whose support, the investigation would have been impossible). I must say that all witnesses from Radford were very candid, open and eager to offer as much as they could to support the investigation.

(6) The initial actions by the Board are so important in establishing a confidence, if you will, in the eyes of the higher headquarters. If this is not achieved, there is the possibility of turmoil resulting from interference in the guise of trying to help. I believe two actions on the part of the Radford Board set the tone and established the confidence needed from our higher

headquarters. The first was an initial telegram, a quick look report, delivered the day after the Board convened. The other confidence builder was the presentation provided to the Commander, Armament Command. General Raaen's visit to Radford was within two weeks after the incident and during the Board's two hours with him, we had a general investigation briefing, review of the TNT process and information about data gathering to include, an audio tape presentation of key witness testimony. Description of missile fragment reconstruction and a "Laboratory" demonstration. The results of these actions somewhat reduced the pressure from the higher echelon.

(7) As I mentioned earlier, from the very beginning, I asked for open and frank discussions and I'm sure you realize that during any committee approach to getting something done, it's extremely difficult to achieve unaminity, especially among a group of Engineers. This was the case during the Radford investigation. And, despite how a higher authority may look upon a minority report, if a member or members choose to present one, it must be included. Majority Board pressure against a minority report would certainly discredit the final report.

(VG 3)

TECHNICAL ASPECTS

As in any investigation, a complete effort is required even though the specific cause might be immediately apparent. It is very easy to become enamored by one seemingly obvious explanation for the cause and be blinded by facts which support a less evident cause. Keep an open, unbiased mind throughout the investigation! Leave no stones unturned.

An approach is to draw a circle around the area and check-out everything that went in or out to include:

People - Their training, competence, supervision, attitude.

Procedures - All written documents such as Safety, Maintenance and of course Operations.

Material Feeds - Quality vs Specifications

Utilities -

Maintenance - History of the process

Reconstruction of missiles from the explosion is also very vital and necessary. Weight, missile plots, photos are all required.

LEGAL ASPECTS

Guided by Army Regulations, a decision had to be made relative to the type of investigation being performed. I had a choice of proceeding along the lines of purely administrative board or an administrative board which would assess liability on the part of individuals. This latter type is known as an adversary board and it must be conducted under most formal legal procedures.

The Radford investigation was treated similarly to an airplane accident investigation where two different boards are convened--one to find out what went wrong and a second to determine specific liability. The prime basis for this approach is that we wanted people to open up and tell what happened so that, if need be, corrective action could be applied at Radford and the three other TNT plants immediately. In an adversary Board, witnesses are usually accompanied by council and free interchange and forthright discussions are difficult to achieve. Conducting the Board under adversary conditions would certainly have set an undesirable precedence for other investigations.

An item of interest is that there were attempts by both OSHA and Union representatives to secure membership on the Investigation Board. Fortunately, my attorney from the Chief Council's Office at Army Material Command, had been briefed concerning this possibility. He simply added support to the local commander and my desire to prohibit such attendance. There were few repercussions after the negative reply on their attendance was issued.

In Investigation Boards such as Radford, I could understand where there might be the possible use of Command influence. This is where a high level Government Official (higher than the Investigation Board President) influences the Board to produce a "Whitewash". Such was not the case at Radford, but investigators should be on guard for this normally remote possibility.

AFTER ACTION

The completion of the investigation write-up doesn't necessarily mean that the work is over.

(1) The area of the explosion must be cleaned up. But this must be done carefully. There may be unexploded materials or other hazards. In the case of Radford, there were extreme hazards to include a build-up of nitric and sulfuric acid on the ground and solidified intermediates of the TNT process in two adjacent production lines. Decontamination of the TNT lines has only now begun due to the complexity of the task and other priority activity.

(2) The sheer volume of the report of investigation (29 pounds in five volumes) required an extensive briefing at ARMAMENT Command before GEN Raaen

and His Staff. the briefing alone took 1 1/2 hours and was presented four days after the report was completed.

(3) If the truth be known, as some of you here may agree, it is easy to draw out the time an Investigation Board is convened in search of added information and data which may be relevant. But, after a reasonable amount of data is gathered, a judgment must be made as to sufficiency. This may not be an easy decision to make. There may be later evidence found that would tend to alter some information presented but that is a risk one has to take. Therefore, there should be action taken to insure information pertinent to the investigation is forwarded even after the report is completed.

(4) Finally, those individuals and support agencies who contributed to the investigation should be recognized. As a minimum, a letter of appreciation from the Headquarters appointing the Board is in order.

(VG 4)

SAFETY

What then, after this extensive investigation and beyond the specific formal recommendations, can be said to minimize the chance for a similar disaster or, if one occurs, to reduce casualties at any other plant or installation?

It is my observation, that in order to minimize the chance of a disaster, the following should be accomplished:

1. First analyze the hazards that are possible at the area of concern.
2. Insure that operating procedures are written correctly, and most importantly, that they are being followed.

3. Seek outside evaluations of the area because it is too easy not to see the forest.

4. Finally, secure periodic re-evaluations relative to hazards.

In order to minimize casualties if a like disaster takes place, the following should be accomplished:

1. Provide correct and immediate actions during a disaster.

2. Have a good disaster control plan and make sure it is studied and known by all.

3. Insure that the disaster control plan is periodically exercised with critique and follow-up corrective action.

4. Alert outside disaster relief agencies (fire, ambulance, police) for possible support requirements.

5. Know where the potentials for disaster are; such as, concentrations of explosives, toxic chemicals, flammables: plus disasters, from natural causes -- fire, flood or other acts of God.

6. Finally, prepare for disaster at the most inopportune time and conditions, Remember Murphy's Law!

Ladies and Gentlemen, I hope that this short presentation covering the administrative, technical, legal and after after aspects of a major explosive incident investigation, plus the remarks relating to safey, have been of interest.

MAJOR DISASTER INVESTIGATION MANAGEMENT

INTRODUCTION

OVERVIEW

ADMINISTRATIVE
TECHNICAL
LEGAL
AFTER ACTION

Figure 1

ADMINISTRATIVE

TEAM MAKE-UP

FIRST DAY ACTIVITY

REGULATORY GUIDANCE

INVESTIGATION PHASES

SUPPORT

INITIAL ACTIONS

MINORITY REPORT

Figure 2

TECHNICAL

APPROACH

RECONSTRUCTION OF MISSILES

LEGAL

TYPE OF BOARD

UNION/OSHA

COMMAND INFLUENCE

AFTER ACTION

CLEAN-UP

CONTINUED INFORMATION FLOW

RECOGNITION

Figure 3

OUTLINE OF INVESTIGATION BOARD TASKS

I - DETERMINE WHAT HAPPENED

- A. GATHER DATA
  - 1. SITE OBSERVATIONS
    - a. BLAST DAMAGE TO PROCESS EQUIPMENT AND STRUCTURES
    - b. DETONATION SOURCE
    - c. MISSILE ANALYSIS
  - 2. PERSONNEL INTERVIEWS
  - 3. REVIEW S.O.P'S AND OTHER PERTINENT DOCUMENTS
- B. DEVELOP OFFICIAL ACCOUNT OF INCIDENT

II - CONDUCT ANALYSIS BASED ON OFFICIAL ACCOUNT

- A. WAS THE INCIDENT A RESULT OF NORMAL OPERATIONS?
- B. WAS THE INCIDENT A RESULT OF SOME UNUSUAL CONDITION?
- C. IS THE DESIGN OR OPERATING PROCEDURE UNSAFE?

III - OTHER CONCLUSIONS AND RECOMMENDATIONS

Figure 4

SAFETY - WHAT CAN WE DO?

MINIMIZE CHANCE OF HAPPENING

MINIMIZE CASUALTIES DURING DISASTER

Figure 5

HAZARD ANALYSIS AS AN ACCIDENT PREVENTION TOOL

Mr. H. E. Lindler
AMC Field Safety Agency
Charlestown, Ind.

DURING THIS PORTION OF THE SESSION I WOULD LIKE TO DISCUSS THE USE OF HAZARD ANALYSIS AS AN ACCIDENT PREVENTION TOOL.

ALTHOUGH THE 31 MAY 1974, EXPLOSION AT RADFORD ARMY AMMUNITION PLANT WILL BE USED FOR DISCUSSION PURPOSES, IT SHOULD BE REMEMBERED THAT THE VARIOUS TECHNIQUES OF HAZARD ANALYSIS CAN BE APPLIED TO ANY PROCESS WITH POSITIVE RESULTS.

A GOOD STARTING POINT FOR THIS DISCUSSION IS MIL-STD-882 (SYSTEM SAFETY PROGRAM FOR SYSTEMS AND ASSOCIATED SUB-SYSTEMS AND EQUIPMENT: REQUIREMENTS FOR, 15 JULY 1969).

THIS DOCUMENT STATES THAT ANALYSES ARE PERFORMED TO IDENTIFY HAZARDOUS CONDITIONS FOR THE PURPOSE OF THEIR ELIMINATION OR CONTROL. IT FURTHER STATES THAT ANALYSES WILL BE CONDUCTED ON THE SYSTEM, I.E. THE PRODUCTION LINE, IN THIS CASE, THE SUBSYSTEM, I.E. FACILITIES, UTILITIES AND WORK STATIONS TO INCLUDE EQUIPMENT, TOOLS, PROCEDURES, AND TRAINING, AND THEIR INTERFACES.

HAZARDOUS CONDITIONS ARE CLASSIFIED BY MIL-STD-882 ACCORDING TO THE MOST SEVERE RESULTS OF PERSONNEL ERROR, ENVIRONMENT, DESIGN CHARACTERISTICS, PROCEDURAL

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DEFICIENCIES OR PROCESS EQUIPMENT FAILURE OR MALFUNCTION. (VIEW #1 - ON) AS YOU CAN SEE, THEY COVER TWO BROAD AREAS, PERSONNEL AND EQUIPMENT SAFETY, AND ARE DIVIDED INTO FOUR CLASSES, I.E. NEGLIGIBLE, MARGINAL, CRITICAL, AND CATASTROPHIC. THE "MIL-STD" REQUIRES THAT ACTION BE TAKEN TO RESOLVE ALL HAZARDS REVEALED BY ANALYSES OR RELATED ENGINEERING EFFORTS AND THAT ALL CATEGORY III AND IV HAZARDS BE ELIMINATED OR CONTROLLED TO AN ACCEPTABLE LEVEL.

ALTHOUGH THESE CATEGORIES DO PROVIDE VALUABLE GUIDANCE, ONE MUST REMEMBER THAT THE FOUR CLASSES ARE INTENDED TO BE APPLICABLE TO A WIDE VARIETY OF PROGRAMS. CONSEQUENTLY, IT IS REALLY NOT FEASIBLE TO EXPECT THESE TERMS TO PROVIDE A USEFUL SERVICE UNLESS SOME EFFORT IS EXPENDED TOWARD ADAPTING THEM TO A PARTICULAR PROGRAM. THIS ADAPTATION SHOULD INCLUDE DEFINITE TRANSITION POINTS FROM ONE CONDITION TO THE NEXT IN ORDER TO PROVIDE THE USER WITH A TOOL TO MEASURE THE MAGNITUDE OF HIS PROBLEMS AND ALLOW HIM TO KNOW WHERE TO CONCENTRATE HIS EFFORT (VIEW #1 - OFF).

(VIEW #2 - ON) FOR THE CASE AT HAND, WE MIGHT MAKE USE OF SOME INFORMATION RECENTLY PUBLISHED BY THE NAVY IN PART IV OF NAVORD OD 44942 (WEAPON SYSTEM SAFETY GUIDELINES

HANDBOOK, HAZARD CONTROL FOR EXPLOSIVE ORDNANCE PRODUCTION, 15 JANUARY 1974).

NOTE THAT GUIDELINES ARE PROVIDED FOR ACCEPTABLE LEVEL OF RISK AS A FUNCTION OF HAZARD CATEGORY AND ESTIMATED PROBABILITY OF OCCURRENCE. NOTE FURTHER THAT ACCEPTABLE PROBABILITIES OF OCCURRENCE FOR CATEGORY IV HAZARDS VARY WITH SEVERITY OF CONSEQUENCE. IN OTHER WORDS, THE FIGURE OF 10^{-6} IS TAKEN AS AN ORDER-OF-MAGNITUDE VALUE OF MAXIMUM ACCEPTABLE PROBABILITY OF ACCIDENT FOR A CATEGORY IV HAZARD. WHEN THE CONSEQUENCES OF A HAZARD EXTEND TO MULTIPLE DEATHS OR SEVERE INJURIES, OR TO OTHER PERSONNEL AND EQUIPMENT BEYOND THE PARTICULAR SYSTEM, SMALLER ACCEPTABLE PROBABILITIES MUST BE ASSUMED (VIEW #2 - OFF).

THIS IS, OF COURSE JUST ONE OF MANY APPROACHES THAT COULD BE USED. THE IMPORTANT THING TO REMEMBER HERE IS THAT PROPER HAZARD CATEGORIZATION IS THE FIRST STEP IN IDENTIFYING HAZARDOUS CONDITIONS AND DOWNGRADING THEM TO AN ACCEPTABLE LEVEL, WHICH IS THE WHOLE POINT OF ANY SAFETY ANALYSIS EFFORT.

INSOFAR AS SPECIFIC ANALYSES ARE CONCERNED, FOUR TYPES

ARE DESCRIBED IN MIL-STD-882. THEY CAN BE INTEGRATED INTO THE PRODUCTION LIFE CYCLE AS SHOWN IN THE VIEW (VIEW #3 - ON) AND INCLUDE:

a. PRELIMINARY HAZARD ANALYSIS (PHA). THE PHA IS JUST WHAT THE TITLE IMPLIES -- IT IS THE PRELIMINARY OR INITIAL EFFORT TO ANALYZE THE DESIGN CONCEPT AND IS A STUDY OF MAJOR HAZARDS IN GROSS TERMS ASSOCIATED WITH THE PRODUCTION LINE. SOME OF THE MORE BASIC HAZARDS THAT MAY BE ENCOUNTERED INCLUDE FIRE, EXPLOSION, PERSONNEL EXPOSURE TO HAZARDOUS MATERIALS, AND INADVERTENT RELEASE OF POTENTIAL AND KINETIC ENERGY. A FAIRLY COMPLETE LIST OF AREAS TO BE CONSIDERED MAY BE FOUND IN MIL-STD-882. BY CONSIDERING EACH OF THESE BASIC HAZARD AREAS, IT IS POSSIBLE TO ASK SUCH QUESTIONS AS: "IS IT POSSIBLE TO HAVE AN EXPLOSION IN THE SYSTEM?" "IS ELECTRICAL ENERGY BEING USED, AND IF SO, HOW MUCH AND WHERE?" IN GENERAL, THE MORE EXPERIENCE THE ANALYST HAS PERTAINING TO SYSTEM/SUBSYSTEM/COMPONENT IN QUESTION, THE MORE THOROUGH AND ACCURATE THE INITIAL HAZARD IDENTIFICATION AND EFFECTS DESCRIPTION WILL BE, AND, IN TURN, THE MORE USEFUL AND VALID THE SAFETY ANALYSIS THROUGHOUT THE PROGRAM WILL BE.

SEVERAL DIFFERENT FORMATS FOR ACCOMPLISHING THE PHA HAVE BEEN DEVELOPED INCLUDING COLUMNAR, NARRATIVE AND LOGIC DIAGRAM. A VERY BRIEF EXAMPLE HAS BEEN PREPARED USING THE COLUMNAR APPROACH. THIS PARTICULAR FORMAT IS USED BY WILLIE HAMMER IN HIS RECENTLY PUBLISHED "HANDBOOK OF SYSTEM AND PRODUCT SAFETY" (VIEW #3 - OFF, VIEW #4 - ON).

AS YOU CAN SEE, THE FORMAT CONSISTS OF FOUR COLUMNS DESCRIBING THE HAZARD, ITS CAUSE, THE RESULTING EFFECTS, THE CATEGORY OF HAZARD, AND A DESCRIPTION OF THE MEASURES TAKEN TO PREVENT THE HAZARD. SINCE THIS IS ONLY A PARTIAL ANALYSIS, IT SHOULD BE NOTED THAT THE COMPLETED PHA WOULD INCLUDE CONSIDERATION OF THE ENTIRE PROCESS INCLUDING NITRATION, PURIFICATION, FINISHING AND THE VARIOUS SUPPORT AREAS.

THE PHA ACCOMPLISHES TWO THINGS IN THAT IT PROVIDES INITIAL SAFETY DESIGN REQUIREMENTS AND IDENTIFIES HIGH-RISK AREAS WHICH MUST BE SUBJECTED TO FURTHER ANALYSIS (VIEW #4 - OFF, VIEW #5 - ON).

b. SUBSYSTEM HAZARD ANALYSIS (SSHA). THE SSHA IS A SYSTEMATIC EVALUATION OF EACH SUBSYSTEM TO DETERMINE HOW MUCH EACH PART COULD CONTRIBUTE TO CREATING A HAZARD IDENTIFIED IN THE PHA.

AT THE POINT IN TIME THAT THIS TYPE OF ANALYSIS IS PERFORMED, CONSIDERABLY MORE WOULD BE KNOWN ABOUT THE SYSTEM. CONSEQUENTLY, THE ANALYSIS CAN GO INTO MORE DETAIL, I.E. IT CAN BE MORE SPECIFIC.

A NUMBER OF TECHNIQUES HAVE BEEN DEVELOPED FOR THIS PURPOSE, INCLUDING THE FAILURE MODE AND EFFECT (FMEA) AND FAULT TREE ANALYSES.

IN THE FMEA THE ANALYST LOOKS AT EACH COMPONENT IN THE SUBSYSTEM AND ASKS THE QUESTION: "HOW CAN THIS PART FAIL AND WHAT IS THE CONSEQUENTIAL EFFECT ON THE SUBSYSTEM AND SYSTEM?" THIS TYPE OF APPROACH IS SOMEWHAT LIMITED IN THAT IT IS BEST SUITED TO THE EXAMINATION OF SINGLE-POINT FAILURES.

SINCE ACCIDENTS USUALLY OCCUR AS A RESULT OF COMBINATIONS OF EVENTS, MUCH USE IS MADE OF THE FAULT TREE TECHNIQUE WHICH HAS THE CAPABILITY OF EXAMINING THE PROCESS IN EXTREME DETAIL AND ESTABLISHING THE VARIOUS COMBINATIONS OF EVENTS WHICH COULD LEAD TO THE UNDESIRED EVENT.

THE FAULT TREE BEGINS WITH SOME UNDESIRED EVENT PREVIOUSLY DEFINED, TYPICALLY BY EITHER A PHA OR FMEA, THEN WORKS BACKWARD TO DIAGRAM, USING THE PRINCIPLES OF

FORMAL LOGIC, CONTRIBUTORY CAUSES IN THE FORM OF A "TREE" WITH CAUSATIVE PATHS AS BRANCHES.

AS AN EXAMPLE OF HOW THIS TECHNIQUE CAN BE USED, CONSIDER THE HAZARD OF "FIRE OR EXPLOSION" IN THE N&P BUILDING IDENTIFIED EARLIER IN THE PHA.

(VIEW #5 - OFF, VIEW #6 - ON) STARTING WITH THIS EVENT, THE QUESTION IS ASKED: "HOW CAN IT OCCUR?" IT CAN BE SEEN THAT THE TOP EVENT CAN BE CAUSED BY FIRE OR EXPLOSION IN EITHER THE TOLUENE FEED SYSTEM, A NITRATOR, THE PURIFICATION SYSTEM, OR THE EXHAUST SYSTEM. THE "TREE" IS EXPANDED BY AGAIN ASKING, "HOW CAN EACH OF THESE EVENTS OCCUR?" THE PROCESS IS REPEATED UNTIL A LEVEL IS REACHED AT WHICH CORRECTIVE ACTION CAN BE TAKEN.

CONSIDER THE CASE OF "EXPLOSION IN A NITRATOR." THIS COULD RESULT IF THERE WERE A FIRE IN THE VESSEL AND TRANSITION TO DETONATION OCCURRED. THE FIRE COULD RESULT IF THE TNT-ACID EMULSION WERE INITIATED BY IMPACT, THERMAL BUILD-UP, FRICTION, OR A FIRE OR EXPLOSION IN THE FUME EXHAUST LINE.

IF INITIATION DUE TO THERMAL BUILD-UP IS DEVELOPED, ONE OF ITS CAUSES CAN BE TRACED TO INADEQUATE COOLING OF THE NITRATOR (VIEW #6 - OFF, VIEW #7 - ON) WHICH CAN RESULT

FROM EITHER INSUFFICIENT HEAT REMOVAL BY THE COOLING COILS OR EXCESSIVE REACTION RATE IN THE NITRATOR. THE LATTER COULD RESULT FROM EITHER AN EXCESSIVE NITRATION RATE OR FROM INCOMPATIBLE MATERIALS BEING INTRODUCED INTO THE NITRATOR (VIEW #7 - OFF, VIEW #8 - ON).

EXAMINATION OF THE INTRODUCTION OF INCOMPATIBLE MATERIALS INTO THE NITRATOR ULTIMATELY LEADS TO THE CONCLUSIONS THAT:

1. ALL LOOSE MATERIALS IN THE NITRATION AND PURIFICATION OPERATION SHOULD BE IDENTIFIED.

2. PRIOR TO ACCEPTANCE, THESE MATERIALS SHOULD BE TESTED FOR COMPATIBILITY/REACTIVITY WITH THE ENTIRE PROCESS TO INCLUDE INTERMEDIATE AS WELL AS END PRODUCTS.

3. THOSE MATERIALS FOUND TO BE INCOMPATIBLE SHOULD BE EITHER DISALLOWED, SUBSTITUTED WITH A COMPATIBLE MATERIAL, OR CONTROLLED IN A POSITIVE MANNER.

4. PROCEDURES SHOULD BE REVIEWED TO INSURE THAT THEY WILL NOT ENCOURAGE THE USE OF UNAUTHORIZED TOOLS OR MATERIALS. (VIEW #8 - OFF).

NOTE THAT WE HAVE DISCUSSED ONLY ONE SMALL PORTION OF THE TREE FOR ONE SUBSYSTEM TO ANY DEGREE OF DETAIL.

WHEN THIS APPROACH IS TAKEN FOR ALL PARTS OF ALL SUBSYSTEMS, A TREMENDOUS AMOUNT OF SAFETY INFORMATION IS GENERATED, EARLY IN THE LIFE OF THE PRODUCTION LINE, RELATIVE TO TRAINING REQUIREMENTS, INPUTS TO OPERATING AND MAINTENANCE PROCEDURES AND FACILITY/UTILITY/EQUIPMENT DESIGN.

(VIEW #9- ON). c. SYSTEM HAZARD ANALYSIS (SHA). THE THIRD TYPE OF ANALYSES DISCUSSED IN "882" IS THE SYSTEM HAZARD ANALYSIS. IT IS PERFORMED TO IDENTIFY HAZARDS ASSOCIATED WITH THE INTEGRATION OF SUBSYSTEMS IN FORMING A COMPLETE SYSTEM, AND THE INTEGRATION OF THE SYSTEM WITH OTHER SYSTEMS, E.G., OTHER PRODUCTION LINES, LOADING DOCKS, ADMINISTRATIVE AREAS, WASTE DISPOSAL AREAS, ROADWAYS, ETC., OR BY THE SYSTEM OPERATING AS A WHOLE. SUBSYSTEMS MAY INDUCE CERTAIN HAZARDS DURING OR AFTER INTEGRATION THAT WERE NOT PRESENT OR READILY APPARENT DURING THE CONDUCT OF THE SUBSYSTEM HAZARD ANALYSIS. THE SHA IDENTIFIES THESE AND OTHER UNSAFE CONDITIONS PERTAINING TO INTERFACE RELATIONSHIPS, SECONDARY FAILURE EFFECTS, INSUFFICIENT SPACING OR CLEARANCES, ENVIRONMENTAL CONTAMINATION, UNSAFE INSTALLATIONS AND OTHER AREAS RELATED TO TOTAL

SYSTEM INTEGRATION. TECHNIQUES SIMILAR TO THOSE DISCUSSED EARLIER ARE USED IN THIS TYPE OF ANALYSIS.

d. OPERATING HAZARD ANALYSIS (OHA). THE OHA IS CONDUCTED TO IDENTIFY THOSE HAZARDS THAT MAY BE ENCOUNTERED DURING OPERATION AND MAINTENANCE OF THE VARIOUS EQUIPMENT AND HARDWARE REQUIRED THROUGHOUT THE PRODUCTION PROCESS. ALTHOUGH THIS ANALYSIS MUST CONSIDER EQUIPMENT DAMAGE THAT COULD RESULT FROM IMPROPER OR CARELESS OPERATION, EMPHASIS IS PLACED ON HAZARDS THAT COULD RESULT IN PERSONNEL INJURY. THE OHA BEGINS AS A FUNCTION OF THE PHA AND EARLY SSHA TO IDENTIFY NECESSARY SAFETY CONTROLS AND CONSTRAINTS TO BE INCLUDED IN EQUIPMENT AND FACILITY DESIGN TO ENSURE MAXIMUM SAFETY OF BOTH OPERATOR AND MAINTENANCE PERSONNEL. HOWEVER, AFTER THE EQUIPMENT HAS BEEN PLACED OR INSTALLED IN ITS OPERATIONAL ENVIRONMENT, A FORMALIZED OHA IS PERFORMED. THE OBJECTIVE IS TO IDENTIFY REAL-LIFE HAZARDS CREATED BY MAN-MACHINE INTERFACES AND TO DEVELOP PROCEDURES OR RECOMMEND EQUIPMENT CHANGES TO MINIMIZE THE EFFECTS OF THESE HAZARDS. (VIEW #9 - OFF, VIEW #10 - ON). A TYPICAL OPERATING HAZARD ANALYSIS MATRIX IS SHOWN ON THE VIEW. BRIEFLY, EACH TASK COMPRISING THE OPERATION UNDER STUDY

IS ANALYZED FOR THOSE ELEMENTS WHICH ARE INHERENTLY HAZARDOUS. RESULTING POTENTIAL ACCIDENTS AND EFFECTS ARE IDENTIFIED, CATEGORIZED ACCORDING TO HAZARD LEVEL AND APPROPRIATE REQUIREMENTS SPECIFIED TO ELIMINATE OR REDUCE HAZARDS. THE OHA WILL IDENTIFY ADDITIONAL SAFETY TRAINING REQUIREMENTS; DEVELOP ADDITIONAL SAFETY INPUTS TO THE STANDING OPERATING PROCEDURE; DEFINE THE NEED FOR WARNING SIGNS AND SAFETY PLACARDS; AND IDENTIFY SAFETY REQUIREMENTS FOR MAINTENANCE PROCEDURES. THE OHA WILL FURTHER DEFINE THE NEED FOR EMERGENCY PROCEDURES AND EQUIPMENT. THE OHA IS UPDATED (NORMALLY WITHIN SIX MONTH INTERVALS AS AN AUDIT) THROUGHOUT THE PRODUCTION PERIOD TO ENSURE THAT THE EARLIER SAFETY CONSIDERATIONS ARE MAINTAINED AND THAT NEW, UNCONTROLLED HAZARDS HAVE NOT BEEN INTRODUCED INTO THE SYSTEM. (VIEW #10 - OFF).

THIS THEN HAS BEEN A BRIEF INTRODUCTION TO HAZARD ANALYSIS AND ITS APPLICATION TO THE PRODUCTION ENVIRONMENT. I WOULD POINT OUT THAT IT IS IMPERATIVE THAT HAZARD CONTROL RECOMMENDATIONS, BASED ON THE RESULTS OF COMPREHENSIVE ANALYSES, BE DEFINED DURING THE EARLY PHASE OF PRODUCTION LINE PLANNING, DESIGN AND LAYOUT SINCE THE INCLUSION OF

HAZARD CONTROLS BECOMES PROGRESSIVELY MORE DIFFICULT AS DEVELOPMENT OF THE PRODUCTION LINE ADVANCES.

IN CONCLUSION, IT SHOULD BE NOTED THAT HAZARD ANALYSIS AS A PART OF THE OVERALL SYSTEM SAFETY TYPE OF APPROACH IS A WAY TO IMPROVED PERFORMANCE, A DESIRE SHARED BY ALL DEDICATED SAFETY PERSONNEL. EVEN THOUGH THERE ARE A FEW NEW CONCEPTS AND TECHNIQUES INVOLVED IN THIS DISCIPLINE, THE BASIC CONCEPT OF ACCIDENT PREVENTION, THE CORNERSTONE OF THE TRADITIONAL SAFETY PROGRAM, STILL PREVAILS. IT IS ONLY IN THE APPROACH TO A PROBLEM THAT THE "OLD" AND "NEW" DIFFER. IN CONTRAST TO THE TRADITIONAL, PROTECTIVE APPROACH, THE SYSTEM SAFETY APPROACH IS PREVENTATIVE IN NATURE, SEEKING SOLUTIONS TO PROBLEMS BEFORE THEY BECOME LOSSES.

THANK YOU AGAIN FOR THIS OPPORTUNITY TO SPEAK ON THE SUBJECT OF HAZARD ANALYSIS AND FOR YOUR KIND ATTENTION.

REFERENCES:

1. MIL-STD-882, System Safety Program for Systems and Associated Subsystems and Equipment: Requirements for, 15 July 1969.

2. NAVORD OD 44942, Weapon System Safety Guidelines Handbook, Part IV, Hazard Control for Explosive Ordnance Production, 15 January 1974.

3. "Handbook of System and Product Safety" by Willie Hammer, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1972.

4. "Introduction to System Safety Engineering" by William P. Rodgers, John Wiley & Sons, Inc., New York, NY, 1971.

HAZARD CATEGORIES
(MIL - STD 882)

CONDITIONS SUCH THAT PERSONNEL ERROR, ENVIRONMENT, DESIGN CHARACTERISTICS, PROCEDURAL DEFICIENCIES, OR SUBSYSTEM OR COMPONENT FAILURE OR MALFUNCTION:

(A) CATEGORY I-NEGLIGIBLE.... WILL NOT RESULT IN PERSONNEL INJURY OR SYSTEM DAMAGE.

(B) CATEGORY II-MARGINAL.... CAN BE COUNTERACTED OR CONTROLLED WITHOUT INJURY TO PERSONNEL OR MAJOR SYSTEM DAMAGE.

(C) CATEGORY III-CRITICAL.... WILL CAUSE PERSONNEL INJURY OR MAJOR SYSTEM DAMAGE, OR WILL REQUIRE IMMEDIATE CORRECTIVE ACTION FOR PERSONNEL OR SYSTEM SURVIVAL.

(D) CATEGORY IV-CATASTROPHIC.... WILL CAUSE DEATH OR SEVERE INJURY TO PERSONNEL, OR SYSTEM LOSS.

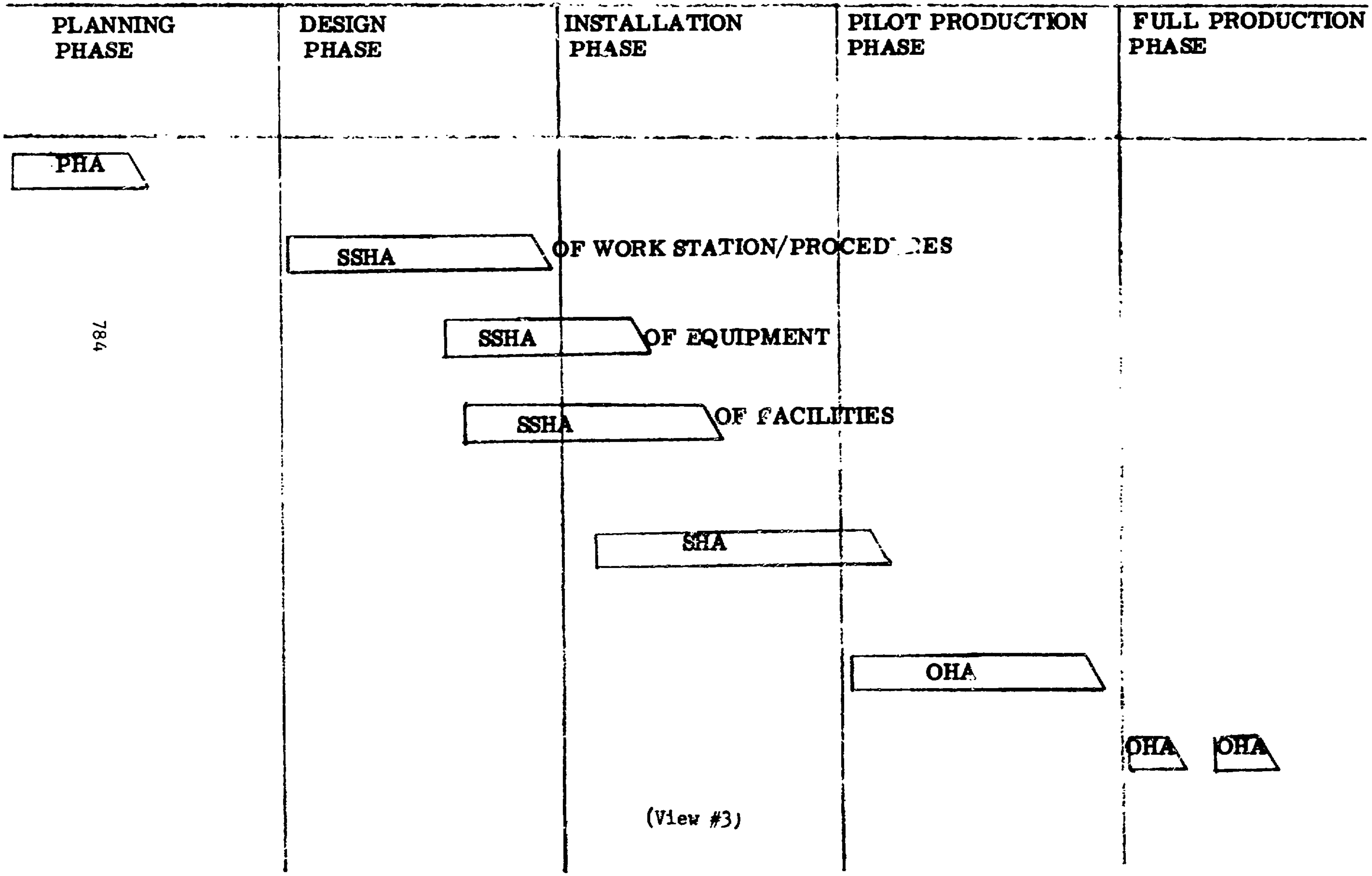
(View #1)

POSSIBLE HAZARD CATEGORIES FOR CONTINUOUS TNT PLANT (ADAPTED FROM MIL - STD 882)

HAZARD CATEGORY	DEFINITION	LIMIT OF RISK ACCEPTABILITY (MAX. ALLOW. PROBABILITY OF OCCURRENCE)
I-NEGLIGIBLE	NO INJURY--<$50 DAMAGE	10^{-1}
II-MINOR	FIRST AID INJURY ONLY--<$10,000 DAMAGE	10^{-2}
III-CRITICAL	FAILURE OF AUTOMATIC CONTROLS WILL RESULT IN CATEGORY IV EVENT	10^{-5}
IV-CATASTROPHIC	SERIOUS INJURY/DEATH TO OPERATOR--<$25,000 DAMAGE	10^{-6}
	SERIOUS INJURY/DEATH TO MULTIPLE OPERATORS--LOSS OF WORK STATION/BUILDING	10^{-9}
	SERIOUS INJURY/DEATH TO MULTIPLE OPERATORS--LOSS OF PRODUCTION LINE	10^{-12}

(View #2)

HAZARD ANALYSIS SEQUENCE IN THE PRODUCTION LINE LIFE CYCLE



(View #3)

PARTIAL PRELIMINARY HAZARD ANALYSIS

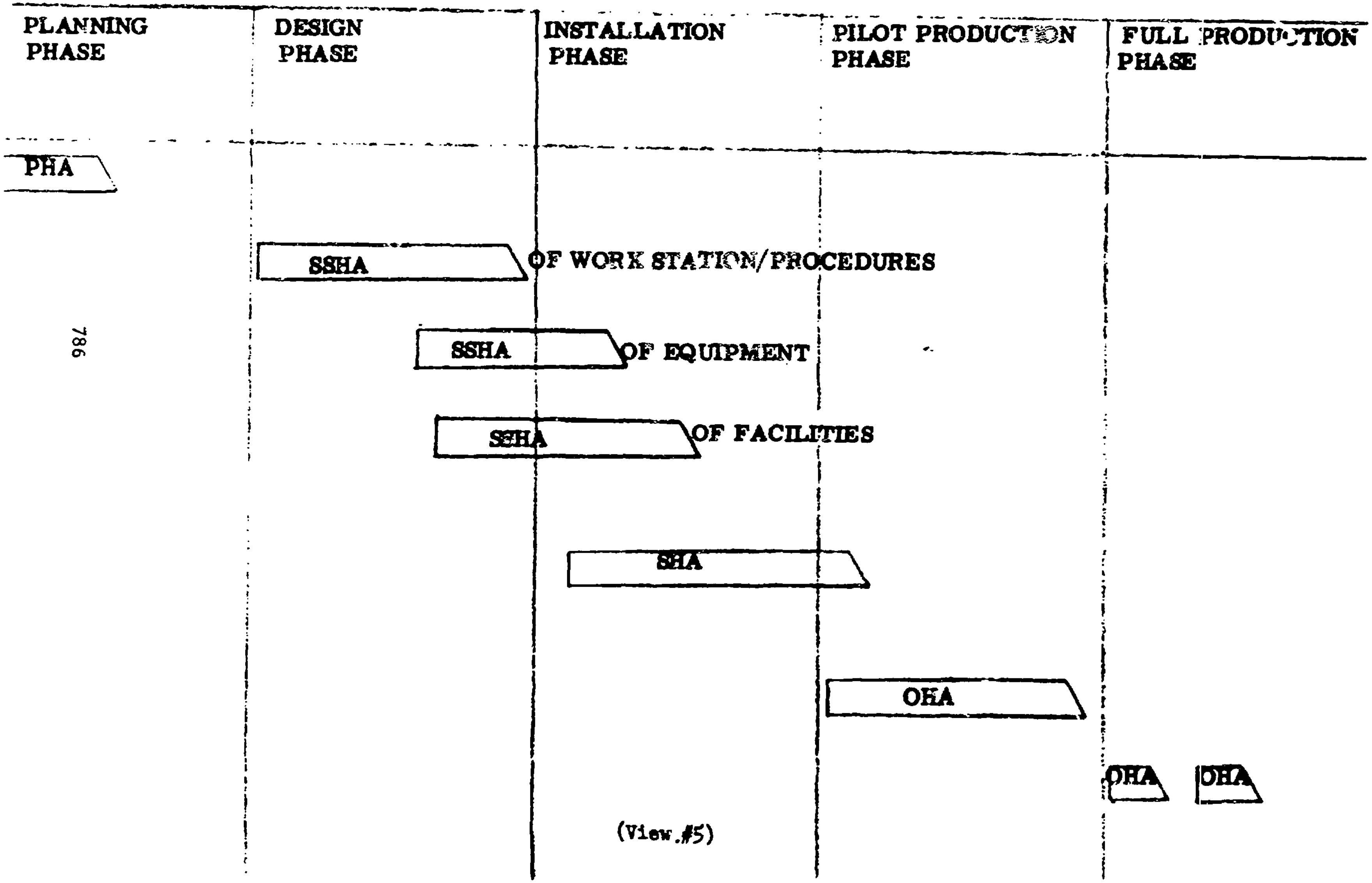
SYSTEM: CONTINUOUS TNT PLANT

SUBSYSTEM: NITRATION

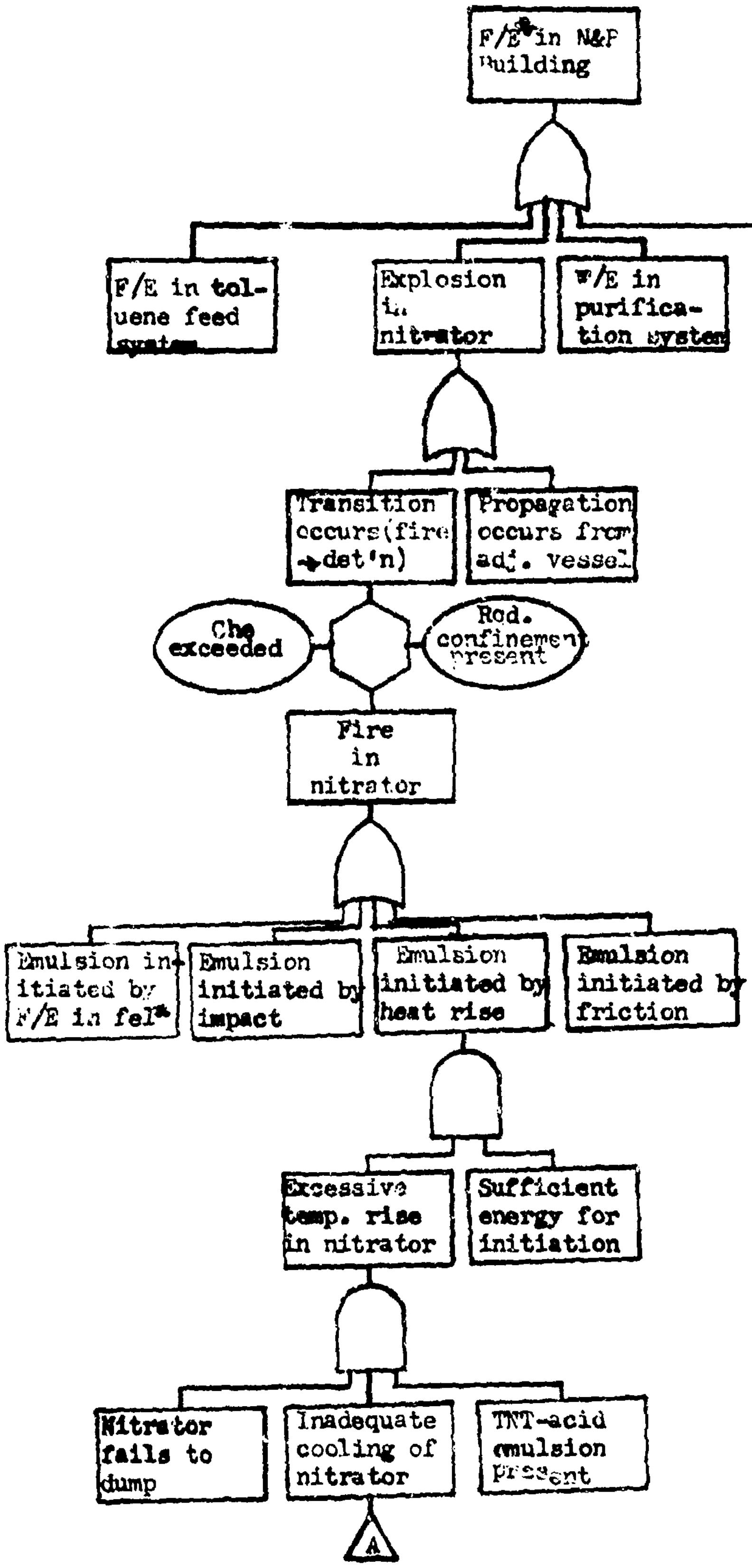
HAZARD/UNDESIRED EVENT	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE/ PREVENTIVE MEASURES
FIRE OR EXPLOSION	INITIATION OF REACTION MIXTURE	SEVERE INJURY/ DEATH TO PERSONNEL--LOSS OF BLDG.	IV	FURTHER ANALYSIS/TESTS TO DETERMINE SOURCES/MODES OF INITIATION
EXPOSURE OF PERSONNEL TO CORROSIVE MATERIALS	RUPTURE OF ACID LINES	SEVERE INJURY TO PERSONNEL--DEATH MAY RESULT IF LEFT UNATTENDED--MAY LOSE CONTROL OF PROCESS	IV	CONSIDER SHIELDING OF LINES CHECK LINES PERIODICALLY FOR SIGNS OF DETERIORATION MAINTAIN CLOSE SUPERVISION-USE BUDDY SYSTEM

(View #4)

HAZARD ANALYSIS SEQUENCE IN THE PRODUCTION LINE LIFE CYCLE

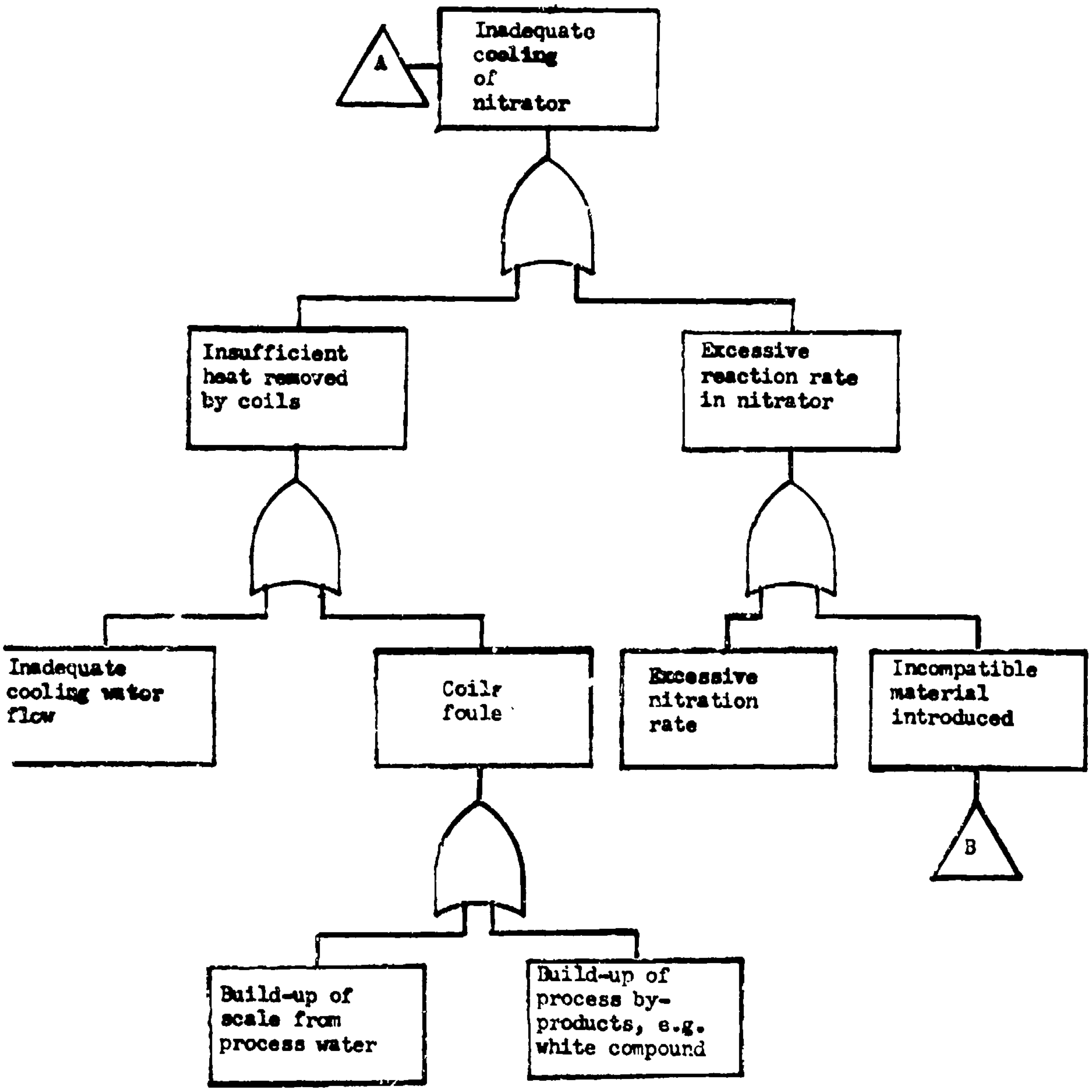


(View.#5)

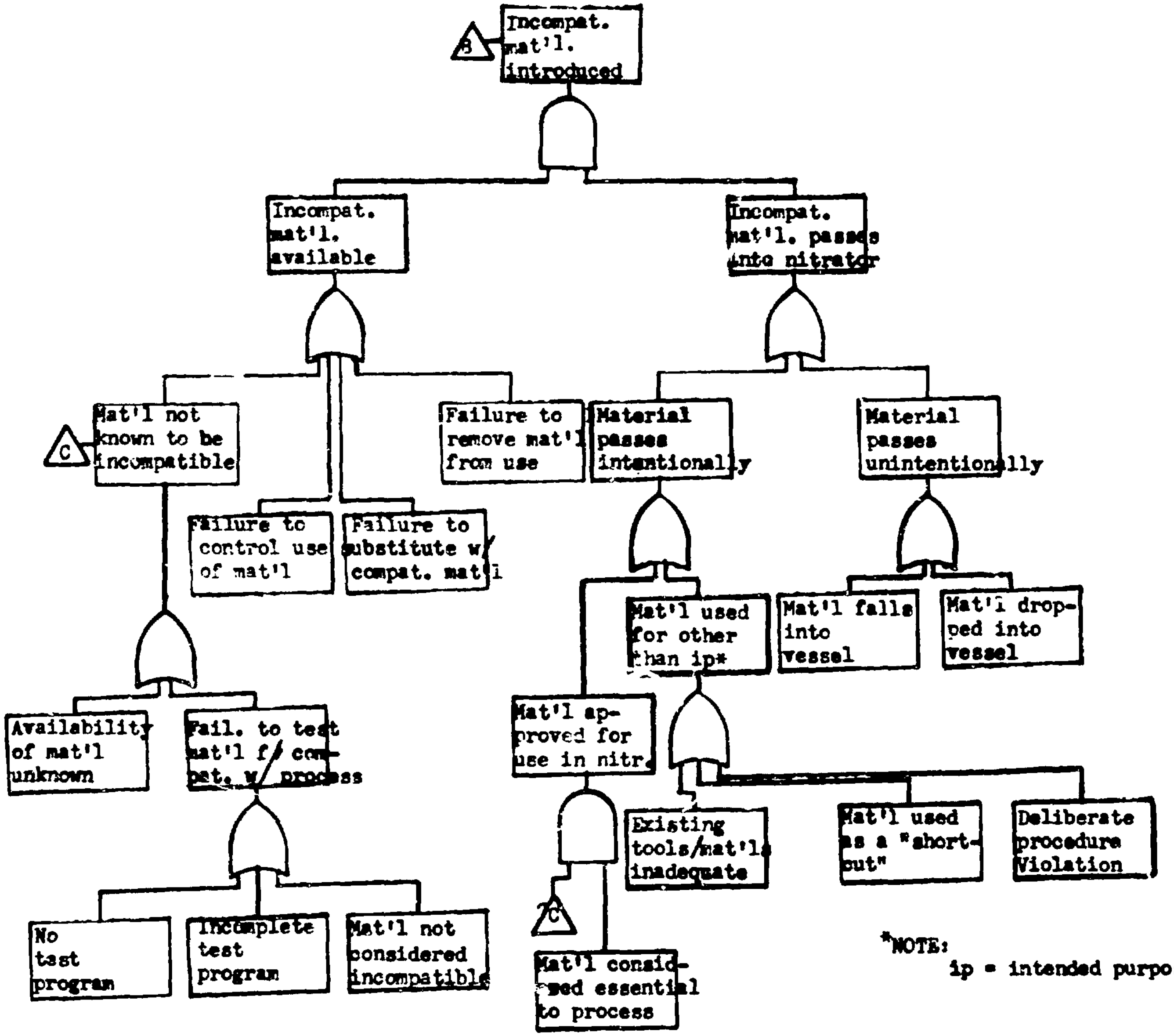


*NOTE:
F/E = fire or explosion
fel = fume exhaust line

(View #6)


A
Inadequate cooling of nitrator
Insufficient heat removed by coils
Excessive reaction rate in nitrator
Inadequate cooling water flow
Coils fouled
Excessive nitration rate
Incompatible material introduced
B
Build-up of scale from process water
Build-up of process by-products, e.g. white compound

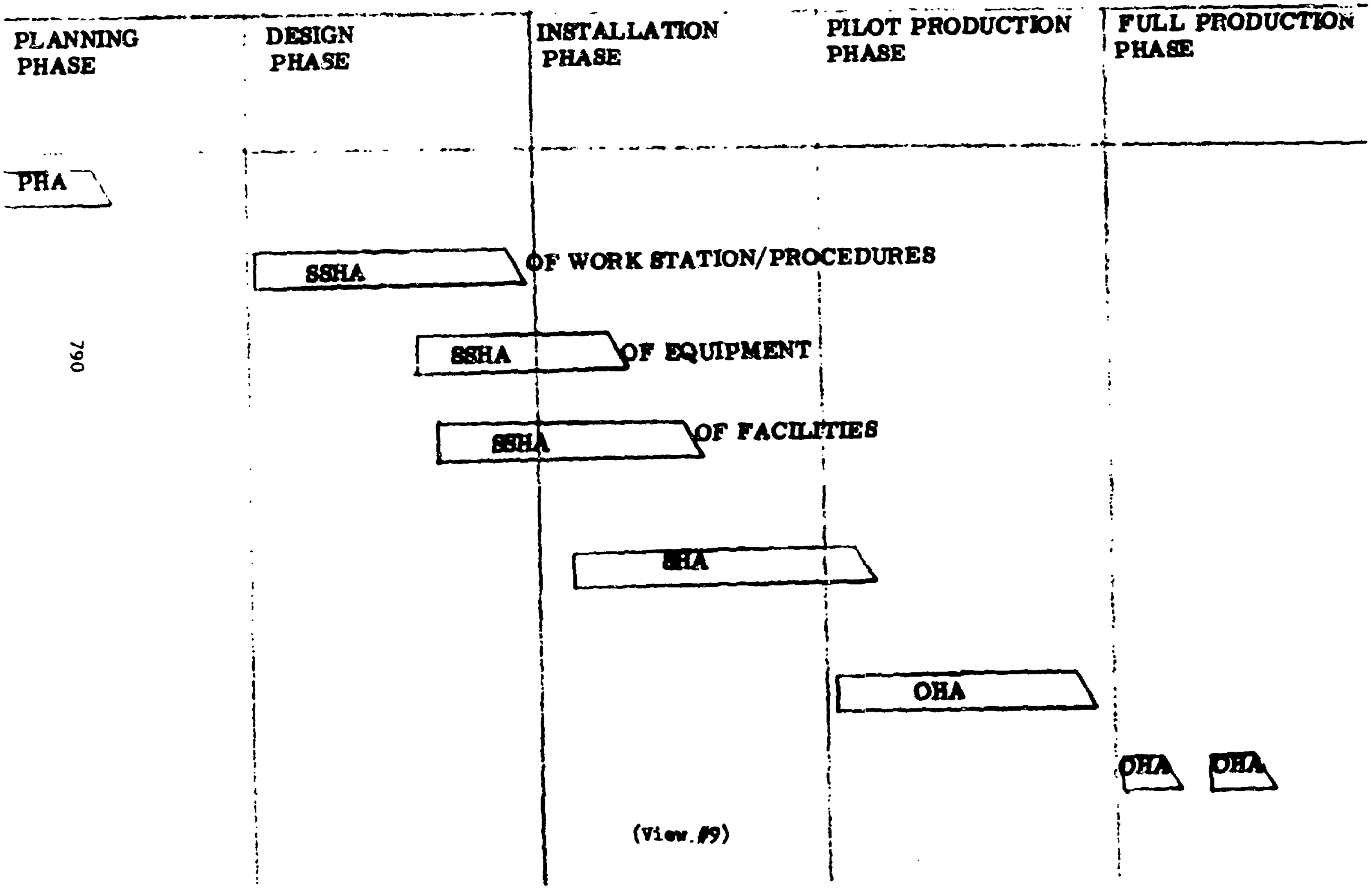
(View #7)



*NOTE:
ip = intended purpose

(View #8)

HAZARD ANALYSIS SEQUENCE IN THE PRODUCTION LINE LIFE CYCLE



(View #9)

TYPICAL OPERATING HAZARD ANALYSIS FORMAT

TASK NO..	TASK DESCRIPTION	HAZARDOUS ELEMENT(S)	POTENTIAL ACCIDENT(S)	EFFECT(S)	HAZARD LEVEL	SAFETY REQUIREMENTS
A NUMBER ASSIGNED TO EACH TASK FOR IDENTIFICATION PURPOSES	A BRIEF DESCRIPTION OF THE WORK TO BE ANALYZED	IDENTIFICATION OF THE ELEMENTS, RELATIVE TO THE TASK BEING ANALYZED, WHICH ARE CONSIDERED HAZARDOUS	IDENTIFICATION OF ACCIDENTS WHICH COULD RESULT FROM THE HAZARDOUS ELEMENTS	POSSIBLE EFFECTS OF THE POTENTIAL ACCIDENT	HAZARD CATEGORY AS DEFINED FOR SYSTEM	PROVISIONS NECESSARY TO ELIMINATE OR REDUCE HAZARDS

(View /10)