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MINUTES
OF THE TWENTY-FIFTH
EXPLOSIVES SAFETY SEMINAR

VOLUME III

Explosives Safety Board
Department of Defense

Anaheim Hilton Hotel
Anaheim, California
18-20 August 1992

Sponsored By
Department of Defense Explosives Safety Board
Alexandria, Virginia

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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.

DAVID K. WALLACE
Captain, USN
Chairman

TWENTY-FIFTH DDESB EXPLOSIVES SAFETY SEMINAR

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RARITAN ARSENAL
UNEXPLODED ORDNANCE REMOVAL PROJECT
EDISON, NEW JERSEY

by Robert Nore

The U.S. Army Corps of Engineers, Huntsville Division (CEHND), is the Mandatory Center of Expertise (MCX) and Design Center for ordnance and explosive waste (OEW) contamination at formerly used defense sites under the Defense Environmental Restoration Program (DERP-FUDS). The former Raritan Arsenal is one of more than 1100 sites on the FUDS inventory which are potentially contaminated with unexploded ordnance. Huntsville Division began an Interim Removal Action at Raritan in April 1991. This paper is a discussion of the site history, community relations, coordination, environmental constraints, contracting, current status, and lessons learned during the study, design and execution phases of the project.

SITE HISTORY

The site consists of 3200 acres located on the banks of the Raritan River in Edison, NJ, approximately 20 miles southwest of Manhattan, NY. Raritan Arsenal was established in 1917 as a storage depot for shipments overseas. Because of its strategic location it was established as a permanent ordnance depot shortly after World War I. Depot operations at that time consisted mainly of vehicle storage and ammunition receiving, storage, shipping, transfer, and re-packing. Types of ordnance handled included 37 mm and 40 mm projectiles, fuzes, pyrotechnics, grenades, training rounds, and TNT. French and British ordnance is also known to have been stored there. From 1919 until 1941, the Ordnance Specialist School was located there. Several accidental explosions occurred during the period from 1919 through World War II in magazine buildings and outdoor storage areas, scattering OEW over large areas.

During World War II, storage facilities, shipping facilities and ammunition igloos were greatly expanded. A products division and field service ammunition school were also added to the Arsenal mission. In 1951 the Provisional Unit Training Center was added to train, supply and activate Explosive Ordnance Disposal units. This center was deactivated in 1952, however.

Many of the arsenal's activities were phased out in the decade of the 1950's. Some waste materials including ordnance and chemical agents were routinely destroyed by burial or by burning in chambers or pits. In 1962 the government declared the site excess to the Army's needs. Final phase-out began in 1962 and lasted until 1964, when Raritan Arsenal was turned over to General Services Administration (GSA) for disposal. Decontamination of the site was performed in 1963 by Raritan Arsenal personnel, and later by Letterkenny Army Depot and the Army Materiel Command Safety Office. An archives search conducted by LEAD in 1963 designated 17 areas as potentially

contaminated and recommended restrictions on future land use. The property when sold by GSA contained the recommended restrictions.

The site is now the home of Middlesex County College, Thomas Edison County Park, Environmental Protection Agency offices, and Raritan Center, New Jersey's largest industrial park. The northern half of the site has been developed extensively. The southern half is primarily wetlands, with limited development since the arsenal closed.

INTERIM REMOVAL ACTION

In 1985, the former Raritan Arsenal was one of the first sites to receive a preliminary assessment under DERP-FUDS. When the potential for ordnance was found, the site was programmed for a large-scale site investigation. The scope of work was developed at CEHND, coordinated with USEPA and New Jersey Department of Environmental Protection (NJDEP), and tasked to U.S. Army Engineer District, Kansas City (CEMRK). In 1987 the site investigation was begun with the intent of confirming or denying both hazardous and toxic waste and ordnance contamination. The study included installation of groundwater monitoring wells, groundwater sampling, soil sampling, and surface and subsurface surveys for ordnance. The final report released in 1990 confirmed the presence of ordnance and chemical contamination of soil and groundwater.

As the MCX and Design Center for OEW cleanups, CEHND determined that the best initial approach to remedial action was to schedule an interim removal action to remove the imminent hazards, and a feasibility study to determine the appropriate approach to the long-term cleanup of the lesser hazards. In 1990 these two projects were added to the DERP-FUDS Workplan for FY91. CEHND and CEMRK held a joint public meeting in August 1990 to discuss CEHND plans for ordnance actions and the CEMRK scheduled Remedial Investigation/Feasibility Study (RI/FS) for hazardous and toxic waste.

Funds were received in February 1991 and three delivery orders were immediately issued to IT Corporation for ordnance removal actions at Area 16, Area 4, and Areas 1, 2, and 3 (see Figure 1), at a total estimated cost of $320,000. During preparation of the contractor's work plans, discussions were held with NJDEP in April 1991 on the issue of permits. We were successful in convincing NJDEP that the on-site removal actions we were conducting are specifically exempted from the environmental permitting process. We also had extensive negotiations with the property owners during April and into May in order to gain rights of entry (ROE). In early May we issued a fourth delivery order for $120,000 to clear Areas 6 through 10, 17, and a spoil area across the Raritan River, and to perform on-site demolition of all ordnance found. We also included a requirement to check out an eyewitness account of buried ammunition at Building 118 on Middlesex County Campus.

On 7 May 1991, we held a public meeting to inform the public of our clearance plans. We began the next day with a clearance at Area 1 (owned by USEPA), since we did not have an executed ROE document for the Raritan Center property. This site, consisting of nearly 1/2 acre, was used as a former demolition ground from World War I to the early 1930s. The clearance of Area 1 was completed that same day, and revealed no evidence of OEW. We began on 10 May 1991 the clearance at the site for Building 643, a former ammunition magazine in Area 16, expecting to find maybe 3,000 unfired, fused 37 mm projectiles. Our clearance operation consisted of excavation of a 150-foot square area with a trackhoe, screening out of ordnance on a mechanical shaker, and storing the ordnance in lockboxes until they could be destroyed. The effort was far greater than previously estimated, due to several factors. First, we expected to find only several thousand 37 mm projectiles, and ended up with over 29,000 rounds. At one point excavation reached 15 feet in depth. This large find required that we field an additional work team to perform full-time demolition, and develop a much larger storage capacity. After a vandalism incident near our worksite, we were required by Edison Township to ensure that the site was guarded at all times. We also found another 1100 37 mm projectiles at an adjacent site (Building 644).

Although Areas 2 and 3 were cleared of brush in May, we delayed an ordnance sweep so that we could concentrate our efforts on Area 16 and on Middlesex College Campus (MCC). Our investigation of the eye-witness account had led in early June to the discovery of a number of booster adapters near Building 118, a former hospital, and now known as North Hall. This discovery came at a very unfortunate time, since the MCC had scheduled a huge festival for the last two weeks of June. Additional funds were requested and received from HQUSACE, since by now we had made the news headlines and incurred the intense interest of U.S. Congressman Bernard Dwyer. We fenced off the building site and began a clearance effort over a two-acre area that we hoped would last only two weeks. However, we located a burial trench about 40 feet wide by 200 feet long by 5 feet deep, loaded with booster adapters, and did not complete clearance at this site until nearly a year later, on 14 April 1992.

The operation at Building 118 consisted of using a backhoe to expose the trench, and then removing the adapters with hand tools. Since the adapters could contain about four ounces of a TNT/Tetryl mixture and had been buried at least 72 years, extreme care was necessary. MCC campus police and a private security servied were hired to escort ordnance from the campus and to provide around the clock security. Ordnance was hauled by pickup truck through the campus and park during the least active hours of the day, to be stored in the lockboxes at Area 16. Unusual problems were encountered and overcome at this site. Tree roots for several old elm trees had grown around individual adapters. The trees had to be cut down, and the roots were taken to the demolition area for destruction. Adapters had been used for aggregrate for a concrete duct bank. The concrete was broken up and hauled to the demolition area for destruction. We discovered an abandoned underground storage tank which had to be disposed of in accordance with NJDEP requirements. We had to move another underground fuel tank being used by MCC, and are still involved in negotiations over whether we should be required to pay for replacement or upgrade of their tank to meet NJDEP requirements. A driveway had to be destroyed to gain access to the adapters buried underneath, and then replaced. None of these costs had been programmed, and each new problem required new modifications and new money from HQUSACE. We removed a total of 84,000 booster adapters from the Building 118 excavation.

Area 4 is a two-acre area which was formerly a salvage and melt-out area for demilitarization of ammunition ranging from 75mm to 12-inch projectiles. The USEPA, alarmed by the findings of the 1990 Site Investigation, had constructed a chain-link fence around Areas 4 and 5 in 1990. Action at Area 4 was delayed until September 25, 1991, until our actions were nearly complete at Area 16. After performing a surface clearance and brush clearance, a decontamination station was set up to treat all men and equipment leaving the area. Grid search lanes were set up and a subsurface clearance commenced. The contractor began a systematic excavation and screening operation in order to separate bulk TNT as small as 1/2-inch from the soil. Equipment consisted of a trackhoe, front-end loader, conveyor belt and mechanical sifter. This activity lasted until 20 March 1992 and resulted in the recovery and destruction of over six tons of bulk TNT, a 20-lb British bomb (inert), 21 75-mm projectiles, and a dozen other miscellaneous ordnance items. Excavation was to a depth of six feet in places.

Area 10, now known as Thomas Edison County Park, was once used for ammunition storage and depriming of cartridge cases. We concentrated on a 10-acre area where a magazine explosion had scattered French rifle grenades. Although we know the site was swept for ordnance before the property was sold, it became a high priority for clearance due to the public's perception of a hazard. Clearance began in October 1991 and is 50 percent complete. Clearance in this area was seriously hampered by wide-spread occurrence of magnetic rock. Approximately 35 French rifle grenades have been found, anywhere from ground level to two feet below ground. Security was provided by Edison Park Police until a chain link fence was erected around the most active area.

Area 17 , a two-acre area once used for property disposal and salvage storage, is located on MCC campus. Our investigation consisted of a subsurface sweep with ordnance locators, mapping of all contacts, and excavating in selected areas based on concentrations of ring-offs. No ordnance was found.

On-site demolition was conducted at Area 12, which is remote from populated areas and had been used in the past as a bomb disposal training area. At the start of our clearance we had the support of the 54th Explosive Ordnance Disposal (EOD) Unit from Fort Monmouth, New Jersey in conducting demolition operations. Initial blasting was conducted by placing the ordnance in one-foot deep trenches, and with no overburden. Noise proved to be such a nuisance to people living across the Raritan River that we asked the 54th to postpone "production blasting" and instead conduct test blasting. We called in a team from Corps of Engineers Waterways Experiment Station in mid-June to measure seismic and noise impacts of our demolition operation. They determined that overpressure and seismic effects were not significant, but that noise levels were in the "nuisance" range. We asked 54th EOD to cover their shots with two feet of sand. The tests showed good noise reduction, so we went back to "production".

The 54th EOD Detachment had been conducting the demolition to the extent that their mission priorities allowed. However, the amount of ordnance recovered from Area 16 in May and June was much greater than anticipated. A large backlog of 37 mm projectiles had accumulated (23,000 by the end of June). When we found that the 54th could conduct demolition for only two days in July because of mission training, we decided on 1 July 1991 to turn demolition duties over to the contractor. After experimenting with different configurations and different explosives, the contractor settled down to a destruction rate of about 2000 projectiles or booster adapters per day.

The Edison Volunteer Fire Department had been asked by the 54th EOD to have an engine standing by in case of fires or need of medical assistance. As the demolition operation expanded, EFD decided that they could no longer afford to finance such volunteer support. Although we argued that we could provide equivalent safety measures under our own power, EFD insisted that they must be involved, and we must pay them. We authorized our contractor to pay them for an engine and three firemen to support the demolition effort. We were also required to have a member of the Edison Police Department's Emergency Management office on hand for all shots.

Our interim removal actions so far have addressed only a few of the suspect areas, and much remains to be done. The dredge spoil area across the river is known to contain French rifle grenades. CEMRK has discovered hard evidence of ordnance while drilling monitoring wells in Area 11 and Area 3. Sampling has yet to be accomplished in several other areas.

FEASIBILITY STUDIES

It was always our intent to conduct a feasibility study for the entire former arsenal, but the unexpected growth of the clearance forced us to use the FY91 study funds for clearance efforts. Funds for study were again programmed for FY92, and were again side-tracked to studies for Area 5, a former mustard agent disposal area. We have been engaged for the last two years in efforts to establish chemical agent disposal procedures to support the DERP-FUDS program. Area 5 at Raritan is the pilot project for the new program, which has resulted in the formation of a new agency, U.S. Army Chemical Munitions Destruction Agency (USACMDA). We will start in September a characterization of Area 5 as the beginning of a full scale Remedial Investigation/ Feasibility Study (RI/FS). This initial characterization is limited to non-intrusive studies only, until USACMDA solves the problem of finding acceptable disposal methods for any chemical warfare material that we might find.

At Congressman Dwyer's insistence, we found emergency funds and awarded a contract for an archives search to Metcalf & Eddy on 8 July. We received a final report for the MCC and park on 30 August and for the remainder of the arsenal on 30 September. This effort involved in-depth study of archives and interviews of former employees to determine any other possible ordnance burial areas. Two new small areas were located on MCC campus that may be worth further investigation.

Current studies at sites other than Area 5 consist of an in-house Engineering Evaluation/Cost Analysis (EECA) for a limited number of ordnance areas to determine the most economical approach to remediation. This EECA is in reality a miniature RI/FS, and will be expanded next year to cover all ordnance areas. In this study, we use our cleanup contractor to sweep the test areas with a magnetometer and map the underground contacts. We use that data to decide whether a clearance is even necessary, and if so, how best to accomplish the cleanup.

GOVERNMENT COORDINATION

Coordination among government agencies is highly complicated, and is spelled out in the Project Management Plan developed by U.S. Army Engineer District, New York (CENAN). Their parent division, the North Atlantic Division, assigned them overall project management responsibilities, in order to ensure that the COE effort is coordinated and that the public perceives the COE as one entity.

CEHND's relationship with CENAN is spelled out in a Memorandum of Understanding signed 13 December 1992, which gives CEHND management responsibilities for planning, design and execution of ordnance studies and removals. CENAN is responsible for public affairs, right of entry, and providing a Contracting Officer's Representative (COR) to oversee the sitework. CEHND is responsible for providing quality assurance for the ordnance cleanup, resolving permit issues, and funding for the ordnance projects.

CEMRK is responsible for conducting the RI/FS for hazardous and toxic waste at Raritan. Since this effort involves drilling of monitoring wells and taking soil samples in potential ordnance contamination areas, we review their work plans to ensure ordnance safety. Some of the areas at Raritan are a combination of ordnance and hazardous waste, so we must coordinate with CEMRK in determining how best to remove the ordnance hazard so that Kansas City can efficiently conduct their actions. We must also jointly plan public meetings and participate in Technical Review Committee meetings.

U.S. Army Engineer District, Omaha is responsible for management of preplaced quick response actions at hazardous waste sites. They must coordinate with CEHND to ensure ordnance safety for their activities. We provided ordnance support for a recent Omaha cleanup at a pond on the USEPA property at Raritan.

USACMDA was formed earlier this year to head the programmatic efforts involved in cleanups of Chemical Warfare Material (CWM) sites. They must develop technologies for monitoring, on-site treatment, transportation and storage of CWM at Raritan and many other suspect CWM sites. We will be responsible for uncovering the CWM and treating in place if necessary. There are many areas where our efforts will interface with those of USACMDA.

USEPA is interested in our efforts for several reasons. They own a portion of the property and have been involved for many years in guiding the hazardous waste investigations. They are under severe criticism for not getting the former arsenal on the National Priority List, and are sensitive to any kind of publicity. We invite USEPA and NJDEP to review and comment on our work plans, although we make it clear that DOD is the response authority for ordnance actions.

COMMUNITY RELATIONS

Since Spring of 1990 the media, local citizens, special interest groups, local officials, and U.S Congressmen have been keenly interested in COE actions at Raritan. This attention springs from a variety of issues, among them a proposal by the owners of Raritan Center for a $1 billion waterfront development. The proposed Rivertown project would include housing, office, retail and warehouse space, and received approval in 1988 from the Edison Planning Board. Opposition is rooted in the certain destruction of a large wetlands area. Another issue affecting public interest is USEPA's proposed use of' their property on the former arsenal as a laboratory to test new methods for cleaning up hazardous waste. USEPA had also considered siting a hazardous waste incinerator on their property, but abandoned the proposal after receiving very heated opposition from the public and media. Finally, local citizens are concerned about the potential health and safety effects posed by the hazardous waste and ordnance at the site.

When the COE began our studies, the media began to interview personnel from Kansas City and Huntsville Division, since at that time New York District personnel were not knowledgeable on the subjects of OEW or HTW. The press played COE personnel against each other, accused us of foot dragging, and damaged COE credibility. After that, we insisted that each COE organization speak only about its particular mission, and the credibility problem was resolved. Our approach to the cleanup was perceived by the public as fragmented, although in fact it was properly coordinated. When the first public meeting was held in August 1990, the special interest groups and politicians began to make their presence known. By the second public meeting in May 1991, the public reaction to the COE was much calmer. Congressional reaction to the media blitz, however, forced North Atlantic Division to assign control of all COE activities at Raritan to New York District. This action was to ensure that the COE response to inquiries was consistent and coordinated.

Other actions taken since then include the institution of weekly and sometimes daily press releases to all the local media and officials, and establishment of a Technical Review Committee. The TRC consists of twenty members representing the involved COE offices, USEPA, NJDEP, owners of the former arsenal, local interest groups and Congressman Dwyer's chief aide. The TRC is very effective as a means of getting accurate information to the community and discussing problems as they arise.

LESSONS LEARNED

Many elements came together over the first year of activity at the former arsenal to put a great strain on our contracting ability. Frequent contract changes were necessary because of new discoveries in the field, new requirements for site security or fire support, and many other problems that were never foreseen. As the project expanded in scope and took on a more permanent nature, it also became necessary to provide more sophisticated field offices both for COE and contractor personnel.

We chose a Time and Materials delivery order contract with a $5 million capacity and a one-year ordering limit. This type of contract lends itself very well to actions where the actual effort cannot be estimated with any degree of confidence. The prime contractor was IT Corporation and the subcontractor for ordnance was EOD Technology, Inc. This combination of a prime with good management experience and a subcontractor with a good track record in ordnance removal projects appeared to be ideal for our purposes.

Although we developed good working relationships with the IT program and project managers, COE and contractor perspectives sometimes led to confusion or misunderstandings.

Our orders for work were often based on funds available, and although we were only ordering a term of work, our objective was to complete an action during that term. The contractor after receiving an order would immediately prepare a request for modification that was their estimate of funds needed to complete the action based on their own estimates of unknown conditions. This request was sometimes a waste of time, since funds would not be available to complete the action.

The contractor initially assigned a project manager from their area office, which by coincidence is located at Raritan Center. This manager had experience in managing smaller projects, and that was fine from the COE perspective, since we initially anticipated spending less than $500,000 over a three-month period. As the complexity grew, the reporting requirements grew, and it became obvious by October that a more sophisticated management team was needed. In December the contractor answered the COE request for a more experienced project manager. They also began new accounting procedures for tracking costs, since by December spending had reached nearly $30,000 per day.

The contractor, with vast experience in hazardous waste remediation, was inclined to follow the lead of the regulatory agencies in preparing the design for a project. We found that we had to take a strong lead with the contractor and with NJDEP simply because our "no permits" policy was foreign to them. We had to prove to NJDEP that Department of Defense is the response authority for ordnance remediation, that ordnance is not hazardous waste, and that we are not required to obtain environmental permits for our action at Raritan. This issue held up completion of our work plans for approximately one month. We were successful in convincing NJDEP that our policy was correct, but have found that we are faced with the general problem of educating the regulatory community each time we begin a project.

After fieldwork commenced, we assigned COR authority to a person from CENAN. This COR was also responsible to New York District for overall coordination of the hazardous waste and ordnance cleanups, and for carrying out any separate agendas that the District might have. Our contractor was sometimes caught between their need to satisfy our contractual requirements and New York District's separate agenda. We felt the need at times to reinforce to the Contractor and the COR their appropriate contract responsibilities.

Another problem we faced was the "deep pockets" syndrome. As stated before, we are still involved in negotiations with the owner of MCC regarding liability for replacement of an underground storage tank. The MCC used this tank for many years and should under DERP-FUDS policy be responsible for upkeep and eventual replacement. However, since the U.S. Government has plenty of money it is expected by many people to cover the costs.

CONCLUSION

Although we have been working at Raritan for well over a year and spent over $5 million on removal of ordnance, our job appears to be only about 20 percent complete. For FY93 we have programmed $3.4 million for cleanup costs and $1.6 million for site characterizations.

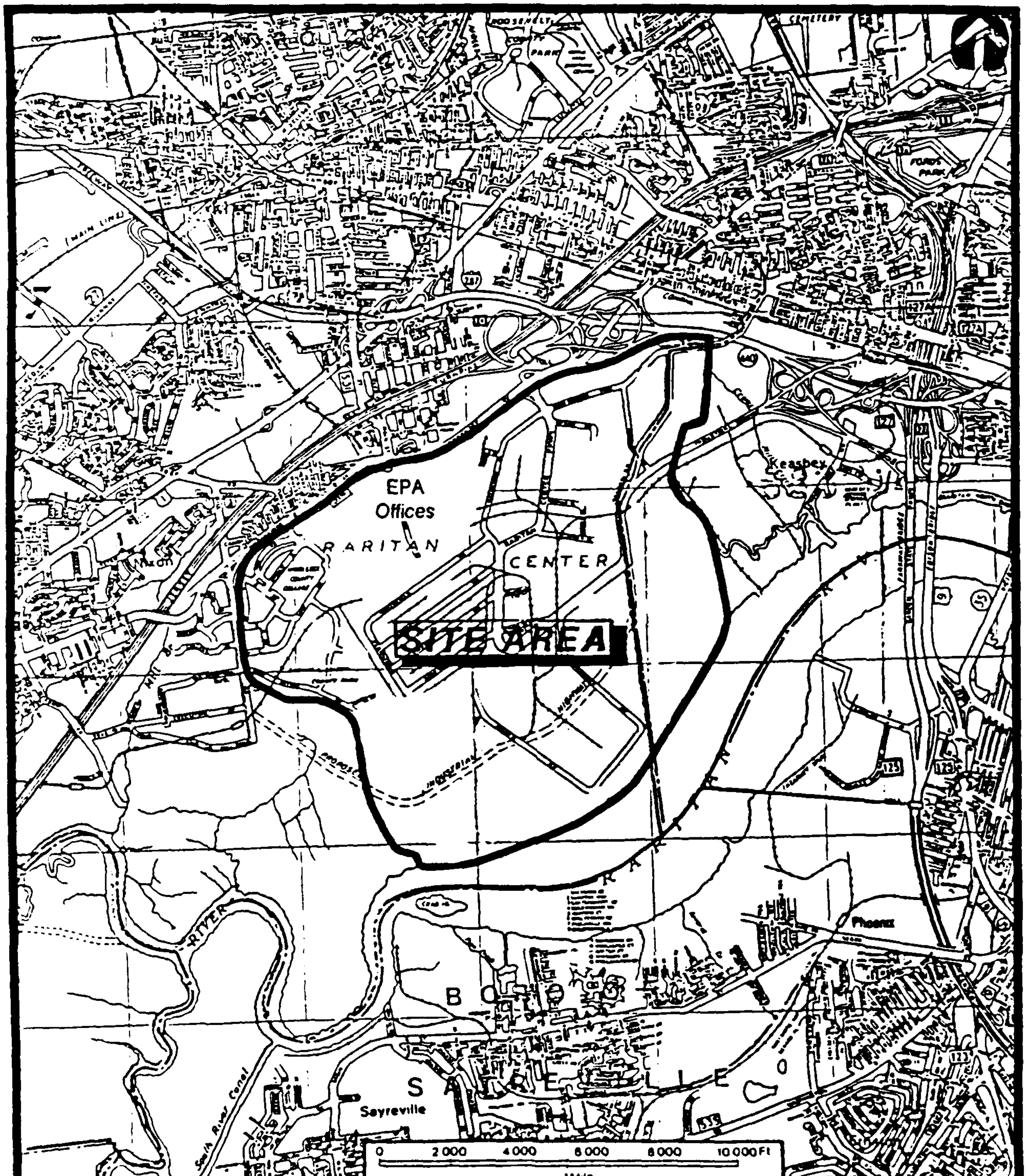
Through the characterizations we can provide a sound engineering evaluation and cost analysis (EECA) which will justify any further action (or inaction) that we take at each area. Up till now our priorities for cleanup of the individual areas have been based first on risk and next on public perception of risk. Through the EECA process we will involve the public in the decision-making process, which may involve their acceptance of some risk in order to keep costs down.

We have been asked at the public meetings if we will provide certification that the former arsenal is 100 percent cleared. Our reply has consistently been that we can never guarantee 100 percent clearance, but we will promise to clear all ordnance detectable using best available technology.

The ordnance removal at Raritan is the first such action attempted by the COE at this type of site. It has proven to be a site rich in surprises and learning experiences. We have discovered much more ordnance than we ever expected, and as a result our expectations of finding more ordnance have increased greatly. Our actions at Raritan will set a precedent for cleanups at former ordnance plants and arsenals throughout the United States. We must therefore take special care to conduct this cleanup in a sound professional manner.

U.S. Army Corps of Engineers
Former Raritan Arsenal

Site Location Map



Source: Taken from Hagstrom Map:
Middlesex County, New Jersey, 1990

FIGURE 1

TWENTY-FIFTH DOD EXPLOSIVES SAFETY SEMINAR
ANAHEIM HILTON HOTEL, ANAHEIM, CA
18-20 AUGUST 1992.

The Decontamination of the Royal Naval Armament Depot, Milford Haven.

By L H Armstrong.

Abstract:

This paper describes the decontamination of the old mine filling factory at the Royal Naval Armament Depot at Milford Haven in Wales. The principal challenge was the safe destruction of massive reinforced concrete structures, up to five feet thick, which unitised the mines during filling and cooling, and which were lightly contaminated with TNT. The methods used are described and illustrated; the end result of this work was the demolition of the factory, resulting in a grass-covered valley with contours similar to those which existed in 1936 before the factory was built.

DECONTAMINATION OF THE ROYAL NAVAL ARMAMENT DEPOT, MILFORD HAVEN

L H Armstrong, BSc, C Eng, MIChem.E, MIExp.E
Registered Safety Professional (I.Chem.E.)

The Site and the Process

RNAD, Milford Haven filled mines during World War II. The first charge case filling was done in September, 1940 and by mid-1941 the filling rate had increased to over one million pounds of explosive per week. The filling ceased at the end of the war and the plant was not used for its designed purpose thereafter.

TNT was imported, weighed out and melted in pans heated by low-pressure steam jackets. Crystalline ammonium nitrate was crushed, dried and stirred into the molten TNT to make Amatol. Up to 80% of ammonium nitrate can be used, although pouring becomes more difficult as the proportion of ammonium nitrate is increased.

Each empty mine case was received from the case preparation area and placed under the outlet of a mixer to be filled. It was then moved to a primary cooling bay. When cool enough, it was moved to the topping room, for the filling to be covered with a layer of molten TNT to waterproof it and the charge case was transferred to a final cooling bay.

The filling areas and the cooling bays were all partitioned off into cubicles, each large enough to accept one mine. The partition walls were of various thicknesses of heavily reinforced concrete, from three-foot thick for most of the partitions to five foot thick for the main spine walls. The purpose of these walls was to "unitise" any accidental explosion; it was intended that the explosion of one mine should not be able to set off any of its neighbours. The safe demolition of these structures was the principal challenge of this work.

Spills of the molten explosive had not been rare, particularly under the strain of early wartime production conditions. The author was lucky enough to have graphic descriptions of these given to him by a retired supervisor who had worked in the plant in 1940. Not only did small spills or splashes happen because of carelessness in pouring, but from time to time the diaphragm on the valve which controlled the outflow from the melter or the mixer would fail, and the entire contents of the vessel would then flow onto the floor. This is unwelcome, but not too serious if only TNT is involved. The spilt explosive can be scraped up when it is cold, melted, filtered and recovered for reuse (once the inspectorate were satisfied of its purity). A spill of Amatol or Minol contains hot ammonium nitrate and this chemical will find its way through any available crack in the gritless asphalt floor covering. The ammonium nitrate will then attack the underlying concrete vigorously, eating away the cement.

The First Decontamination

The process plant had been removed in 1969, and much cleaning had then been done. Contaminated asphalt and plaster had been stripped from the factory floor and walls and dumped at sea, and some attempt to cleanse the walls by "flaming" had then been made. No complete record of the performance of this work could be found; all that was available was a report, describing the work that had been planned. These operations had stripped the asphalt and left the bare concrete walls and floor exposed, but chemical tests on the walls and floor with a mixture of acetone and caustic soda solution showed that traces of TNT were still present. The method of working had to allow for this finding.

After this work, the remains of the filling factory had been allowed to lie idle. Deterioration of the structure by the action of wind and weather continued, until real concern was felt about the safety of any person who had to enter the building or even to walk in the area. The upper floors of the building were slippery with deep deposits of bird-droppings, and hazardous because of unfenced holes where equipment had been removed.

The principal problem was to find a method of safely removing and disposing of the massively-reinforced concrete structures of the filling and cooling bays on the ground floor. But before this task could be attempted, it was necessary to make the rest of the building safe, to remove all the insecure material from the upper floors so that workers were not endangered during stormy weather. Dismantling without precautions was not permissible, because traces of explosive were found, despite the work done during the 1969 decontamination. Normally, explosive cutting techniques might have been considered for such a site, but the noise caused by detonation of charges large enough to destroy the concrete structures or to divide the unusually massive girders which supported the walkways would have been unacceptable. And then a further problem appeared.

Bats

The upper floor of the melting room was thickly coverd with bird-droppings. A member of an Ecological Protection Society visited the site, and identified some bat droppings amongst that mess, suggesting that the building had been used or was being used as a shelter or roost by the Greater Horseshoe Bat. Bats are a protected species in the UK, and recent legislation makes it an offence to disturb them or to interfere with their habitat. You can be fined up to £1,000 per bat affected! This discovery delayed the start of the work until it could be confirmed that bats no longer used the building. This observation was difficult to make, but the upper floor was cleard of all the deposits, and no more bat excreta were deposited.

Roof Removal

In the first part of the present work, many loose corrugated iron sheets needed to be removed from the roof area of the building. Hot TNT sublimes, and it was possible that some had condensed on these sheets, on the under-side of the roof. To gain safe access to all of the roof area to test for the presence of traces of TNT would have been most difficult, involving erection and movement of substantial structures of scaffolding, so a method of sheet removal which would not initiate any traces of TNT was required. The use of hammers and chisels was prohibited, and two methods of removing the sheets from the angle-iron frames were specified; either to treat the nuts with penetrating oil and to remove them from the hook bolts with well-fitting double-offset ring spanners, or to cut the shanks of the bolts with a pair of hand-operated double-toggle bolt-croppers.

The contractor then asked permission to use flame-cutters to speed up this work, a request that showed that he did not fully appreciate the risks to be expected from small quantities of explosive, nor did he understand the vital role of the chemical testing which assured freedom from explosive of the area tested, but only of that area. So a demonstration of the startling power of a small quantity of high explosive was arranged for all of his workforce. A single electric detonator, containing only one gram of explosive, was passed round for inspection, then put into a half-gallon paint tin and the lid closed. This assembly was then placed at the far end of the site behind a concrete wall and fired, shredding the tin, throwing the lid high into the air and producing a loud bang. This demonstration worked well; it was large enough to impress them, without causing sheer terror, and caused the contractors to take the laid-down safety precautions much more seriously.

All of the roof sheets were removed without incident, using spanners and bolt-croppers. TNT contamination was observed on some sheets, in the typical fine, hair-like crystals, resembling short, white teddy-bear fur. It was easily wiped off. It was then possible to climb over the steel roof framework in reasonable safety, though not without some difficulty, and test for the presence of any traces of TNT. At every place where cutting was needed to remove a frame, the metal was checked with caustic/acetone mixture, and if no sign of reaction were found, the area was marked with an aerosol spray can of paint. A colour reaction to the test required the frame to be washed and retested. When clear, the area was paint-marked. The contractor was then authorised to use an oxy-propane flame cutter to cut and remove each paint-marked frame, and drop it to the ground. After a further chemical check to give confidence that no trace of explosive remained, the scrap frames were marked to certify them free from explosive and loaded for removal by the contractor for sale as scrap metal. The overhead walkways and gantries were now accessible for testing, marking, and flame-cutting at the marked places.

Concrete Removal

It was difficult to be sure of the extent of explosive contamination of the concrete. No certificate of freedom from explosive (from the 1969 work) could be found. There had been the plan to "flame" the walls, that is, to pass a flame over them to destroy traces of explosive. It was not clear where or how thoroughly this had been done. This process cannot now be recommended; it does not destroy any explosive which is buried in the wall or in intimate thermal contact with the concrete. Heating of much longer duration is necessary. Nor is the process free from all risk to the operator. Tests with acetone/alkali mixture showed that traces of TNT still persisted, so the flaming had not been completely effective. But this test for the presence of TNT is very sensitive, and cannot distinguish between mere traces of TNT of no importance, and substantial amounts which could explode and cause injury or death to anyone demolishing the wall.

It was therefore necessary to find a method of disposing of the concrete safely; a tentative proposal to fill up the volume between all the concrete walls to produce a level surface, and so to "decontaminate" the site by burial of the walls without any further treatment was considered and rejected. It did not give enough confidence in the unconditional future safety of the site.

Overall, a small explosion during the concrete removal was thought to be unlikely, but not impossible. So remotely-controlled methods of removal would be preferred, and required investigation. But no method which merely cuts the walls would be acceptable; the problem of disposing of the large, cut lumps of concrete afterwards remains. Thus, diamond-tipped circular saws, abrasive-coated wire rope, or high-pressure water jets, with or without entrained grit, were not adopted. More orthodox concrete-breaking techniques were then considered. Pneumatic or hydraulic hammers are effective, and hydraulic hammers are to be preferred, because they are powerful and quieter in use. If such a hammer were to be fixed on the end of the arm of a mechanical digger, it can easily be manoeuvred into whatever position is desired for best attack on the structure. Concrete can be broken into whatever size is required. But would the explosive safety be acceptable? It seemed likely that the action of a steel chisel would be able to initiate any traces of explosive present.

The problem was discussed with colleagues, and it was agreed that if water could be reliably and continuously provided at the cutting edge, the chance of initiating an insensitive explosive like TNT would be very small indeed. The operator would be protected from any flying particles of concrete from the action of the chisel by his distance from the cutting edge, and by the laminated glass windows of his cab.

The water flowing away may contain traces of TNT, but if the concentration is low enough to avoid the formation of any pink colour, (caused by the traces of alkali naturally present in the water reacting with the TNT) it may be ignored as not harmful. No such colour was noted during the work; the large volumes of water used provided sufficient dilution.

One mechanical digger was originally brought on site, with a hydraulic hammer attached. The wetting of the concrete was done with a firehose, fed from the fire water main, fixed to a monitor bracket which allowed its position and angle to be closely controlled, and trial breaking of the reinforced concrete frame of the building was started. Initially, progress was very slow; the concrete frames and floors were massively reinforced and difficult to break. After a few days experience, the contractor thought that he could make better progress by using a cracker ball, swung from the jib of a crane, and a trial was authorised on an area of brick panel infilling a reinforced concrete frame. This was even less effective; within one day, the jib of the crane had been bent, no concrete and little brick had been removed, and the cracker ball was quietly discarded.

Better progress was made when larger machines, fitted with larger hydraulic hammers, were hired; at the peak of the demolition task, eight such concrete breakers were simultaneously in action. Once the breaking was well under way, the fire water supply was no longer used, for cost reasons and because of the need regularly to refill the feed reservoir, and submersible pumps were used to draw supplies of water from a natural stream running at the side of the site. The pump produces a smaller, but sufficient spray; the waste water drained back to the stream after use. Once the chisels had cut well into the mass of concrete, and chemical tests showed no trace of TNT to be present, dry breaking of the material was authorised in those parts of the building which had been tested.

Cutting of the substantial reinforcing bars (many of them were over an inch in diameter) was only barely possible with the hydraulic chisels, and cutting of the floor girders with them was quite impractical. So whenever the concrete had been thoroughly broken away, the exposed metal was tested to prove absence of explosive, marked with paint at the tested places, and flame-cutting was authorised at those lines.

Recovered steel scrap was inspected, every piece was chemically tested to prove absence of any trace of explosive, and then the scrap was exported from the site for sale. The concrete broken out from the structure of the building, together with any small bits of reinforcement which it still contained, was cleared to one end of the site with mechanical shovels. When all the building had been levelled, it had been intended to spread the rubble out evenly over the floor area, to restore the original contours of the valley to what they had been in 1936.

The Floor

Before this was done, inspection of the original building construction drawings showed that the concrete floor of the building (which was to be left undisturbed, under the rubble, once it had been tested and shown to be explosive-free) did not rest upon the natural ground, but was laid upon a series of brick arches. No infill of the arches was shown upon the drawings, and it seemed possible that cavities existed below the floor, into which explosive might possibly have penetrated. The ground rose up on either side, so that the ends of the arches could not be seen. So a series of holes was drilled in the floor, which showed that all the arches had been entirely filled with rubble or soil, and that no contamination existed below the floor. The broken concrete was then spread on the floor, covered with a layer of topsoil, and grass planted overall. The grass was first mown in autumn, 1990, and is now growing well; the valley contours have been restored substantially to their original shape.

**Department of Defense
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EXPLOSIVE ORDNANCE ENGINEERING

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ABSTRACT

Explosive ordnance engineering is the technical evaluation of risk to the public associated with ordnance contaminated sites, the formulation of risk reduction measures, trade off analysis to compare alternate risk reduction measures and recommendation of the best alternative with respect to engineering judgments and public input. The analysis and evaluations must be mindful all factors normally associated with a full public interest review including a complete range of environmental considerations. We are now engaged in a formalized decision making process were simple solutions require detailed analysis to assure the validity of face value assumptions. We can no longer rely on DOD's or the general public's intolerance for ordnance related risk. Acceptable solutions must appraise environmental consequences, cost and public acceptance, along with safety consideration.

Explosive ordnance engineering is interdisciplinary planning, study, design, and remedial action involving ordnance and explosive waste contamination in accordance with CERCLA and the National Contingency Plan (NCP). Programmatic planning and decision making require engineering and other professional disciplines. They are - site inspections, engineering reports (remedial investigations), feasibility studies, engineering evaluations, cost analysis, miscellaneous route surveys, and others.

The Explosive ordnance mission has two major objectives:

a. To reduce risk to the general public through CERCLA response actions for sites contaminated with ordnance and explosive waste (OEW).

b. To execute response actions for sites contaminated with explosive ordnance with minimum risk to Government personnel and contractors.

This paper provides a descriptive overview of the authorities we are operating under, a definition of ordnance and explosive waste, a description of the ordnance contamination problem, disposal options, and an assessment of the regulatory climate this program operates under.

1. AUTHORITIES.

a. In 1980, Congress enacted the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 USC 9601 et seq.

b. In 1983, the Environmental Restoration Defense Account (ERDA) was established by Public Law 98-212. This congressionally directed fund was to be used for environmental restoration at Department of Defense (DOD) active installations and formerly used properties. The DOD designated the Army as the sole manager for environmental restoration at closed installations and formerly used properties. The Secretary of the Army assigned this mission to the Corps of Engineers (USACE) in 1984.

c. In 1986 Congress decided that explosive ordnance is a form of contamination that should be remediated under the Comprehensive Environmental Restoration and Compensation Liability Act (CERCLA). Chapter 160 of the Superfund Amendments and Reauthorization Act Amended CERCLA and established the Defense Environmental Restoration Program (DERP). The program goals are:

(1) The identification, investigation, research and development, and cleanup of contamination from hazardous substances, pollutants, and contaminants.

(2) Correction of environmental damage (such as detection and disposal of unexploded ordnance) which creates an imminent and substantial endangerment to the public health or welfare or to the environment.

(3) Demolition and removal of unsafe buildings and structures, including buildings and structures of the Department of Defense, at sites formerly used by or under the jurisdiction of the Secretary.

These goals gave rise to the hazardous and toxic waste mission. The explosive ordnance engineering mission, and the unsafe debris mission being exacted by the Corps of Engineers.

d. The DERP requires that a CERCLA response action be undertaken whenever such contamination is found at:

(1) Facilities or sites owned by, leased too, or otherwise possessed by the United States and under the jurisdiction of the Secretary of Defense.

(2) Facilities or sites that were under the jurisdiction of the Secretary of Defense and owned by, leased to, or otherwise possessed by the United States at the time of actions leading to contamination.

(3) Vessels owned or operated by the Department of Defense.

e. The National Contingency Plan (NCP) was established by the Clean Water Act of 1972. The NCP has been revised and broadened several times since then. Its purpose is to provide the organizational structure and procedures for remedial actions taken in response to the presence of hazardous substances, pollutants, and contaminations at a site. Section 105 of the 1980 CERCLA states that the NCP shall apply to all response actions taken as a result of CERCLA requirements.

f. In March 1990, the NCP became the National Oil and Hazardous Substances Pollution Contingency Plan given in 40 CFR part 300. Paragraph 300.120 states that "DOD will be the removal response authority with respect to incidents involving DOD military weapons and munitions, or weapons munitions under the jurisdiction, custody, and control of DOD.

2. ORDNANCE PROBLEM.

a. The use of explosive ordnance by the military predates the Revolutionary War. It is possible for ordnance items to remain dangerous for many, many years. Hazardous pieces or ordnance are still found occasionally on Civil War battlegrounds. Advances in materials make it likely that some of today's weapons will be lethal for hundreds of years. In the United States, former battlegrounds are not the most common types of sites containing OEW. Firing ranges and testing areas, munition manufacturing areas, weapon and ammunition storage areas, munition disposal areas, and weapon transport staging areas are all likely to contain OEW contamination.

b. Prior to about 1970, land burial of unneeded ordnance was an accepted practice if sea burial or demilitarization was not practical. If a facility handled ordnance at some time in the past, there is a good possibility that there are some ordnance burial pits at the site. Manufacturing processes were very poorly regulated for many years. Pipes, drain lines, and old structures can contain enough explosive residue to be dangerous. Washout lagoons near manufacturing plants can have virtually anything in them. Some are very hazardous, containing both OEW and hazardous and toxic waste (HTW) contaminants.

c. Not all OEW contamination in the Unites States consists of U.S. ordnance. During and after military campaigns, it has long been common practice for captured foreign weapons and ammunition to be brought into the United States for test and evaluation, or for disposal. After World War II, for example, train cars of foreign ordnance items were brought to munitions plants and eventually buried. This practice adds to the complexity of OEW remediation since very little of this foreign material even enters the inventory records.

d. Thorough recordkeeping was not an enforced requirement until recent decades. Very few of the older sites have accurate logs of what types of ordnance were used, where they were used, or how and where disposal took place. Even in cases where a previous attempt was made to clean up OEW at a facility, the remedial action generally produced only cursory records and few maps showing what was found where.

e. One of the strongest drivers making OEW contamination a serious concern now is the increasing value and scarcity of undeveloped land. At many active defense sites, space is at a premium. It is no longer economically acceptable to keep large sections of land from being used because of OEW contamination.

Urban encroachment has caused ordnance activities to cease at many sites. These former defense properties now look very desirable to developers in sprawling municipalities. In fact, many ordnance contaminated sites are currently subdivisions, parks, and schools.

f. There are over 7,000 formerly used defense sites that have been sold to other Government organizations or to private corporations and citizens. About 1,100 of these sites have been associated with ordnance at some time in their history. All too often, the land use restrictions that were enacted where the DOD disposed of the property are forgotten or ignored. These formerly used defense sites (FUDS) are a special target of CERCLA response actions under the second goal of the Defense Environmental Restoration Program.

3. <u>ORDNANCE AND EXPLOSIVE WASTE (OEW) DEFINED</u>.

Ordnance and explosive waste (OEW) is a form of contamination that presents imminent hazards to exposed individuals. It is typically unique to military operations in that the material comprising the contamination was munitions or munitions related and generally designed to do damage to enemy personnel or material. Ordnance and explosive waste consists of the following types of materials:

a. bombs and warheads,

b. guided and ballistic missiles,

c. artillery, mortar, and rocket ammunition,

d. small arms ammunition,

e. antipersonnel and antitank land mines,

f. demolition charges,

g. pyrotechnics,

h. grenades,

i. torpedoes and depth charges,

j. containerized or uncontainerized high explosives and propellants,

k. materials depleted uranium projectiles,

l. chemical warfare materials (mustard, nerve, etc. agents),

m. components of the above items that are explosive in nature or otherwise designed to cause damage to personnel or materiel (e.g., fuzes, boosters, bursters, rocket motors),

n. soils with explosive constituents in concentrations sufficient to present an imminent safety hazard.

4. DISTINCTION BETWEEN OEW AND HTW.

a. The Defense Environmental Restoration Program that was created in 1986 by the Superfund Amendments and Reauthorization Act requires correction of several types of environmental damage. Ordnance and explosive waste that presents an imminent and substantial endangerment to the public or the environment must be eliminated. In addition, remedial action must be taken if hazardous and toxic waste (HTW) is present. The HTW program is more mature than explosive ordnance engineering and many professionals have grown to associate CERCLA response with HTW. DERP has three (3) goals including HTW, OEW, and unsafe debris.

b. The OEW and HTW contamination categories are separate and distinct. Neither one is a subset of the other.

c. There are some fundamental differences between the characteristics and behavior of OEW and HTW contamination. These differences make it necessary to use different remediation equipment, procedures, and safeguards for OEW and HTW environmental restoration efforts. Consequently, personnel skill requirements and training needs are also somewhat different between the two categories. The following paragraphs summarize factors that set OEW and HTW contamination apart. The distinctions represent the majority of cases, but are not absolute. Exceptions exist to all of them.

(1) Mobility. The HTW contaminants are generally more mobile than OEW contaminants. Hazardous and toxic waste products can move through the environment by direct contact with humans and animals, by becoming entrained in the air, by seeping through the soil, by mixing with groundwater or surface water, or by being absorbed into the food chain of humans and animals. Most of these mobility options do not apply to OEW, particularly not to cased explosive materials. Once deposited at a site, OEW typically remains at that site. There have been instances where OEW objects were moved by localized flooding and erosion. In some climates, the freeze and thaw cycle of the ground causes vertical movement of buried objects. About the only ways that OEW will move any significant distance are through ocean tidal action, or through a deliberate human action, e.g., a dredging operation, or a person collecting souvenirs.

(2) Chemical Determination. Laboratory analysis of soil, air and water samples collected at a HTW site can give an accurate indication of the type and concentration of chemical present. Similar determination cannot be made at the typical OEW site. It is too hazardous to attempt to open old ordnance items to sample the energetic materials inside. Examination of the exterior of an ordnance item often does not give a reliable indication of the interior contents. For example, a given

artillery shell design may get filled with inert simulant, any of a number of different explosives, a shaped charge, multiple explosive bomblets or mines, or chemical surety material (CSM). There are few external clues except paint to indicate the type of fill. At manufacturing and training sites, there can be a wide variety of ordnance items present. Discovery and identification of one ordnance item does not give much information about what type might be located a few feet away.

(3) Concentration. The severity of a HTW hazard and the type of response action selected are strong functions of the concentration level of the HTW remediation actions can stop. On the other hand, concentration has little meaning with respect to OEWcontamination, except in the case where uncased explosive is mixed with soil. OEW concentration is sometimes interpreted as the number of items present per unit volume, but this definition has serious shortcomings. It is difficult to quantify since OEW does not spread uniformly over an area. Also, the definition does not take into account the size of the items. There is no minimum acceptable concentration level associated with OEW. It only takes one item to produce a casualty.

(4) Population at Risk. The target population for HTW contamination can be very broad. Because of the mobility of the HTW, people can be placed at risk long distances from the source of contamination. People who have no direct contact at all with the contamination can still be affected through the food chain. This is not true for OEW. The population at risk is effectively limited to those people on the site who can have nearly direct personal contact with the OEW items.

(5) Onset of Effect. Exposures to HTW contaminants can produce near term and/or long term negative effects. In the case of long term consequences of exposure, a direct cause and effect relationship is often hard to establish for a given individual because the health of an exposed individual is also being affected by so many other stimuli and events unrelated to the HTW contamination. However, statistical assessments covering many years and many individuals have made it clear that prolonged exposure to HTW is a serious health hazard. The effects of ordnance and explosive waste exposures are much more immediate, and easier to measure. Most of the time, being in close proximity to OEW does not produce any lasting negative effect. When an OEW accident does occur, the result is immediate and there is little doubt about the cause and effect relationship.

(6) Control. An individual's control over HTW exposure can be very low. The contaminations generally are not obvious to the individual. The exposure path is often related to life requirements such as breathing, drinking, and eating, so options for avoiding contamination are limited. In contrast, an

individual's control over OEW exposure is usually higher. Being in close proximity to ordnance does not automatically lead to adverse effects. In most cases, the ordnance has to be disturbed in some way before a significant health hazard exists. Curiosity is the most common reason for disturbing an ordnance item. An adult who has been informed of the danger has total control over exposure.

d. It sometimes happens that both OEW and HTW coexist at the same site. In such a case, the ordnance hazard is dealt with first. The OEW remediation personnel must wear protective clothing to safeguard against HTW exposure. Subsequently, when the HTW remediation effort begins, it must be conducted using OEW safety protocols.

e. Ordnance and explosive waste cleanup operations fall under the control of the Department of Defense. Hazardous and toxic waste cleanup operations are under the jurisdiction of the Environmental Protection Agency (EPA). The Department of Defense consults with the EPA regarding environmental concerns, but the EPA does not have regulatory control of the OEW remediation operations. As long as the operations do not transfer OEW from the site, RCRA Part B permits are not required; nor are permits required from local or state Governments. In order to obtain this independence of operation, the DOD must substantiate that the OEW at a site is an imminent and substantial endangerment to the public or the environment in accordance with the provisions of the Superfund Amendments and Reauthorization Act.

5. EXPLOSIVE ORDNANCE UNDER NCP PROCEDURES.

a. NCP Process Overview. The overriding regulation for the OEW cleanup process is CERCLA. The format for the CERCLA response is given in the National Contingency Plan. The usual actions and decisions process associated with a CERCLA OEW response are shown in Figure

b. Preliminary Assessment.

(1) Many sites were "cleared" after World War II. However, OEW hazards exist due to encroachment and erosion. For instance, the techniques used to clear a site were, until relatively recently, quite limited in scope. Therefore, an old report of clearance activity must be weighed carefully to determine if additional clearance action is warranted.

(2) The preliminary assessment (PA) is performed by the local District and Division, and results in an Inventory Project Report (INPR), which is forwarded to the Huntsville Division. A preliminary assessment includes the following:

(a) a detailed description of the site,

(b) description of former site use,

(c) current site uses, ownership, and deed restrictions (results of real estate records review),

(d) detailed description of area inspected (site map is recommended),

(e) risk assessment code (required for OEW projects only).

(3) After the INPR is reviewed, either a project is assigned or a no further action (NOFA) report is filed for the record. The RAC score greatly influences the prioritization of work plans for future years. The program managers' office is developing a SOP for implementation priority which addresses ranking factors.

(4) The site priority list is constantly changing because the site evaluations trickle in over time. For example, an evaluation on a high priority site may be completed after work at some lower priority sites from the previous year started. The ranking of projects is constantly changing. Priorities and response plans are reevaluated after each action is complete. The process is iterative.

(5) A summary of the options available after an INPR is submitted is presented below. Further detail on these alternatives is presented in the sections that follow:

(a) Immediate time critical response needed. An interim removal action will be funded as an emergency response.

(b) An interim removal is needed, but it is not time critical. An Engineering Evaluations/Cost Analysis (EE/CA) will be funded to plan the interim removal action.

(c) Additional information is still needed. An additional site inspection will be funded.

(d) Significant cleanup will be needed. An RI/FS to guide the course of action is required.

(e) No further action required.

c. Site Investigation.

(1) If there is reason to believe that OEW may be at the site, a site investigation is programmed and performed.

(2) The results of the site inspection are used to decide what option to take next from the list of 5 given in the section above. For example, it may be decided that urgency is such that an immediate interim removal action is needed.

d. Engineering Evaluation/Cost Analysis (EE/CA).

(1) An EE/CA is best described as an abbreviated RI/FS and is also known as a scoping assessment. The goal is to do enough study to focus on interim removal or removal action.

(2) If an imminent hazard is judged to exist, there are not many options. Either a clean up is called for, or access can be restricted. OEW remediation offers few choices, unlike HTW where there is a myriad of remediation options. With OEW, the remediation choices are related more to the land use (i.e., who is at risk) than to the type of contamination.

(3) In any OEW remediation, cost estimation is very difficult. Experience to date indicates the cost estimates have been law at virtually every cleanup site. A big part of the problem is accurately estimating the quantity of OEW that will need to be cleaned up. The OEW does not generally get distributed in predictable fashion the way HTW distributes

itself. The OEW is not distributed according to natural laws that can be modeled. Geophysical readings give so many anomalies along with true readings that it is hard to sort out the OEW from the "background noise." Furthermore, the geophysical instruments only indicate the presence of "something," they don't identify the type of item that must be dealt with.

(4) The EE/CA involves an assessment of what was used at the site based upon historical records. Estimates of the maximum penetrations, in the case of impact areas, and how much of the OEW presents a problem in the context of projected land use are made in order to recommend a cleanup depth.

e. Interim Removal Action.

(1) An Interim Removal Action (IRA) may be initiated in one of several modes: at a rapid pace as the result of a site visit which indicates that an urgent response is needed, or at a slower pace following completion of an EE/CA for a site. Imminent hazards which present substantial exposure are judged to require an urgent interim removal action to reduce the imminence of the threat before spending time on an EE/CA or a remedial design. Erection of a fence may sometimes be enough to reduce the emergency nature of the site.

(2) Minimal paperwork and approvals are used for emergency IRAs. A notice that the IRA will take place is sent out and the project is started. No interagency coordination or clearances are sought. Emergency IRA situations do not occur frequently. Real emergencies are generally handled some other way than by funding a CERCLA response.

(3) There is no formal design associated with an interim removal action. Standard removal techniques are used. Ordnance removal follows detection. The interim removal action is a dynamic process in response to an urgent threat. Environmental coordination is accomplished by allowing regulators to review and comment on the work plans.

(4) An after action report must be prepared following each interim removal action.

f. Remedial Investigation/Feasibility Study (RI/FS).

(1) The purpose of the remedial investigation/feasibility study (RI/FS) is to assess site conditions and evaluate alternatives to the extent necessary to select a remedy. Developing and conducting an RI/FS generally includes the following activities: project scoping, data collection, risk

assessment, and analysis of alternatives. The scope and timing of these activities should be tailored to the nature and complexity of the problem and the response alternatives being considered. RI/FS is used for larger and most complex sites, where it is difficult to clearly define problems present.

(2) The CERCLA and NCP goal is to select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste.

(3) The remedial investigation (RI) produces a thorough characterization of the site. The criteria given in the NCP to guide the feasibility study (FS) in selection of remedy are the following:

(a) overall protection of health and the environment,

(b) long-term effectiveness,

(c) short-term effectiveness,

(d) conformance with applicable and relevant and appropriate requirements (ARARS),

(e) reduction of toxicity, mobility, or volume through treatment,

(f) cost,

(g) State acceptance,

(h) community acceptance,

(i) implementability.

(4) All reasonable alternatives will be considered to address the hazards. Site control, including repurchase or purchase of limited interest to preclude unreasonable use of contaminated property, will be considered along with cleanup measures using traditional and innovative technologies.

(5) The RI/FS serves as both the decision guidance which leads to the record of decision (ROD) <u>and</u> as the environmental documentation.

g. Remedial Design/Remedial Action (RD/RA).

(1) The RD/RA stage includes the development of the actual design of the selected remedy and implementation of the remedy through construction. All RD/RA shall be in conformance with the remedy selected in the RI/FS and set forth in the record of decision (ROD) or other decision document for that site.

(2) All applicable federal, state, and local standards that are identified in the ROD for the action are met. USAEDH oversees design of project; if approved, the District may take over the project at the construction stage and administer the remedial action aspects.

(3) Guidance for the conduct of RD/RA activity is presented in 40 CFR 300.435. Preparation of a scope of work by USAEDH will guide remediation contractors in the preparation of their work plan and cost proposal. Contractors' work plans shall include a Quality Assurance Project Plan, a Site Safety & Health Plan, and a Field Sampling Plan if any analytical samples will be taken to demonstrate compliance with standards set forth in the record of decisions.

(4) Depth of cleanup is site specific and is limited by the state-of-the-art in detection technology. There is no statement or certification issued after an RA which states that the site is now "clean." No one can truthfully make such a statement. DOD 6055.9-STD, "Ammunition and Explosive Safety Standards," states that sites which go from active to former status must be cleaned up to be innocuous. This is sometimes unapproachable with today's technology. The practical standard is use of the best available technology. Land use restrictions are an option when an adequate confidence level cannot be assured. An after action report must be filed following every RA.

(5) Quality assurance checks are made throughout remedial actions. At the end of a project, a QA review is conducted.

(6) Community relations requirements for RD/RA are also specified by the NCP.

h. Post Remediation.

CERCLA requires that post remedial monitoring is required if the selected action allows any contamination to remain on site. Each site must be revisited at a minimum of every 5 years.

6. ORDNANCE AND EXPLOSIVE WASTE (OEW) DISPOSAL.

a. When OEW is found at a site, the location used for disposal is selected from three options:

(1) The OEW is destroyed or rendered safe in-place.

(2) The OEW is transported to a remote area on or in the general vicinity of the OEW site and destroyed.

(3) The OEW is transported off the OEW site to an active military installation and destroyed at the installation.

b. The main consideration when deciding which option to take is the imminence of the hazard. Two primary factors must be weighed: the suspected sensitivity of the OEW to movement and the level of public exposure. Transport of OEW increases the risk to the Government and contract personnel, and also increases public exposure. Consequently, the preferred option is to destroy the OEW in place, assuming it can be accomplished safely, and the least desirable option is to transport the material off the OEW site to an active military installation.

c. On-Site Demolition/Disposal.

(1) OEW items are usually disposed of on-site whenever the situation allows. This is in keeping with the primary criterion of minimizing public exposure to the OEW. RCRA permits and state/local blasting permits are not required for this action.

(2) Once OEW has been detected and exposed, the standard technique for destruction is to use a countercharge. This demolition charge is placed in contact with the OEW and detonated. The goal is to cause the sympathetic detonation of the ordnance and/or apply sufficient pressure and heat to completely neutralize the hazard. The countercharge is positioned to maximize the likelihood of complete destruction of the OEW while controlling and containing debris. After the detonation, the area is always carefully re-examined to make sure that destruction was complete.

(3) Safety constraints may not always permit OEW disposal in-place. An alternative is to collect the items at a specific location on the site where destruction can safely take place. The countercharge destruction method can again be used to destroy the collected items. Burning is another destruction technique. Detonation or burning of explosive wastes are currently the most effective means of on-site OEW disposal.

(4) Burning has been a widely used ordnance disposal technique for many decades. It has disadvantages; however, that are now curtailing its use in many OEW remediation operations. An incendiary device is used to initiate burning of the OEW. Safety procedures must always prepare for the possibility that the burn will transition to a detonation. In particular, primary explosives such as lead azide, mercury fulminate, lead styphnate, and tetracene can be expected to detonate when involved in a fire. Some explosives give off toxic fumes when burned. Explosives that have been exposed to fire, but not completely destroyed must be treated with extreme care. Chemical and physical changes may have occurred that make the material much more sensitive than in its original state.

(5) The fuze is considered the most hazardous component of unexploded ordnance. The condition of the fuze is one of the factors considered when deciding whether or not to transport munitions. Often the fuze condition cannot be ascertained from an external examination of an unexploded ordnance item. In such cases, the fuze is assumed to be in the armed condition, and in-place destruction should be used. Piezoelectric fuzes are of particular concern. They are extremely sensitive and can fire at the slightest physical change.

d. Transport to an Installation.

(1) If OEW must be transported off-site for disposal, the provisions of 49 CFR 100-199, TM 9-1300-206, and state and local laws shall be followed.

(2) When a decision is made to transport OEW over public roads, a careful and detailed risk assessment should be conducted to select the route and timing that minimizes public exposure to the material. The risk analysis should take into consideration the following characteristics of the shipment and the alternative routes:

(a) number of transport vehicles to be used and the net explosive weight of each,

(b) vehicle accident statistics specific to the region,

(c) traffic density of candidate roads,

(d) population density along candidate routes,

(e) locations of significant public gathering places such as schools, hospitals, shopping malls, etc.,

(f) sensitive environmental areas traversed by the routes,

(g) availability of emergency response teams and equipment in the communities along the route.

e. Noise and Blast Control.

(1) Noise is one of the concerns for communities that are adjacent to proposed OEW remediation sites. It is very important that remediation plans include steps to reduce noise. Project personnel who participate in public hearings about the remedial action should be well versed on what noise reduction measures will be taken.

(2) The noise produced by a detonation is characterized by a high peak and a very short duration. At some distance from the explosion, exposure to a relatively high sound level (e.g., 140 db) will not produce physiological damage because the duration is so short. Repetitive exposures can; however, certainly be a nuisance that will produce complaints.

(3) The most straighforward way to reduce noise levels is to place limits on the amount of explosive material that can be detonated at one time. The benefit of reduced noise per detonation must be traded off against the increased number of detonations that will be required to dispose of a given amount of material.

(4) Detonations in open holes and trenches are the noisiest option. Digging a deeper hole or trench does little to reduce noise levels for the depths that are practical in most OEW scenarios. Tamping holes or trenches with fill material is an effective way to reduce the noise level.

(5) Weather conditions can have a significant effect on the noise characteristics of a detonation. A clear sky is the best condition for blasting operations. Heavy overcast can cause the sound to carry to greater distances.

(6) A computer program is available for predicting the noise levels from a detonation as a function of distance from the explosion. This program is based upon empirical data compiled from a large number of detonations under varying conditions. Scaling charge weight, burial depth, and observer distance allows the data to be applied to a variety of circumstances.

7. <u>REGULATORY CLIMATE</u>.

a. General.

(1) The Army is an environmentally conscious organization. Therefore, conduct of all program will ensure that the environment is protected to the greatest extent possible.

(2) DOD is the recognized national expert in matters relating to the safe handling and disposition of military munitions and ordnance. DOD and Army regulations governing transportation, storage, maintenance, inspections, safety, and security in handling of military munitions and ordnance are very stringent and provide maximum protection for personnel and the environment. Further, Section 300.120(C) of the Final National Contingency Plan state that DOD is the removal response authority for incidents involving military weapons and munitions. The USEPA has concurred in the preparation of AR 200-1 which requires that clearance of conventional ordnance from private lands be conducted under Ammunition and Explosives Safety Standards (AR 385-64). As stated in Section 1-4 of this document, the DOD is the lead agency for ordnance and explosive waste (OEW) remediation. Authority has been delegated to the Huntsville Division of the Corps of Engineers as a mandatory center of expertise (MCX) and Design Center. The EPA is the lead agency for hazardous and toxic waste (HTW) remediation, but within the USACE, the Missouri River Division is the MCX and Design Center for HTW.

(3) OEW removal activities do not require HTW-type or RCRA Part B permits from local, state, or federal agencies. USAEDH uses environmental regulators and state agencies as consultants regarding environmental and other concerns; however, no permits are solicited from environmental regulators or other agency in the remediation of OEW on or off site.

(4) There are distinctions between the following terms: act, regulations, guidance, and policy. They are defined as follows: the Act describes Congress' intent in statutory terms and gives the administrator of EPA or other Removal Response Authority the power to implement the Act. Regulations are published in the Federal Register and codified in the Code of Federal Regulations (CFR); they spell out how an Act's directives are to be carried out. Guidance is issued by the EPA or other Removal Response Authority to provide instructions on how a procedure must be conducted. Policy refers to statements developed by EPA or other Removal Response Authorities to provide instructions on how a procedure must be conducted or to outline a position on a particular topic.

b. Federal Regulations.

(1) Each of the major environmental acts impacts any remedial activity. A brief synopsis of those acts follows.

(2) The first major step taken by Congress in establishing a national charter for environmental protection and preservation was the National Environmental Policy Act (NEPA) of 1969. Its intent was to provide information to public officials and citizens on proposed actions so informed decisions could be made. It also requires incorporation of environmental evaluation with other project planning. The NEPA requirements are spelled out in 40 CFR, Parts 1500-1508.

(3) The Clean Water Act (CWA), enacted in 1972, was established to control pollutant discharges to navigable waters. A significant component of the CWA was the establishment of the National Oil and Hazardous Substances Pollution Contingency Plan, known more commonly as the National Contingency Plan (NCP). The NCP was revised in 1990 and is the primary guidance document for remedial response under CERCLA (to be discussed below).

(4) The Safe Drinking Water Act (SDWA) was enacted in 1974 to protect the nation's underground and surface drinking water supplies. The SDWA was amended in 1986 to establish a schedule which required EPA to regulate 83 specific chemical contaminants.

(5) The Toxic Substances Control Act of 1976 (TOSCA) established regulations controlling specific chemical substances or mixtures that pose an imminent hazard.

(6) In 1980, Congress enacted the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). CERCLA provides the methodology for remediation of former operations, and is presented in 40 CFR Parts 300-311. CERCLA rules all environmental remedial actions. Part 300 sets forth the mechanism for implementing the NCP.

(7) The National Contingency Plan (NCP), as amended in 1990, defines the format for response, from planning, to decision making, to post remediation monitoring. The NCP was originally a component of the Clean Water Act. Paragraph 300.120(c) states that "DOD will be the removal response authority with respect to incidents involving DOD military weapons and munitions or weapons and munitions under the jurisdiction, custody and control of DOD." An important aspect is that permitting is not required for OEW response actions; this distinction is important because it facilitates quick response action.

(8) In 1983, the Environmental Restoration Defense Account (ERDA) was established to fund an expanded effort at active DOD installations and formerly used defense sites (FUDS). The DOD assigned management of FUDS to the Army, who then delegated the mission to the USACE in 1984.

(9) CERCLA was reauthorized and amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). Chapter 160 of SARA established the Defense Environmental Restoration Program (DERP). Goal two of the DERP calls for "correction of environmental damage (such as detection and disposal of unexploded ordnance) which creates an imminent and substantial endangerment to the public health or welfare or to the environment" at:

(a) A facility or site that is owned by, leased to, or otherwise possessed by the United States and under the jurisdiction of the Secretary of Defense. A facility or site that was under the jurisdiction of the Secretary of Defense and owned by, leased to, or otherwise possessed by the United States at the time of actions leading to contamination;

(b) A vessel owned or operated by the Department of Defense.

(10) Three categories of contamination are specified for the three situations listed above; they are:

(a) Hazardous Materials. The identification, investigation, research and development, and cleanup of contamination from hazardous substances, pollutants, and contaminants.

(b) Other Environmental Damage (including OEW). Correction of other environmental damage (such as the detection and disposal of unexploded ordnance) that creates an imminent and substantial danger to the public's health or welfare or to the environment.

(c) Unsafe Structures. Demolition and removal of unsafe buildings and structures, including DOD buildings and structures at sites formerly used by or under the jurisdiction of the Secretary of Defense.

(11) The broad goals of the Resource Conservation and Recovery Act (RCRA) are to: protect human health and the environment; to reduce waste, conserve energy and natural resources, and to reduce or eliminate the generation of hazardous waste.

(a) Three distinct and interrelated programs exist under RCRA and are defined under the following subtitles:

1. Subtitle D promotes environmentally sound disposal of hazardous waste. It provides technical standards for landfills and guidelines for state solid waste plans and financial aid to the States. It defines "solid waste," which turns out to be a very broad definition; it includes garbage, refuse, sludges, and other discarded materials, including solid, semisolid, liquid, or contained gaseous materials. Exceptions to the definition of "solid waste" are: domestic sewage in a sewer system, industrial wastewater regulated under the Clean Water Act, irrigation return flows, nuclear materials, and mining materials that are not removed from the ground during the extraction process.

2. Subtitle C established the "cradle to grave" management system for hazardous waste. It defines hazardous waste as a "solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may: (A) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed." In simpler terms, a solid waste is hazardous if it meets one of the following four conditions: (1) exhibits a characteristic of a hazardous waste, (2) has been listed as a hazardous material, (3) is a mixture containing a hazardous waste, or (4) it is not excluded from regulation as a hazardous waste. The four characteristics of a hazardous waste are ignitibility, corrosivity, reactivity, and EP Toxicity. All treatment, storage, and disposal facilities (TSD) must comply with these regulations.

3. Subtitle I regulates petroleum product and hazardous substances (as defined under Superfund) stored in underground tasks.

(b) RCRA and CERCLA overlap in a number of ways. For disposal of Superfund wastes, material taken off-site must be treated or disposed of at a site with a RCRA permit; on-site treatment, storage or disposal must meet certain RCRA criteria. EPA now has two mechanisms for corrective action: Superfund and the 1984 RCRA amendments called the Hazardous and Solid Waste Amendments (HSWA). Both CERCLA and RCRA require action towards an imminent hazard.

(c) RCRA's relationship with other environmental acts can be summarized as follows:

1. Clean Air Act: defines the performance standards for air emissions from any TSD.

2. Clean Water Act: any TSD that discharges to a sewer that leads to a Publicity Owned Treatment Works (POTW) must comply with pre-treatment standards. Any discharge to a navigable water must comply with the National Pollutant Discharge Elimination System permitting system.

3. Safe Drinking Water Act: the maximum contaminant levels (MCL) of this Act may be used in ground water monitoring programs at RCRA sites.

4. Toxic Substances Control Act: any facility that handles hazardous waste containing cited chemicals at specified concentrations is regulated under this act as well.

(d) Ordnance found on FUDS may require expedited responses, which includes the resulting treatment and transportation involved to the extent necessary to abate the immediate threat. EOD emergency response action required to abate an immediate safety threat to personnel or property is not subject to regulation under RCRA. Emergency response threat to personnel or property is not subject to regulation under RCRA. Emergency response action is a CERCLA action. Any HTW residue at an open burning/open detonation (OB/OD) site will be cleaned up to applicable standard.

(12) Labor safety laws are embodied in the requirements of the Occupational Safety and Health Administration (OSHA) requirements published in 29 CFR 1910.

(13) Department of Transportation (DOT) requirements are very strict about the use of proper packaging and markings for the shipment of hazardous and toxic materials. Additional detail on the DOT labeling requirements is presented in the previous chapter under training requirements. The DOT regulations are published in 49 CFR Part 173.

(a) Analytical samples that will be collected from streams, ponds, lakes, wells, and soils that are not expected to be contaminated with hazardous materials may be considered to be low concentration (less than 10 ppm of any one contaminant), or environmental samples. Samples of soils and materials collected from drums, storage tanks, or visibly contaminated wells, ponds, or lagoons, and leachates from hazardous waste sites, should be shipped as medium concentration (greater than 10 ppm and less than 15% of any one contaminant), or hazardous material samples. (Preservation of a sample with acid or sodium hydroxide to the required pH does not, by itself, make a sample hazardous.)

(b) The transportation of surety material without escort by a Technical Escort Unit (TEU) is prohibited. Under no circumstances may civilian aircraft be used for transport of surety material, including dilate material. Military requirements supersede DOT requirements in the case of surety material. Transportation of analytical samples may be by civilian personnel provided the material meets dilute criteria; however, under no circumstances may vehicles used for transport be civilian owned. AR 50-6 is under review and may impact response operations.

(14) Public affairs coordination must be conducted in accordance with the directives for a CERCLA response action as described in the NCP, 40 CFP 300.

c. State and Local Regulations.

(1) No state and local regulations apply to OEW remediation activities; however, the remediation designers and project managers give due consideration to local requirements. The fact that one is doing OEW remedial work does not provide exemption from state and local laws. The objective of the Corps is to be sensitive to the wishes of the local population in accomplishing its goals. Permits will not be sought by the Corps prior to an OEW remediation.

(2) Local and State organizations play an important role in assisting Corps engineers to understand the special concerns of a community or region and what needs to be protected. The Corps will respect and respond to these concerns.

d. Army Regulations.

(1) This bulletin will not attempt to list every Army regulation that may apply to ordnance and environmental remediation. However, some of the more important policy documents are as follows.

(2) 385-16, "System Safety Engineering and Management," establishes responsibilities, requirements, and procedures for risk definition, acceptance, and management. It encompasses all aspects of systems or facilities throughout their life cycle.

The definition of responsibilities is quite detailed. Policy is defined and objectives are stated. Sample formats for documentation of risk assessment and safety releases are provided. further, it reviews risk acceptance criteria via a decision authority matrix.

(3) AR 200-1, "Environmental Protection and Enhancement," prescribes Department of Army responsibilities, policies, and procedures to preserve and protect environmental quality. Definition of responsibilities is broken down into management and commands. It incorporates all relevant requirement for air and water pollution; solid and hazardous waste management; research and development; noise, radon, and asbestos control and abatement; contingency planning and emergency response; and application of CERCLA requirements under the installation restoration program. The guidance presented under "Environmental Restoration Programs" applies to Formerly Used Defense Sites.

(a) It states that the Army will "protect the health and safety of installation personnel and the public and the quality of the environment by identifying and addressing, in a timely manner, the threats posed by uncontrolled hazardous materials on or from Army activities and FUDS." It further states that the Army will address explosive ordnance as defined in AR 75-14 and unexploded ordnance as defined in AR 75-15, in CERCLA activities.

(b) Under "CERCLA requirements," it directs DOD to conduct research on improved methods; requires notification of EPA, State and local authorities; provides opportunity for EPA, State and local authorities to review and comment on plans; establishes a technical review committee; and calls for annual report to congress on the DERP.

(4) AR 50-6, "Chemical Surety," applies to all personnel involved with chemical surety material (CSM), including RDTE solutions, with the exception of Army National Guard or U.S. Army Reserve personnel. It implements the chemical surety program, which defines the facets of safety, security, and reliability, including: accountability of munitions, compliance with safety, security, certification of personnel, accident response, and established procedures to implement plan requirements.

(a) Requirements of the chemical personnel reliability program (CPRP) are detailed. Qualifications of personnel, security clearance, suitability for duty, training requirements, recordkeeping, and medical evaluation and continuing monitoring are covered. Exact procedures are defined for qualification and disqualification for personnel.

(b) Procedures for transportation of CSM are specified. Public LAW 91-212 (5) USC 1511-1518) as amended by PL 91-441 establishes specific provisions to be followed. Movement is governed by class of agent and generally requires technical escort and armed guards. "Safety and security will not be compromised in any way for the sake of economy or ease of operations." Emergency disposal may be conducted free of the prior approval restrictions imposed by Public Law 91-120, 91-121, and 91-441. CSM found on an installation or in the public domain which does not have a military mission will be transported by EOD or technical escort unit (TEU) personnel to the closest installation that has a CSM storage or demilitarization mission for that particular type of CSM.

(c) Chemical Accident and Incident Response and Assistance (CAIRA) refers to a specific set of circumstances and required responses. Responsibilities are defined and reporting procedures are outlined. Specific actions to be taken for public affairs action are defined with examples.

(d) The safety program for chemical surety programs is defined: safety and health considerations, monitoring for agents, first aid, medical surveillance, security alert facilities, and hazard markings.

1. A hazard analysis incorporating a maximum credible event (MCE) consistent with Department of Defense Explosives Safety Board (DDESB) Technical Paper No. 10 will be completed and will accompany the preliminary site plan.

2. Minimum levels of protective clothing will be established by following the criteria in TM 9-1300-206.

3. Personal protective equipment (PPE) will be tested and certified according to procedures specified every three months.

4. Facilities for showering and change out of PPE must be provided. Facilities will be configured and clearly marked to allow segregation of clean and potentially contaminated articles.

5. A dedicated emergency vehicle must be available during all work hours.

6. A decontamination facility must be set up at the site with a minimum of five personnel trained to operate it.

7. Drinking, eating, and smoking are prohibited in limited areas.

8. Personnel working with nerve agents must be checked for symptoms of agent poisoning 30 minutes after leaving the work area and prior to leaving the installation.

9. Personnel working with chemical agents must carry medical alert identification at all times.

10. Workplace monitoring must be carried out during all work hours. Perimeter monitoring should be carried out continuously if there is a possibility of causing a release through agitation of soil or other means. Expert assistance is imperative in the design and operation of the monitoring system.

(e) Procedures to deal with counterintelligence and operational security are specified. Important point for this purpose are procedures for reporting threats and significant incidents.

(f) Accountability requirements for chemical surety material is defined, the significance of which must not be underestimated.

(g) CPRP supplemental guidance for contractor operations is presented.

(h) Procedures for fitting of protective masks is defined in detail.

(5) AR 50-6-1, "Chemical Agent Security Program," applies to all personnel involved with chemical surety materiel (CSM) including RDTE solutions, with the exception of Army National Guard or U.S. Army Reserve personnel. It defines minimum requirements for physical security of CSM in the possession of the Army. It applies to the storage and transportation of CSM worldwide in peacetime and within the continental U.S. during wartime. Coverage includes: responsibilities, policy, national security considerations, inspections, the two-person concept, security planning, vulnerability assessment, and tactical defense planning. It also discusses perimeter security and storage requirements, support facilities, security procedures, key and lock controls, security forces and training, security during transport of CSM, and demilitarization processing facility requirements.

(6) DA Pam 50-6, "Chemical Accident or Incident Response and Assistance (CAIRA) Operations," directs that EOD personnel, assisted by the technical escort unit (TEU) will locate, secure, and render safe all explosively hazardous munitions and seal or containerize any remaining leaking agent containers or munitions. RCRA will not apply until the CM has been determined to be safe, and if possible, transported to the nearest CM installation.

(7) "Safety Provisions for Contracts Involving Chemical Surety Materiel and other Related Military-Unique Chemical Compounds," July 1988, US Army Chemical Research, Development and Engineering Center Safety Office, Aberdeen Proving Ground, Maryland, provides a succinct definition of the requirements for contractors involved in chemical surety work.

(8) HNDP 385-3-1, "Facility System Safety Program Manual," describes the elements of a Facility System Safety (FASS) program. The various analysis techniques used to assess hazards and risk in a FASS are presented and guidance is given for which analysis technique is most appropriate at various stages of facility design and construction. Topics discussed include: risk assessment methods, hazard controls, energy trace .nd barrier analysis, fault tree analysis, and failure modes and effects analysis.

(9) DOD 6055-9 STD, "Ammunition and Explosives Safety Standards," addresses DOD property contaminated with ammunition and explosives.

(a) Disposal policy is summarized as follows: permanent contamination is unacceptable, disposal by burial or discharge into waterways is unacceptable, burial at sea is acceptable only with certain restrictions.

(b) Each site must maintain permanent records and maps identifying contaminated areas. Contaminated areas must be well marked.

(c) Plans for site activity must be reviewed and approved by the DDESB. Use of contaminated land is restricted to activities that do not disturb the ground below the depth cleared by the decontamination method. Mineral exploration, drilling, and mining are prohibited on contaminated lands and such activity must be separated from contaminated lands by appropriate explosives safety distances and public exclusion distances.

(10) AMC-R 385-100, "Safety Manual," is a comprehensive manual for all manner of activity. Standards for construction, protective clothing, storage of military peculiar items, fire protection, quantity-distance tables, explosives shipment, and transportation are included. One important point made is tha the open pit burning of lethal or incapacitating agents or agent filled munitions in any quantity is prohibited.

SUMMARY

This paper describes the explosive ordnance engineering requirements associated with CERCLA response actions at sites contaminated with ordnance and explosive waste. The challenges of explosive ordnance engineering is to incorporate engineering principles, environmental sensitivity, public awareness, and economic reality into what was a unilateral decision process for explosive ordnance disposal and safety personnel.

REACTIVITY OF EXPLOSIVE - CONTAMINATED SOILS TO FLAME AND SHOCK STIMULI

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ABSTRACT

Extensive testing was conducted by Hercules Incorporated for Arthur D. Little, Inc. and the United States Army Toxic and Hazardous Materials Agency (USATHAMA) to investigate and define the reactivity of explosive-contaminated soils to flame and shock stimuli. These tests were conducted with laboratory prepared, water-wet and dry samples of the explosives RDX or TNT mixed with sand. The flame and shock tests were conducted using Bureau of Mines (BOM) protocols and determined that explosive-contaminated soils containing ≤12% explosive will not react explosively to induced shock or submerged flame initiation stimuli (Figure 1). This study resulted in a technical data base suitable for use as reactivity criteria for assessing the explosive reactivity of contaminated soils to flame and shock stimuli on the basis of soil composition.

Since completion of this study, 86 process waste samples containing up to 4.4% NC or <1% of other explosives (DNT, DEGDN, NG, TNT, RDX, etc.) were tested and determined to be non-reactive to the BOM flame and shock protocols (see Appendix C). These waste samples are now being classified as non-reactive by chemical analysis.

INTRODUCTION

Explosives manufacture and ammunition load, assembly and pack (LAP) operations result in the generation of explosives-contaminated wastewater. Over the years, the Department of the Army has used lagoons for treatment of these wastewaters by evaporation/percolation. Chemical analyses by others[1] determined that the principal sludge components at Savanna Army Depot (SAD) and Louisiana Army Ammunition Plant (LAAP) are TNT, RDX, HMX, water, sand and clay. Other solid, reactive materials and heavy metals are present in concentrations of 0.1% or less. These explosives-contaminated waters and sludges are listed as hazardous wastes under federal regulations promulgated under the Resource Conservation and Recovery Act (RCRA). The basis for this listing is the assumed explosive reactivity of these wastes if subjected to a strong initiating source or if heated under confinement (Refer to 40 CFR 261.23).[2] Presently, tests to determine the explosive reactivity of wastes are not specified. Different tests have been

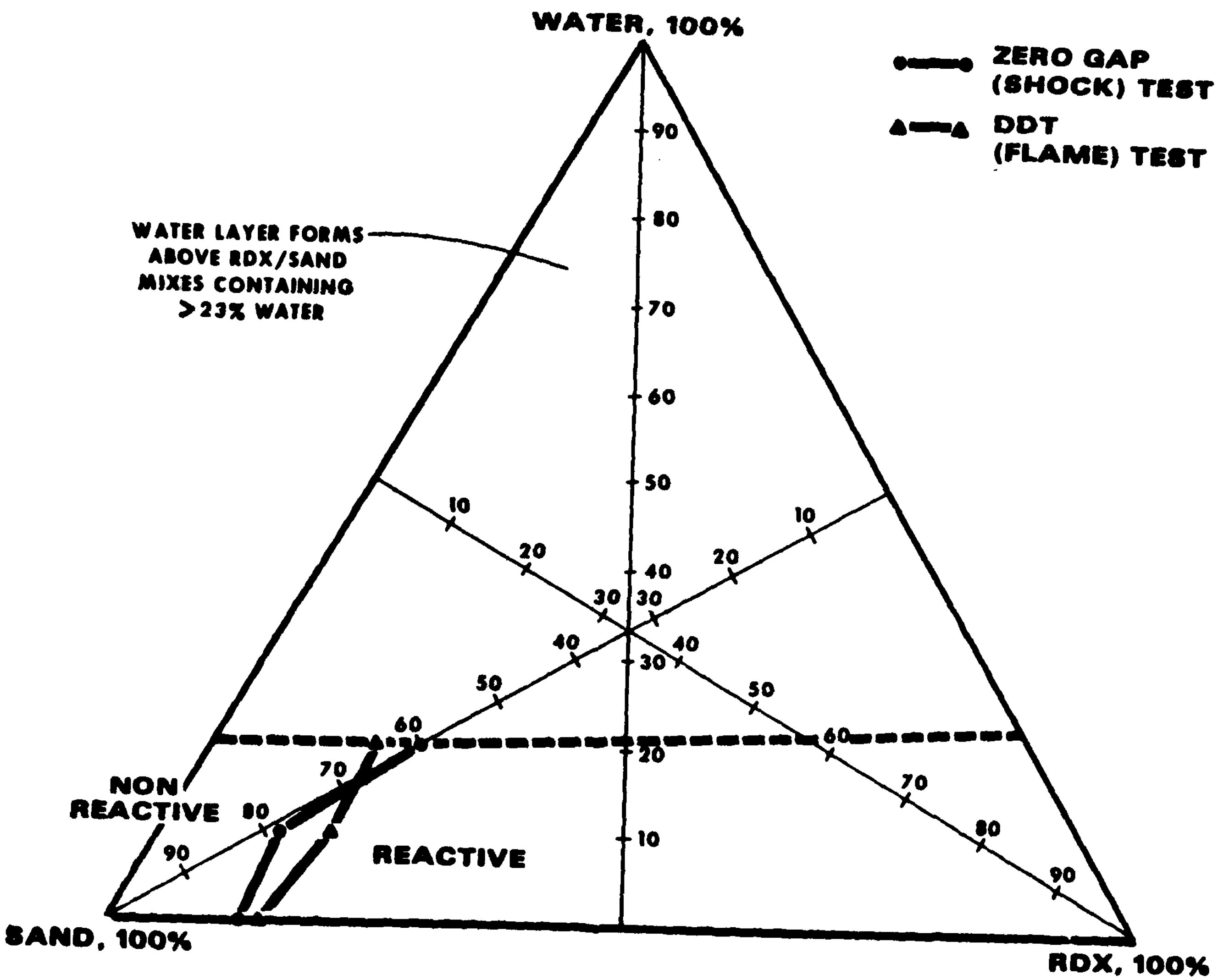

Figure 1. Combined Results of DDT and Zero Gap Tests

Source: Hercules Incorporated (Radford Army Ammunition Plant)

under consideration. Two of these test series are discussed in the following.

The first series of tests are similar to those used by the Department of Transportation (DOT) to determine the shipping classifications for hazardous materials. These inexpensive, small-scale tests determine if a material will burn or explode when subjected to an elevated temperature of 167°F for 48 hours, flame, shock of a No. 8 blasting cap, and BOE Impact Apparatus at 10 and 4-inch drop heights. These tests were listed in U. S. Environmental Protection Agency SW-846 (1980) "Test Methods for Evaluating Solid Waste."[3]

Another series of tests were developed by the BOM in cooperation with DOT to assist the United Nations (UN) Group of Experts on Explosives in preparing recommendations for the international transport of dangerous goods. These test protocols are known as the Zero Gap shock and Deflagration to Detonation Transition (DDT) flame tests (Appendix A). These tests are more expensive and time consuming than the EPA SW-846 tests mentioned previously. One advantage of these tests is that test samples are subjected to greater shock and flame energy in stronger (steel) confinement than in EPA SW-846 tests and therefore test results are more safety conservative.

USATHAMA funded this project for the purpose of investigation and defining the relationship between explosive-contaminated soil reactivity to BOM flame and shock tests, and explosive content. This study provides data for the development of a technical data base that may be used to predict the reactivity of explosive contaminated soils to flame and shock stimuli on the basis of compositional analyses of explosive(s) content. Substitution of laboratory analyses of explosive contaminated sludges for Zero Gap and DDT testing of sludge compositions would result in lower costs for determining the reactivity of contaminated soils.

DISCUSSION

Overall Test Plan

Major explosive contaminates and type of soil in Army lagoons were identified from available analyses (Table 1). The initiation sensitivity and explosive reactivity of the major solid explosive components were assembled from Hercules data files and the literature, and compared to establish which are more sensitive/reactive than the others (Table 2). Based upon these analyses and data the most sensitive/reactive explosive and typical inert test materials were selected for BOM flame and shock tests. Laboratory prepared compositions were then tested using BOM Zero Gap test protocols to determine compositions which were reactive and non-reactive in this test. Various compositions were then tested using BOM DDT test protocols to determine if compositions

Table 1

Typical Army Lagoon Sludge Compositions[a]

Component	Range, % (Dry Basis)[b]
A. Explosive:	
1. TNT	5-41
2. RDX	0.1-10
3. HMX	0.5-1.5
4. TNB, DNB, 2-Amino, DNT	ND -0.1
Total Explosives Content	9-41
B. Inerts:	
1. Sand 2. Clay	$\geqslant$ 52

[a]Based upon analyses from Reference 1.

[b]Moisture content ranged from 11 to 30%.

ND - None Detected

Table 2

Comparison of RDX, HMX and TNT Initiation, Flame and Shock Sensitivity Characteristics[a]

Initiation Stimuli	Units	Test Conditions	TNT	RDX	HMX
1. Mechanical					
a. Impact, TIL[b]	ft-lb/in.^{2}	Steel/steel	10.2	13.3	3
b. Sliding Friction, TIL[b]	psi @ 8 fps	Steel/steel	70,000	21,000	23,000
2. Electrostatic Spark Discharge, TIL[b]	Joules	N/A	0.025	0.024	0.065
3. Thermal					
a. Differential Thermal Analysis	°C	-	300	232	~ 280
b. Explosion Temperature	°C	Ignition in 1 s	520	316	327 (in 5 s)
4. Flame					
a. Critical Height to Explosion		Schedule 40 Steel Pipe			
2-in. diameter	In.		12	2	3
4-in. diameter	In.		⩾ 24	5	7
5. Shock					
a. Detonation Velocity	m/s	-	6,825	8,180[c]	9,124
b. Critical diameter for explosive propagation	In.	Schedule 40 Steel Pipe	⩽ 0.27	⩽ 0.27	⩽ 0.27
c. Rifle Bullet Impact	N/A	30 caliber	40% Expl. 60% Unaff.	100% Expl.	-

[a]See Glossary in Appendix D for definitions and test criteria.

[b]Lowest values included only. Higher values available reflect effect of sample thickness, particle size, density, etc.

[c]Pressed pellet; density = 1.65 g/cc.

NA - not applicable

Source: RAAP materials sensitivity laboratory files and AMC Pamphlet 706-177, "Explosive Series, Properties of Explosives of Military Interest," March 1967.

were reactive or non-reactive in this test. Test results were evaluated statistically and presented for use in determining explosive-contaminated soil compositions which can be classified as reactive or non-reactive to the BOM tests based upon chemical analysis.

·Selection of Test Sample Materials

1. General

The reactivity of Army lagoon sludges will depend upon the type of explosive present, its concentration in the non-reactive (inert) components and the degree of confinement afforded by the inerts in handling and storage containers. Typical soil analyses from two Army lagoons are shown in Table 1. The data is based upon chemical analyses of explosives-contaminated sludges from Savanna Army Depot (SAD) and Louisiana Army Ammunition Plant (LAAP).[1] These analyses show that the principal solid explosives present are TNT, RDX and HMX. Other solid components include water, sand, clay and low (≤0.1%) concentrations of other explosives and heavy metals.

2. Explosive Component

A review of initiation sensitivity and explosive reactivity data summarized in Table 2 shows that RDX and HMX exhibit similar initiation characteristics when subjected to mechanical, electrostatic and thermal stimuli. When confined and subjected to submerged flame initiation (critical height test), each transits from burning to an explosion reaction at low sample heights. Both materials sustain a detonation reaction and have critical diameters for explosive propagation of ≤0.27 inch in schedule 40 steel pipe. For purposes of this study, it is concluded that RDX and HMX are equivalent in initiation sensitivity and explosive reactivity.

A comparison of RDX, TNT and HMX initiation sensitivity and explosive reactivity data in Table 2 shows that TNT reacts similarly to impact and electrostatic discharge stimuli. However, TNT is much less sensitive to sliding friction and thermal stimuli as it requires greater energy for initiation. Flaked TNT is also less likely to transit to detonation as evidenced by a critical height of ≈24 inches in 4 inch diameter confinement. In contrast, RDX and HMX have critical heights of 5 and 7 inches, respectively, in the same confinement.

TNT, RDX and HMX are all capable of detonation in small diameters (≤0.27 inch). The TNT shock wave propagation rate is slower (6,825 m/s) than those of RDX and HMX (8,180 and 9,120 m/s), respectively). From this comparison, it is concluded that TNT is no more initiation sensitive and a less reactive explosive than RDX and HMX.

It is concluded that the selection of either RDX or HMX, rather than TNT, for BOM flame and shock testing will result in a conservative estimate of explosive reactivity for compositions containing TNT or other secondary explosives of equal sensitivity in these tests. Since typical lagoon analyses indicate that there is up to 6 times more RDX than HMX in the lagoons, RDX was selected as the candidate explosive for use in this study. The presence of small concentrations (≤0.1%) of explosives other than TNT, RDX or HMX will have a negligible effect upon the overall reactivity of sludge.

Type II, Class 1 RDX[4] was purchased from Holston Defense Corporation for use in this study. A RAAP chemical analysis of the Type II RDX determined that it also contained 8.6% HMX and 2.8% of other nitramine variations formed during RDX manufacture.

Limited testing was also conducted with TNT fines obtained from the RAAP TNT Plant. Chemical analysis determined it to contain 99.84% 2, 4, 6 TNT, 0.2% 2, 3, ′ TNT, and small amounts (0.06% total) of DNT and water. The TNT particle size distribution was determined microscopically. Most TNT particles fell in the range of 3μm to 200 μm (average ≈14 μm). Some of the larger particles measured were agglomerates instead of single crystals.

3. Inert Components

(a) Soil

Soil samples from SAD and LAAP were characterized by sieve analysis. Using U. S. Bureau of Public Roads soil-classification protocol, the LAAP soil was identified as loamy sand and the SAD soil as sand.

Several graded and ungraded sand and soil samples taken and analyzed at RAAP identified a New River sand bar sample which closely matches the SAD soil sample. Approximately 2,000 lb of New River ungraded sand was placed in cotton bags, air dried at 140°F for 48 hours, passed through a 20-mesh screen to remove foreign material (grass, branches, roots, rocks) and used in this study.

(b) Water

Since Army lagoon sludges also contain up to 30% water, both water-wet and dry RDX/sand mixtures were investigated in this study. Support laboratory tests conducted with a one liter graduated cylinder and beam balance determined that settled beds of sand or Type II, Class 1 RDX in water contain 20.0% and 22.9% (wt. basis) water, respectively. The addition of more water results in a layer of water above the settled RDX/sand mixture (two phases). The presence of a water head above a settled RDX/sand/water mixture should have little effect upon the reactivity of the settled RDX/sand mixture to flame or shock. Furthermore, Zero Gap and DDT test configurations are not very well suited for testing two phase systems. Since most flame and shock tests were conducted with RDX/sand mixtures containing more sand than RDX, all trials conducted with settled RDX/sand in water mixtures were conducted with 20% (wt) water added. Visual inspection of 20% water-wet RDX/sand mixtures after loading into test pipes showed a thin water layer on top of samples indicating that all intergranular voids were full of water. Partly water-wet beds of RDX/sand mixtures were also tested with 10% water added.

4. Mix Preparation

Portions of RDX or TNT, sand and water (when required) were weighed to ± 1 gram and manually tumbled together to achieve a uniform mixture immediately before loading in test pipes. Mixes weighing up to 30 lb were prepared in sealed, conductive plastic bags in contact with a grounded, conductive surface to minimize the risk of electrostatic initiation of the explosive. Mixes were kept sealed in the plastic bags until used in tests to preclude loss of moisture by evaporation.

·Test Results

The following sections discuss the results of flame and shock sensitivity tests conducted with RDX/sand/water mixtures and the results of the flame and shock confirmatory tests conducted with TNT/sand mixtures.

1. Zero Gap Shock Test Results

Wet and dry RDX/sand mixtures were tested to define mixture shock reactivity as a function of RDX content. Testing was conducted using the BOM developed Zero Gap test described in Appendix A and shown in Figure A1. In this test, samples were confined in 1.44-inch diameter steel tubing and subjected to an explosive shock wave induced at one end by two Pentolite pellets. RDX/sand/water compositions reacting explosively were identified using BOM test protocols. Standard probit statistical techniques[5] were used to establish an RDX level in wet and dry sand that has a low (0.5%) probability of reacting explosively to shock in the BOM test configuration.

(a) Initial Trials

Initial trials were conducted using 100% RDX, 100% sand, 100% water and an 80% sand/20% water mixture to verify that the Zero Gap shock test is capable of identifying material samples reactive or non-reactive to shock. These test results are presented in Appendix B, Table B1 and verified that the test is capable of identifying samples reactive or non-reactive to shock in the BOM test configuration.

Trials with RDX produced a positive result and demonstrated RDX reactivity to shock. In both the water and sand trials (three each), end-to-end pipe fragmentation occurred during one trial. Both materials also transmitted a fairly stable shock wave in one or more trials at velocities just below the >1,500 m/s criterion for an explosive reactive material. Water and probably any continuous phase (liquid or solid) material should be expected to transmit the donor induced shock wave effectively to the end of the comparatively short, 16-inch long pipe. It is suspected that much longer pipes would be required to detect shock wave degradation (decaying reaction) in continuous phase materials. Although sand is not a continuous phase material (contains air in granular interstices), another mechanism is thought to have caused the test container to fragment into long strips or appear to propagate the shock wave (positive results). In one sand trial, sand remaining within the undamaged portion of the pipe had been compressed and wedged into the pipe. It is theorized that in other trials with sand, a slug of tightly compressed sand was driven up the steel tube with sufficient force to rupture and fragment the tube and indicate propagation of a shock wave to the end of the 16-inch long test container. It is not likely that both tube fragmentation and indication of a shock wave by mechanical force of sand on the velocity probe would occur at the same time. A plug of sand hard enough to rupture the pipe would be expected to push the velocity probe out ahead of it and no velocity trace would result.

Zero Gap tests with 20% water filling spaces between sand granules gave indications of a pressure wave propagation velocity of ≤770 m/s. None of the sand and/or water (inert) trials transmitted sufficient shock to puncture the 1/8 inch thick, mild steel witness plate.

Zero Gap tests with inerts (sand and water) indicate that positive velocity and/or fragmentation results may occur with inerts in the BOM test configuration. It is speculated that this is why the BOM protocols require at least 2 of 3 different reaction criteria (velocity, pipe fragmentation and/or hole in the witness plate) be met before declaring a positive test result. If a trial with inert material resulted in a positive test result, the resulting data and test conclusions would be safety conservative. It appears unlikely that a shock sensitive material would not react positively in the Zero Gap test.

(b) RDX/Sand/Water Trials

Zero Gap tests were conducted with 0, 10 and 20% water-wet RDX/sand mixtures containing 15-25% RDX. These test results are presented in Appendix B, Table B1.

Test results summarized in Table 3 and shown in Figure 2 indicate that dry RDX/sand mixes containing 15% RDX are not reactive to induced shock in the BOM test configuration at the 0.5%

Table 3

Summarv of Zero Gap Shock Test Results

Composition Tested, %			Average Bulk Density, g/cc	No. Trials	Average Shock Propagation Rate,[b] m/s	Positive Reactions[c] %
RDX	Sand[a]	Water				
20	80	0	1.342	11	2,220	73
18.75	81.25	0	1.294	10	3,030	20
17.5	82.5	0	1.339	10	2,670	20
15	85	0	1.345	20	1,864	0
25	65	10	1.285	5	2,550	100
23.5	66.5	10	1.262	10	2,760	60
22	68	10	1.289	10	2,480	30
19	71	10	1.273	10	2,620	10
18.5	61.5	20	1.760	2	3,960	100
17	63	20	1.752	10	3,120[d]	50
16.5	63.5	20	1.746	10	1,140	10
16	64	20	1.768	20	887	0

[a]Sand 0.8 to 0.2% water-wet.

[b]Shock propagation rate recorded by velocity probe in the upper half of the test sample (shock was induced into the bottom of the test sample).

[c]Two of the three following positive test result criteria are recorded: (A) Clean hole punched through, 1/8-in. thick steel plate; (B) Pipe fragmented along its entire length; (C) Stable propagation velocity > 1,500 m/s. Refer to Appendix B, Table B1 for complete listing of tests.

[d]Five trials averaged. Others were decaying reactions (variable rates).

Source: Hercules Incorporated (Radford Army Ammunition Plant)

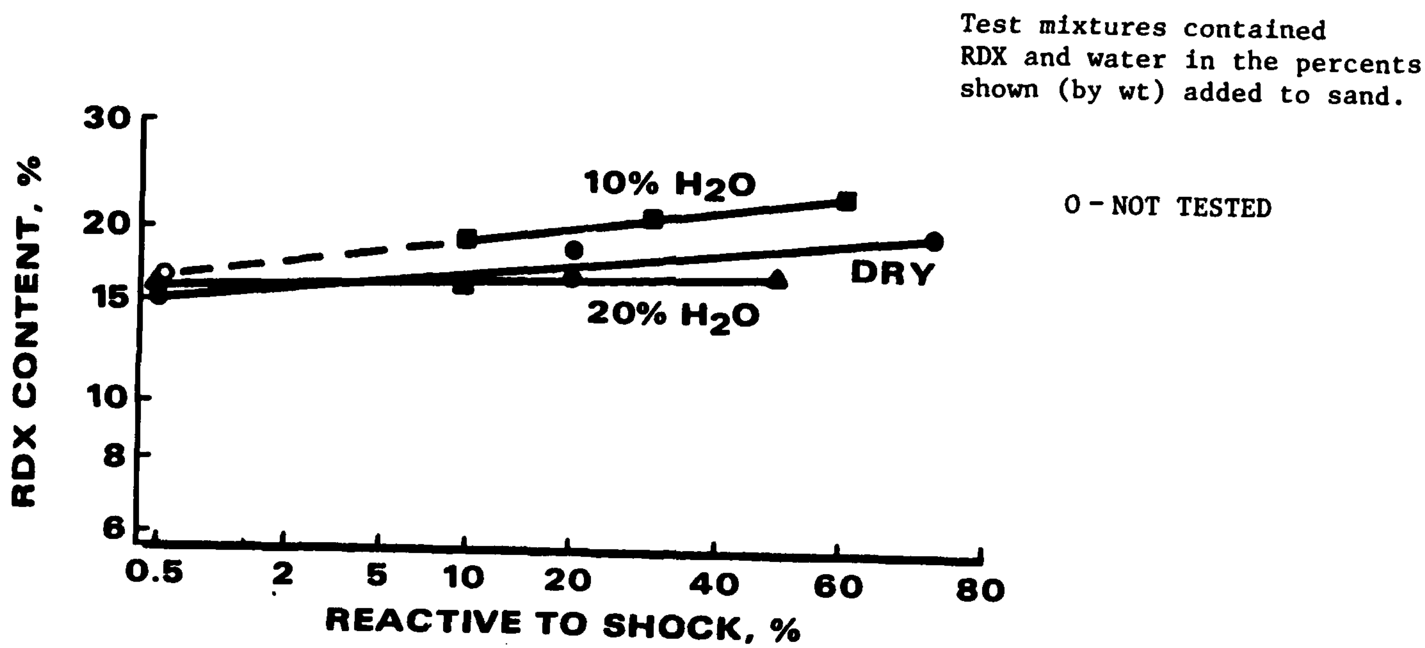

Figure 2. RDX/Sand/Water Shock Reactivity in Zero Gap Tests.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

reactivity level. Twenty consecutive trials with 15% RDX in sand tested negatively and verified at the 90% confidence level that this RDX/sand composition is unreactive at the 0.5% reactivity level.

Zero Gap tests with 20% water-wet RDX/sand mixes determined that mixes containing 16.0% RDX are also 0.5% reactive at the 90% confidence level. A comparison of 0 and 20% water-wet test results indicate that the substitution of up to 20% sand with water has little effect upon sample reactivity at the 0.5% reactivity level.

The predicted 0.5% reactive RDX concentration (16.5%) in the 10% water-wet RDX/sand mixes was nearly the same at those obtained at the 0 and 20% water-wet levels. Figure 2 shows the results of all RDX/sand samples tested in the Zero Gap test configuration.

Comparing the results of RDX/sand Zero Gap tests at higher reactivity levels (Figure 2), it can be seen that substitution of 10% sand with water reduces sample reactivity. However, substitution of an additional 10% sand with water (20% water content) has the opposite effect. The reason for these results is likely changes in bulk density. Experiments by others have demonstrated that, for a given explosive in cylinders of large diameter, the detonation velocity is nearly a linear function of the initial bulk density.[6] A more recent report of critical diameter (C_d) studies with loose, crystalline explosives concluded that increase of the explosive charge density as a result of pressing (charge consolidation) or filling voids with water decreases the charge air content, improves the conditions for shock wave propagation in a given medium and results in lower C_d.[4] An examination of the measured bulk densities of test mixtures shows that the bulk density of dry and 10% water-wet RDX/sand mixtures were essentially the same and averaged 1.2 g/cc. However, the bulk density of 20% water-wet RDX/sand mixtures was significantly higher and averaged 1.7 g/cc. The higher bulk density apparently caused the observed shift between the 10% and 20% moisture parameters.

It is concluded that water-wet or dry RDX/sand mixtures containing ≤15% RDX are not likely to sustain propagation of a shock wave in the BOM Zero Gap test. In contrast, RDX contaminated soils containing >15% RDX may be desensitized to shock stimuli by adding uncontaminated soil to reduce the RDX content to ≤15% RDX.

2. Deflagration to Detonation Transition (DDT) Test Results

Wet and dry RDX/sand mixtures were also tested to define mixture flame reactivity as a function of RDX content. Testing was conducted using the BOM DDT test described in Appendix A and shown in Figure A2. In this test, samples are confined in 3-inch, schedule 80 steel pipe and subjected to flame from a 20-gram igniter. RDX/sand/water compositions reacting explosively were identified using BOM test protocols. Standard probit analysis techniques[5] were used to establish an RDX level in wet and dry sand that has a low (0.5%) probability of reacting to flame in the BOM DDT test configuration.

(a) RDX/Sand/Water Trials

The DDT flame test results are summarized in Table 4 and plotted in Figure 3. All individual trial results are listed in Appendix B, Table B2 for reference. The DDT tests were conducted with 0, 10 and 20% water-wet RDX/sand mixes containing 12 to 28% RDX. Figure 3 shows that dry RDX/sand mixes containing ≤13% RDX should not react explosively when subjected to submerged flame initiation in the BOM test configuration. Twenty consecutive trials with 13% RDX in sand gave negative results, and verified at the 90% confidence level that this RDX/sand composition is unreactive at the ≤0.5% reactivity level.

DDT tests with 10% water-wet RDX/sand mixtures reacted about the same as tests with dry RDX/sand mixtures. Twenty consecutive trials with 10% water-wet RDX/sand mixes containing 12% RDX gave negative results, and verified at the 90% confidence level that this RDX/sand/water composition is also unreactive at the 0.5% reactivity level.

DDT tests conducted with 20% water-wet RDX/sand mixtures determined that these mixtures are not as reactive to flame as other moisture levels tested. Figure 3 indicates that a 20% RDX/60% sand/20% water composition should be 0.5% reactive in the BOM DDT test configuration. Verification tests were not conducted since previous verification tests have consistently been successful in demonstrating low (≤0.5%) reactivity for projected low reactivity compositions. However, all DDT trials conducted with 20% water-wet RDX/sand mixtures containing 25% RDX generated sufficient pressurization to rupture the schedule 80 pipe. Many pipes were split end-to-end and flattened. It is apparent that the 25% RDX/55% sand/20% water composition is reactive to flame in the steel pipe confinement, but that water at the 20% level moderated (slowed down) and prevented a DDT reaction most of the time. Fragmentation of the pipe or cap into two or more separate pieces (BOM criteria) occurred in only three of 10 trials conducted (30% reactive).

During DDT testing, 2 out of 10 trials were negative for dry 25% RDX/75% sand samples. This result is not in agreement with 20% RDX/80% sand tests resulting in 10 positive results out of 10 trials, or the correlation between RDX/sand compositions and percent positive reactions shown in Figure 3. A review of test records show nothing abnormal to indicate the cause of the two negative results. It is concluded that these results may be indicative of test variability.

Table 4

Summary of DDT Test Results for RDX/Sand Mixtures

Composition Tested, %			Average Bulk Density g/cc	No. Trials	Positive Reactions,[b] %
RDX	Sand[a]	Water			
50	50	0	-	1	100
30	70	0	-	1	100
25	75	0	1.28	10	80
20	80	0	1.32	10	100
17.5	82.5	0	1.34	10	70
15	85	0	1.33	10	10
13	87	0	1.43	20	0
19	71	10	1.34	3	100
15	75	10	1.41	10	30
12	78	10	1.49	20	0
28	52	20	1.70	10	80
26.5	53.5	20	1.71	4	25
25	55	20	1.73	10	30
13	67	20	1.77	5	0

[a]Sand ≈ 0.25% water wet.

[b]Pipe and/or at least one end cap fragmented into two distinct pieces.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

Refer to Appendix B, Table B2 for complete listing of tests.

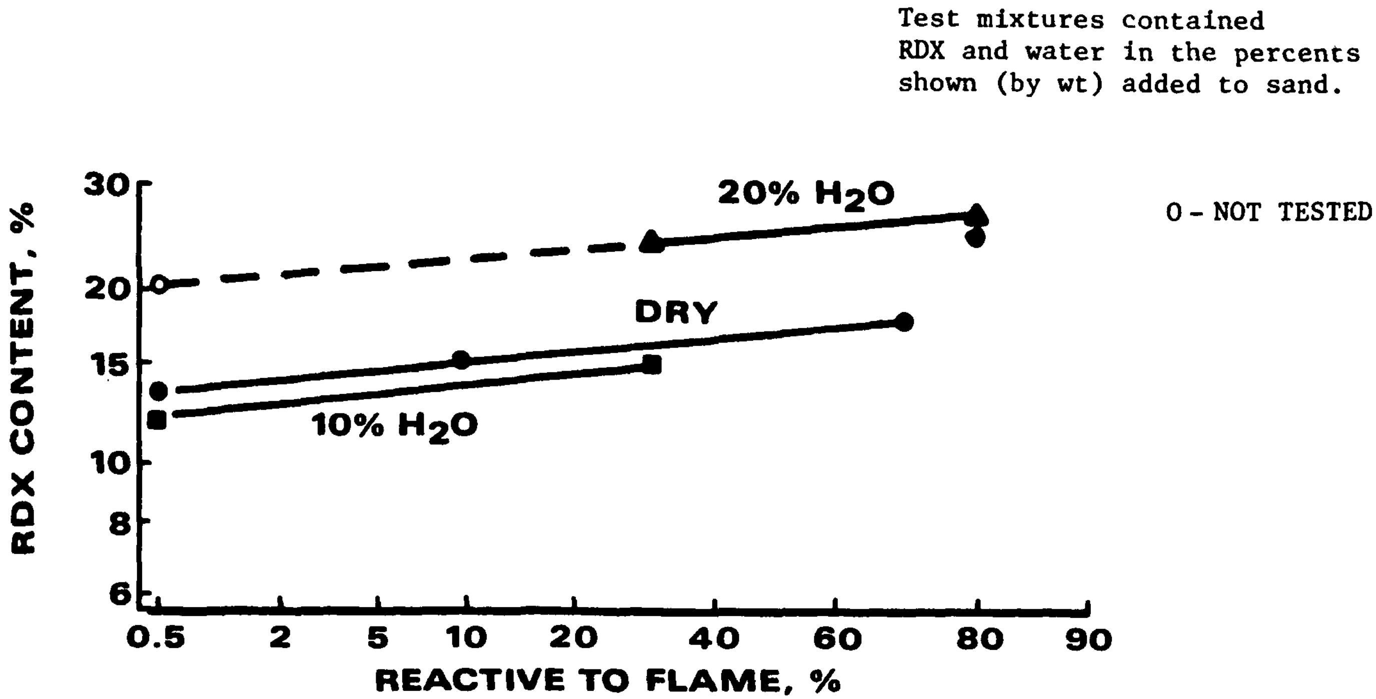

Figure 3 RDX/Sand/Water Flame Reactivity in DDT Tests.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

As determined during Zero Gap tests, the bulk density of 20% water-wet RDX/ sand mixtures averaged 1.8 g/cc and was greater than that of dry and 10% water-wet mixtures which ranged from 1.3 to 1.4 g/cc. The effect of increased density upon the sensitivity of RDX/sand mixtures to flame initiation is not clear based upon DDT test results. It is suspected that the decrease in RDX/sand mixture reactivity experienced with 20% water-wet mixtures is due primarily to the flame quenching effect of the water rather than increased bulk density.

DDT tests at the predicted 0.5% reactive composition levels resulted in "no reactions" in 20 consecutive trials and verified that wet or dry mixtures of RDX/sand containing ≤12% RDX are not flame sensitive in the BOM DDT test. Likewise, the DDT test results also show that reactive RDX contaminated soils containing >12% RDX may be desensitized to flame by adding uncontaminated soil and reducing the RDX content to ≤12% RDX.

·Reactivity Criteria

Predicted 0.5% reactive RDX/sand/water compositions for both the Zero Gap and DDT tests are also plotted on the trimodal plot in Figure 1. This plot identifies dry and settled RDX/sand compositions not reactive to flame and shock in the BOM tests. A dotted line has been drawn to show the maximum percent of water which will be present in settled RDX/sand mixtures and the limits of this study. However, it is likely that any RDX/sand/water composition not reactive to BOM tests in the settled state will also be non-reactive if the same weights of an RDX/sand mixture are suspended in greater amounts of water.

The trimodal plot serves as a quick means to identify explosive-contaminated soils which are reactive or non-reactive to the BOM flame and shock tests based primarily on sample composition. Using this reactivity criteria, comparatively quick and inexpensive chemical analysis of Army lagoon soil samples may be used instead of the more time consuming and expensive BOM Zero Gap and DDT tests to establish the reactivity of soils containing secondary explosives contaminates such as RDX, HMX, TNT, etc.

·Confirmatory Tests With TNT

Dry TNT/sand mixtures were prepared and tested in the BOM DDT and Zero Gap tests to confirm that TNT is no more reactive in these tests (Figure 4) than RDX. Test results are presented in Tables 5 and 6 and discussed in the following.

Zero Gap tests were conducted with a mixture of 19% TNT fines in sand. This composition was selected for comparison with a 19% RDX/81% sand mixture determined previously to react positively to shock 50% of the time in the Zero Gap test configuration (see Figure 4). Test results for this TNT/sand mixture are listed in

Table 5

Summary of Zero Gap Shock Test Results for TNT/Sand Mixtures

Trial No.	Composition, % TNT[a]	Sand[b]	Water	Loading Density, g/cc	Shock Propagation Rate Thru Sample,[c] m/s	BOM Test Criteria[d] Velocity > 1,500 m/s	Hole in Plate	End-to-End Pipe Fragmentation	Type Reaction[e]
1	19	81	0	1.26	g	g	-	+	h
2	19	81	0	1.31	g	g	-	-	-
3	19	81	0	1.26	f	-	-	-	-
4	19	81	0	1.29	3,796	+	-	-	-
5	19	81	0	1.30	2,179	+	-	-	-
6	19	81	0	1.24	1,072	-	-	-	-
7	19	81	0	1.26	1,419	-	-	-	-
8	19	81	0	1.26	1,166	-	-	-	-
9	19	81	0	1.24	1,473	-	-	+	-
10	19	81	0	1.27	2,032	+	-	-	-
11	19	81	0	1.27	2,748	+	-	-	-
			Averages =	1.271	1,921				

[a]Type II, Class 1.

[b]Moisture in sand ≈ 0.25%.

[c]16-in. long steel tubing; 1.44-in. I.D.; 0.22-in. wall thickness.

[d]"+" indicates positive result. "-" indicates negative result. See Appendix A for further description of BOM criteria.

[e]"+" indicates positive result; 2 or 3 criteria are positive and therefore the test indicates sustained propagation of the shock wave through the sample. "-" indicates negative result. See Appendix A for further description of BOM criteria.

[f]Decaying reaction. No steady state velocity in sample.

[g]Propagation rate not recorded - Oscilloscope trigger did not function.

[h]Insufficient criteria to determine if reaction was positive or negative.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

Table 6

Summary of DDT Test Results for TNT/Sand Mixtures

Trial No.	Composition, %			Loading Density, g/cc	Type Reaction[c]
	TNT[a]	Sand[b]	Water		
1	17	83	0	1.32	-
2	17	83	0	1.28	-
3	17	83	0	1.32	-
4	17	83	0	1.33	-
5	17	83	0	1.28	-
6	17	83	0	1.29	-
7	17	83	0	1.32	-
8	17	83	0	1.32	-
9	17	83	0	1.32	-
10	17	83	0	1.30	-
			Average =	1.309	

[a]Type II, Class 1.

[b]Sand ≈ 0.25% water wet.

[c]"+" indicates positive result - that the pipe or an end cap fragmented into 2 or more distinct pieces; "-" indicates negative result. See Appendix A for further description of BOM criteria.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

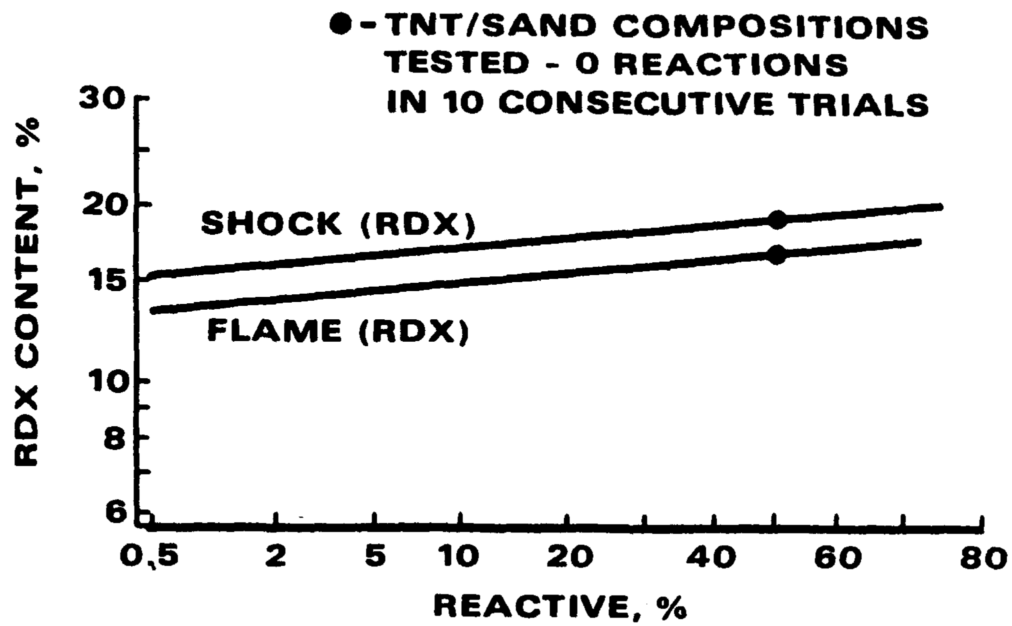

Figure 4 Dry RDX/Sand vs Dry TNT/Sand Reactivity

Source: Hercules Incorporated (Radford Army Ammunition Plant)

Table 5 and show that no positive reactions occurred in 10 consecutive Zero Gap trials. It is concluded that additional (>19%) TNT must be added to TNT/sand mixtures to achieve a reactivity level (50%) equivalent to a 19% RDX/81% sand mixture in the BOM Zero Gap shock test.

Likewise, DDT tests were conducted with a mixture of 17% TNT fines in sand. This composition was selected for comparison with a 17% RDX/83% sand mixture determined previously to react positively to flame initiation 50% of the time in the DDT test configuration (see Figure 4). Test results for this TNT/sand mixture are listed in Table 6 and show that no positive reactions occurred in 10 consecutive trials. It is concluded that TNT is less reactive in the BOM DDT flame initiation test than RDX.

DDT and Zero Gap tests with TNT verified that TNT is less reactive than RDX used to establish Figure 1 reactivity criteria. This study's findings further confirm that the sample reactivity based on compositional analyses can be used to predict the reactivity of contaminated soils in BOM flame and shock tests.

·ANALYSIS

Standard Probit analysis techniques[5] were used to establish an RDX level in wet and dry sand mixtures that has a low (0.5%) probability of reacting to shock in the BOM Zero Gap and DDT test configurations. Ten test trials were conducted for each wet and dry RDX/sand composition tested to obtain percent reaction data; i.e., some of the trials reacted positively. Since only 10 trials were conducted at each RDX level, resulting probabilities of a positive reaction ranged from 10 to 90% in increments of 10. The percent reactive data was plotted on probability paper to convert a logarithmic function between the probability of a positive reaction in the Zero Gap test, and the RDX content in dry and moisture-wet samples tested to a straight line. Then a straight line was drawn through the data and extrapolated to the 0.5% reactive level. The RDX level expected to react positively at the 0.5% reactive level was determined from the extrapolated plot and tested to verify that the wet or dry RDX/sand composition has a low level of reactivity in the BOM Zero Gap test. Verification testing was accomplished by conducting 20 confirmatory trials with the predicted 0.5% reactive composition. Statistically, there was a 90% chance of achieving 0 positive reactions in 20 consecutive trials. Achievement of no reactions in 20 consecutive trials was accepted as proof of low composition reactivity.

WARRANTY AND DISCLAIMER

Within the scope of work, Hercules warrants that it has exercised its best efforts in performing the hazards analysis and testing reported herein, but specifically disclaims any warranty, expressed or implied, that hazards or accidents will be completely eliminated or that any particular standard or criterion of hazard or accident elimination has been achieved if the findings and recommendations of Hercules Incorporated are adopted.

TWE:lmc

abstract

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APPENDIX A

Procedures for the Classification of Explosive Substances

These tests determine whether the substance is explosive. Two tests are used to determine the response of the substance under test to a strong shock wave and to a strong thermal stimulus: The Bureau of Mines Gap Test and the Bureau's Deflagration/Detonation Transition (DDT) Test. The Gap Test subjects the substance to a strong shock from a pentolite donor charge and indicates whether the substance is able to propagate the detonation. In the DDT test, the substance is ignited inside a steel pipe bomb and an observation is made of whether it will continue to burn or will transit to detonation.

DESCRIPTION OF TESTS

1. GAP TEST FOR SOLID MATERIALS

The experimental arrangement used for the gap test is shown in Figure A1. The test sample is contained in a cylinder consisting of a 40.6 cm (16-inch) length of cold-drawn seamless carbon steel "mechanical" tubing 4.76 cm (1.875 inches) in outside diameter with a thickness of 0.56 cm (0.219 inch) and inside diameter of 3.65 cm (1.438 inch). The sample in this test is a granular solid at room temperature that is loaded to the density attained by tapping the cylinder until further settling becomes imperceptible or clay tamped gently into place. The bottom of the cylinder is closed with two layers of 0.0076-cm (0.003 inch) thick polyethylene sheet tied on with gum rubber bands and polyvinyl chloride electrical insulating tape. The sample is subjected to the shock wave generated by the detonation of two cast pentolite density 1.65 g/cm^3 (50/50 pentaerythritol tetranitrate PETN/TNT) pellets 5.08 cm (2-inches) in diameter and 2.54 cm (1 inch) thick. The pellets will be in direct contact with the bottom of the sample tube ("zero gap"). The pentolite pellet is initiated by a U. S. Army Engineers special detonator having a base charge of 0.935 gram (14.4 grains) of the PETN and a primary charge of 0.35 gram (5.4 grains) of diazo dinitrophenol which is butted against the bottom surface of the pentolite pellets and held in place by a cylinder of wood or a metal chip. Instrumentation consists of a continuous rate probe made of a thin aluminum tube with an inner diameter of 0.051 cm (0.02 inch) and a wall thickness of 0.0038 cm (0.0015 inch) with an axial nylon (skip wound) resistance wire of 0.0079 cm (0.0031 inch) diameter, having a resistance of 3.0 ohms/cm (7.52 ohms/inch). The outer tubing is crimped against the inner wire at the lower end, forming a resistor. When this assembly is inserted in a medium that transmits a shock wave, the outer wall crushes against the inner wire as the wave moves up the tubing, shortening the effective length and changing the resistance. If a constant current (usually 0.06 ampere) is made to flow between the outer and inner conductors, the voltage between them is proportional to the effective length and can be recorded as a function of time using an oscilloscope. The scope of the oscilloscope trace is thus proportional to the velocity of the shock wave.

Criteria. Results of this test are considered to be positive if a stable propagation velocity greater than 1.5 km/sec is observed. Additional diagnostic information is provided by a mild steel witness plate 15.24 cm (6 inches) square and 0.3175 cm (0.125 inch) thick, mounted at the upper end of the sample tubing and separated from it by spacers 0.16 cm (0.063 inch) thick. A hole punch cleanly through the plate is an indication of a positive result.

A third source of diagnostic information is the fragmentation of the sample tube. The results of the test are considered to be positive only if the tube is fragmented along its entire length. The fragments range, depending on the material tested, from a few long strips to nearly a hundred small fragments; bulging, cracking, or "banana-peeling" of the acceptor is not considered a positive result.

In most cases, the results of the above three diagnostic methods agree. In some they do not, particularly with low-energy material, e.g., benzoyl peroxide, in which the witness plate is not punched through, but the tube is fragmented; also with certain propellants, the witness plate is punched, but little damage is done to the tube, evidently indicating a localized explosion at the upper end of the tube. In such cases, since there are essentially three criteria (witness plate, tube fragmentation, and rate probe), the result is assessed on the basis of the two criteria that agree; i.e., if any two criteria indicate a detonation, the result is considered positive, but not so if only one indicates a detonation. Some cases of doubtful propagation can also be resolved by using a longer sample tube. As applied in Zero Gap test, a negative result in this test is interpreted to mean that the substance does not have significant explosive properties.

2. DDT TEST

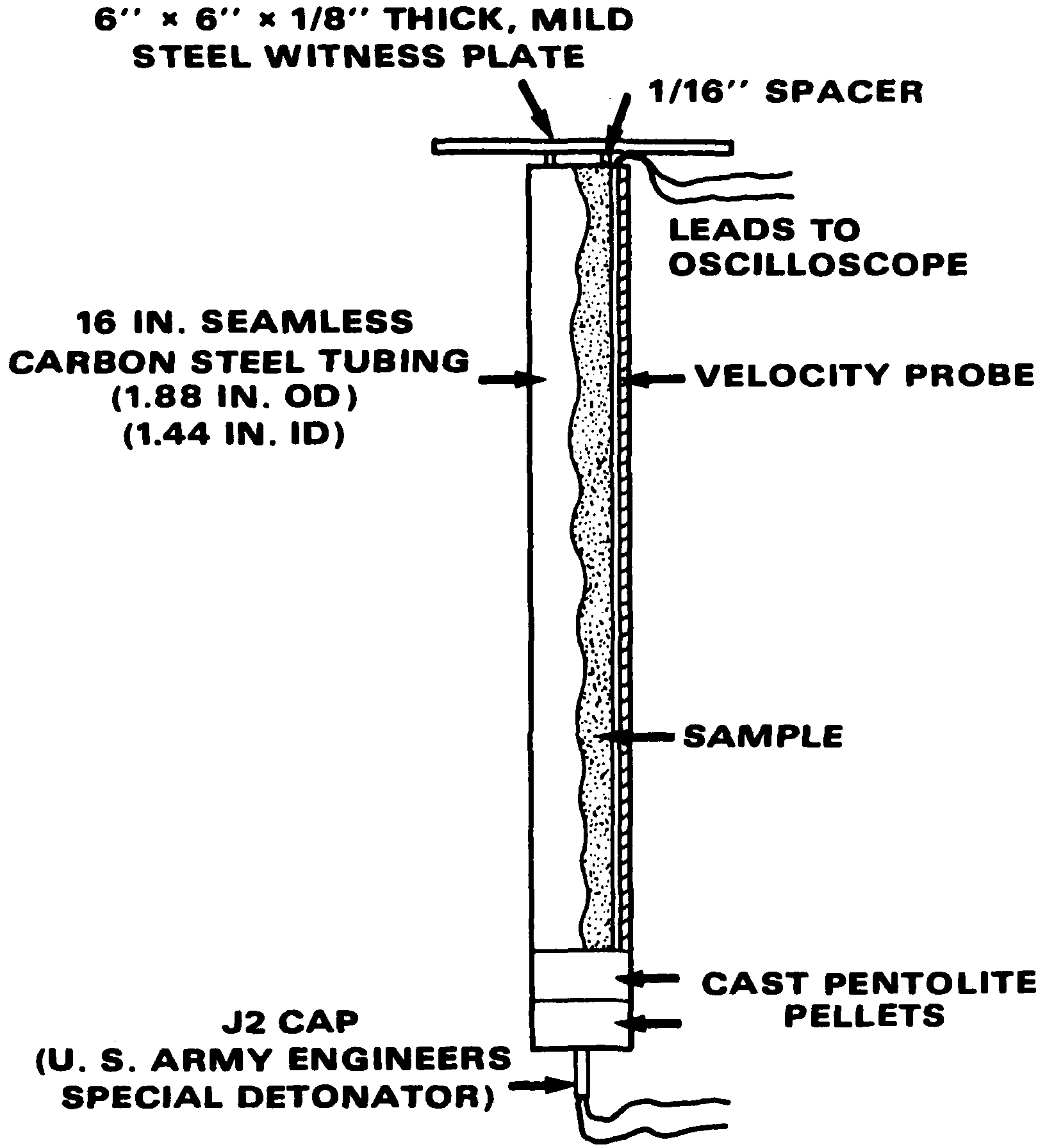
The experimental arrangement for the DDT Test is shown in Figure A2. The sample of material to be tested is contained in a 45.7 cm (18-inch) length of 3-inch diameter schedule 80 carbon steel pipe with inside diameter of 7.37 cm (2.9 inches) and wall thickness of 0.75 cm (0.30 inch), capped at both ends with "3000 pound" forged steel pipe caps.

The sample is subjected to the thermal and pressure stimulus generated by an igniter consisting of a mixture of 50 percent RDX and 50 percent grade FFF_g black powder located at the center of the sample vessel. The igniter assembly consists of a cylindrical container 2.06 cm (0.81 inch) in diameter and of variable length, which is made from 0.0254 cm (0.01 inch) thick cellulose acetate held together by two layers of nylon-filament-reinforced cellulose acetate tape. The length of the igniter capsule is 0.32 cm (0.125 inch) for each gram of igniter material. The igniter capsule contains a small loop formed from a 2.54 cm (1 inch) length of nickel-chromium alloy resistance wire 0.03 cm (0.012 inch) in diameter lead wires 0.066 cm (0.026 inch) in diameter; the overall wire diameter including insulation is 0.127 cm (0.05 inch). These lead wires are fed through small holes in a brass disc approximately 1 cm (0.4 inch) in diameter and 0.08 cm (0.03 inch) thick, which is soldered to the end of 23 cm (9-inch) length of "1/8 inch" steel pipe having a diameter of 1.03 cm (0.405 inch); this pipe is threaded at the outer end and screwed into a threaded hole on the inside of one of the pipe caps. This pipe supports the igniter capsule and serves as channel for the igniter wires. The igniter is fired by a current of 15 amperes obtained from a 20-volt transformer.

Criteria. The criterion currently used in the interpretation of this test is that for a positive result either the pipe or at least one of the end caps be fragmented into at least two distinct pieces, i.e., results in which the pipe is merely split or laid open or in which the pipe or caps are distorted to the point at which the caps are blown off are considered to be negative results. Although it may be argued that a small number of fragments does not indicate the development of a detonation, it at least indicates a very rapidly rising pressure which in a larger sample could lead to development of detonation.

DDT Testing using a 20-gram (308-grain) igniter provides a strong thermal stimulus. Substances that yield a negative result with a 20-gram (308-grain) igniter are interpreted to have no significant explosive properties.

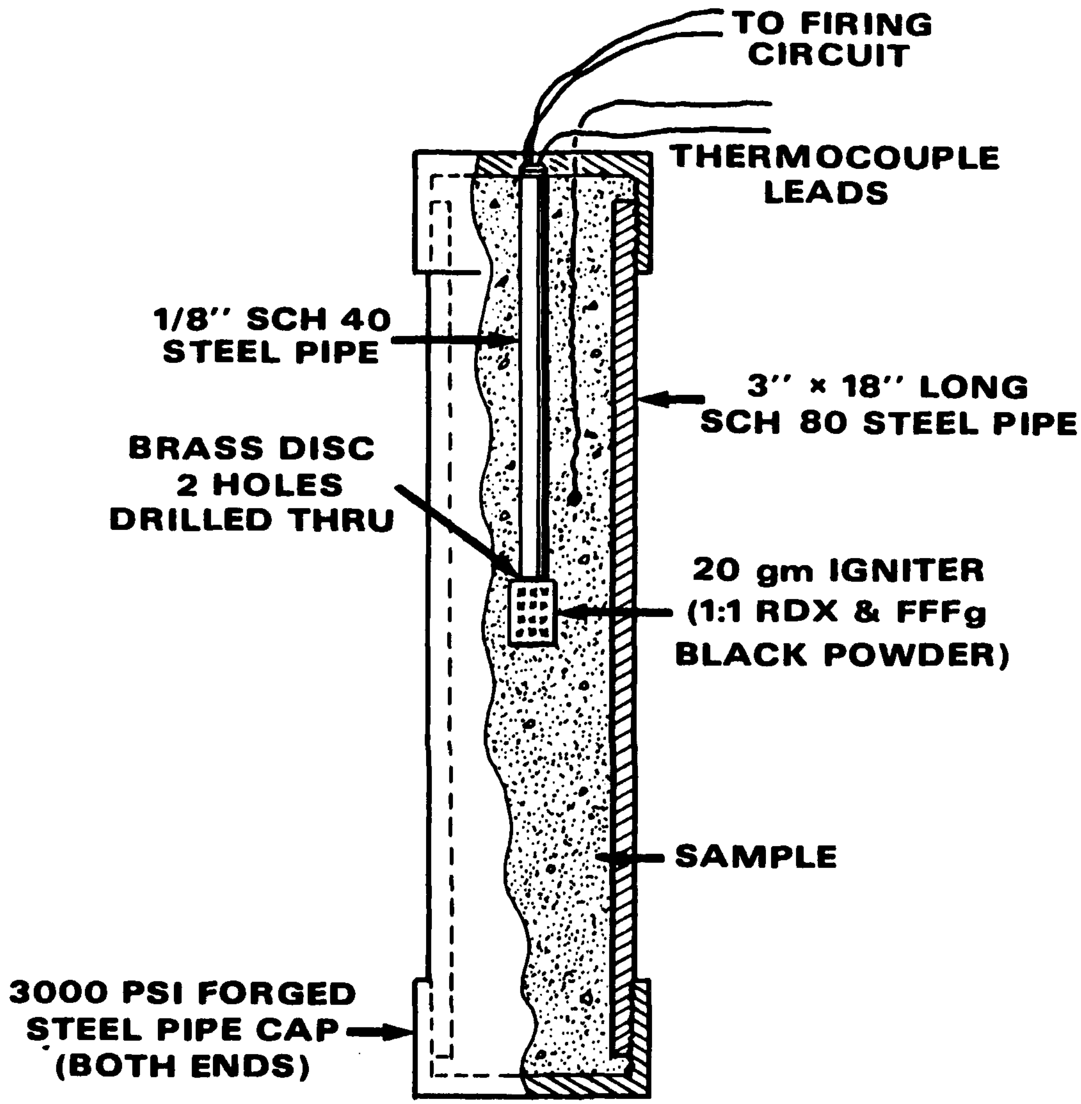
SOURCE: J. Edmund May, Richard W. Watson, and Richard J. Mainiero, U. S. Bureau of Mines, Department of the Interior, Pittsburg, PA 15236.



ZERO GAP SHOCK TEST

Figure A1

Source: U.S. Bureau of Mines, Department of the Interior



DDT TEST

Figure A2

Source: Hercules Incorporated (Radford Army Ammunition Plant)

APPENDIX B

Summary of Bureau of Mines Zero Gap Shock and Deflagration-to-Detonation Test Results for RDX/Sand/Water Mixtures

Table B1

BOM Zero Gap Shock Test Results - RDX/Sand Mixtures

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Shock Propagation Rate Thru Sample,[c] m/s	BOM Test Criteria[d]: Velocity > 1,500 m/s	Hole in Plate	End-to-End Pipe Fragmentation	Type Reaction[e]
1	100	0	0	1.088	6,110	+	+	+	+
2	100	0	0	1.096	5,780	+	+	+	+
3	100	0	0	1.191	6,475	+	+	+	+
4	100	0	0	1.079	6,882	+	+	+	+
5	100	0	0	1.088	6,882	+	+	+	+
6	0	100	0	1.422	1,215	-	-	-	-
7	0	100	0	1.446	f	-	-	-	-
8	0	100	0	1.417	f	-	-	+	-
9	0	0	100	0.997	1,364	-	-	-	-
10	0	0	100	0.981	1,366	-	-	-	-
11	0	0	100	0.981	1,419	-	-	+	-
12	0	80	20	1.879	766	-	-	-	-
13	0	80	20	1.854	f	-	-	-	-
14	0	80	20	1.862	724	-	-	-	-
15	50	50	0	1.207	3,362	+	+	+	+
16	30	70	0	1.306	1,826	+	+	+	+
17	20	80	0	1.294	3,790	+	-	+	+
18	20	80	0	1.352	2,788	+	-	+	+
19	20	80	0	1.352	1,763	+	-	+	+
20	20	80	0	1.372	1,959	+	-	+	+
21	20	80	0	1.347	2,504	+	-	+	+
22	20	80	0	1.310	> 2,500	+	-	-	-
23	20	80	0	1.347	1,763	+	-	+	+
24	20	80	0	1.335	2,101	+	-	+	+
25	20	80	0	1.347	1,417	-	-	-	-
26	20	80	0	1.352	1,826	+	-	+	+
27	20	80	0	1.352	2,029	+	-	-	-
28	18.75	81.25	0	1.298	2,337	+	-	-	-
29	18.75	81.25	0	1.277	3,240	+	-	+	+
30	18.75	81.25	0	1.286	3,644	+	-	-	-
31	18.75	81.25	0	1.273	3,644	+	-	-	-
32	18.75	81.25	0	1.282	3,644	+	-	-	-
33	18.75	81.25	0	1.331	1,829	+	-	+	+
34	18.75	81.25	0	1.261	4,129	+	-	-	-
35	18.75	81.25	0	1.286	4,129	+	-	-	-
36	18.75	81.25	0	1.339	1,419	-	-	-	-
37	18.75	81.25	0	1.306	2,256	+	-	-	-
38	17.5	82.5	0	1.339	> 3,900	+	-	+	+
39	17.5	82.5	0	1.339	> 2,800	+	-	-	-
40	17.5	82.5	0	1.343	g	g	-	-	-
41	17.5	82.5	0	1.343	g	g	-	-	-
42	17.5	82.5	0	1.327	g	g	-	-	-
43	17.5	82.5	0	1.323	2,253	+	-	-	-
44	17.5	82.5	0	1.364	1,892	+	-	+	+
45	17.5	82.5	0	1.335	2,101	+	-	-	-
46	17.5	82.5	0	1.347	3,000	+	-	-	-
47	17.5	82.5	0	1.327	2,594	+	-	-	-
48	15	85	0	1.359	1,313	-	-	-	-
49	15	85	0	1.384	1,471	-	-	-	-
50	15	85	0	1.310	> 3,400	+	-	-	-
51	15	85	0	1.380	> 2,500	+	-	-	-
52	15	85	0	1.331	> 3,000	+	-	-	-
53	15	85	0	1.327	2,891	+	-	-	-
54	15	85	0	1.364	765	-	-	-	-
55	15	85	0	1.319	3,951	+	-	-	-
56	15	85	0	1.393	1,701	+	-	-	-
57	15	85	0	1.372	g	g	-	-	-
58	15	85	0	1.389	g	g	-	-	-
59	15	85	0	1.368	f	-	-	-	-
60	15	85	0	1.347	g	g	-	+	h

Table B1 (cont)

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Shock Propagation Rate Thru Sample,[c] m/s	BOM Test Criteria[d] Velocity > 1,500 m/s	Hole in Plate	End-to-End Pipe Fragmentation	Type Reaction[e]
61	15	85	0	1.327	g	g	-	+	h
62	15	85	0	1.327	f	-	-	+	-
63	15	85	0	1.335	f	-	-	-	-
64	15	85	0	1.323	g	g	-	-	-
65	15	85	0	1.352	f	-	-	-	-
66	15	85	0	1.319	f	-	-	-	-
67	15	85	0	1.327	2,029	+	-	-	-
68	15	85	0	1.327	f	-	-	-	-
69	15	85	0	1.319	f	-	-	-	-
70	25	65	10	1.261	3,644	+	-	+	+
71	25	65	10	1.269	1,894	+	-	+	+
72	25	65	10	1.310	2,256	+	-	+	+
73	25	65	10	1.335	2,693	+	-	+	+
74	25	65	10	1.249	2,256	+	-	+	+
75	23.5	66.5	10	1.306	2,256	+	-	+	+
76	23.5	66.5	10	1.269	3,240	+	-	+	+
77	23.5	66.5	10	1.269	4,314	+	-	+	+
78	23.5	66.5	10	1.286	1,829	+	-	+	+
79	23.5	66.5	10	1.265	3,502	+	-	-	-
80	23.5	66.5	10	1.265	2,604	+	-	+	+
81	23.5	66.5	10	1.224	2,890	+	-	-	-
82	23.5	66.5	10	1.257	1,765	+	-	-	-
83	23.5	66.5	10	1.265	2,420	+	-	+	+
84	23.5	66.5	10	1.219	g	g	-	-	-
85	22	68	10	1.273	3,502	+	-	+	+
86	22	68	10	1.277	2,337	+	-	+	+
87	22	68	10	1.339	2,337	+	-	-	-
88	22	68	10	1.287	1,473	-	-	-	-
89	22	68	10	1.269	3,502	+	-	-	-
90	22	68	10	1.228	3,235	+	-	-	-
91	22	68	10	1.277	1,641	+	-	-	-
92	22	68	10	1.319	2,417	+	-	-	-
93	22	68	10	1.294	1,763	+	-	+	.
94	22	68	10	1.327	2,594	+	-	-	-
95	19	71	10	1.261	3,790	+	-	-	-
96	19	71	10	1.306	1,526	+	-	+	+
97	19	71	10	1.306	2,689	+	-	-	-
98	19	71	10	1.302	1,213	-	-	+	-
99	19	71	10	1.310	3,115	+	-	-	-
100	19	71	10	1.249	1,473	-	-	-	-
101	19	71	10	1.265	1,166	-	-	-	-
102	19	71	10	1.236	4,957	+	-	-	-
103	19	71	10	1.249	2,896	+	-	-	-
104	19	71	10	1.244	3,367	+	-	-	-
105	18.5	61.5	20	1.755	3,957	+	+	+	+
106	18.5	61.5	20	1.764	3,957	+	+	+	+
107	17	63	20	1.784	g	g	+	+	+
108	17	63	20	1.759	3,957	+	+	+	+
109	17	63	20	1.780	3,957	+	+	+	+
110	17	63	20	1.714	603	-	-	-	-
111	17	63	20	1.751	3,441	+	-	+	+
112	17	63	20	1.784	f	-	-	+	-
113	17	63	20	1.677	f	-	-	+	-
114	17	63	20	1.776	f	-	-	+	-
115	17	63	20	1.731	f	-	-	-	-
116	17	63	20	1.764	3,644	+	-	+	+

Table B1 (cont)

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Shock Propagation Rate Thru Sample,[c] m/s	BOM Test Criteria[d] Velocity > 1,500 m/s	Hole in Plate	End-to-End Pipe Fragmentation	Type Reaction[e]
117	16.5	63.5	20	1.739	564	-	-	-	-
118	16.5	63.5	20	1.722	893	-	-	-	-
119	16.5	63.5	20	1.731	724	-	-	-	-
120	16.5	63.5	20	1.751	766	-	-	-	-
121	16.5	63.5	20	1.743	g	g	-	-	-
122	16.5	63.5	20	1.743	564	-	-	-	-
123	16.5	63.5	20	1.784	4,129	+	+	+	+
124	16.5	63.5	20	1.739	684	-	-	-	-
125	16.5	63.5	20	1.751	850	-	-	-	-
126	16.5	63.5	20	1.755	1,119	-	-	+	-
127	16	64	20	1.755	643	-	-	-	-
128	16	64	20	1.764	981	-	-	-	-
129	16	64	20	1.804	850	-	-	-	-
130	16	64	20	1.751	1,315	-	-	-	-
131	16	64	20	1.776	808	-	-	-	-
132	16	64	20	1.772	643	-	-	-	-
133	16	64	20	1.751	766	-	-	-	-
134	16	64	20	1.743	525	-	-	-	-
135	16	64	20	1.755	564	-	-	-	-
136	16	64	20	1.817	808	-	-	+	-
137	16	64	20	1.780	1,072	-	-	+	-
138	16	64	20	1.776	1,116	-	-	+	-
139	16	64	20	1.755	g	g	-	-	-
140	16	64	20	1.747	1,215	-	-	+	-
141	16	64	20	1.764	f	-	-	+	-
142	16	64	20	1.776	f	-	-	+	-
143	16	64	20	1.768	g	g	-	-	-
144	16	64	20	1.764	g	g	-	-	-
145	16	64	20	1.768	937	-	-	+	-
146	16	64	20	1.764	1,072	-	-	+	-

[a] Type II, Class 1.

[b] Moisture in sand ranged from 0.8 to 0.2%.

[c] 16-in. long steel tubing; 1.44-in. ID; 0.22-in. wall thickness.

[d] "+" indicates positive result. "-" indicates negative result. See Appendix A for further description of BOM criteria.

[e] "+" indicates positive result; 2 or 3 criteria are positive and therefore the test indicates sustained propagation of the shock wave through the sample. "-" indicates negative result. See Appendix A for further description of BOM criteria.

[f] Decaying reaction. No steady state velocity in sample.

[g] Propagation rate not recorded - Oscilloscope trigger did not function.

[h] Insufficient criteria to determine if reaction was positive.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

Table B2

BOM Deflagration to Detonation Transition Test Results - RDX/Sand Mixtures

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Type Reaction[c]
1	50	50	0	d	+
2	30	70	0	d	+
3	25	75	0	1.23	+
4	25	75	0	1.39	+
5	25	75	0	1.19	-
6	25	75	0	1.28	+
7	25	75	0	1.27	-
8	25	75	0	1.35	+
9	25	75	0	1.27	+
10	25	75	0	1.26	+
11	25	75	0	1.29	+
12	25	75	0	1.28	+
13	20	80	0	1.42	+
14	20	80	0	1.31	+
15	20	80	0	1.29	+
16	20	80	0	1.32	+
17	20	80	0	1.31	+
18	20	80	0	1.33	+
19	20	80	0	1.30	+
20	20	80	0	1.32	+
21	20	80	0	1.32	+
22	20	80	0	1.28	+
23	17.5	82.5	0	1.29	-
24	17.5	82.5	0	1.33	-
25	17.5	82.5	0	1.35	+
26	17.5	82.5	0	1.33	+
27	17.5	82.5	0	1.34	+
28	17.5	82.5	0	1.36	+
29	17.5	82.5	0	1.34	+
30	17.5	82.5	0	1.35	+
31	17.5	82.5	0	1.35	-
32	17.5	82.5	0	1.34	+
33	15	85	0	1.26	-
34	15	85	0	1.38	-
35	15	85	0	1.34	+
36	15	85	0	1.32	-
37	15	85	0	1.32	-
38	15	85	0	1.32	-
39	15	85	0	1.34	-
40	15	85	0	1.36	-
41	15	85	0	1.30	-
42	15	85	0	1.35	-
43	13	87	0	1.44	-
44	13	87	0	1.43	-
45	13	87	0	1.44	-
46	13	87	0	1.44	-
47	13	87	0	1.47	-
48	13	87	0	1.46	-
49	13	87	0	1.44	-
50	13	87	0	1.40	-
51	13	87	0	1.43	-
52	13	87	0	1.37	-
53	13	87	0	1.42	-
54	13	87	0	1.46	-
55	13	87	0	1.39	-
56	13	87	0	1.39	-
57	13	87	0	1.47	-
58	13	87	0	1.39	-
59	13	87	0	1.45	-
60	13	87	0	1.48	-
61	13	87	0	1.46	-
62	13	87	0	1.35	-

Table B2 (cont)

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Type Reaction[c]
63	19	71	10	1.32	+
64	19	71	10	1.37	+
65	19	71	10	1.32	+
66	15	75	10	1.33	-
67	15	75	10	1.43	-
68	15	75	10	1.42	+
69	15	75	10	1.36	-
70	15	75	10	1.45	-
71	15	75	10	1.43	-
72	15	75	10	1.46	+
73	15	75	10	1.41	-
74	15	75	10	1.43	-
75	15	75	10	1.42	+
76	12	78	10	1.47	-
77	12	78	10	1.51	-
78	12	78	10	1.50	-
79	12	78	10	1.45	-
80	12	78	10	1.51	-
81	12	78	10	1.53	-
82	12	78	10	1.50	-
83	12	78	10	1.44	-
84	12	78	10	1.53	-
85	12	78	10	1.52	-
86	12	78	10	1.50	-
87	12	78	10	1.48	-
88	12	78	10	1.44	-
89	12	78	10	1.48	-
90	12	78	10	1.50	-
91	12	78	10	1.47	-
92	12	78	10	1.55	-
93	12	78	10	1.47	-
94	12	78	10	1.44	-
95	12	78	10	1.53	-
96	28	52	20	1.72	+
97	28	52	20	1.71	+
98	28	52	20	1.69	+
99	28	52	20	1.72	+
100	28	52	20	1.74	-
101	28	52	20	1.71	+
102	28	52	20	1.70	+
103	28	52	20	1.67	-
104	28	52	20	1.67	+
105	28	52	20	1.70	+
106	26.5	53.5	20	1.70	+
107	26.5	53.5	20	1.74	-
108	26.5	53.5	20	1.68	-
109	26.5	53.5	20	1.73	-
110	25	55	20	1.74	-
111	25	55	20	1.66	-
112	25	55	20	1.77	+
113	25	55	20	1.74	+
114	25	55	20	1.74	+
115	25	55	20	1.75	-
116	25	55	20	1.71	-
117	25	55	20	1.76	-
118	25	55	20	1.70	-
119	25	55	20	1.71	-
120	13	67	20	1.85	-
121	13	67	20	1.82	-
122	13	67	20	1.79	-
123	13	67	20	1.66	-
124	13	67	20	1.72	-

Table B2 (cont)

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[a]Type II, Class 1.

[b]Sand ≈ 0.25% water wet.

[c]"+" indicates positive result - that the pipe or an end cap fragmented into two or more distinct pieces; "-" indicates negative result. See Appendix A for further description of BOM criteria.

[d]Not determined.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

APPENDIX C

The attached is a summary of tests conducted at Radford AAP, during the period of 1986 to 1991, to determine the reactivity of explosive contaminated wastes (dirt and ash mixtures) to flame and shock stimuli. These tests used the Bureau of Mines (BOM) Flame and Shock Test Protocols. Each sample listed was subjected to 3 shock and 3 flame tests. If the sample showed reactivity in any single test, it would have been listed as reactive. None of the samples tested showed evidence of reactivity.

As a result of these tests, and the previous tests conducted with RDX, sand and water, it was concluded that all Radford process wastes with very low explosive content are not reactive to the BOM flame and shock protocols. Currently, these process wastes are not tested using the BOM protocols. Reactivity is determined by chemical analysis of the waste samples to verify the low explosive content.

APPENDIX C

Table C1

Compilation of Reactivity Test Results for Contaminated Dirt/Ash/Residue at RAAP [a]

	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
Burning Ground Ash												
1.	-		X	.05	<.005	<.005	<.005	<.005	-	<.005	NC Trace	12/09/85
2.	-		X	.01	<.005	<.005	<.005	<.005	-	<.005	-	12/09/85
3.	-		X	<.005	.02	.05	<.005	<.005	-	<.005	NC Trace	12/09/85
4.	-		X	.04	.05	.28	.01	.11	-	ND	NC Trace 1,2-DNG- .02	07/16/86
5.	-		X	<.001	<.0005	<.0005	.0005	.0005	-	.0005	NC Trace	09/09/86
6.	-		X	.002	.002	.002	.002	.002	-	.002	1-3 DNG- .002 1-2 DNG- .002	09/10/86
7.	-		X	.0607	.014	ND	ND	ND	ND	.095	-	12/09/86
8.	-		X	ND	.001	.001	ND	.01	.001	.001	-	12/22/86
9.	-		X	ND	ND	ND	ND	ND	ND	ND	-	12/28/86
10.	-		X	.014	.004	ND	.0005	.0003	ND	.016	-	12/29/86
11.	-		X	ND	.003	.001	ND	.01	ND	.03	-	01/00/87
12.	-		X	.024	ND	ND	ND	ND	ND	ND	NC Trace	02/00/87
13.	10		X	ND	.2822	.008	.003	.004	.0038	.0066	-	03/00/87
14.	12		X	.004	.067	ND	ND	.007	ND	ND	-	04/08/87
15.	13		X	.03	ND	.02	ND	ND	ND	ND	-	05/05/87

[a] Composit samples of contaminated dirt/ash were subjected to flame and shock tests. Testing was accomplished in accordance with guidelines and criteria described in Bureau Of mines (BOM) report "Procedures for the Classification of Explosive Substances."

Table C1 (cont)

	Test No.	Test Results Expl	Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
Burning Ground Ash (cont)												
16.	14		X	.01	.004	<.001	<.001	<.001	<.001	<.001	-	06/02/87
17.	15		X	.001	.007	<.001	<.001	<.002	ND	.020	-	06/22/87
18.	16		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	07/17/87
19.	18		X	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	NC-<.001	08/25/87
20.	19		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	09/17/87
21.	21		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	09/30/87
22.	22		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	11/03/87
23.	23		X	<.013	<.012	<.0002	<.001	<.001	<.003	<.001	NC-<.001	11/12/87
24.	24		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	12/17/87
25.	25		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	12/10/87
26.	26		X	.009	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	02/01/88
27.	27		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	02/18/88
28.	29		X	<.01	<.01	<.01	<.01	<.01	<.01	<.01	NC-<.01	03/23/88
29.	30		X	.18	.0018	.005	<.01	<.01	<.01	<0.1	-	04/14/88
30.	31		X	.09	<.01	<.01	<.01	<.01	<.01	<0.1	-	05/16/88
31.	32		X	<.01	<.01	<.01	<.01	<.01	<.01	<0.1	-	05/19/88
32.	33		X	.27	.04	<.01	<.01	<.01	<.01	<.01	NC-<.01	05/16/88

Table C1 (cont)

	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
Burning Ground Ash (cont)												
33.	34		X	.011	<.01	<.01	<.01	<.01	<.01	ND	-	06/16/88
34.	35		X	<.01	<.01	<.01	<.01	<.01	<.01	ND	-	07/12/88
35.	37		X	.027	.018	.015	<.01	<.01	<.01	<.01	-	08/18/88
36.	38		X	.0068	.0107	.0107	ND	ND	ND	ND	-	09/01/88
37.	41		X	.03	<.01	<.01	<.01	<.01	<.01	<.01	-	10/10/88
38.	43		X	.88	<.01	<.01	<.01	<.01	<.01	<.01	-	11/08/88
39.	44		X	ND	ND	ND	ND	ND	ND	ND	-	12/20/88
40.	46		X	ND	ND	0.18	ND	ND	ND	ND	-	01/25/89
41.	47		X	.045	ND	.18	ND	ND	ND	ND	-	03/02/89
42.	48		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	-	03/22/89
43.	49		X	<.001	.0018	.0025	<.001	<.001	<.001	<.001	-	04/13/89
44.	50		X	0	0.03	ND	ND	ND	ND	ND	-	05/11/89
45.	51		X	ND	ND	.19	ND	ND	ND	ND	-	06/09/89
46.	52		X	0.02	ND	ND	ND	ND	ND	ND	-	07/19/89
47.	53		X	ND	.0002	.03	ND	ND	ND	ND	-	07/17/89
48.	54		X	.06	ND	ND	ND	ND	ND	ND	-	08/16/89
49.	55		X	ND	ND	ND	.04	ND	ND	ND	-	08/21/89
50.	56		X	ND	.20	.12	ND	ND	ND	ND	-	10/06/89
51.	57		X	.001	.04	ND	ND	ND	ND	ND	-	10/06/89
52.	58		X	ND	ND	ND	ND	ND	ND	ND	-	10/19/89
53.	59		X	.02	ND	.17	ND	ND	ND	ND	-	12/01/89
54.	60		X	ND	.03	.01	ND	ND	ND	ND	-	12/01/89
55.	61		X	.02	ND	ND	ND	ND	ND	ND	-	12/24/89

Table C1 (cont)

	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AkII	2,4,6 TNT	Other	Date Tested
Burning Ground Ash (cont)												
56.	62		X	ND	ND	ND	ND	ND	ND	ND	-	02/01/90
57.	63		X	ND	ND	ND	ND	ND	ND	ND	-	02/01/90
58.	64		X	.02	ND	ND	ND	ND	ND	ND	-	02/15/90
59.	65		X	.002	ND	ND	ND	ND	ND	ND	-	02/15/90
60.	66		X	.02	ND	ND	ND	ND	ND	ND	-	04/05/90
61.	67		X	ND	ND	ND	ND	ND	ND	ND	-	05/01/90
62.	68		X	ND	ND	ND	ND	ND	ND	ND	-	05/03/90
63.	69		X	.02	ND	ND	ND	ND	ND	ND	-	05/10/90
64.	71		X	ND	ND	ND	ND	ND	ND	ND	-	07/25/90
65.	73		X	.0001	.0006	.023	.0003	.0003	ND	ND	-	08/16/90
66.	74		X	.008	ND	ND	ND	ND	ND	ND	-	08/22/90
67.	75		X	0.03	.004	.008	ND	ND	ND	ND	-	09/17/90
68.	76		X	0.004	ND	ND	ND	ND	ND	ND	-	10/04/90
69.	77		X	ND	ND	ND	ND	ND	ND	ND	-	11/02/90
70.	78		X	ND	.02	.06	ND	ND	ND	ND	-	11/29/90
Incinerator Ash												
1.	11		X	ND	ND	ND	ND	ND	ND	ND	-	03/00/87
2.	17		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC- <.001	07/17/87
3.	28		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC- <.001	02/23/88
4.	36		X	.01	<.01	<.01	<.01	<.01	<.01	<.01	ND	08/12/88
5.	40		X	<.01	<.01	<.01	<.01	<.01	<.01	<.01	ND	09/22/88
6.	42		X	<.01	<.01	<.01	<.01	<.01	<.01	<.01	NC- <.01	11/08/88

Table C1 (cont)

	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected: 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
Nitrocellulose												
1. Lagoon #403-2	-		X	ND	ND	ND	ND	ND	ND	ND	NC- 4.4	01/09/89
2. Lagoon #403-3	-		X	ND	ND	ND	ND	ND	ND	ND	NC- 1.1	01/09/89
Hazards Test Area												
1. Sand Recovered After Hazards Stack Test on NOSIH-AA2	-		X	<.0005	<.0005	<.0005	<.0005	<.0005	-	<.0005	1,2 DNG <.0005 1,3 DNG <.0005	
2. Crushed Stone From Hazards Test Pit	20		X	<.001	<.011	.034	.009	.185	<.001	<.001	NC- <.001	09/17/87
3. Crushed Stone From Hazards Test Pit	39		X	.002	.02	.02	.01	.19	.003	.013	ND	09/07/88
Miscellaneous												
1. Hazards Waste Mgt Site 4	45		X	ND	ND	ND	ND	ND	ND	ND	NC- <.01[c] NO_2- 320 Mgm[34] NO_3- 108 Mgm[34] Cyanide- .0052 Mgm[36]	01/16/89
2. Lagoon	-		X	ND	ND	ND	ND	ND	ND	ND	ND	04/19/89
3. Clarifer Tank Study	-		X	ND	.01	.03	ND	ND	.12	ND	NC- .07	12/27/89
4. Activated Carbon from Building 3555	70		X	ND	ND	ND	ND	ND	ND	ND	0.4 Acetone Extractables	06/19/90
5. Incinerator Sludge Tanker #TTL-26	72		X	ND	ND	ND	ND	ND	ND	ND	ND	08/06/90

APPENDIX D

Glossary

Critical Diameter Test	Defined as the greatest container diameter tested which did not sustain propagation of a shock wave introduced at one end of the sample by a high-energy donor.
Critical Height to Explosion	Defined as the greatest material height tested in a given container diameter which did not result in transition from burning to an explosive reaction.
Deflagration to Detonation (DDT) Test	See Appendix A.
Detonation Velocity	Rate at which a shock wave induced at one end of a sample travels through and is sustained by the sample.
Differential Thermal Analysis	A test used to determine at what temperature propellant and explosive samples begin to thermally decompose.
Electrostatic Spark Discharge Threshold Initiation Level	The maximum electrostatic discharge energy which will not ignite propellant or explosive samples.
Explosion Temperature	The temperature which produces an explosion, ignition or decomposition of a sample in 5 seconds.
Frictional Threshold Initiation Level	The maximum frictional (sliding) energy which will not ignite propellant or explosive material.

HMX	Cyclotetramethylene-tetranitramine (also known as Homocyclomite or octagen).
Impact - Threshold Initiation Level	The maximum impact (falling weight) energy which will not ignite propellant or explosive materials.
RDX	Cyclotrimethylene trinitramine (also known as Cyclonite, Hexogen or T4).
Rifle Bullet Test	Determines the reactivity of a sample loaded into a 3 inch pipe nipple and subjected to the impact of a caliber .30 bullet.
TNT	Trinitrotoluene
USATHAMA	United States Army Toxic and Hazardous Materials Agency.
Zero Gap Test	See Appendix A

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ELECTROSTATIC HAZARDS OF EXPLOSIVE, PROPELLANT AND PYROTECHNIC POWDERS

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ABSTRACT

Electrostatic charges developed during the handling and processing of bulk powder such as explosive, propellant and pyrotechnic powders can be sufficient to cause ignition under certain conditions. This paper addresses the electrostatic hazards in terms of electrostatic charging mechanisms, charge accumulation and electrostatic discharge conditions. Processing and handling conditions which are safe from an electrostatic discharge standpoint are identified relative to powder electrostatic characteristics.

INTRODUCTION

To investigate the potential of electrostatic discharge in a bulk powder operation, Safety Consulting Engineers, Inc. conducted extensive studies in electrostatic hazards of industrial and commercial bulk powder handling operations. The studies utilize systematic hazard analysis techniques such as Failure Modes and Effects and Fault Tree Analysis, in addition to new methods of hazard detection.

This paper describes a systematic method to evaluate electrostatic hazards in bulk powder handling operations.

BASIC HAZARDS DEFINITION

Basically, a hazard exists in a powder if the powder develops a dust suspension in air. This powder/air mixture can react explosively once ignited by an electrostatic discharge or other energy source. This reaction would propagate into explosions (primary and secondary) over large areas of manufacturing operations. Electrostatically hazardous conditions may occur if one or more of the following conditions exist:

- Powder is reactive.
- Electrostatic charges develop.
- Electrostatic discharges occur.
- Powder in dust suspension or layer.
- Dust suspension in areas where personnel are not properly grounded.

In our analysis of the overall hazards, our first endeavor is that of determining whether the material is reactive in either a dust layer or a dust suspension. If it is reactive, the next step in the hazard analysis is to determine the minimum energies required to initiate the particular dust material. If we find that the initiation energies are extremely low (low ignition temperature or low electrostatic discharge initiation energies), we then evaluate the powder electrostatic charging characteristics. From this, we can determine whether sufficient electrostatic charge energies can develop in various stages of bulk powder handling to constitute an initiation hazard. The next step in the overall hazard analysis is that of determining ways in which the hazard can develop in the manufacturing or process plant operations and the probabilities that these events will occur. From this information, critical hazards can be defined and corrected before catastrophic consequences can occur. A summary of this methodology is shown in Table 1. The corresponding flow chart utilized to evaluate electrostatic hazards is shown in Figure 1.

TABLE 1

BULK POWDER HANDLING ELECTROSTATIC
HAZARD ANALYSIS METHODOLOGY

Step 1 - Determine Powder Reactivity In:

- Dust Cloud
- Dust Layer

Step 2 - Determine Minimum Electrostatic Discharge Energy To Ignite Powder.

Step 3 - Characterize Powder Electrostatic Charging Characteristics

Step 4 - Determine Powder Electrostatic Dissipation Characteristics

Step 5 - Analyze Bulk Powder Handling System For Electrostatic Charge Buildup, Storage and Discharges

Step 6 - Define Ways That The Electrostatic Hazards Can Arise and Assign Probabilities

Step 7 - Define Critical Electrostatic Hazards

Step 8 - Define And Apply Corrective Actions.

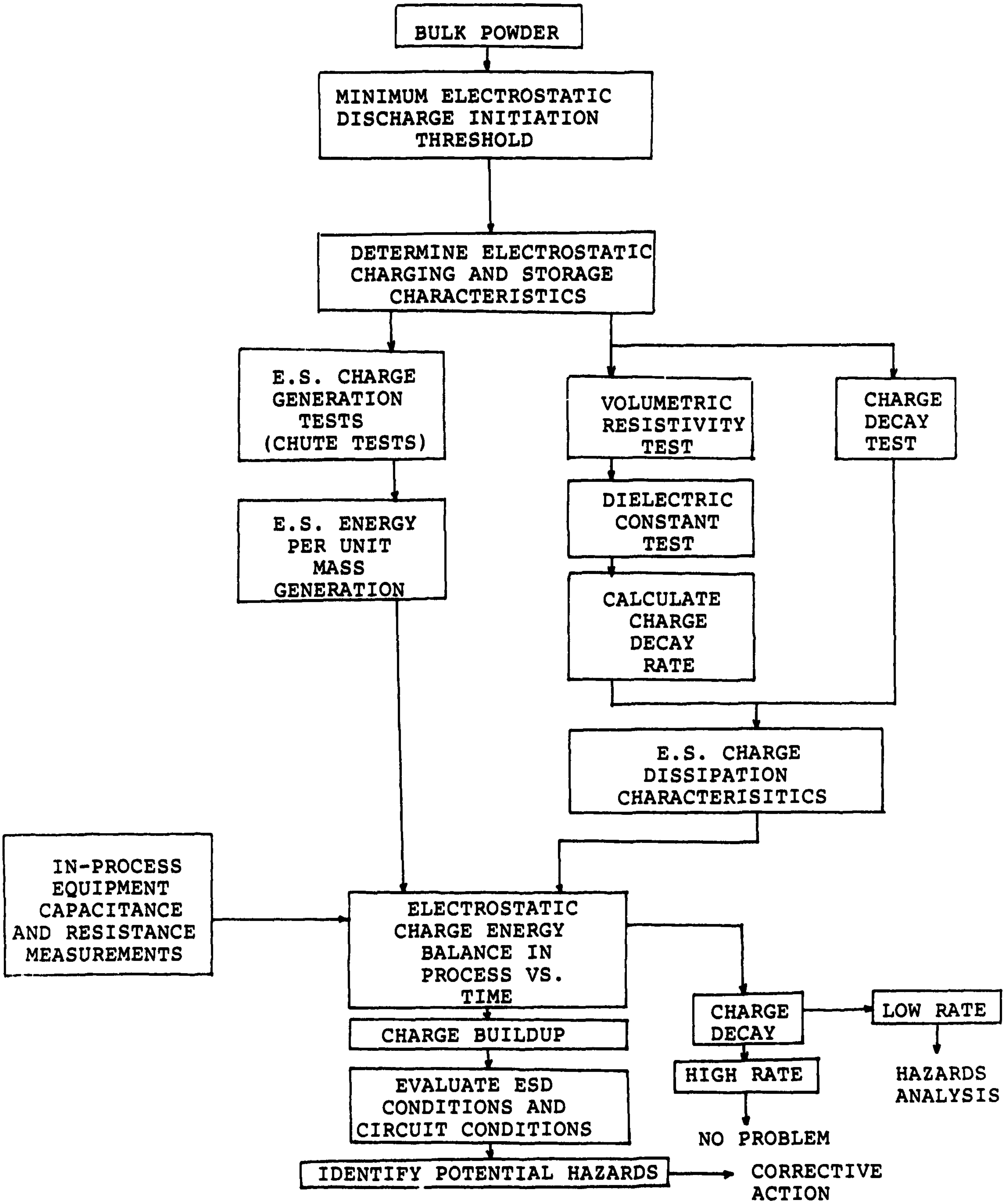

Figure 1. Flow chart utilized to evaluate electrostatic hazards.

POWDER CHARACTERIZATIONS

A. Reactivity Tests

Normally at Safety Consulting Engineers, Inc., bulk powder is first characterized to determine if it is reactive by utilizing a 20-liter spherical dust explosion chamber where various powder concentrations are lofted into the air to determine if they are explosive. See Figure 2 for an illustrated setup.

Once certain powder concentrations have been found which are reactive, minimum electrostatic discharge initiation energy tests are conducted on the powder dispersions. In our testing, we have found that not only the energy, but the energy rate in the electrostatic discharge controls the initiation threshold of dust/air mixtures. Testing is performed using three different circuit arrangements [1]. The electrical circuit configurations illustrated in Figure 3 consist of the following:

- capacitive circuit
- capacitive-resistive circuit
- capacitive-inductive circuit

The capacitor circuit consists of a high-voltage supply (0-30 KV) connected to an isolating resistor (300 MΩ) and then connected to a high-voltage capacitor (from 0.1 μF to 0.0001 μF). One capacitor is connected to the stainless steel electrodes and the charging/discharging of a capacitor is established by vacuum relay. The capacitive (discharge) circuit, contains no additional resistance (except line resistance which is negligible).

The capacitive-resistive circuit consists of parts described above. In addition, circuit resistances of 20 KΩ, 100 KΩ, 1 MΩ, and 2 MΩ can be connected to the discharge terminal. At this configuration, when the charged capacitor is discharged to the electrode (spark) the arc time is affected by the resistors used.

The capacitive-inductive circuit consists of a voltage supply (0-500 VDC) and is connected to a series of capacitors (5, 10, 20, 50 and 75 μF). The output of one or more capacitors is connected to the high-voltage transformer input (0-12,000 V). The output of the high-voltage transformer is used to create an arc to the electrodes. The resistor (0, 20, 100, 1MΩ) is added at the discharge part of the circuit to alter the current flow during spark. The discharging of a charged capacitor(s) is accomplished by using a high voltage-high speed vacuum relay.

Spark energy is calculated by direct measurements of voltage, current and spark time. These parameters are measured by using voltage and current probes.

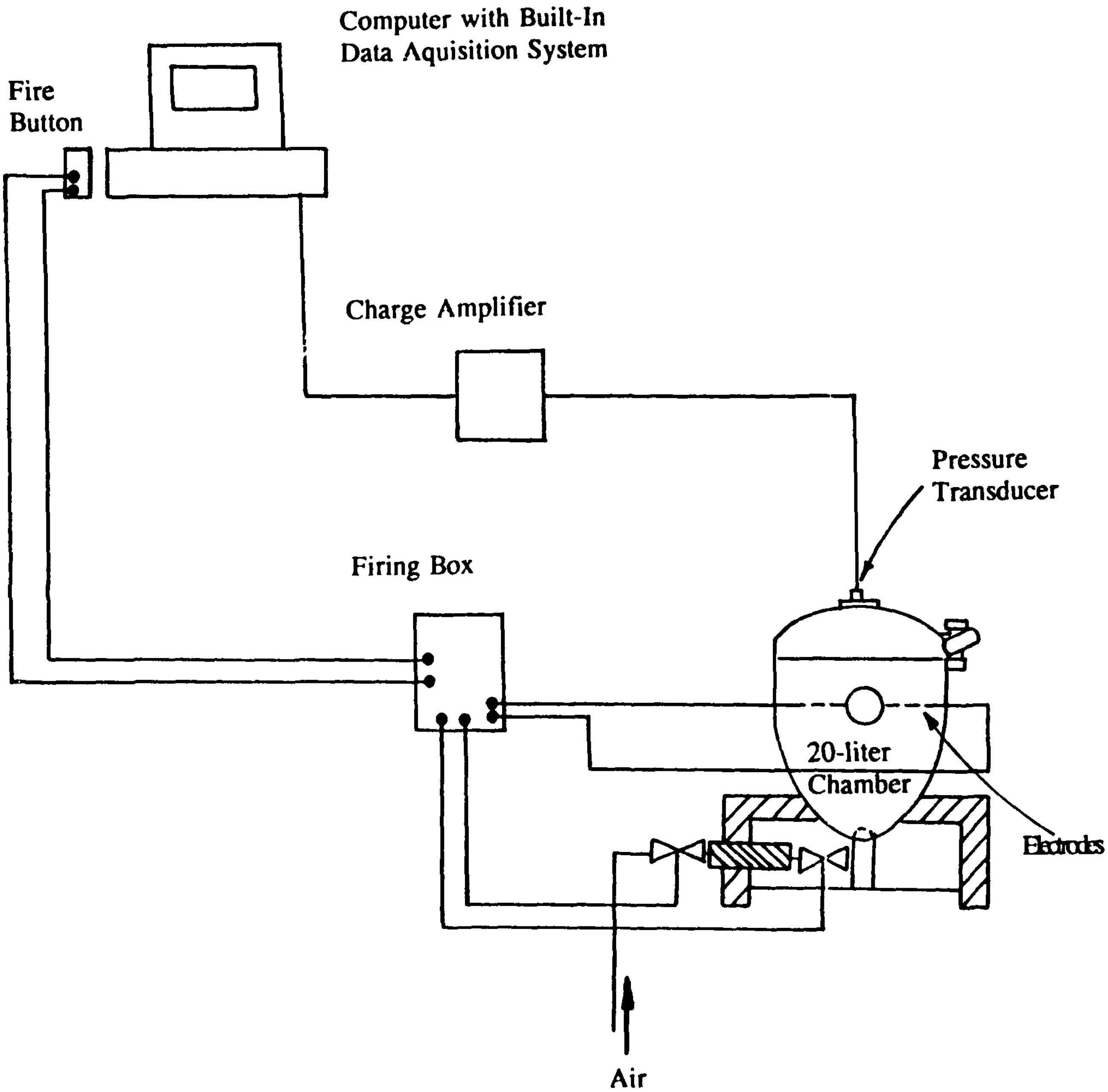

Figure 2. 20-liter spherical chamber setup.

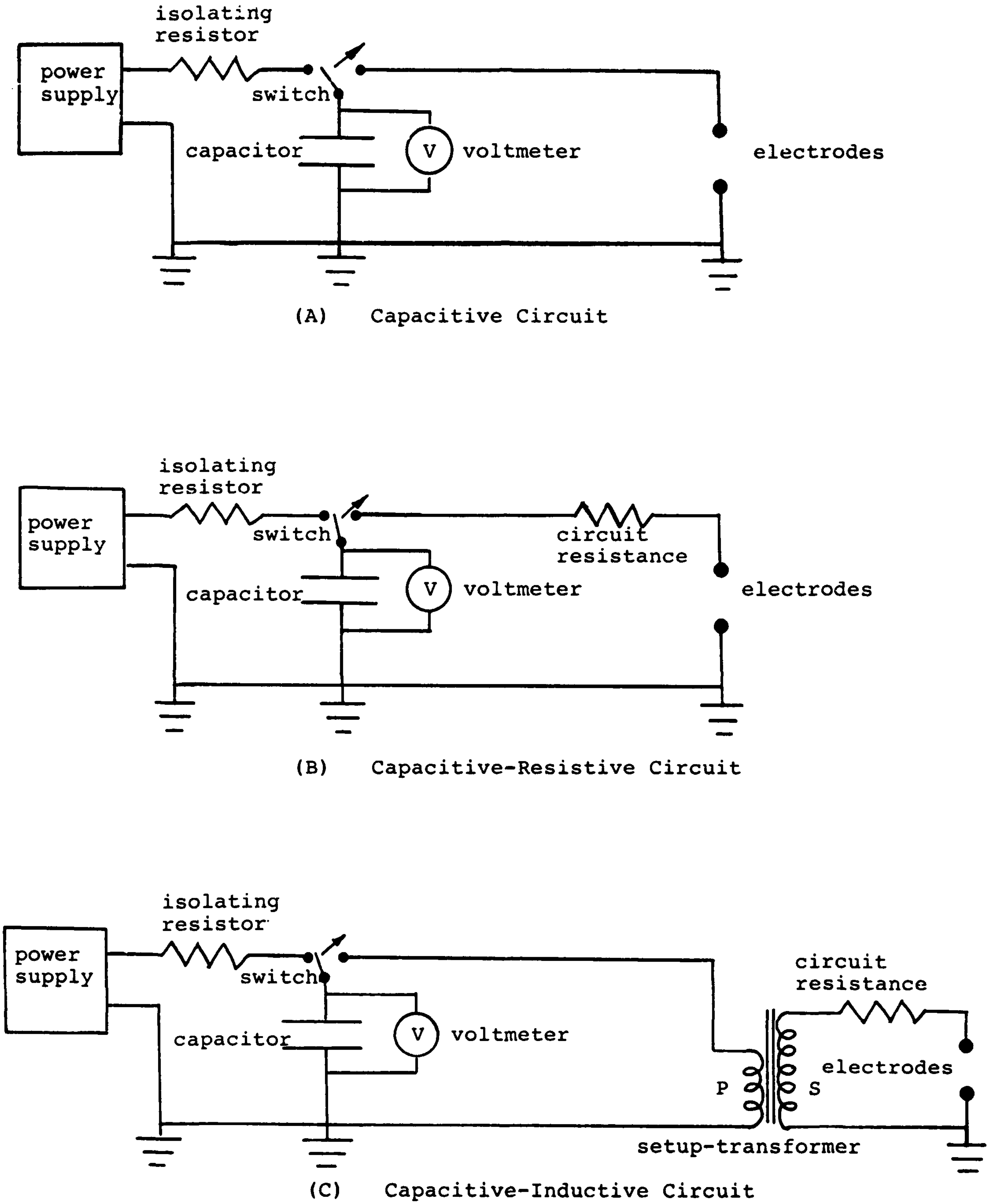

Figure 3. Electrical circuit configurations for electrostatic sensitivity testers at Safety Consulting Engineers, Inc.

The test chamber used for the test is a 1.2-liter Hartmann chamber [2]. Two painted stainless steel electrodes insulated with Teflon were positioned inside the chamber. Electrostatic discharge energy initiation tests on lycopodium dust were performed using the setup described above. Results are tabulated in Table 2.

B. Powder Charging Characteristics

Once the powder is found to be very reactive, we conduct a series of tests to determine its electrostatic characteristics. The first test that we conduct is usually an electrostatic charging test to evaluate the materials' tendency to generate an electrostatic charge and to hold that charge. Basically, this test utilizes an incline chute of various angles whereby powder is poured down the chute and collected in an aluminum pail. The charge and energy developed in this mode of operation is measured by utilizing a high-voltage probe and electrometer. A typical setup is illustrated in Figure 4. In this test, we utilize two or three quantities of powder and measure the energy per unit weight of powder to determine its charging efficiency. Actually, the charge per unit weight of powder is also utilized as a comparison.

C. Electrostatic Charge Dissipation

To determine the ability of the powder to drain its charge once developed by powder motion, we run volumetric and surface resistivity measurements on the powders. In addition, we conduct a test to determine the dielectric constant on powders of unknown values. With these parameters defined by tests, the powder decay time can be measured. The relaxation time or powder decay time is usually calculated by the following equation:

$$t_r = 8.85 \times 10^{-14} \epsilon \sigma (\text{sec})$$

Where:

ϵ = dielectric constant or permitivity

σ = volumetric resistivity (ohm-cm)

This is the time it takes for the charge to dissipate by leaking through the powder. These characteristics are very helpful to determine how long it will take powder to dissipate its charge once it has generated the charge. These parameters are especially important for dust suspensions developed in the bulk handling operation processes.

D. Dust Suspension Characteristics

Dust suspension characteristics and time-of-fall calculations should be made based on particle size and crystal densities of powder. With these two parameters, the settling

TABLE 2

MINIMUM ELECTROSTATIC DISCHARGE (ESD) ENERGY
FOR LYCOPODIUM USING DIFFERENT
TYPES OF TESTERS

ESD TESTER CIRCUIT CONFIGURATION	RESISTOR (KΩ)	STORED ENERGY (mJ)	SPARK ENERGY (mJ)
Capacitive - Inductive	0	56.3	15.4
	20	36.0	3.2
	100	42.3	4.3
	1000	49.0	7.5
	5 μF capacitor 1/8" gap		
Capacitive - Resistive	20	140.6	8.1
	100	160.0	8.4
	1000	422.5	3.4
	0.005 μF capacitor 1/8" gap		
Capacitive - Resistive	20	225.6	2.0
	0.005 μF capacitor 3/8" gap		

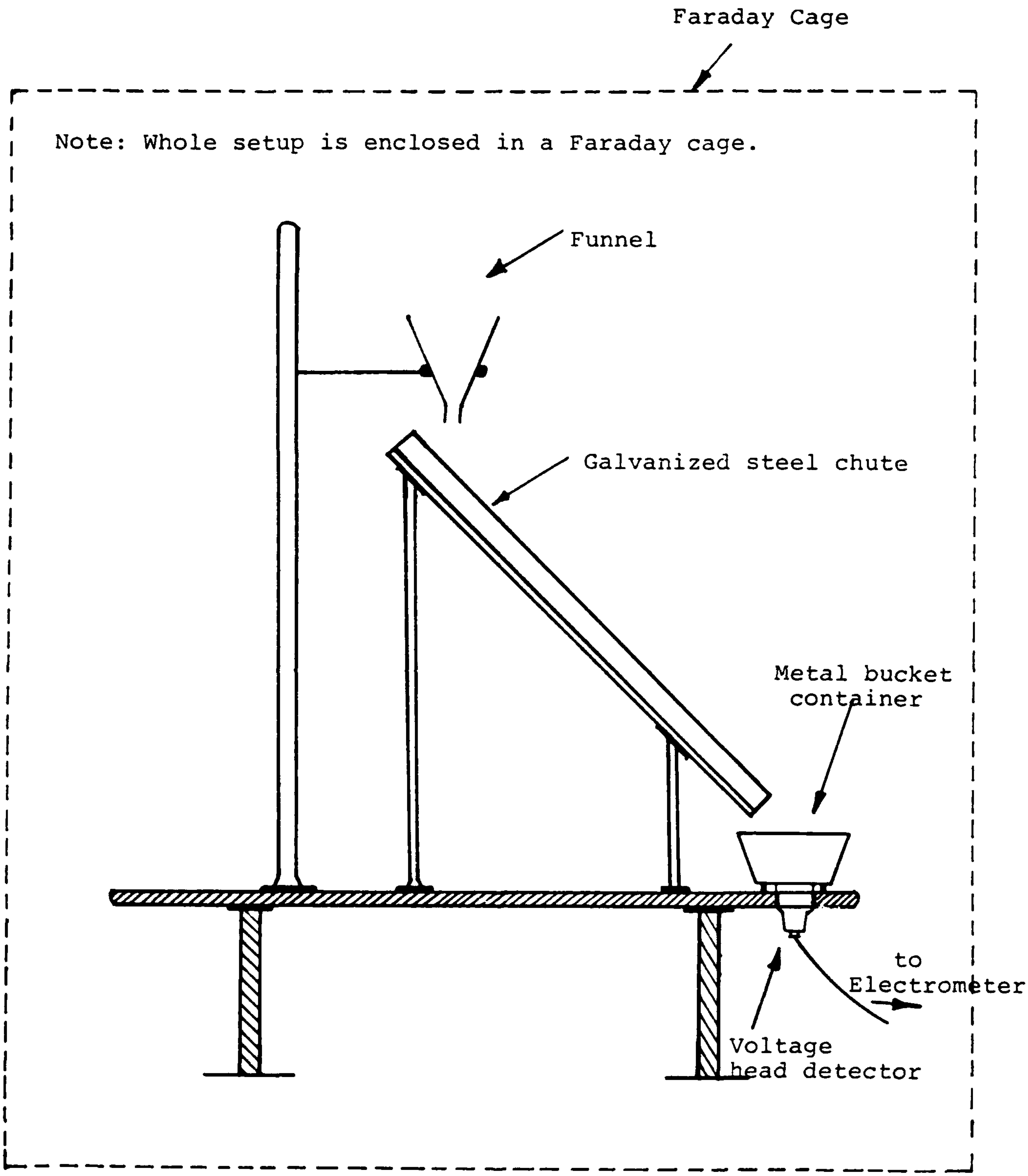

Figure 4. Electrostatic charging test setup.

velocity of the powder can be calculated.

HANDLING EQUIPMENT AND PERSONNEL CHARGE STORAGE AND DISCHARGE

The next step in the hazards evaluation is that of reviewing through process equipment to determine where electrostatic charges can store and where discharges could occur. If grounding and bonding is not adequate in a system, very high electrostatic charges could develop within isolated parts and components such as hoppers, bins, etc.

A. Personnel Hazards

Personnel in the bulk powder handling operations also constitute a major electrostatic hazard in that they can store sufficient energies to cause initiations of dust explosions. It has been found by previous work [3], that a person can store up to 100 millijoules if he/she wears insulating sole shoes in dry process environments. Thus, to prevent dust explosions, all personnel should be properly grounded and relative humidities controlled (greater than 70%) so that electrostatic charges can be reduced or eliminated.

B. On-Site Electrostatic Charge Tests

Safety Consulting Engineers, Inc. has done extensive testing on site to measure the electrostatic charging and storage of bulk powders. Usually, a good rule of thumb for electrostatic charging of bulk powders is as follows:

> THE GREATER THE POWDER AGITATION, THE GREATER THE ELECTROSTATIC CHARGING.

Thus, we expect that air-conveying of powders on high velocity and high powder-to-air ratio would yield high electrostatic charging characteristics.

A more unique problem in bulk powder handling is that of determining the amount of electrostatic energy stored on insulating containers such as bins, etc., made from polyester reinforced fiberglass. We know from electrostatic measurements that a great deal of electrostatic energy can develop on these types of insulators. There has been much debate regarding the amount of electrostatic discharge energy which could be drawn off of an insulating bin. In our recent studies for various industrial clients, we have conducted on-site electrostatic discharge energy measurements to determine the level of energy which could be discharged by bringing a grounding rod in proximity with the insulating bin. We measured the electrostatic energy by two methods. The first method is that of utilizing a current and voltage probe combination attached to an oscilloscope (100 MHz frequency response) and integrating the current and voltage curves to determine the actual energy in the electrostatic discharge. The second method that we utilized is that of taking an electrode, tying it to a Faraday cage type of bucket suspended above a Keithley high-voltage probe so that we can actually measure the electrostatic energy accumulated on the pail after the electrode has contacted the surface of the insulating bin. Previous research has shown that up to 2×10^{-9} coulomb/cm^2 charge densities can be developed on polyethylene materials of 225 cm^2 area. Sufficient electrostatic energy was liberated when a grounded rod touched it to ignite a gas/air mixture [4].

CONCLUSIONS

This paper outlines several methods to evaluate electrostatic hazards of bulk powder by analyzing their reactivity, their electrostatic charging characteristics, and evaluating the electrostatic stored energy and discharge characteristics of in-process equipment and personnel. Electrostatic discharge energies of as great as 1 to 5 Joules have been measured on in-process equipment. As much as 100 millijoules of electrostatic energy can be discharged from the human body in proximity of a dust environment. Most reactive industrial dusts can ignite in energies down to less than 2 millijoules.

As discussed earlier, ESD energy varies with different conditions. Precaution is recommended when testing dust material to determine the minimum electrostatic discharge (ESD) energy.

Electrostatic hazard analyses of complex bulk powder handling systems can be very complex. Extreme caution should be exercised in the analysis to be certain that all electrostatic hazard potentials have been identified. Corrective actions should also be carefully reviewed so that they do not introduce additional system hazards.

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DEVELOPMENT OF RF-INSENSITIVE ELECTRIC PRIMERS

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ABSTRACT

The Naval Surface Warfare Center, Dahlgren Division (NSWCDD), is the lead technical activity in an effort to develop electric primers which are insensitive to radio frequency (RF) energy. The program is specifically directed at solving the Navy's worst Hazards of Electromagnetic Radiation to Ordnance (HERO) problem, 20 mm ammunition used with the PHALANX Close-In Weapon System (CIWS). The technical approach highlights a novel semiconductor device, which is used as an ignition element for the primer. By eliminating the need to ignite the mix directly with the firing voltage, it is possible to replace the electrically sensitive mix with a less sensitive, non-conductive mix. This significantly reduces the risk of initiation from stray RF energy. Results from direct current (DC) firing, RF sensitivity, and interior ballistics tests are very encouraging. RF-insensitive electric primers will greatly improve the safety of electrically primed ammunition without the need to limit the emissions of critical shipboard surveillance and communications equipments.

1.0 BACKGROUND

The incompatibility of electrically initiated ordnance with radiated electromagnetic environments (EMEs) poses an enormous safety problem for the U.S. Navy. This problem is most severe during shipboard operations as ordnance is transported and/or handled while being exposed to high levels of radiation from radars and communications equipments. The Navy's concern for the Hazards of Electromagnetic Radiation to Ordnance (HERO) problem is evidenced by the vast amount of resources that are expended annually to reduce the possibility of a HERO accident. Much of this effort is concentrated on measuring EMEs at selected ship and shore station ordnance operating areas and on assessing the sensitivity of specific weapon systems/ordnance to those environments. Another important part of the HERO program is concerned with what might be called "protection engineering", i.e., the application of effective design practices and hardening technologies[1]. This effort includes participation in design reviews and consulting with manufacturers to ensure that good grounding, shielding, and filtering techniques are incorporated. For ordnance which employs bridgewire type electroexplosive devices (EEDs), such techniques, when used properly, generally provide adequate protection against even the most severe EMEs found aboard U.S. Navy ships. The result is HERO SAFE ordnance, which can be handled aboard ship without the need to limit the output of critical radar and communications transmitters.

However, the M52A3B1 Electric Primer represents a type of EED so sensitive to RF energy that no intrinsic measures have been developed that provide adequate protection against accidental initiation. When configured in MK 149 PHALANX Close-In Weapon System (CIWS) ammunition (Figure 1), these conductive composition primers constitute the root cause of a severe HERO problem. The problem is exacerbated because:

(a) The primers are extremely sensitive to RF energy across a wide frequency range.

(b) PHALANX ammunition is found throughout the Fleet as almost all ships have one or more PHALANX systems.

(c) A combination of emission control (EMCON) and ammunition handling restrictions[2] are necessary to reduce the risk of RF-induced (accidental) initiation; such restrictions can be detrimental to the ship's warfighting capability.

For these reasons, PHALANX ammunition is widely regarded as the Navy's worst HERO problem.

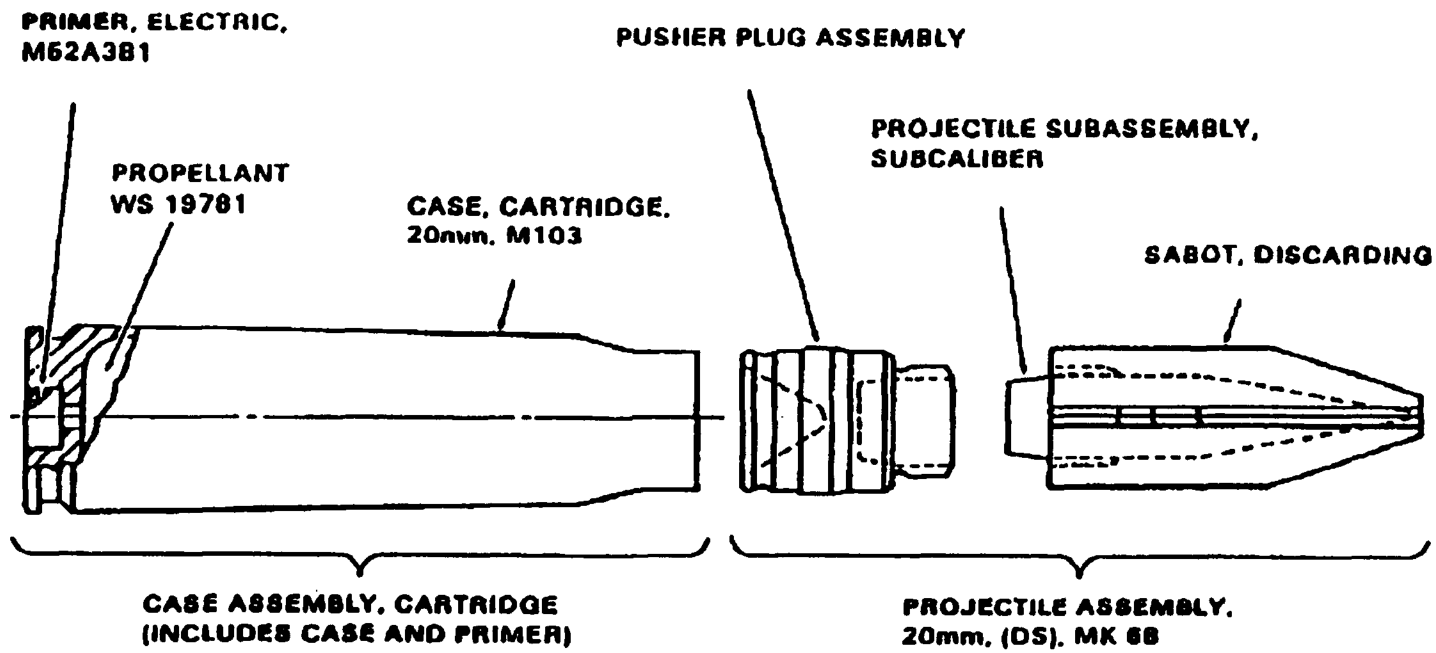


Figure 1. MK 149 Cartridge (with M52A3B1 Electric Primer)

Some measure of protection is afforded by the MK 7 Radiation Hazard (RADHAZ) link. PHALANX ammunition is normally stored and transported in the linked configuration and is de-linked only as it is loaded into the PHALANX ammunition feed system. As shown in Figure 2, each link has a metal tab which extends across the base of the cartridge and the primer. Preventing physical contact with the primer button is the single most effective protective measure against RF actuation, aside from turning off the sources of the radiation. Unfortunately, the metal tab creates a resonance condition at certain radar frequencies, actually making this configuration more susceptible. In addition, the tab is known to increase the chance of gun jams during loading operations. However, the biggest drawback with this form of protection is that it isn't "built into" the ammunition. Once a cartridge is de-linked, whether it is in the ammunition feed system or outside the gun altogether, there is no way to prevent incidental contact of the primer with conducting objects; such contact greatly increases RF pickup into the primer much like a receiving antenna enhances the pickup to an FM radio. Bare or loose cartridges can be actuated at very low radiation levels if the primer is touched or even brought close to electrically conductive objects, e.g., screwdrivers, components of the gun system feed system, fingers, etc. The most reliable form of protection does not depend on links, shrouds, enclosures, or other external hardware - intrinsic protection is clearly the best way to ensure the safety of electrically primed ammunition.

In the past, attempts to develop a "HERO SAFE" primer were unsuccessful because of failure to achieve an adequate level of RF protection or because the primer's firing reliability had been compromised. More recently, however, the Navy has employed semiconductor technology to develop an RF-hardened primer that also satisfies firing reliability requirements. This paper will describe the approach and summarize the positive test results to date.

2.0 THE SEMICONDUCTOR IGNITOR PRIMER

2.1 Hardening Design Concepts

The RF-insensitive primer is best explained as a modification to the existing M52A3B1 design, which is illustrated in Figure 3. The firing voltage (from the firing pin) is applied to the brass button, and ground return is provided through the brass primer cup, which is common with the cartridge case. The firing circuit's capacitive discharge current thus flows directly through the conductive FA 874 explosive mix. The extreme electrical sensitivity of the mix accounts for the very low firing

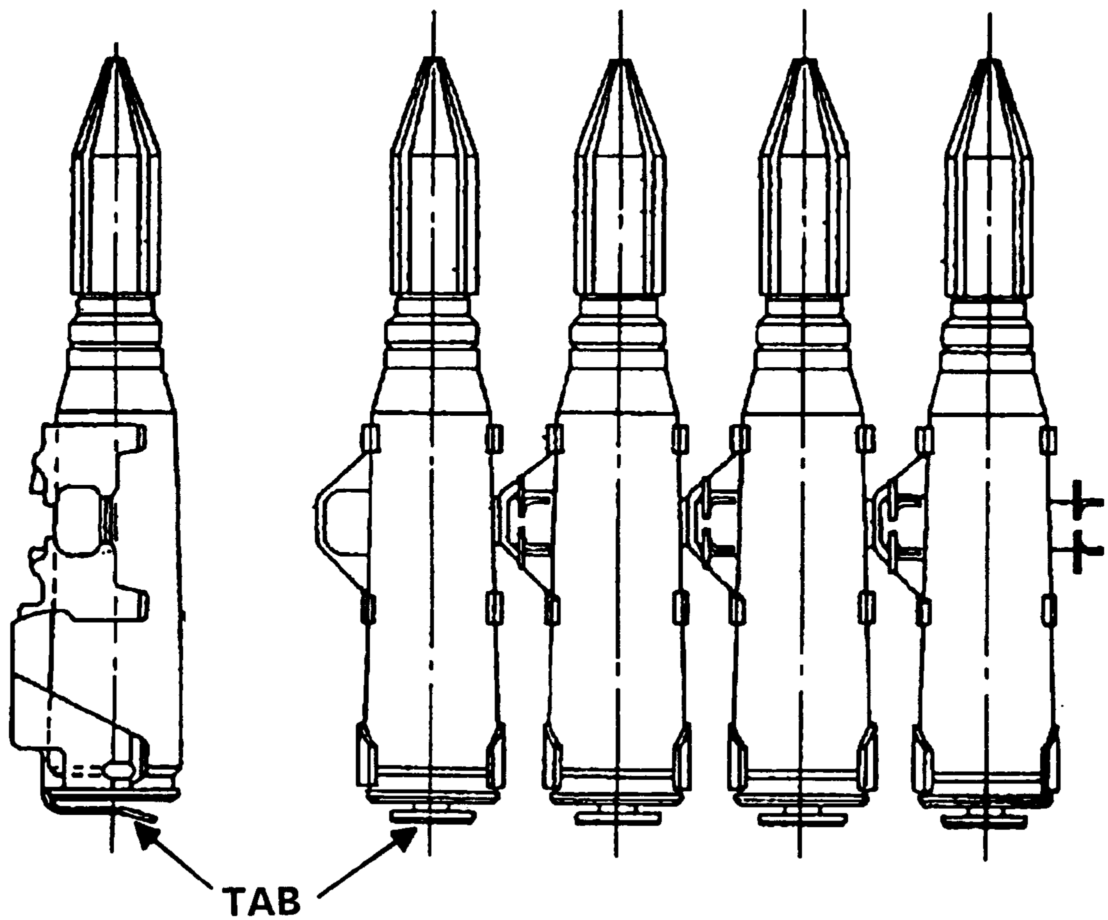


Figure 2. MK 7 RADHAZ Links

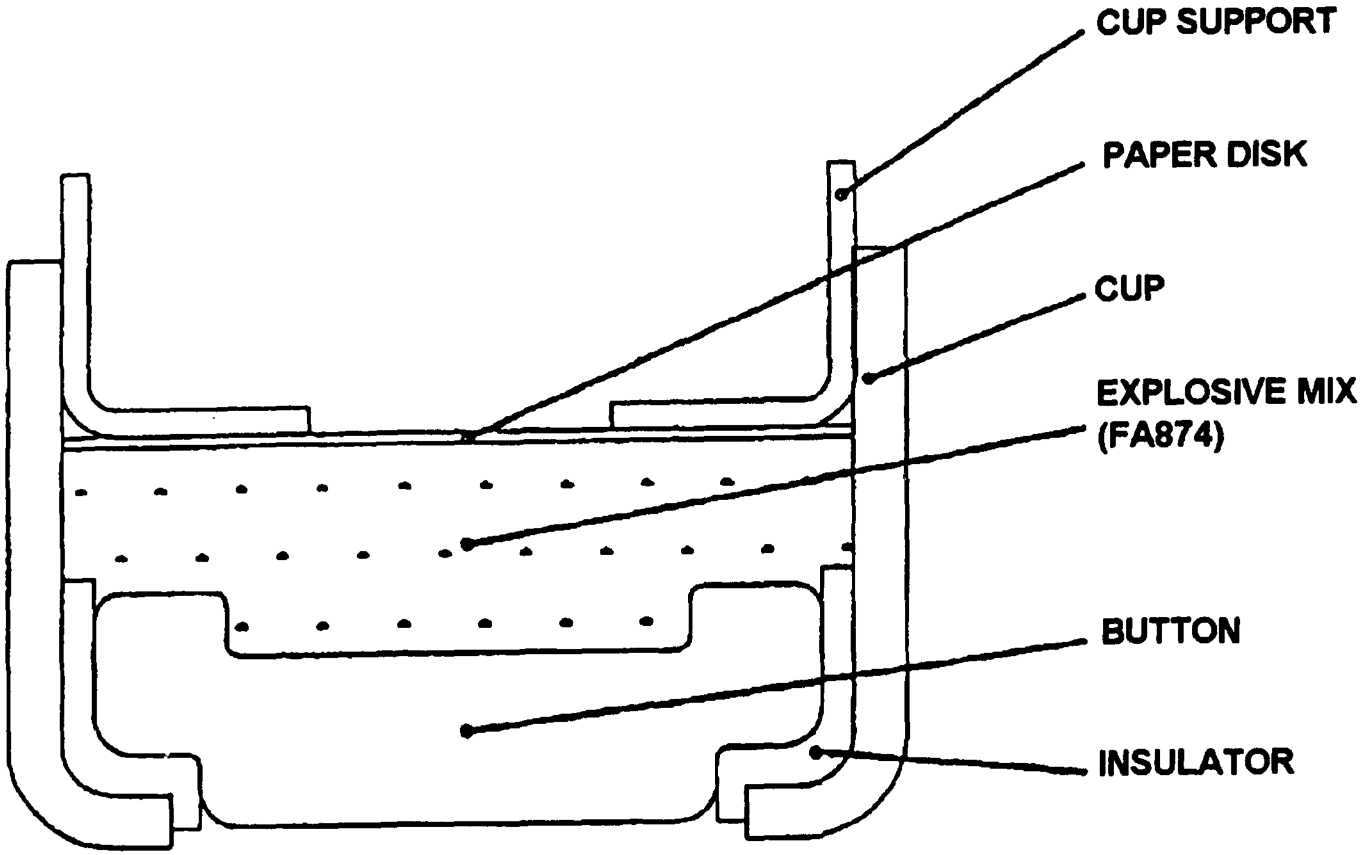


Figure 3. M52A3B1 Electric Primer

energy threshold, less than 50 mJ, which promotes a high degree of (DC) firing reliability. Unfortunately, the mix cannot discriminate against stray RF energy and is subject to unintentional initiation if such energy propagates from various shipboard emitters to the primer. Conceivably, the primer could be desensitized by blocking the flow of RF energy into the mix; however, the method(s) used must not interfere with the path for (legitimate) DC firing voltages. An alternative is to simply replace the FA 874 with another mix that is less sensitive to RF energy, e.g., a non-conductive composition like the type used in percussion primers. The problem then becomes how to ignite this electrically insensitive mix with the relatively low firing energy available. A novel device called a Semiconductor Ignitor (SCI) provides a solution to the problem. This semiconductor "chip", conceived by Dr. Tom Baginski of Auburn University[3], was designed as an electrothermal transducer to convert a low energy electrical discharge into a thermal impulse, capable of igniting most primary explosives. The device itself is inherently immune to the adverse effects of RF energy and will "trigger" only at a specified DC voltage threshold; thus it also discriminates against both RF and sub-threshold DC (or low frequency) voltages. By semiconductor industry standards, the SCI is a rather simple device, easy to manufacture and reasonably inexpensive in high volume production.

2.2 The SCI: Construction and Theory of Operation

The physical construction of the SCI is illustrated in Figure 4. Although the SCI is large compared to most semiconductor devices, it is small enough to fit into the M52A3B1 primer body. The electrical design (shown in Figure 5) consists of two diodes, one at the top of the chip (the cathode) and one at the bottom (the anode). The diodes are configured in a back-to-back arrangement, so that when a voltage is impressed across the device, the bottom diode is forward biased and the top diode is reversed biased. When a sufficiently high voltage is impressed across the device, current will flow with the characteristic current/voltage relationship shown in Figure 5. Returning to Figure 4, it can be seen that the top diode area is very small compared to the bottom diode area; the result is a highly concentrated current flow at the top center region of the chip as depicted in Figure 6a. Typical gun firing circuits provide more than enough capacitive discharge energy to melt the aluminum metallization at the top surface as shown in Figure 6b. The melting temperature of aluminum (660 degrees Centigrade) exceeds the ignition temperatures of most explosives (250-600 degrees Centigrade). Thus, as an electrothermal transducer, the chip is an excellent candidate as an ignition element for EEDs.

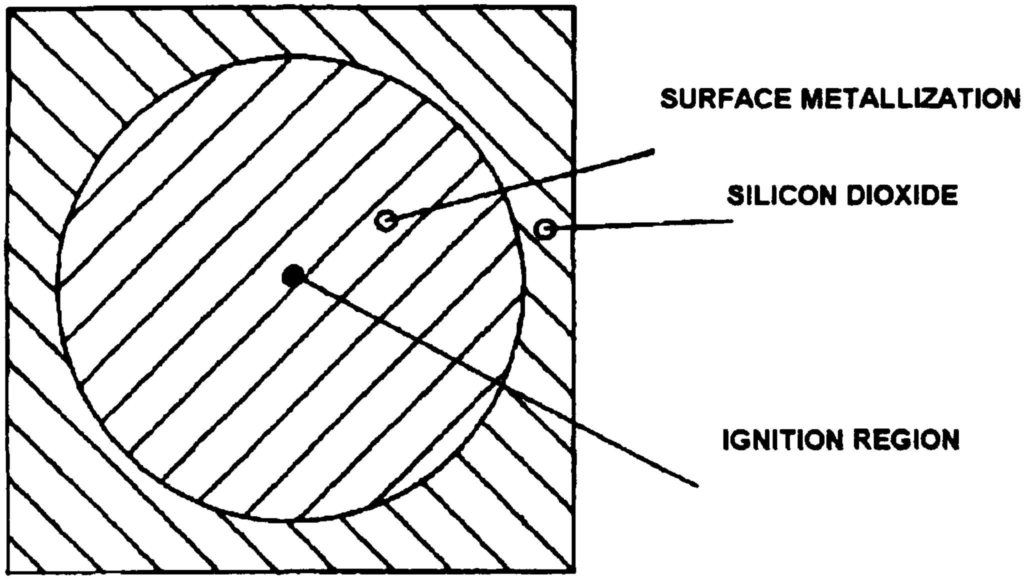


Figure 4a. Top View SCI

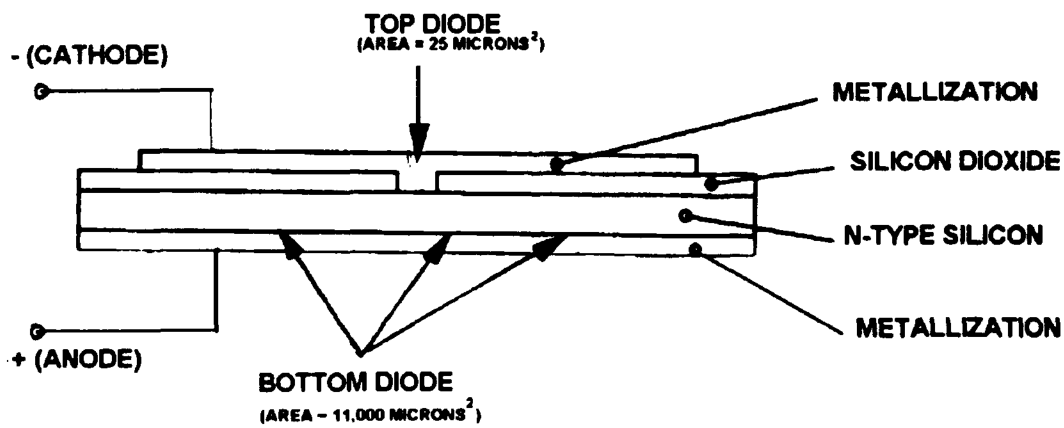


Figure 4b. Cross Section of SCI (not to scale)

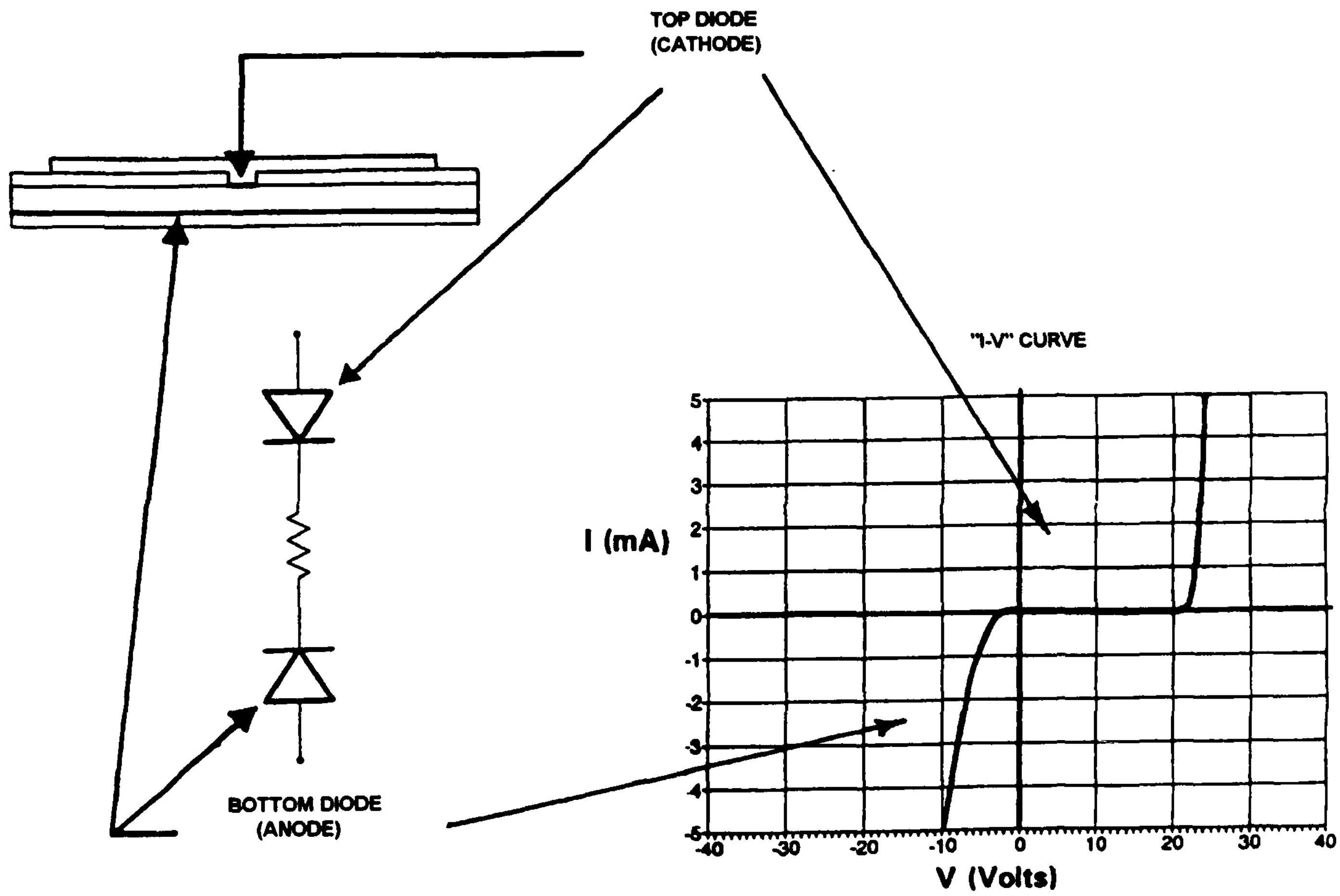


Figure 5. SCI DC Characteristics

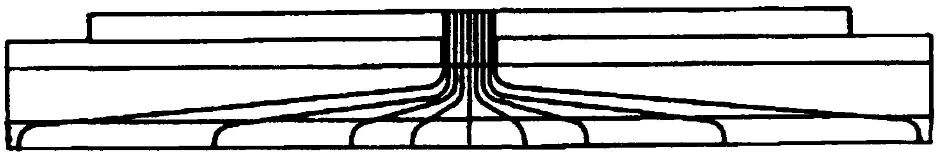


Figure 6a. Current Concentration at Top Diode

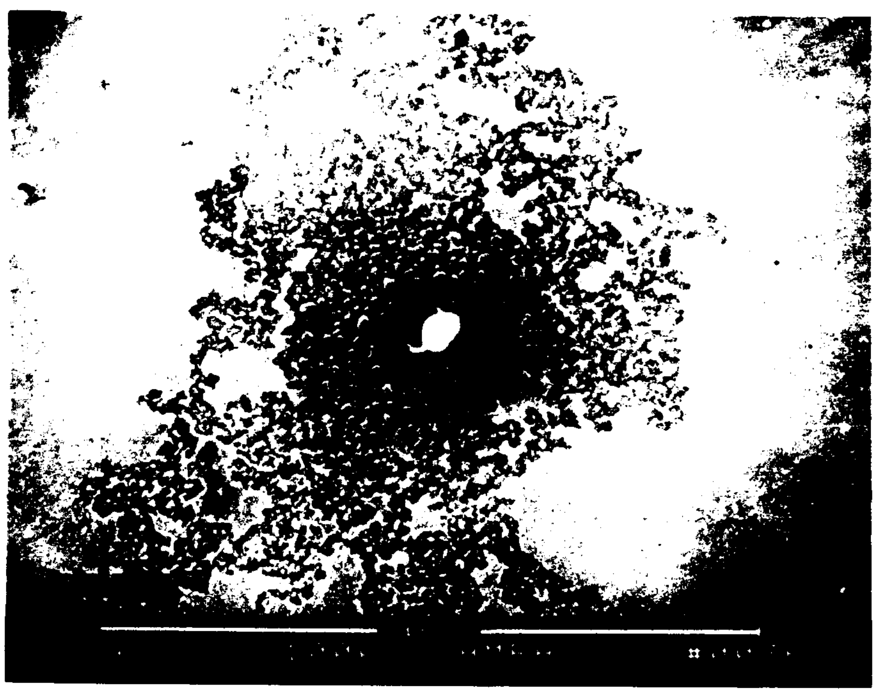


Figure 6b. Surface Metallization Melting at Top Diode Region

Equally important is the RF immunity offered by the SCI. Figure 7 depicts the device as essentially capacitive at RF, which means that as RF currents flow across the device, there is little real power absorbed, i.e., there is little heat generated. Of course, in practice it is impossible to build a purely capacitive device, particularly at microwave frequencies. There are semiconductor substrate resistances and parasitic inductances and resistances associated with the interconnection elements and other primer components. The associated resistances are undesirable as they will absorb RF power and generate heat. Fortunately, most of the primer components are good thermal conductors (as is the cartridge case), and there is good thermal contact between the chip and the primer cup; this natural heat-sinking system counters the heat buildup by conducting the heat away from the chip-mix interface.

2.3 Integration of the SCI into the Primer

As shown in Figures 8 and 9, the SCI is integrated into the primer between the button and the explosive mix. Electrical contact must be established between the bottom of the SCI and the primer button (primer anode) and between the top of the SCI and the primer support cup (cathode). Conductive epoxy is used for this purpose. The most recent integration schemes use a paste type epoxy at the bottom and a pre-formed epoxy washer at the top, both of which are cured at elevated temperatures (150 degrees Centigrade). Thin, electrically insulating outer washers at the top and bottom prevent shorting and provide a cushion for the SCI when the epoxy is cured and when the explosive mix is consolidated into the assembly under high pressure.

2.4 Prototype Primers

The development of RF-insensitive primers has relied heavily on building and evaluating a series of prototype lots. The iterative design/build/modify approach began with a "pre-prototype" lot to resolve basic engineering issues and has since included two additional prototype lots. These latter two prototype lots have been a crucial element in the assessment of basic performance and the impact of minor changes to the chip design and primer assembly, specifically by helping to:

(a) Select the best materials for certain primer components,

(b) Identify and solve primer assembly problems,

(c) Provide samples needed for performance testing, and

(d) Identify and solve problems related to quality assurance.

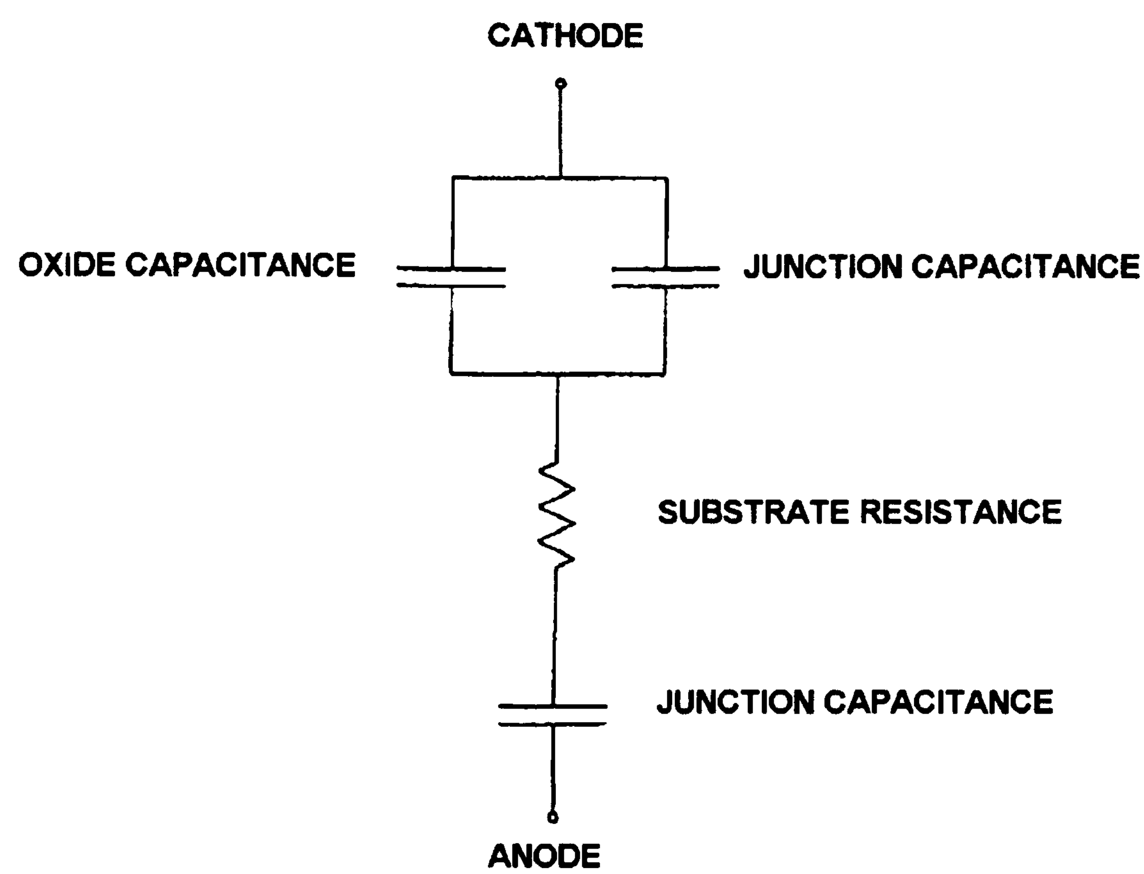


Figure 7. SCI RF Equivalent Circuit

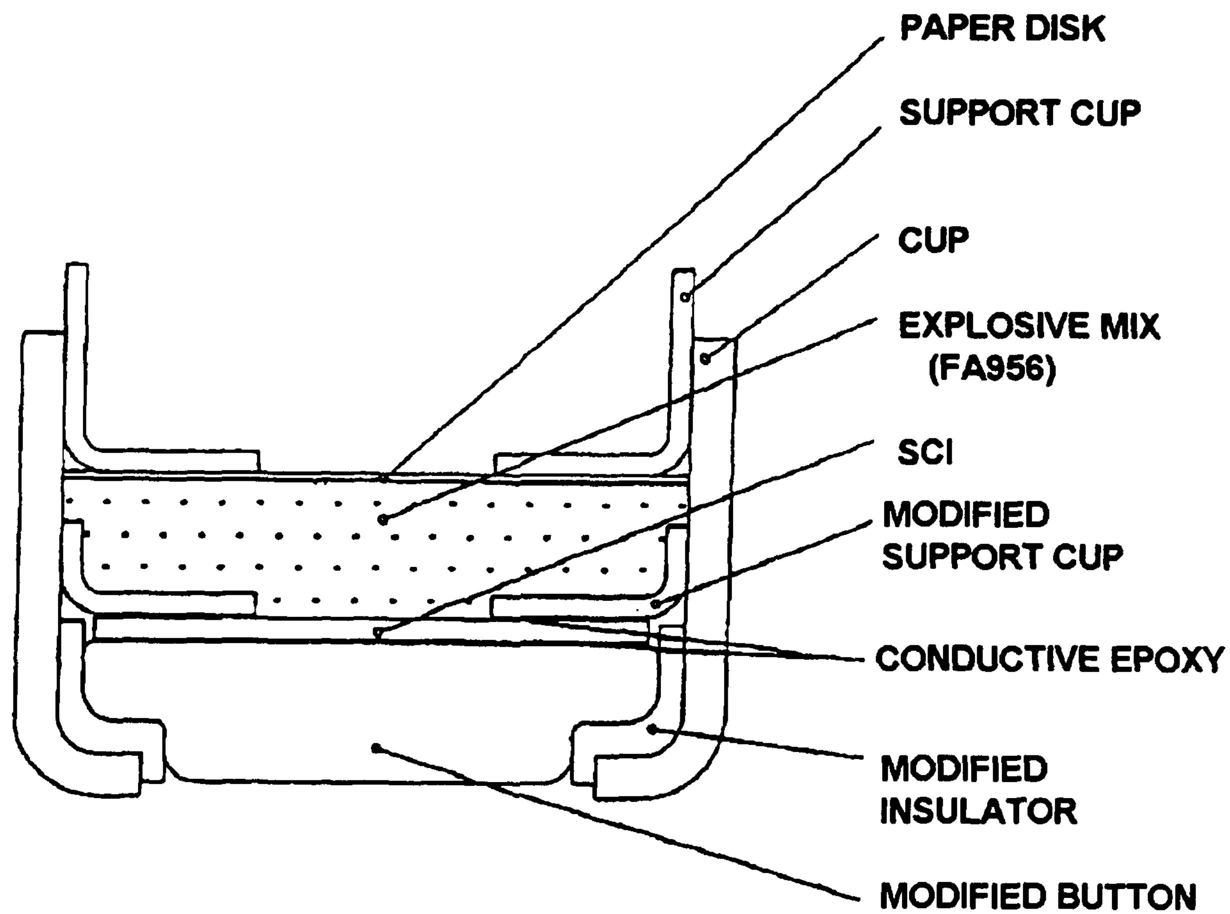


Figure 8. Semiconductor Ignitor (SCI) Primer

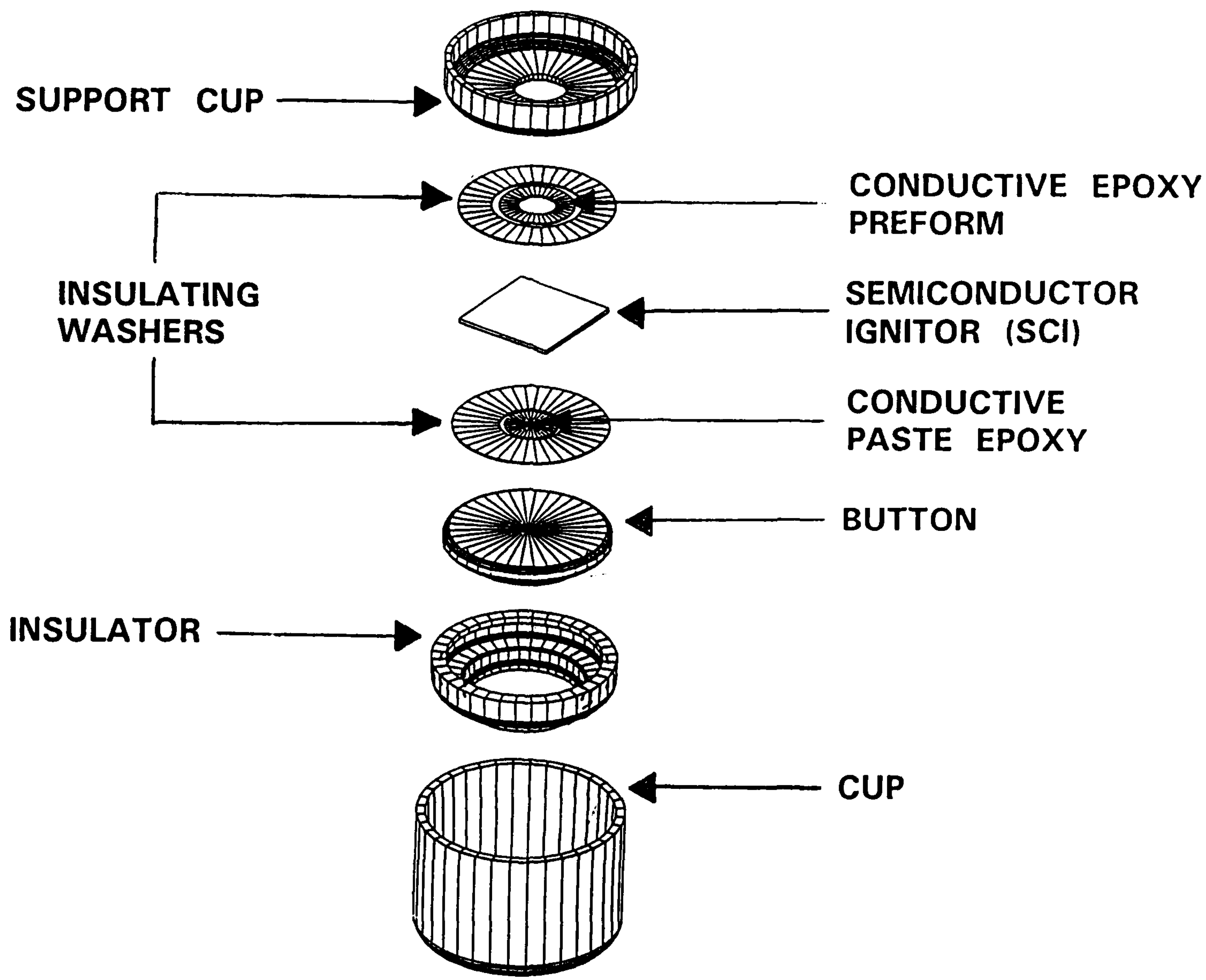


Figure 9. SCI Primer Subassembly (Exploded View)

A technical team was established, consisting of specialists from various Department of Defense (DOD) laboratories, the primer manufacturer, and support contractors, to be the driving force for prototype development. This team has been responsible for identifying and resolving design and assembly problems, overseeing the fabrication of the prototype lots, and evaluating the performance of the SCI primers/cartridges. The team's ultimate goal is to finalize a primer design which is both practical for high volume production and satisfies the performance requirements for PHALANX ammunition[4]. Table 1 identifies the team members and their respective responsibilities.

Table 1. Technical Team

TEAM MEMBER	RESPONSIBILITY
NAVAL SURFACE WARFARE CENTER DAHLGREN DIVISION	LEAD LABORATORY SCI INTEGRATION RF TESTING
NAVAL SEA SYSTEMS COMMAND PHALANX PROGRAM OFFICE (PMS-413)	PROGRAM DIRECTION TECHNICAL REVIEW
HARRY DIAMOND LABORATORIES	SCI DESIGN PROTOTYPE SCI FABRICATION FAILURE ANALYSIS
NAVAL SURFACE WARFARE CENTER INDIAN HEAD DIVISION	PRIMER DESIGN/ASSEMBLY/TEST DOCUMENTATION
OLIN CORPORATION	PRIMER DESIGN PRIMER MANUFACTURER
AT&T (KANSAS CITY)	PROTOTYPE SCI FABRICATION SCI INTEGRATION
DEFENSE TECHNOLOGY, INC BOOZE-ALLEN & HAMILTON EG&G	SUPPORT CONTRACTORS

Details concerning the construction and evaluation of the Pre-Prototype and Prototype Lots follow.

2.4.1 Pre-Prototype Lot

Fabricating and evaluating the Pre-Prototype Lot helped the technical team resolve specific concerns about primer assembly procedures and the choice of materials and dimensions for certain primer components. In addition, there were questions about the choice of a non-conductive explosive mix to replace the FA 874 as well as the optimum mix consolidation pressure (pressure at which the mix is pressed onto the SCI during primer charging). Besides helping the technical team resolve these engineering issues, the Pre-Prototype Lot demonstrated that SCI primers could be produced by the primer manufacturer with the same production equipment used for M52A3B1 production. A total of 240 cartridges, consisting of eight combinations of mix type and consolidation pressure, were built and evaluated; Table 2 summarizes this Pre-Prototype Lot matrix. The two candidate percussion mixes, FA 956 and 5061, were selected on the basis of their relative insensitivity to RF energy (compared to the FA 874 composition) and, as a practical matter, their availability at the primer manufacturing site.

Table 2. Pre-Prototype Lot Matrix

MIX TYPE	MIX CONSOLIDATION PRESSURE (PSI)			
	2000	3000	4000	5000
FA 956	GROUP A	GROUP B	GROUP C	GROUP D
5061	GROUP E	GROUP F	GROUP G	GROUP H

The choice of consolidation pressure was considered to be a tradeoff between the minimum needed to ensure proper primer explosive performance and a maximum above which the SCI would suffer mechanical stress damage, i.e., fracture during primer charging. Prior to the assembly of the Pre-Prototype Lot, samples of FA 956 and 5061 were subjected to direct injection RF sensitivity testing[5] at Franklin Research Center, Philadelphia, PA. Both compositions were less sensitive to initiation than FA 874, but with little difference between the two. Other tests showed that there was no appreciable difference in firing reliability or ballistics performance as a function of consolidation pressures between 2000 and 5000 psi. Interior ballistics performance and firing reliability test results were excellent. In summary, the Pre-Prototype Lot helped to establish a baseline SCI primer design. The dimensions of all primer components were finalized, and FA 956 was selected as the explosive mix, consolidated at 4000 psi; the first prototype lot was built to these specifications.

2.4.2 Prototype Lots 1 and 2

Two prototype lots of SCI primers and cartridges have been fabricated and evaluated thus far. Both lots were built under contract by Olin Corporation and were provided to the Navy as contract deliverables. The primers were assembled at the Lake City Army Ammunition Plant (LCAAP), Independence, Missouri, and the cartridges were assembled at Olin Corporation's facility at Marion, Illinois. Harry Diamond Laboratories fabricated the SCIs and AT&T, Kansas City Works, was subcontracted to assemble them into inert primer subassemblies. Mix loading and final assembly is accomplished at LCAAP. The prototype lots consisted of 180 inert cartridges (cartridges with live primers but no propellent) and 70 all-up rounds (AURs). These samples were electrically interrogated at various stages of assembly to determine the health of the SCI and the integrity of the connections to the SCI. After final assembly, they were evaluated for firing reliability, RF sensitivity, and ballistics performance.

2.4.3 Firing Reliability Tests

Two types of firing reliability tests have been conducted: static tests in a Mann barrel (Figures 10 a,b) and dynamic firing tests using PHALANX M61A1 gun systems (Figure 11) operating at normal firing rates (3000 or 4500 shots/minute, depending on Block number of the PHALANX system). The primers were configured in inert cartridges, i.e., live primers pressed into cartridges without propellent. Reliability was calculated as the number of successful fires divided by the total number of firing attempts. In both tests a PHALANX Gun Control Unit (GCU) supplied the firing stimulus, a 300 volt discharge from a 3.0 microfarad capacitor through a 60 ohm series current limiting resistor. Table 3 summarizes the firing reliability test results for each of the prototype lots. It was determined that the poor performance of Prototype Lot 2 was due to a component misalignment problem, which occurred during the SCI integration assembly stage. The misalignment allowed arcing to occur within the primer, away from the ignition area, and the associated loss of energy prevented the SCI from functioning properly.

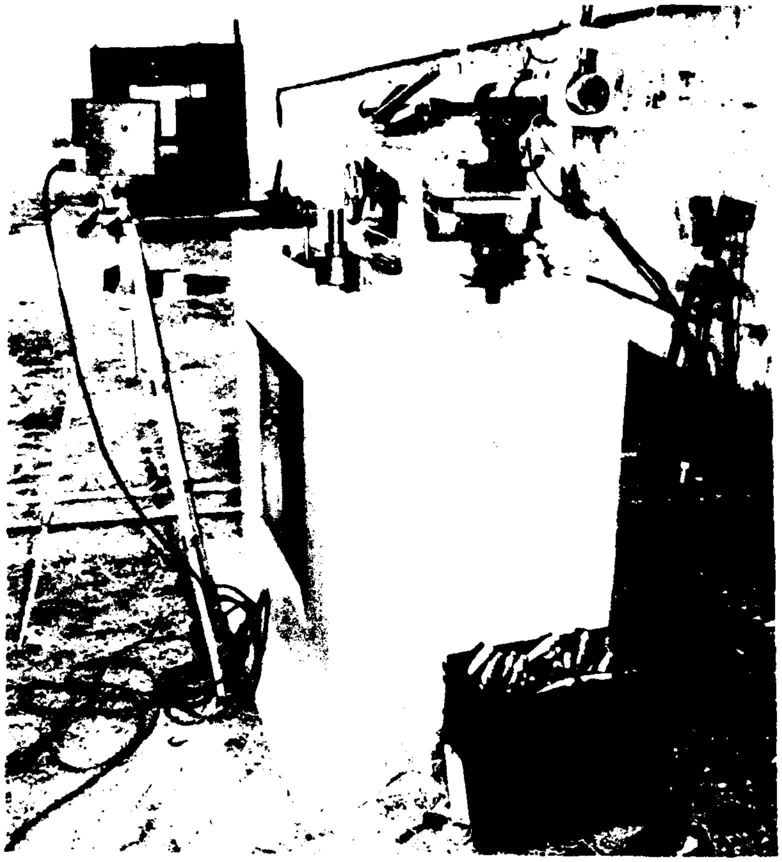


Figure 10a. Ballistic Testing: Instrumented Mann Barrel

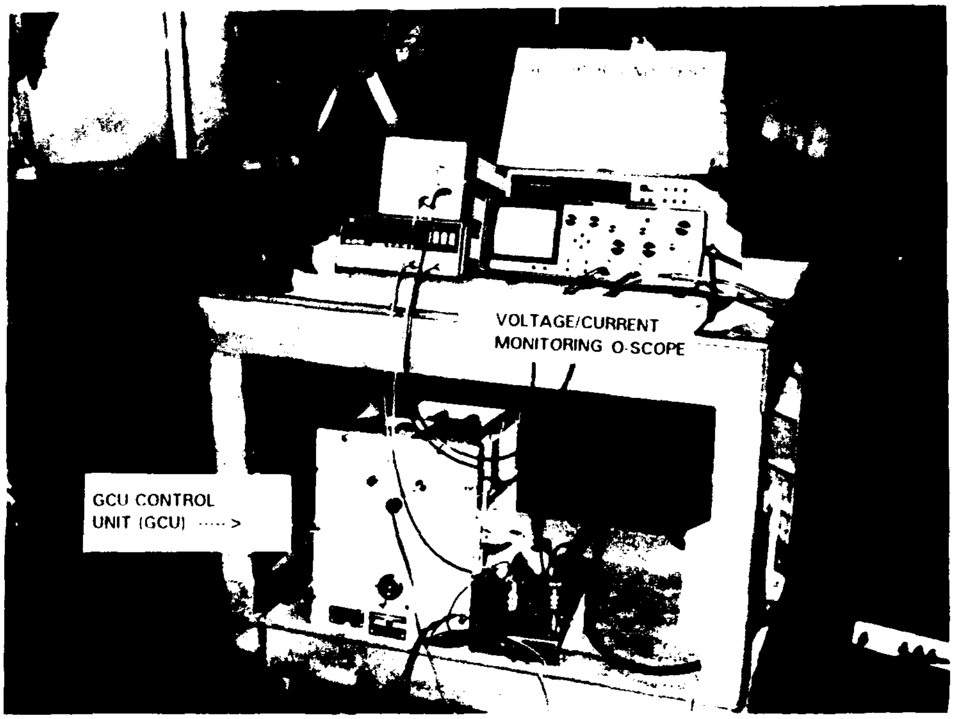


Figure 10b. Ballistic Testing: Firing Circuit/Instrumentation

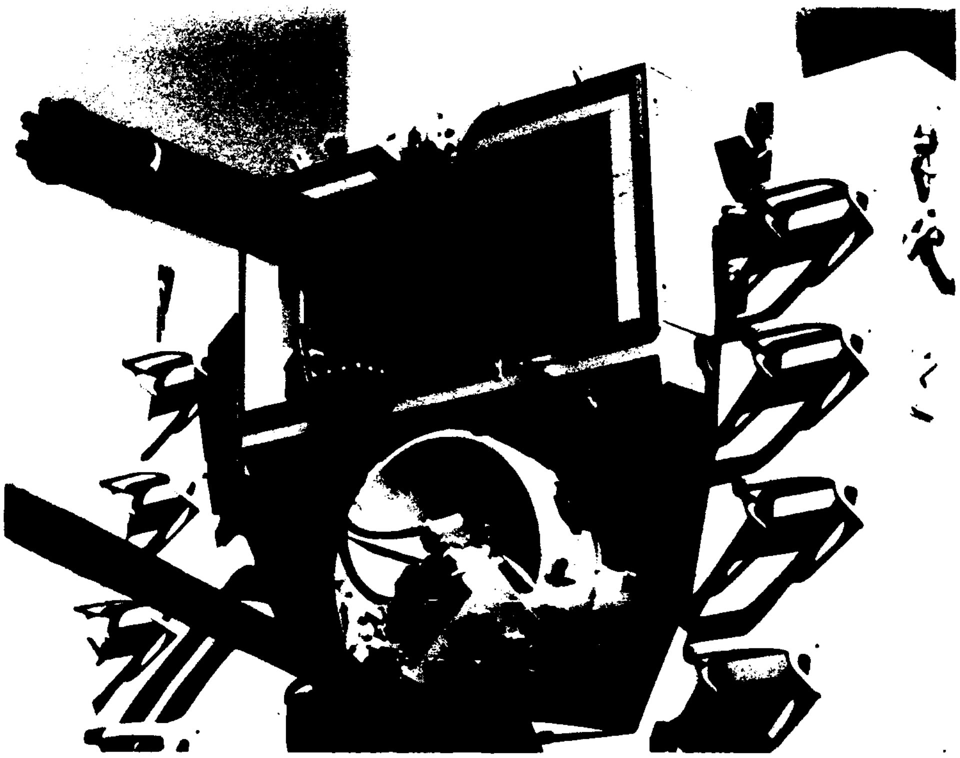


Figure 11. M61A1 Gun (PHALANX)

Table 3. Firing Reliability Test Results

PROTOTYPE LOT	TYPE TEST	NO. OF ATTEMPTS	NO. FIRED	RELIABILITY (PERCENT)
PRE-PROTOTYPE	MANN BARREL	240	238	99
	PHALANX M61A1	320	317	99
1	MANN BARREL	65	65	100
	PHALANX M61A1	50	50	100
2	MANN BARREL	85	60	71
	PHALANX M61A1	75	55	73

Aside from the problem with Prototype Lot 2, results are very encouraging. Of course, it is recognized that statistical confidence suffers from the small number of samples tested, but there is a strong indication that excellent firing reliability can be achieved.

2.4.4 RF Sensitivity Tests

There are two basic types of primer RF sensitivity tests, conducted (sometimes called direct injection), and radiated. The former is a laboratory test in which a known amount of RF power is matched into the primer. The latter test exposes the primers to very high level radiated RF environments similar to those produced by shipboard radars and communications equipments. Direct Injection tests were very useful for comparing the relative sensitivities of primers made up with different explosive mixes, such as FA 874, 5061, and FA 956. However, in most of the RF sensitivity testing, the primers were exposed to radiated environments similar to those produced by shipboard radars and communications equipments. The objectives of the tests were to:

(a) Determine if SCI primers, configured in inert 20 mm cartridges, could be initiated when exposed to maximum (worst case) shipboard EMEs, and

(b) Determine the susceptibility thresholds (minimum EME levels that cause primer ignition) for both SCI and M52A3B1 primers.

Radiated testing was conducted at the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) HERO Ground Plane Facility, Dahlgren, VA. The facility, shown in Figure 12, consists of a large (30.5 x 73.2 meter) steel ground plane with radar and communications equipments for generating high intensity radiated EMEs. Thresholds were established in terms of either the minimum field strength for High Frequency (HF, 2-30 MHz) environments or power density for radar (200-10,000 MHz) environments. During ground plane testing, there is an emphasis on handling the ammunition in the same manner as would be done aboard ship in the presence of high level radiated EMEs. This includes touching the primers to metal objects, loading the cartridges into the PHALANX gun, and cycling the gun as the ammunition feed system is exposed to the RF test environment. Handling procedures tend to increase the coupling of RF energy into the primer; such procedures included:

(a) Touching the primer to the wing of an aircraft which is being radiated by HF test environments (Figure 13);

(b) Touching the primer to M61A1 gun barrels (Figure 14); and

(c) Touching a screwdriver blade to the primer (Figure 15).

Other so-called "presence" tests, which do not involve handling the cartridges, included:

(a) Two cartridges in a "tip to tail" configuration (Figure 16);

(b) Cartridges in MK 7 RADHAZ links (Figures 17a,b); and

(c) Gun cycling, at slow rates (Figure 18).

Previous tests of M52A3B1-primed cartridges at the Ground Plane Facility had provided a data base of "worst case" configurations, i.e., those combinations of frequency, polarization, and handling procedures, where the primers are most susceptible. Cartridges with SCI primers were tested under these same worst case conditions to determine their RF immunity relative to cartridges with M52A3B1 primers. Some of the procedures used in this test were, admittedly, improbable and/or unauthorized for PHALANX ammunition operations. However, these procedures supported the objective of determining how much more RF-resistant the SCI

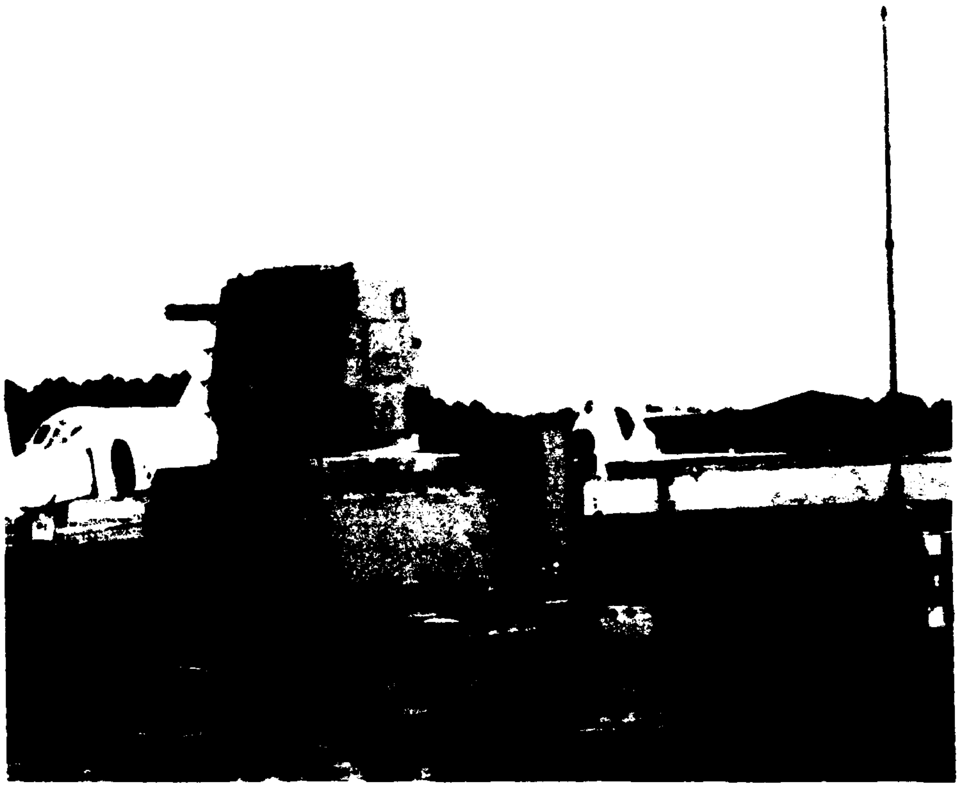


Figure 12. NSWCDD HERO Ground Plane Test Facility

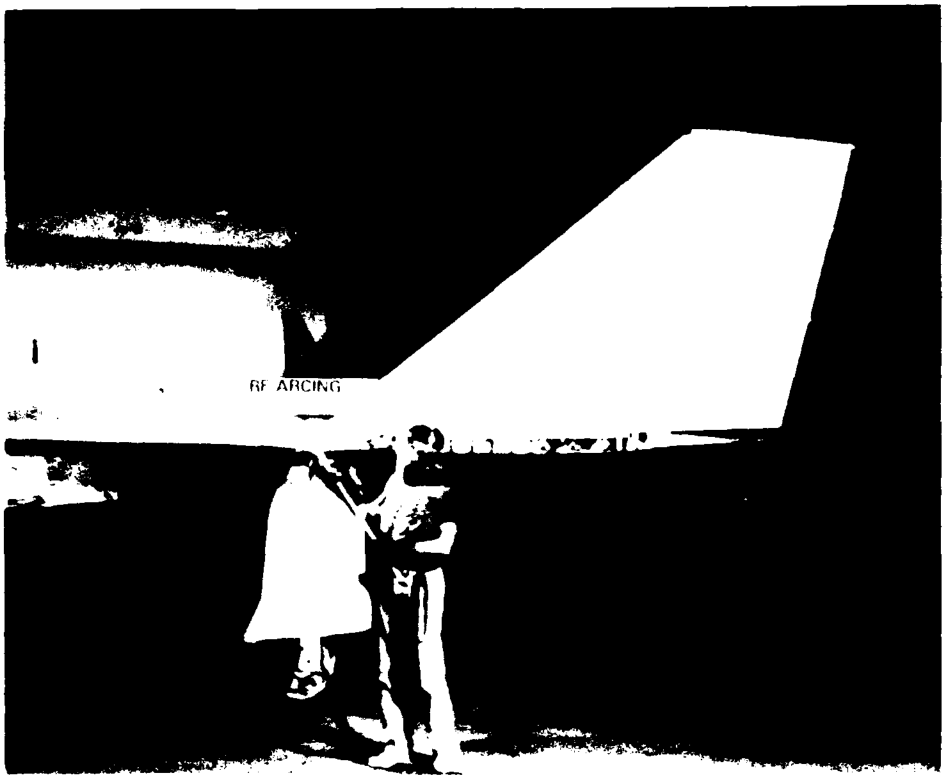


Figure 13. Primer Touching Aircraft Wing (Note Arcing)

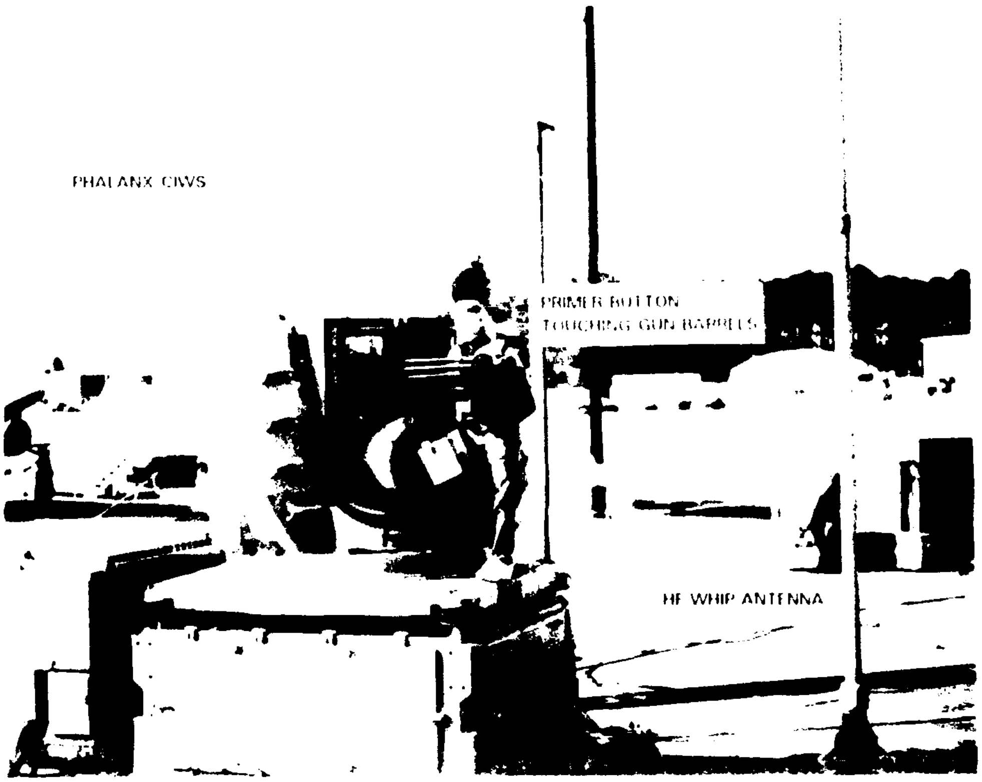


Figure 14. Primer Touching M61A1 Gun Barrels

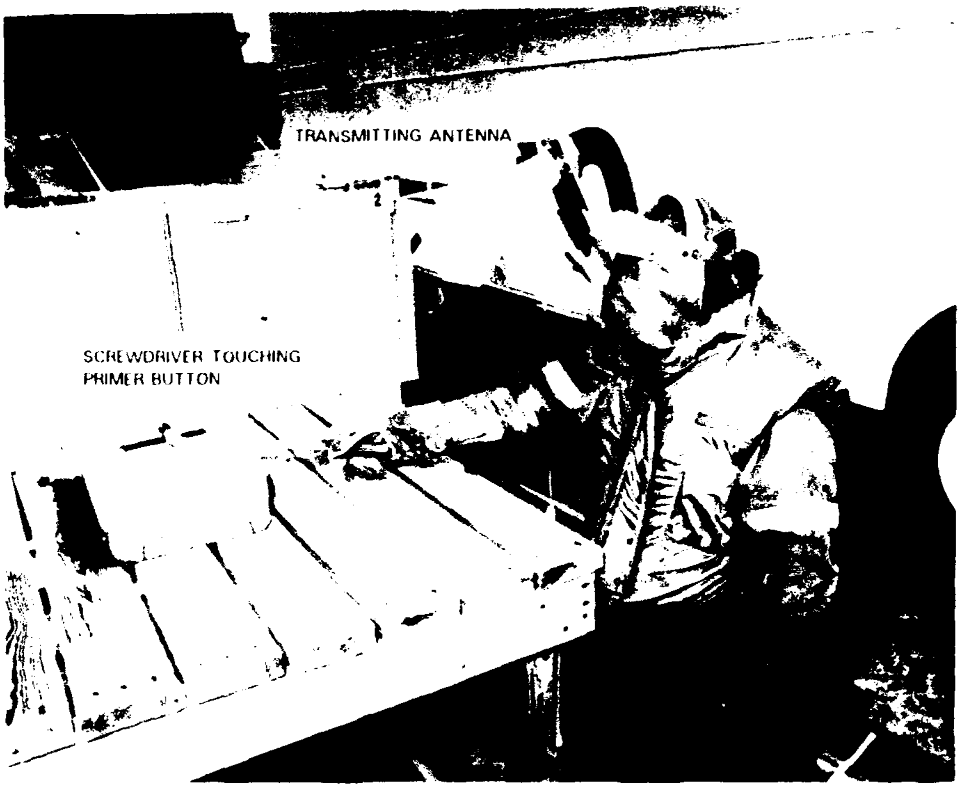


Figure 15. Screwdriver Touching Primer

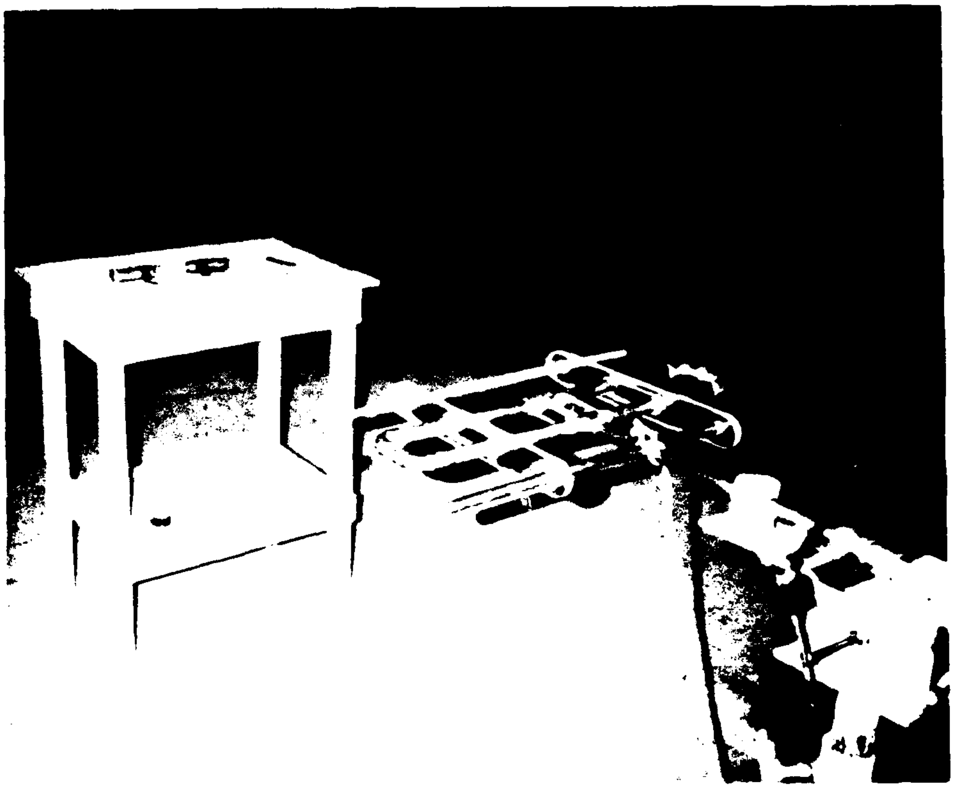


Figure 16. Cartridges in Tip to Tail Configuration

Figure 17a. Cartridges in MK 7 RADHAZ Links

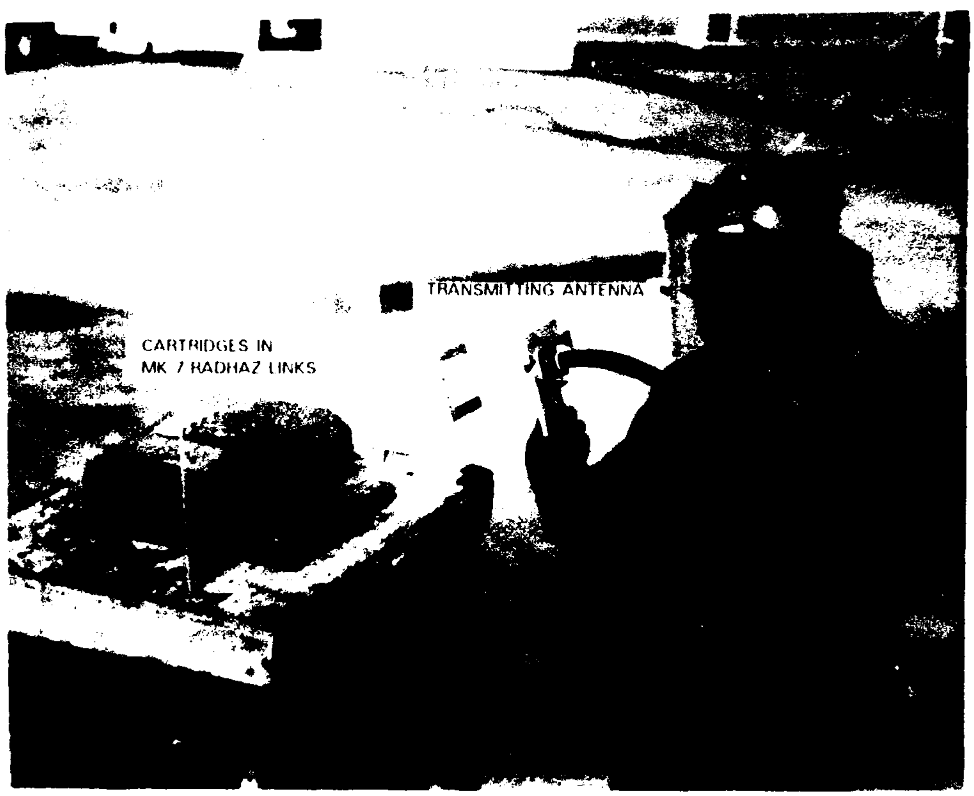


Figure 17b. Cartridges in MK 7 RADHAZ Links (Being Radiated)

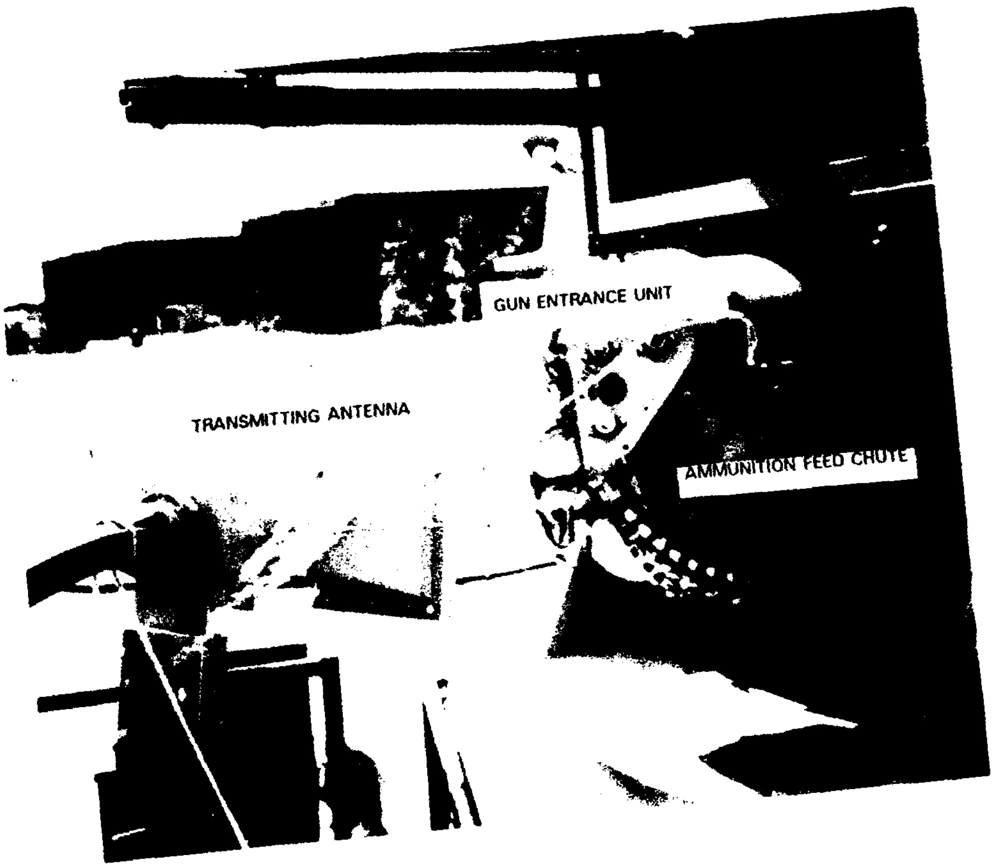


Figure 18. Gun Cycling

primers were than the M52A3B1 primers. For example, in one HF procedure, the primer was touched to the M61A1 gun barrels of a PHALANX system located ten feet from a transmitting HF whip antenna. In this configuration, at some HF test frequencies, arcs were drawn to the primer as it was touched to the tip of the barrels. An even more severe test consisted of touching the primer to the wingtip of an F-4 aircraft located ten feet away from a HF transmitting antenna. This configuration is conducive to the generation of intense arcing to the primer, as seen in Figure 13. Another procedure involved touching a screwdriver to the primer (while being radiated) to simulate inadvertent contact during removal of a jammed round from the ammunition feed system.

Table 4 provides a sample of the radiated susceptibility data (at radar frequencies), comparing the RF susceptibility thresholds for Prototype Lot 1 cartridges to the thresholds of M52A3B1 primed cartridges. As the table indicates, the Prototype Lot 1 primer is much less sensitive to RF energy. Except in one instance at 5650 MHz, no actuation resulted from exposure of the test cartridges at any of the radar test environments. (The one exception at 5650 MHz occurred when the test environment exceeded the HERO certification level specified in MIL-STD-1385B, and that actuation occurred only when a screwdriver was touched directly to the primer.

TABLE 4. RADIATED SUSCEPTIBILITY OF PROTOTYPE LOT 1 CARTRIDGES AT RADAR FREQUENCIES SUMMARY OF NSWCDD HERO GROUND PLANE TEST THRESHOLDS

FREQ (MHZ)	MODULATION		MAX EME (MW/CM^2)		AVERAGE THRESHOLDS[1] (MW/CM^2)			PEAK THRESHOLDS[1] (MW/CM^2)			TEST CONFIGURATION
	PRF (Hz)	PW (uSEC)	AVG	PEAK	M52[2]	PROTO 1	DELTA[3] (DB)	M52[2]	PROTO 1	DELTA[3] (DB)	
215	310	20	20	3.2K	2.0	> 20	> 10	0.32K	> 3.2K	> 10	PRESENCE: TIP - TAIL
410	300	33	50	5.1K	2.5	> 50	> 13	0.25K	> 5.1K	> 13	PRESENCE: TIP - TAIL
1300	150	1.0	12	80K	6	> 12	> 3	40K	> 80K	> 3	SCREWDRIVER ON PRIMER
2875	1000	1.0	400	400K	100	> 400	> 6	100K	> 400K	> 6	SCREWDRIVER ON PRIMER
5650	1000	1.0	400	400K	200	> 600	> 4.8	200K	> 600K	> 4.8	GUN CYCLING EXPOSURE
5650	1000	1.0	600	600K	100	600	7.8	100K	600K	7.8	SCREWDRIVER ON PRIMER
7800	1000	1.0	150	150K	75	> 150	> 3	75K	> 150K	> 3	IN MARK 7 RADHAZ LINKS
7800	200	0.5	18.2	182K	4.6	> 18.2	> 6	45.5K	> 182K	> 6	IN MARK 7 RADHAZ LINKS

NOTES:

(1) THRESHOLDS ARE MINIMUM POWER DENSITIES AT WHICH AT LEAST ONE PRIMER FIRED, UNDER WORST CASE TEST CONFIGURATIONS. A ">" INDICATES THE PRIMER DID NOT FIRE AT THE MAXIMUM TEST ENVIRONMENT GENERATED; THE ACTUAL THRESHOLDS ARE THUS HIGHER THAN ANY LEVELS PRECEDED BY A ">".

(2) M52A3B1 THRESHOLDS ARE DETERMINED FOR THE PURPOSE OF ESTABLISHING A REFERENCE (BASELINE) SUSCEPTIBILITY THRESHOLD.

(3) A COMPARISON BETWEEN M52A3B1 AND PROTOTYPE LOT 1 THRESHOLDS, TERMED "DELTA", IS CALCULATED AS: 10 LOG (PROTOTYPE LOT 1 THRESHOLD / M52A3B1 THRESHOLD).

2.4.5 Primer Output Tests

Primer output tests were conducted at the Naval Surface Warfare Center, Indian Head Division[6], to compare performance of M52A3B1 and Prototype Lot 1 primers. One of the concerns was that the SCI primer, loaded with FA 956, might be too brisant for the propellent used in the MK 149 cartridge since FA 956 contains PETN. It was theorized that similar energetic yields from the two primers would produce equivalent cartridge ballistic performance; different energetic yields would imply different ballistics, suggesting a need for some modification to the primer design (e.g., changing the charge weight, consolidation pressure, etc.) The method of measuring primer energy output used the McDonnell Douglas Energy Sensor[7]. In this test, the output of the primer acts against a piston that, in turn, crushes a column of aluminum honeycomb. The honeycomb has the characteristic of having a uniform crush strength once it has been pre-crushed a short distance. The energy required to crush the honeycomb can be calculated as the crush distance times the crush strength. It is believed that this type of test offers a reasonable method of comparing the outputs of the two respective primers.

Fifty-one M52A3B1 primers and forty SCI primers were tested. It was reassuring to find that the outputs were nearly identical, with the M52A3B1 samples averaging 613 inch-pounds of force and the SCI primer averaging 612 inch-pounds. This was regarded as a preliminary indication that the SCI primer would not degrade the cartridge ballistic performance. Of course, this conclusion ignores possible differences in the primer combustion rates, a fact that could also influence propellent ignition.

2.4.6 Interior Ballistics Tests

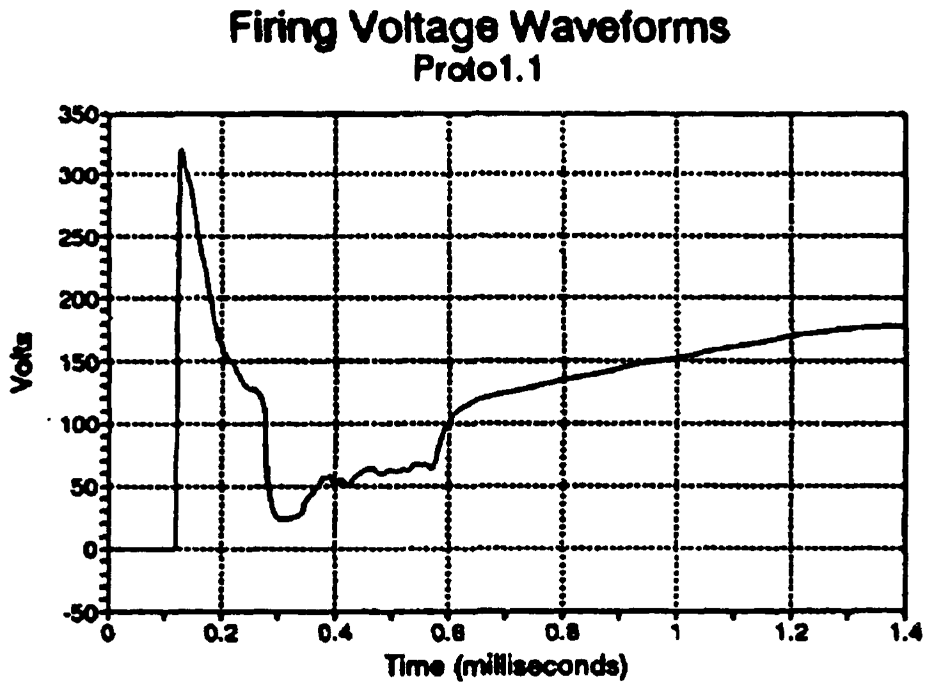
Interior ballistics tests were conducted at the Olin-Marion ballistic test range on all-up rounds from the prototype lots. Muzzle velocity, peak chamber pressure, and action time were measured as basic performance indicators on cartridges preconditioned at temperatures of -20, 70, and 150° F. All cartridges were fired in a 20 mm Mann barrel, which was instrumented with copper crush gauges and piezo-electric sensors. A PHALANX GCU was used in all ballistics tests to provide the firing stimulus, and firing voltage and current waveforms were recorded. Ten Prototype Lot 1 cartridges, loaded with 628 grains of WC859-lot 64 propellent, were tested at each temperature. For Prototype Lot 2, a total of eighty-five cartridges, loaded with the same propellent lot (WC859-lot 64) with a 628 grain charge weight, were tested (twenty-five at -20 and 150° F and thirty-five at 70° F).

Figure 19 shows typical current and voltage waveforms measured across the primer with a storage oscilloscope and a representative plot of a pressure-time history, measured with a piezo-electric sensor, is shown in Figure 20.

In all cases, the data verify that ballistic performance meets the specifications for PHALANX ammunition with respect to velocity, peak chamber pressure, and action time. Table 5, is a representative sample of such ballistics data, summarizing the performance of Prototype Lot 2 cartridges conditioned at 70° F. Note that the Test Lot satisfies the PHALANX Weapon Specification WS 21703A.

Table 5. Example of Interior Ballistics Performance (70° F)

CHARACTERISTIC	MK 149 REFERENCE LOT	PROTOTYPE LOT 2	WS 21703A
MUZZLE VELOCITY (ft/sec)	3664	3686	3650-3720
PEAK CHAMBER PRESSURE (psi)	52,590	53,823	< 60,500
ACTION TIME (msec)	2.29	2.36	< 4.00



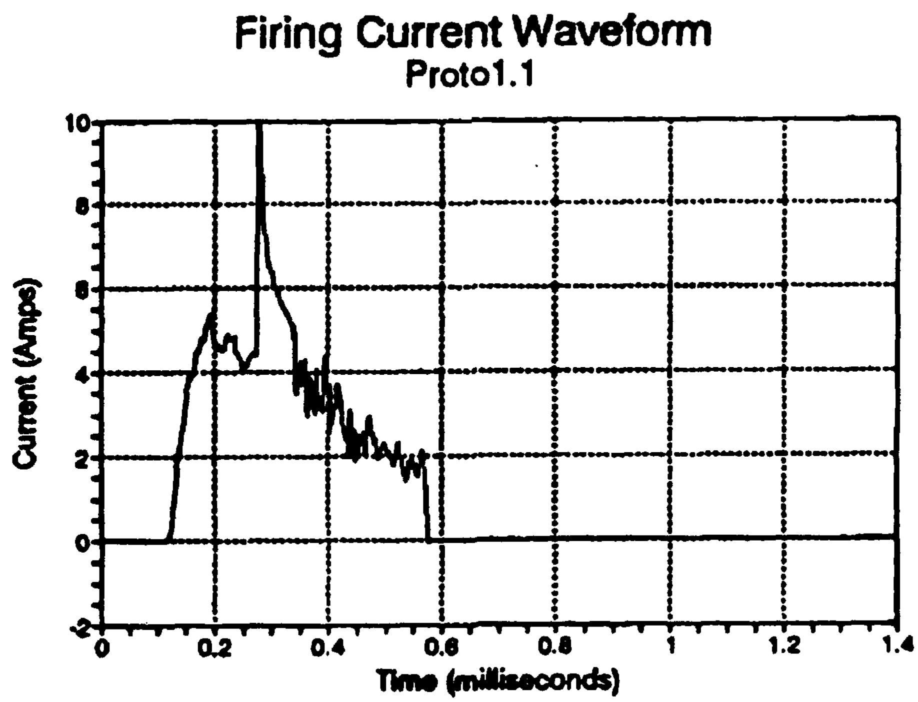
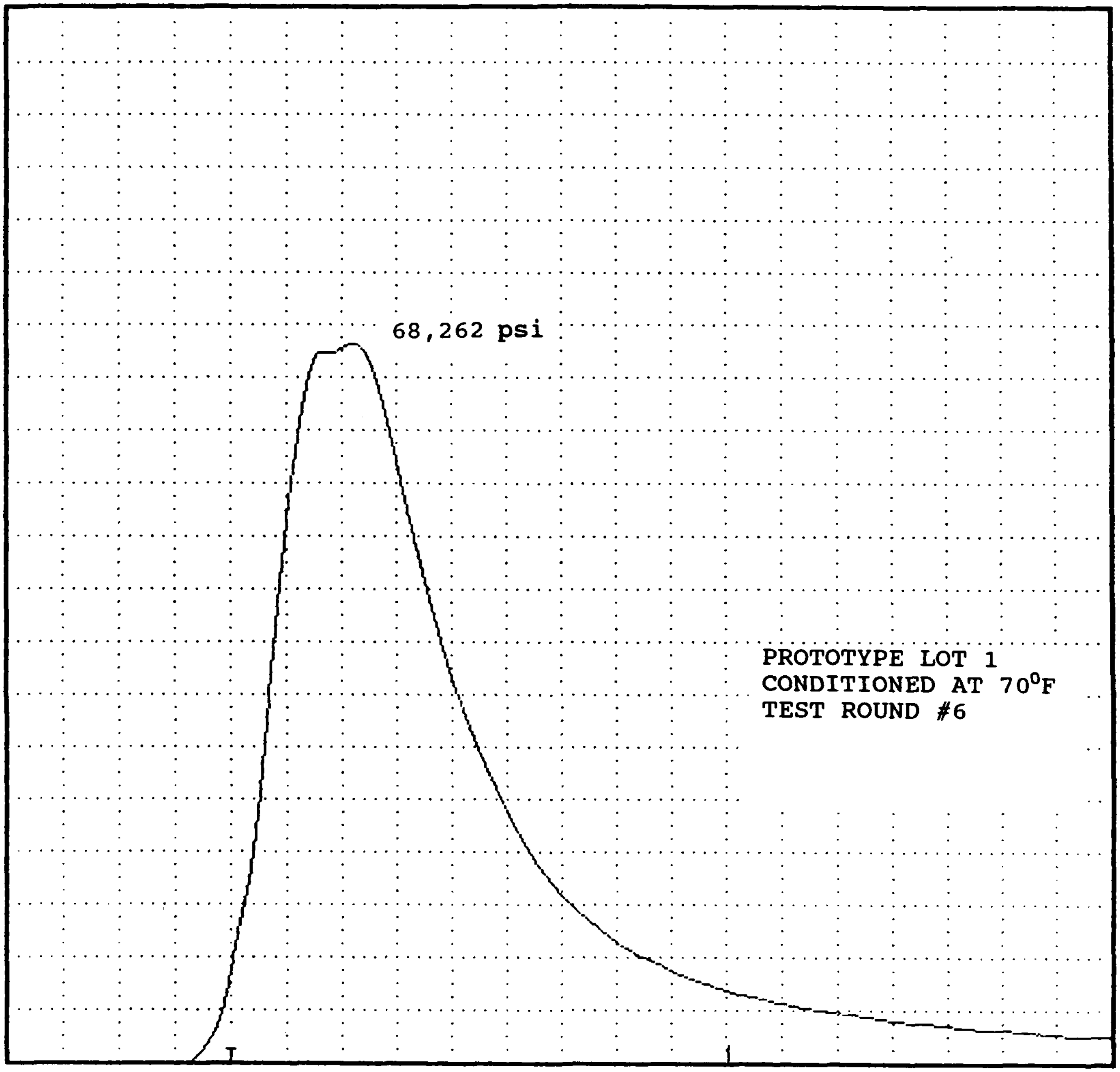


Figure 19. Typical Voltage and Current Waveforms



Curve #18 of File D:A06801L1.CRV
5000 PSI per division and 200 microseconds per division
Plot includes offset of 0 PSI.

Time from FIRE to "T" trigger point = 577 microseconds.
Time from FIRE to "!" muzzle point = 2382 microseconds.

Figure 20. Time-Pressure Curve (Typical)

3.0 CONCLUSIONS AND PROJECTIONS

The Navy is making great progress toward solving it's worst HERO problem, PHALANX MK 149 ammunition. The technical team is attacking the problem at its source, the extremely RF-sensitive M52A3B1 electric primer, because it is recognized that the most effective solution is to build the protection directly into the primer itself. The effort thus far demonstrates success of the technical approach, evidenced by the excellent performance of prototypes in firing reliability, RF sensitivity, and ballistics tests. The most significant benefits of a successful development effort will be:

(a) Improved ammunition safety - the risk of a HERO accident will be minimized; and

(b) Relief from emission control and ammunition handling restrictions - the limitations on critical radars and communications equipments can be reduced/eliminated.

Interestingly, this most recent attempt to harden the primer has not involved the development of any new technology but rather the marriage of traditionally unrelated technologies. As a further break from tradition, the SCI represents a semiconductor device "designed to fail". This unconventional use of semiconductors may represent only the "tip of the iceberg"; there is no reason why RF immunity could not be similarly built into other electric primers or the myriad of bridgewire EEDs, used in countless military and commercial applications.

As far as the HERO SAFE PHALANX ammunition development program is concerned, future efforts will focus on improving Quality Assurance (QA) test methods and determining appropriate pass/fail criteria. This work is very important to ensure that there is a reliable method for screening defective primers. Verification of an acceptable QA test is expected to be demonstrated in a third prototype lot presently being built. After completing the prototype phase, a 29,000 sample qualification lot will be manufactured and extensively evaluated. A successful qualification phase is a prerequisite for approval for production.

5.0 ACKNOWLEDGEMENTS

The author wishes to acknowledge the funding support provided by the Naval Surface Warfare Center, Crane Division, Code PM 414, and for the program direction provided by the Naval Sea Systems Command, PHALANX Program Office (PMS-413).

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EVALUATION OF LIGHTNING PROTECTION SYSTEMS FOR EXPLOSIVES*

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ABSTRACT

The unpredictable nature of lightning requires that lightning protection systems (LPS) be described in statistical terms such as the "expected efficiency of protection" or the "probability of failure". This implies, as has been observed, that lightning channels occasionally penetrate what has been considered to be a "zone of protection" provided by the LPS. This lightning penetration exposes assets, such as explosives and related fusing and test electronics, to possible direct effects of being part of the lightning current path. Depending on the current amplitude, these direct effects can cause malfunction, upset, or catastrophic damage to these assets and perhaps to personnel and structures in the immediate vicinity.

Even in cases where the LPS has not "failed" there are indirect effects caused by inductive and capacitive coupling which transfers electromagnetic energy to the interior of the "zone of protection" in the proximity of down conductors and other elements connected to the LPS. These conductors and elements can carry the bulk of the lightning current or temporarily store a significant amount of charge from the strike. These indirect effects can also cause malfunction, upset or damage to assets depending on the vulnerability of the asset to electric and magnetic fields and currents. Vulnerability depends on operational configurations, such as, 1. stored in an underground igloo in closed metal containers or 2. exposed in a maintenance building connected to electronic test equipment. Some military and industrial LPS specifications require the LPS to be bonded to other metal objects and to other electrical grounding systems. In some geometrical configurations, this additional bonding can enhance (rather than reduce) the possibility of direct and/or indirect coupling to assets.

A computer model solving the three dimensional Maxwell's Equations for various LPS environments and corroborated by data from triggered lightning tests is used to show that there are areas within the "zone of protection" which are safer than other areas. These calculations are used to establish statistical "safe zones" within the "zone of protection" which are determined by building geometry, the geometrical layout of the LPS, the bonding of the LPS to other metal objects and electrical grounds, the earthing configuration of the LPS, and the vulnerability of the asset in its presumed operational configuration. A quantitatively-based assessment method for LPS evaluation (TESLA) is suggested, which relates survivability to asset strength and the stress from the lightning environment which penetrates typical LPS's.

* Presented at 25th DoD Explosives Safety Seminar, Anaheim, California, August 18-20, 1992

1.0 INTRODUCTION

1.1 Background

The purpose of this section is to orient the reader to the different aspects of lightning protection (LP). These aspects include:

1. Types of LP Systems (LPS)
2. Earth Ground Systems
3. Bonding
4. Direct Effects vs. Indirect Effects
5. Statistical Effects and Protection Philosophy

1.2 Types of Lightning Protection Systems

There are three basic types of LPS:

1. Integral Systems (Figure 1.1)
2. Mast Systems (Figure 1.2)
3. Mast plus Catenary Systems (Figure 1.3)

The integral system consists of three parts: the air terminals, the down conductors, and the earth ground system. The air terminals are spaced in a manner which gives protection over the entire facility as shown in Figures 1.1 and 1.7.

The mast system consists of a mast located some distance away from the facility, but close enough to it to provide a protection zone enclosing the facility. The protection zones are defined by either the cone of protection concept or the Horvath rolling sphere method [7], based on the statistical concept of "striking distance" as shown in Figure 1.2 and 1.3. Typical protection zones are shown in Figures 1.2 through 1.7. The mast plus catenary systems provide additional protection coverage from cables attached to one or more masts.

The Faraday Cage Shield (which can be used for additional protection) refers to the asset being protected inside a completely closed metal container, theoretically impervious to electric charges and electric fields. In practice, the containers are never completely closed, having seams, access ports, insulated electrical feedthroughs, or apertures of various kinds allowing energy to penetrate to the interior of the container. Other examples of partial Faraday shielding include screened rooms and networks of iron rebar in re-enforced concrete enclosures. Partial Faraday shielding can reduce the effects of lightning. The screen or aperture size determines the frequency of protection at distances far from the screen or aperture. Low frequency penetration and capacitive effects occur near the screen surface or location of the aperture.

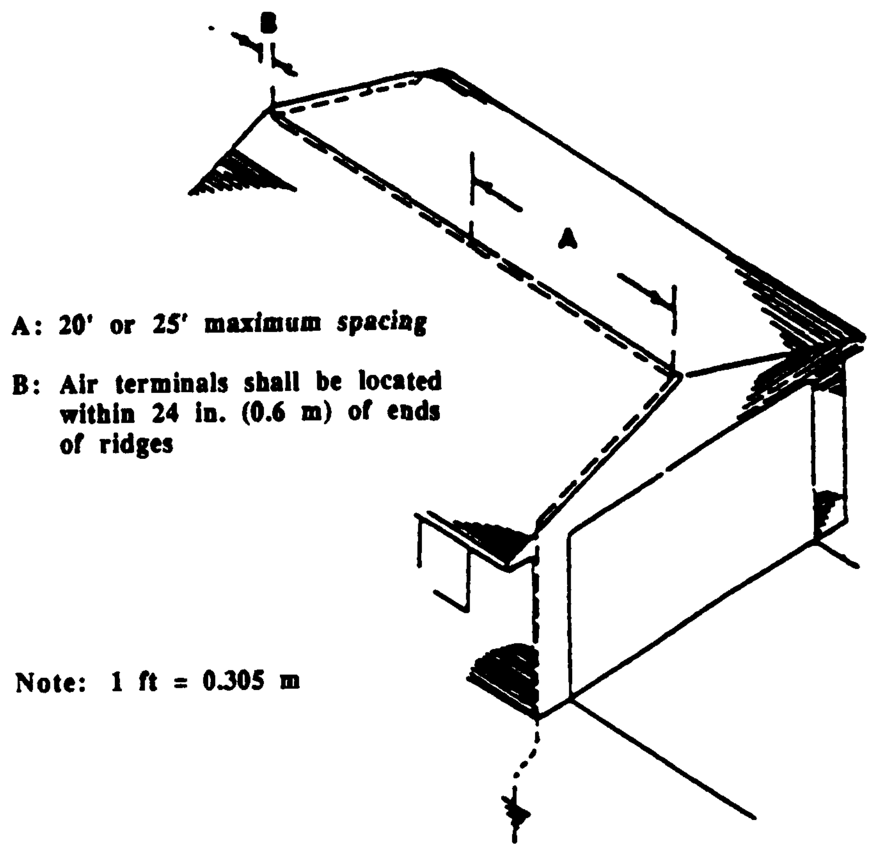
1.3 Earth Ground Systems

The earth ground system may consist of a ground rod (Figure 1.8) or a counterpoise system (Figure 1.9). The resistance to earth is a function of the rod's length and diameter, and the earth's resistivity. Military requirements usually specify a maximum resistance of 10 Ω to 25 Ω. Multiground rod systems arranged on a counterpoise can be used to achieve low resistance. Formulas exist for computing the DC resistance of various types of ground rod systems (for example, MIL HANDBOOK 419). There have been no clear specifications given for the inductance or the high frequency impedance of earth ground systems which can affect peak voltages during a strike.

A facility frequently has more than one ground system. Inside the facility, there may be a signal ground (technical ground), a facility ground, and an ordnance ground. Separate earth ground systems may also exist, including a facility earth ground and perhaps a LPS ground. Some military and industrial specifications require that all of these ground systems be connected to each other at one point as shown in Figures 1.8 and 1.10.

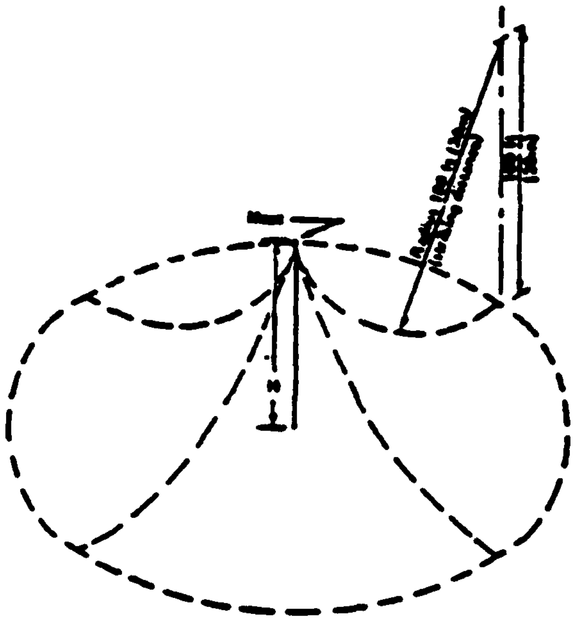
1.4 Bonding

Lightning protection requirements specify conditions under which large metallic objects inside a facility be connected (bonded) to each other and to the earth ground system. The rationale behind this is to prevent arcing between metallic objects, which could create a fire hazard. However, this practice also allows the lightning environment to penetrate into the facility interior.



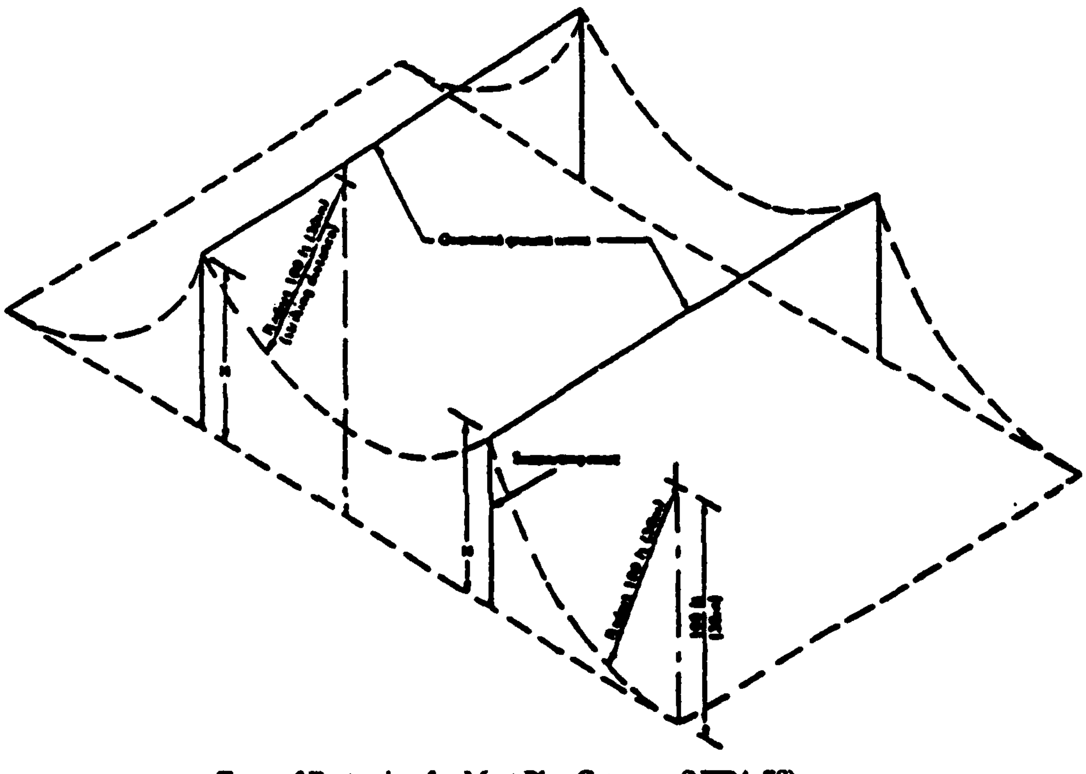
Air Terminals on Peaked Roof (NFPA 78)

Figure 1.1 Integral Lightning Protection System



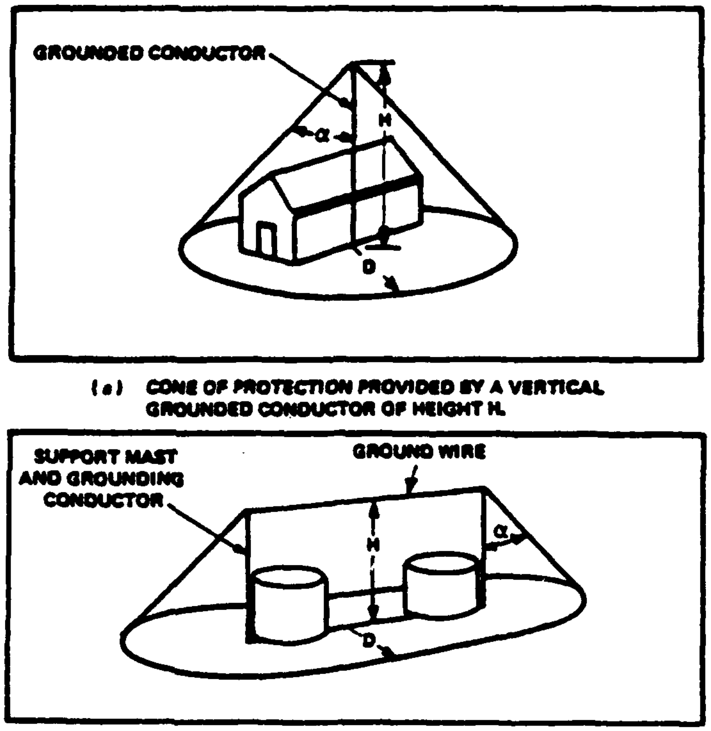
Zone of Protection for Mast (NFPA 78)

Figure 1.2 Mast Type



Zone of Protection for Mast Plus Catenary (NFPA 78)

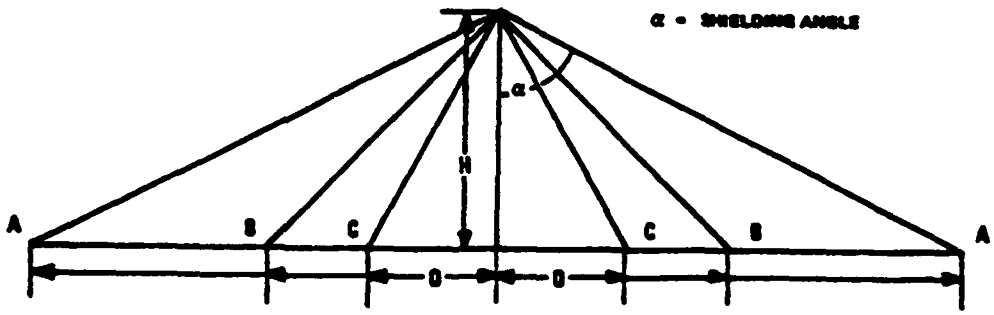
Figure 1.3 Mast Plus Catenary



(a) CONE OF PROTECTION PROVIDED BY A VERTICAL GROUNDED CONDUCTOR OF HEIGHT H.

(b) ZONE OF PROTECTION PROVIDED BY A HORIZONTAL AERIAL GROUND WIRE AT HEIGHT H.

Zones of Protection Established by a Vertical Mast and a Horizontal Wire (MIL HDBK 419A)



ZONE	D/H	α	REFERENCE	RECOMMENDED FOR
AOA'	2/1	63°	NFPA 78	ORDINARY CASES
BOB'	1/1	45°	NFPA 78 BRITISH CODE	IMPORTANT CASES ORDINARY STRUCTURES
COC'	0.58/1	30°	BRITISH CODE	CRITICAL STRUCTURES

Some Commonly Used Lightning Shielding Angles (MIL HDBK 419A)

Figure 1.4 Zones of Protection

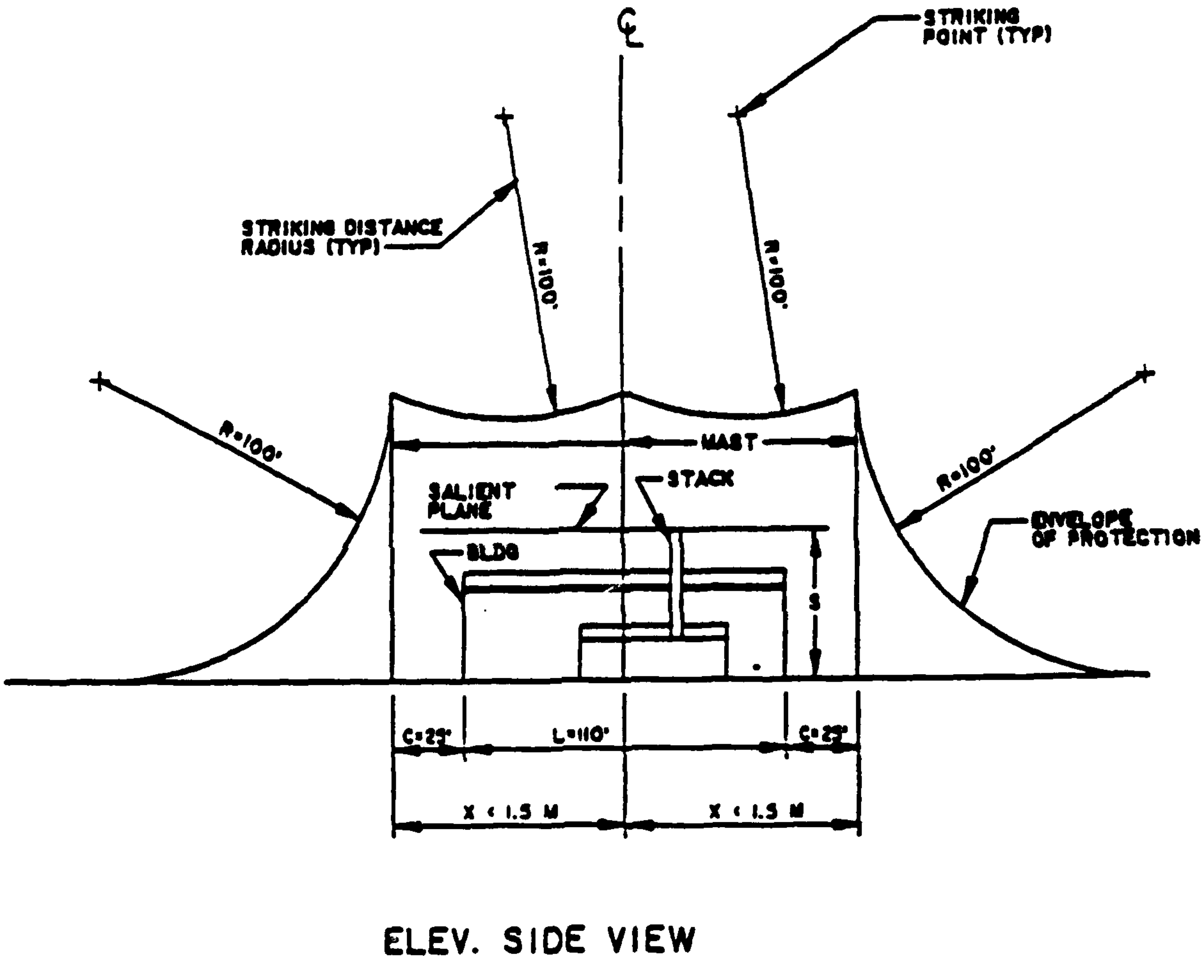


Figure 1.5 Primary Lightning Protection Design for Ordnance Handling Facilities (MIL-HDBK 1004/6)

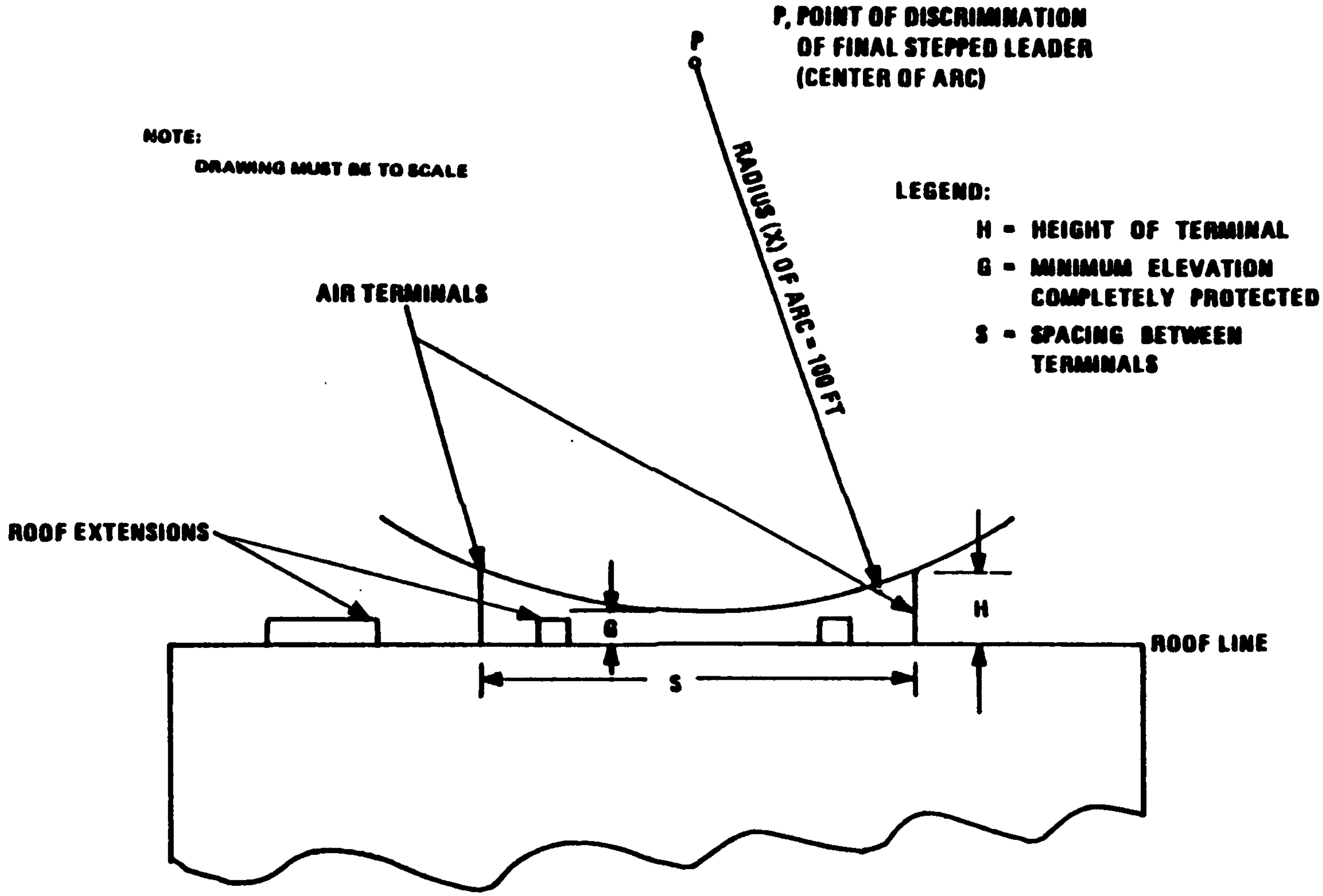


Figure 1.6 Illustration of Method for Determining the Protection of Flat Surfaces as Provided by Air Terminals (1-4) (MIL HDBK 419A)

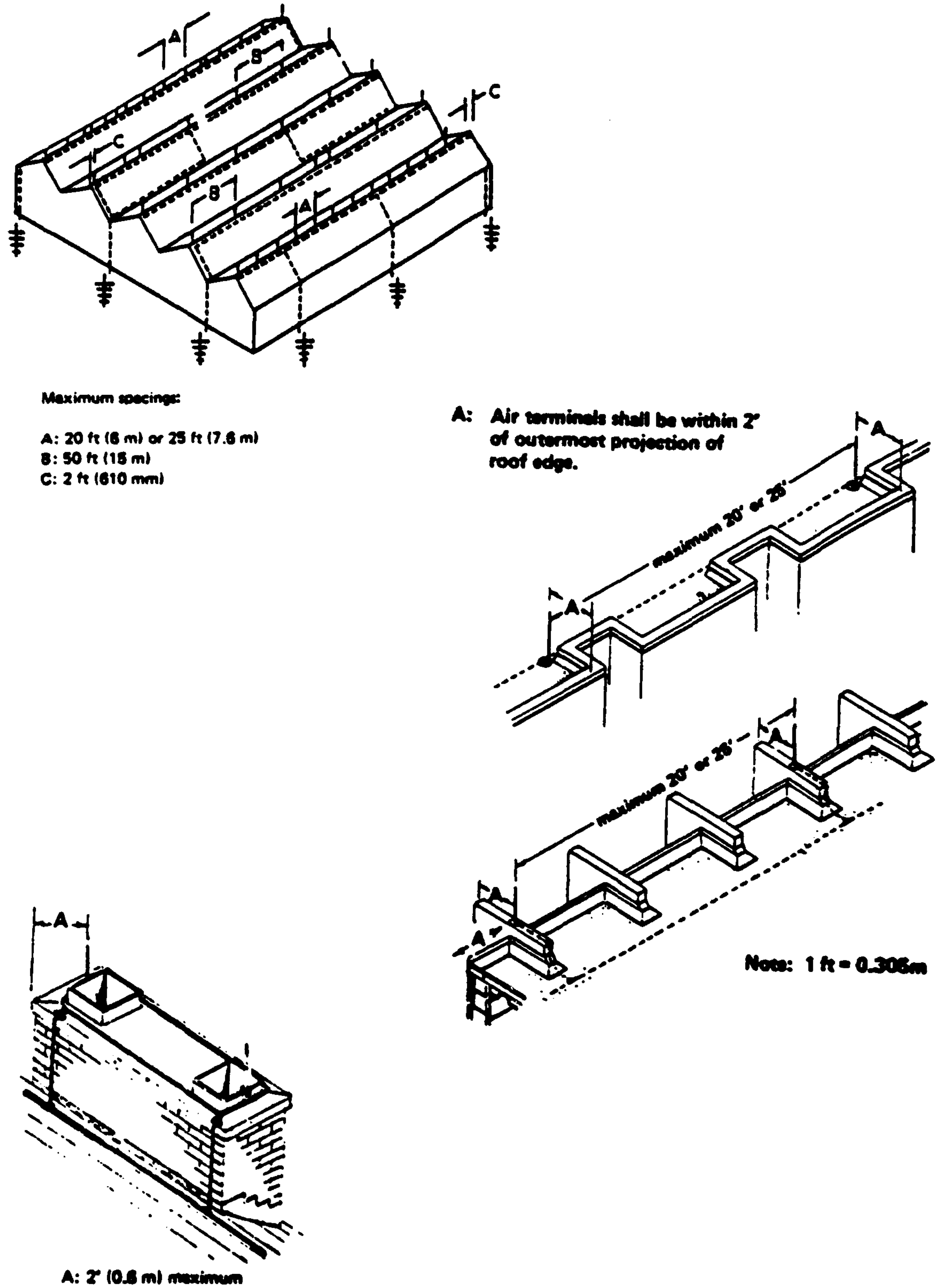


Figure 1.7 Locations of Air Terminals (NFPA 78)

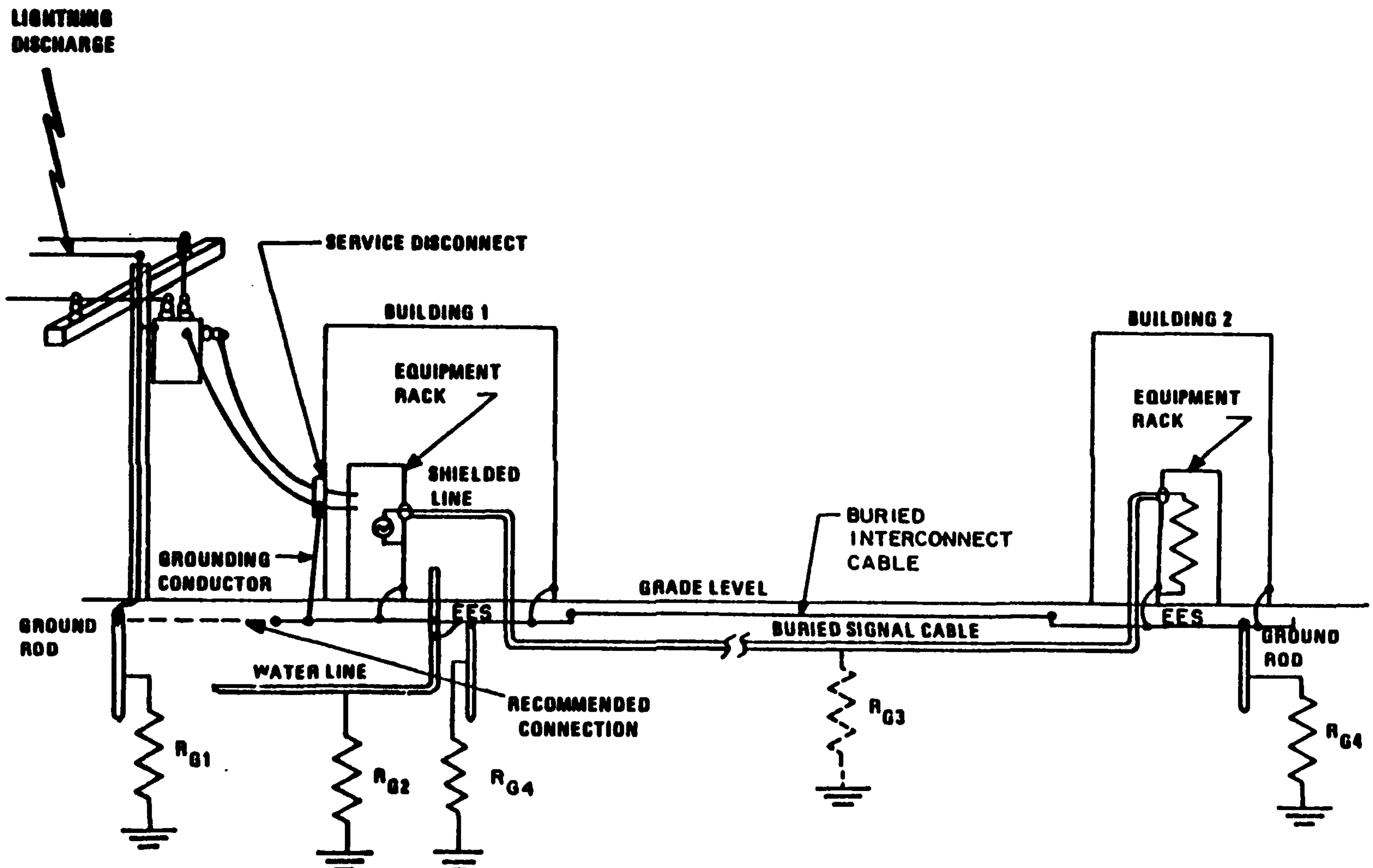


Figure 1.8 Coupling of Lightning Energy Through an Interconnected Facility (MIL HDBK 419A)

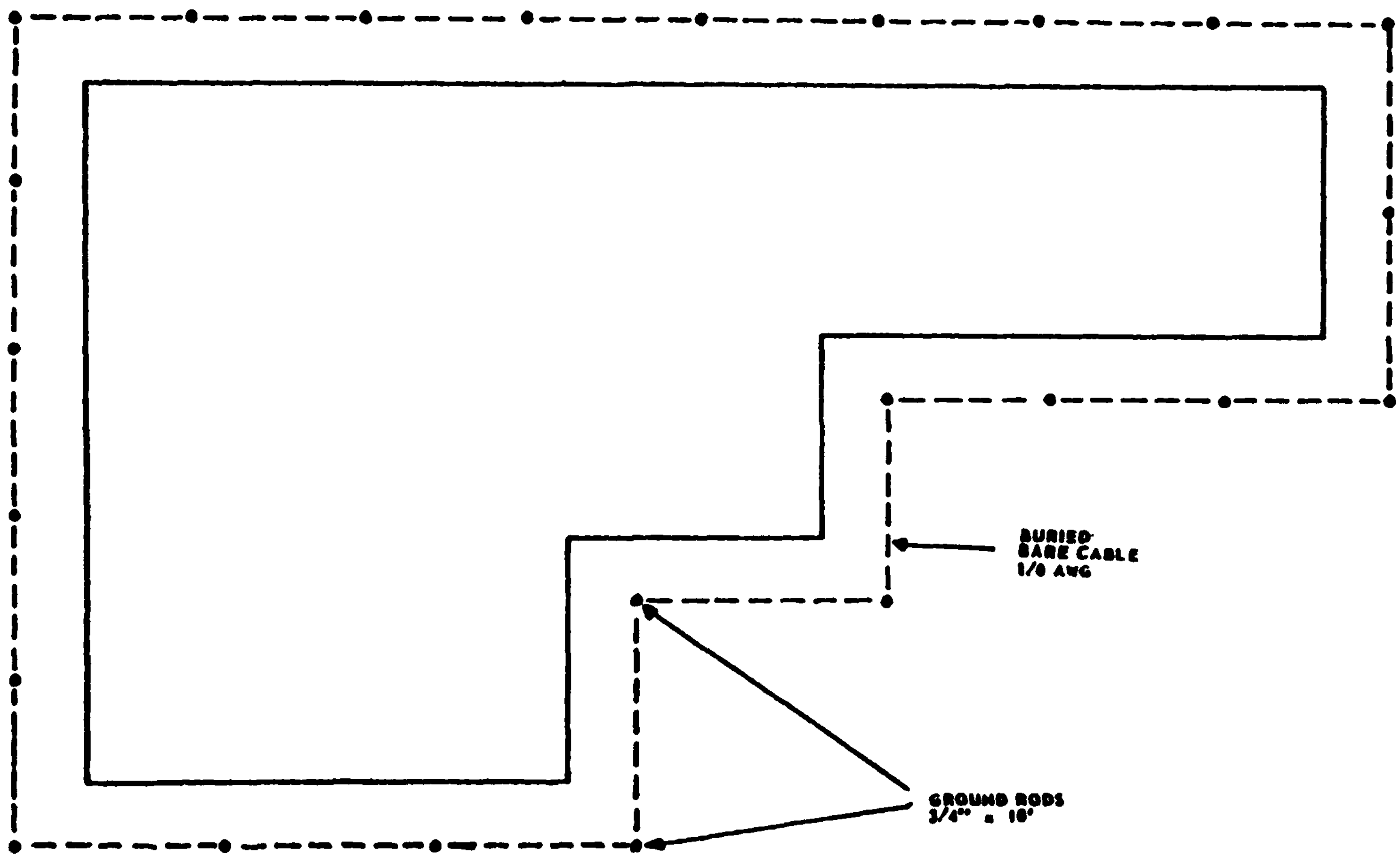


Figure 1.9 Electrode Configuration for Irregular Shaped Facility (MIL HDBK 419A)

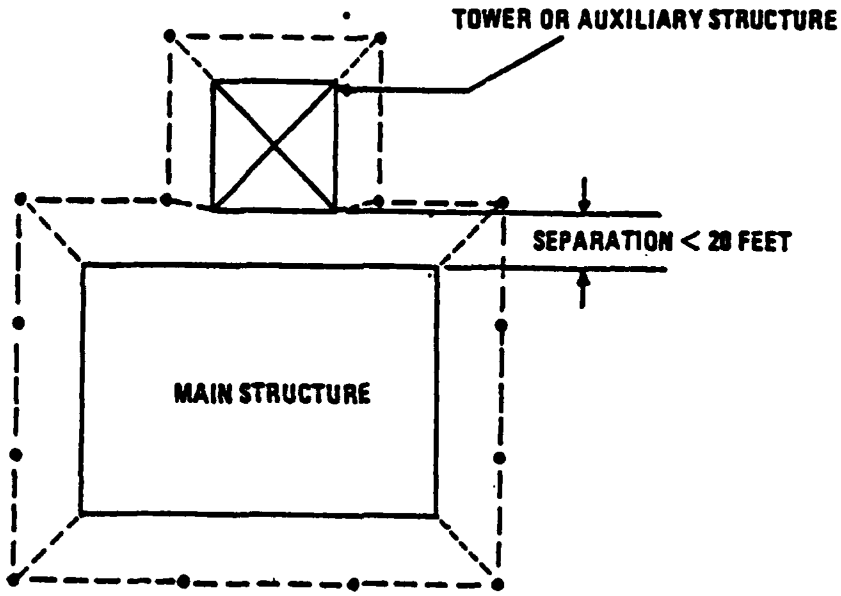


Figure 1-8. Electrode Configuration for Adjacent Structures

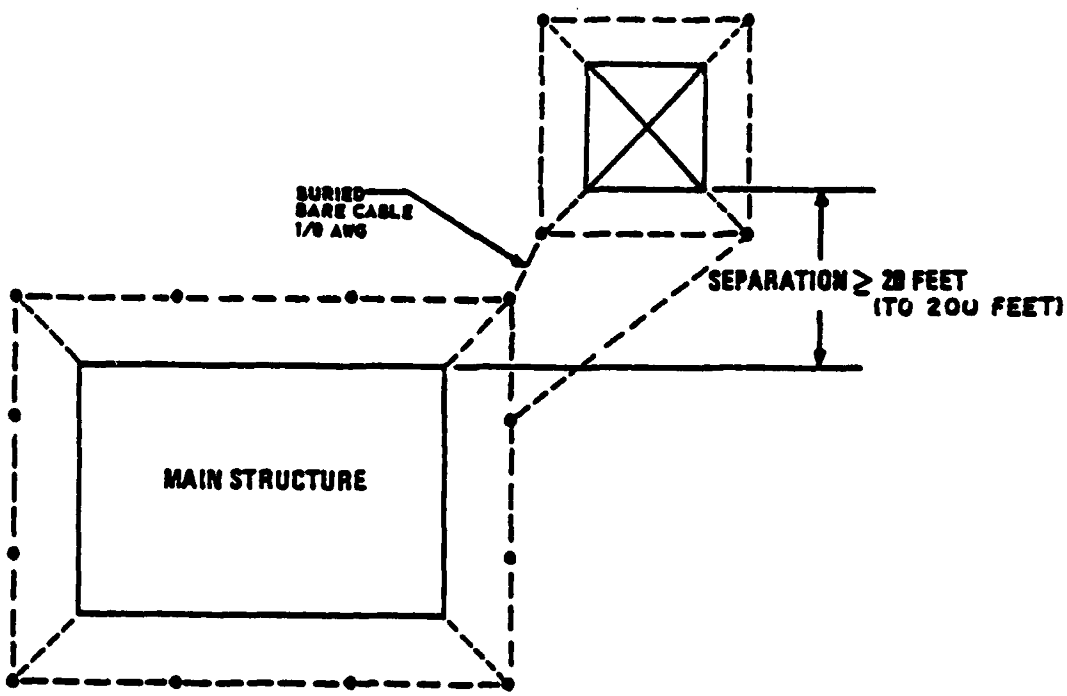


Figure 1.10 Electrode Configuration for Closely Spaced Structures (MIL HDBK-419A)

Some specifications require that external conductors, such as nearby railroad tracks and fences, also be connected to the ground system. The rationale for this may be that this will prevent arcing, and also that it will create a lower impedance earth ground system. It should be noted that this practice will also increase the lightning capture area of the facility.

1.5 Direct Effects vs. Indirect Effects

There are two primary phenomenon which couple energy from the lightning strike to assets and other objects:

1. Direct Coupling, where the object in question provides a path for all or part of the electrical current in the lightning strike,

2. Indirect Coupling, where the object is coupled electromagnetically, through electric and magnetic fields caused by charge and current and the temporal change of these quantities in the lightning stroke. (Temporal changes in electric and magnetic fields are sometimes referred to as E-Dot and B-Dot, respectively).

Induced currents from indirect coupling can cause damage at significant distances from primary conductors carrying the bulk of the lightning current. Because of electromagnetic induced effects, it is not proper to consider lightning energy to be confined to the air terminals, down conductors, and earth grounding systems.

Both direct and induced currents can cause damage by heating and burning. Direct and induced arcing can ignite fuels, explosives, and flammable materials. Mechanical damage can be caused by melting, by projectiles (e.g., wood, concrete) which have been spalled from structural elements, and by mechanical whipping of wires and cables. Indirect currents and fields can cause physiological damage to personnel.

1.6 Statistical Effects and Protection Philosophy

Lightning is, by nature, unpredictable. This unpredictability includes the location and frequency of strikes, the strike amplitude, risetime to peak amplitude, the number of strokes in each strike, and the intermediate current state preceding the lower amplitude continuing current of each stroke.

Statistical formulas and isoceraunic maps (giving the local frequency of thunderstorms and/or lightning strikes per unit area) are useful in determining the likelihood of a strike in any given area. Experimental evidence gives statistical distributions of strike amplitude, risetime, intermediate and continuing currents. Much more precise data is available from lightning locator systems. Local anomalies exist for various local varieties in terrain, for example, mountain peaks or the edge of a bluff.

Lightning Protection Systems can be designed from a consideration of what is "likely to happen" given a "normal" strike, or by considering what "could happen" in a "worst case" scenario. Worst case scenarios are often described in terms of 1% likelihood; that is, something "worse" than a "worse case" is expected to happen in less than 1% of the cases. Lightning protection systems can be described in statistical terms such as "the expected efficiency of protection" or "the probability of failure". This implies, as has been observed, that lightning channels occasionally penetrate what has been considered to be a "zone of protection" provided by the LPS. These statistical probabilities are often analyzed in terms of Horvath's "Rolling Sphere" Model [7].

For something as serious as explosives and related electronic circuitry, the "normal" lightning protection specifications are considered inadequate. (For example see MIL-HDBK 419A Vol. 1 p.3-13). It remains to determine what is an "adequate" specification of LPS for explosives and related assets. Even in cases where the LPS has not "failed", indirect effects can cause damage if the assets are not properly placed within the system.

Presently, most design specifications in present manuals are independent of asset vulnerability considerations and usually do not consider "safe zones" for particular assets. The balance of this paper will address primarily a calculation method based on explicit numerical solutions of Maxwell's Equations which are capable of defining the safe zones for a given lightning attachment to an LPS or to a structure location point in the event that the LPS has "failed". These calculation methods have been validated well within an order of magnitude from triggered lightning experiments on an underground storage igloo [1, 2].

2.0 DESCRIPTION OF THE NUMERICAL MODELS

The numerical model of the structure and surrounding environment is based upon a finite difference time domain solution of Maxwell's equations. The solution technique is explicit and accurate to second order in the time and spatial increments, which in these models correspond to the three dimensional Cartesian coordinate increments as obtained by Merewether and Fisher [3] with further discussions by Collier, McKenna, and Perala [4,5].

A problem space containing the facility and surrounding environment is divided into rectangular cells. Each cell has a staggered spatial grid, as shown in Figure 2.1, composed of the vector components of E and H (the electric and magnetic fields, respectively). There are approximately one million cells in the lightning strike problem spaces discussed in this paper. The cell dimensions Δx, Δy and Δz are 12"x6"x6" for the igloo and 6"x12"x12" for the building. The field components in each cell are calculated numerically via the finite difference form of Maxwell's Equations [3].

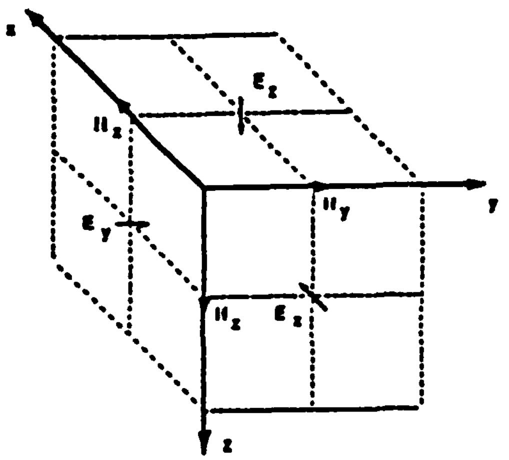


Figure 2.1 Staggered Spatial Grid

MAXWELL'S EQUATIONS

$$\mu\frac{\partial H}{\partial t} + \nabla \times E = M \quad (1)$$

$$\varepsilon\frac{\partial E}{\partial t} + \sigma E - \nabla \times H = -J \quad (2)$$

$$\nabla \cdot E = \frac{\rho}{\varepsilon} \quad (3)$$

$$\nabla \cdot H = 0 \quad (4)$$

In addition to the appropriate boundary and initial conditions, the material properties at each cell location must be specified. This consists of the magnetic permeability, μ, in equation (1); the conductivity, σ, in equation (2) and the dielectric constant, ε, in equations (2) and (3). If the material is homogeneous within the cell (for example, volumes of air, soil, concrete, etc.) then the appropriate values of μ, σ, and ε are included in the time advance equations for the cell in question.

If the material properties are inhomogeneous in each cell (detailed structure, etc.) then a decision must be made on how to represent the properties in each cell. In some cases average properties are sufficient and in other cases they are not. Special considerations are available for treating apertures in metal walls and also for pipes and thin wires (radii much smaller than cell dimensions) which may run throughout the problem space. These pipes and wires can be carriers of high current.

The buildings and facilities of interest usually have a great deal of "thin wire" situations in the form of signal and power lines, rebar in reinforced concrete, pipes, plumbing, metal poles, the lightning protection air terminals, down conductors, counterpoise, etc.

The thin wires and rods are implemented in a self consistent fashion by making use of the telegrapher's transmission line equations. The telegrapher's equations (5), (6) are a one dimensional solution of Maxwell's in terms of currents, I_W, and voltages, V_W, on the wires, which are required to have diameters less than cell size (spatial increment). The per unit length inductances and capacitances are defined (7), (8) with respect to the cell size and the wire diameter, 2a.

The One Dimensional Transmission Line Equations are:

$$\frac{\partial V_W}{\partial z} = - L_W \frac{\partial I_W(k)}{\partial t} - I_W R_W + \bar{E}z(i_W, j_W, k) \tag{5}$$

$$\frac{\partial I_W}{\partial z} = - C_W \frac{\partial V_W}{\partial t} - G_W V_W \tag{6}$$

where L_W and C_W is the in-cell inductance and capacitance of the wire per unit length.

$$L_W = \frac{\mu o}{2\pi} \ell n\left(\frac{\Delta y}{2a}\right) \tag{7}$$

$$C_W = \frac{2\pi a \varepsilon E_r(a)}{V_W} = \frac{2\pi\varepsilon}{\ell n\left(\frac{\Delta y}{2a}\right)} \tag{8}$$

G_W is the in-cell conductance from the wire to the surrounding conductive medium

$$G_W \equiv \frac{\sigma}{\varepsilon} C_W \tag{9}$$

The wire resistance per unit length, R_W, is obtained by considering the surface conduction of the metal in question using the skin depth obtained for a frequency of 1 MHz. The resistance for pipes, wire, iron rebar, etc., is normally on the order of 10^{-3} Ohms/meter. In practice, the major results at early time seem to be relatively insensitive to variations of the resistance.

In the computer code, the wires and pipes are embedded into the staggered grid and are driven by the electric field component (see Equation (5)) calculated by the three dimensional solution of Maxwell's equations. In order to maintain electrical charge conservation, this wire current must also be injected back into the driving electric field component as a source current via Maxwell's Equation (2). At the interconnections, which are voltage nodes, Kirchoff's law is invoked. At locations where the wires are situated in the soil or concrete, the wires are in electrical contact with the soil or concrete with in-cell conductance given by G_W in equation (9). This is also true of the facility ground wire which is in contact with the soil.

Complex networks of thin wires (e.g., concertina or metal rebar mesh embedded in conducting concrete) are included in the model by a vectorized extension of the transmission line formalism. Vectorized average wire currents coincide with the electric field vectors in each cell and a corresponding average inductance and resistance is associated with each wire current vector. Six component tensors exist at the cell corners (nodes) describing the equivalent transmission line voltages, wire capacitance, and conductance to the embedding medium. A 36 component connectivity tensor exists at each node describing the ways that wires are connected at the nodes.

At the boundaries of the problem space, some termination condition must be applied to both the counterpoise extensions and the power and signal lines and metal pipes entering the problem space. The boundary condition is applied at current nodes and is the equivalent of the Mur boundary condition applied to the magnetic fields [4].

The problem is initiated by imposing a pre-determined lightning wave form from the top edge of the problem space to a specific point on the structure. In a typical computational case described below, the lightning current waveform is characteristic of a 1% stroke of negative lightning. The lightning current appears without propagation delays in a line of vertical electric fields (E_Z) from the top of the computational volume to the attach point. The lightning current is injected into the electric fields by dividing the current by the cell area whose normal is parallel to the vertical direction. This becomes the source current density, J, in Maxwell's equation (2).

The computer model contains features of interest such as, soil, concrete, rebar, counterpoise, etc., which are included in the computer model in a modular form. These separate features may be included or excluded from the model by calling subroutines specific to the features desired. The computations are performed on a CRAY II computer. Typical run times are 1 hour of computer time for each microsecond of real time for problem spaces which, in the cases described here, contain approximately one million cells as shown in Figure 2.1.

3.0 CALCULATION OF SAFE ZONES

The analysis of the preceding sections has been applied to two structures: (1) an earth covered storage igloo with iron rebar reinforced concrete walls as shown in Figure 3.1 and, (2) a rectangular constructed building with a metal roof as shown in Figure 3.2.

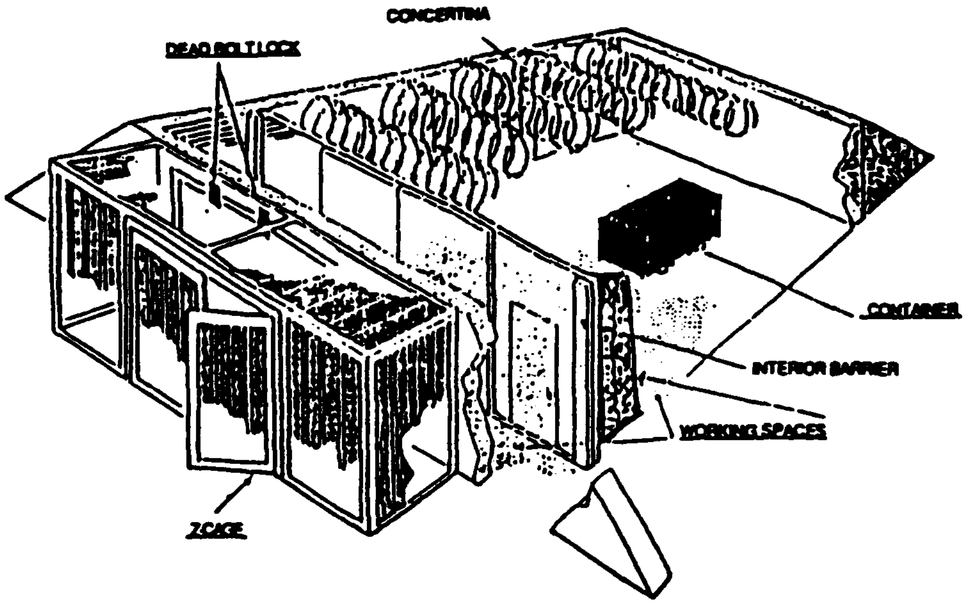


Figure 3.1 Earth Covered Storage Igloo -- Lightning Strike Model

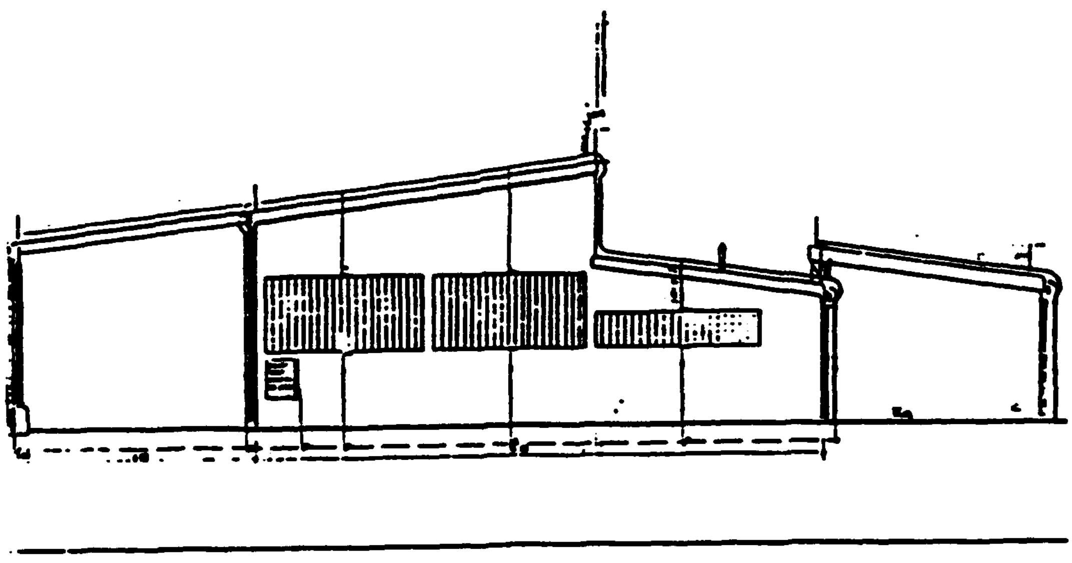


Figure 3.2 Building - Right Side View With Window Screens and Lightning Protection System

The igloo interior is completely surrounded with either metal or iron rebar which forms a "leaky" electromagnetic shield for the interior. A schematic drawing of the igloo vertical mid-cross-section is shown in Figure 3.3.

The building is made of concrete block outer walls with no rebar, a metal roof, and concrete with rebar floor and inner walls with rebar. Thus the building cannot be considered as having a contiguous shielding effect.

For both models the numerical computer output from a simulated lightning strike may be categorized as follows for the establishment of safe zones:

1. Contour Plots - These are "snapshots in time" of the electric and magnetic field structures on a plane cross-section of the building at some time after the initiation of the strike. These contour plots outline areas of constant field magnitude and are used to establish the boundaries of the safe zones for various levels of asset vulnerability. Areas for B-Dot, E-Dot, and total energy are established in the same manner.

2. Time Dependent Plots - these are time dependent graphs of electric and magnetic fields at selected points in the problem space. Currents and voltages on thin wires and rods also have time dependent plots at selected points.

3. Current Arrays - These are spreadsheet tabulations of wire currents in specific areas of the building.

4. Field Maxima - These are computer searches at selected times to find the maximum electric and magnetic fields and the maximum time derivative of the magnetic field within a specified boundary inside the building. This output can be used to check field maxima within safe zones or conversely can identify areas of high threat.

5. Time lapse video presentations showing the magnitudes of the electric and magnetic fields on specific plane cross-sections of the buildings are used for visual development of safe zones [5].

Figure 3.4 shows a contour plot of the vertical mid-plane longitudinal cross-section of the igloo corresponding to the schematic in Figure 3.3. The electric field pattern outlines some of the prominent features of the igloo, i.e., the z-cage, soil berm over the igloo, headwall, backwall, etc. The vectors show the projection of the electric field vector at each cell onto the mid-plane at a time 1 μsec after the initiation of the strike. The length of the vector is proportional to the logarithm of the electric field. The contour lines show lines of equal electric field magnitude labeled as powers of 10 of the field magnitude in volts per meter. For example, the line labeled 4.0 represents field magnitudes of 10,000 volts/meter.

Figure 3.5 shows a contour plot on a vertical x-z plane of the building cutting through wire mesh on the window nearest the strike. The view is as if looking from the back of the building. The field patterns show essential geometrical features of the model, i.e., roof, supporting I-beams, outer wall, etc.

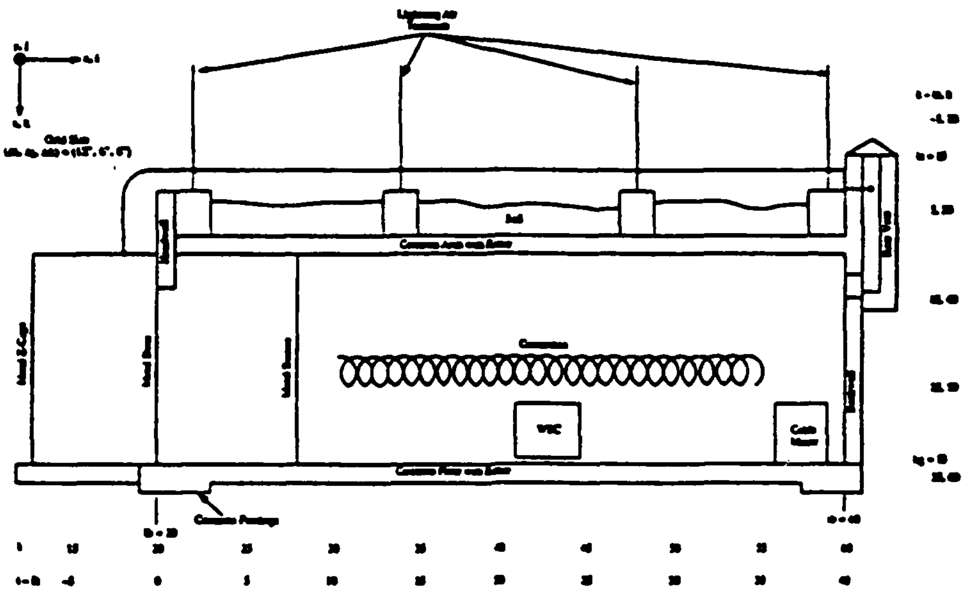


Figure 3.3 Igloo Vertical Cross-Section at j = jm = 75

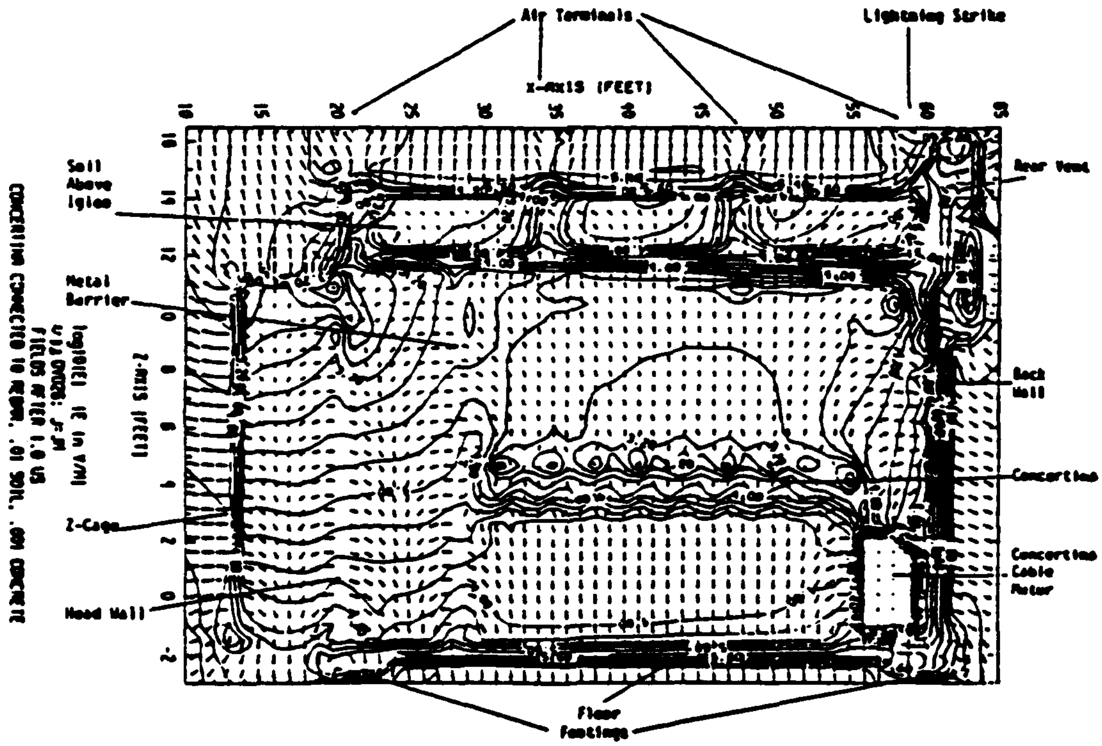


Figure 3.4 Electric Field Vector and Magnitude Contour Plot for Vertical Mid-Cross-Section of Igloo

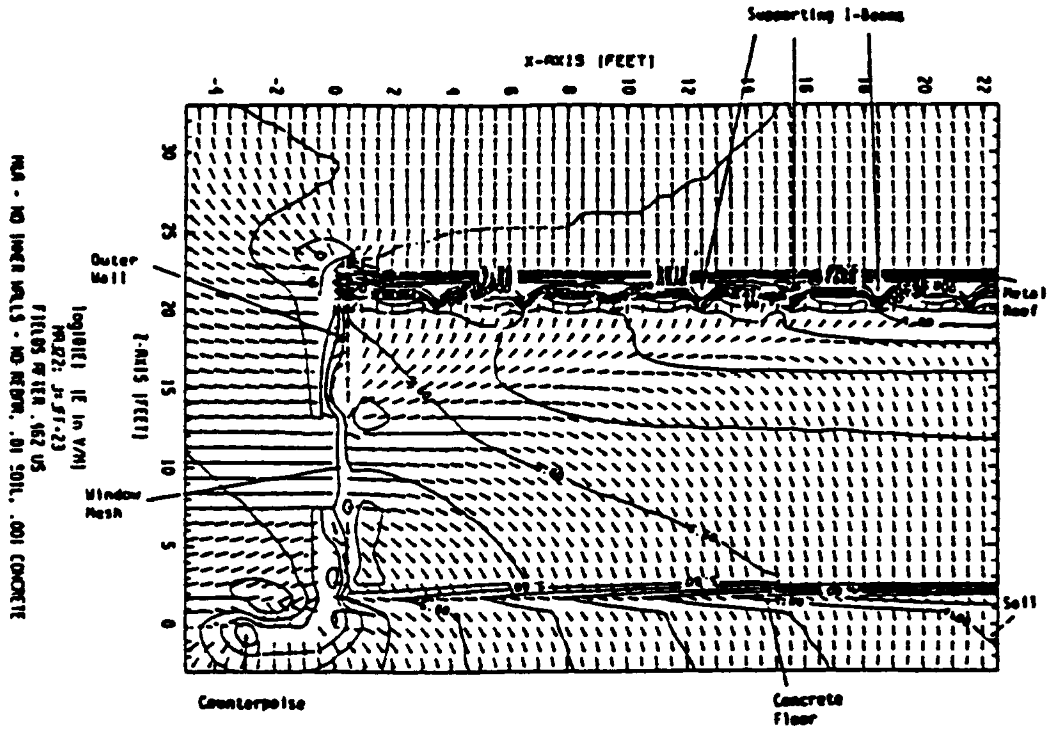


Figure 3.5 Electric Field Vector and Magnitude Contour Plot for a Vertical Plane Passing Through the Window Mesh of the Building .426 µsec After Attachment

Figure 3.6 shows the effect of adding an I-beam (perpendicular to the contour plane) with a hanging metal cable hoist. The field at the bottom of the hoist is on the order of a few mega-volts/meter and represents a potential for arcing between the hoist and the floor rebar (or any other piece of grounded equipment). In this case the lightning protection system is in contact with the metal roof which is also in contact with the I-beam.

4.0 TESLA ASSESSMENT METHOD

The Expert System for Lightning Assessment TESLA procedure for a full/detailed assessment is outlined here for a complicated electronic system; the process was planned to include possible experimental tests and measurements as well as possible extensive calculations [6].

Figure 4.1 shows a block diagram of the work flow for the proposed assessment. The basic activity is a calculation of a margin, that is, a ratio of strength to stress. The stress is compared to strength for interfaces such as electrical lines (e.g., power, telephone) for surges, such as occurs through equipment case seams (for field penetration). These calculations may be performed at various locations throughout the facility to establish safe zones for particular classes of assets.

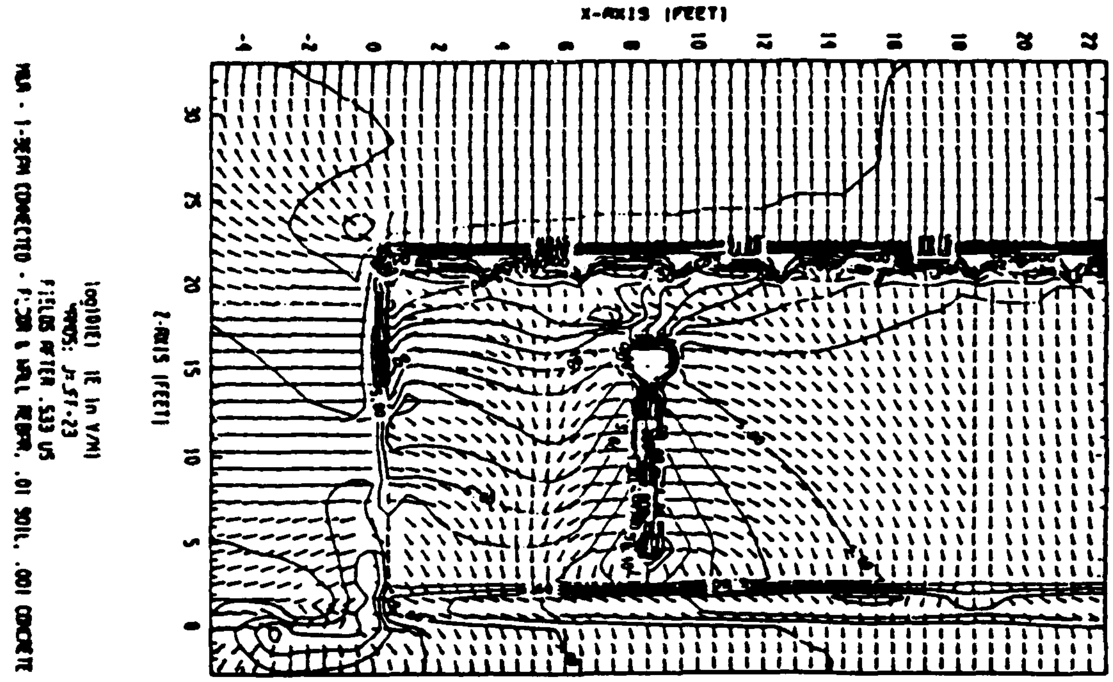


Figure 3.6 Electric Field Vector and Magnitude Plot for Building Showing the Effect of an Internal I-Beam and Metal Cable Hoist

As shown in Figure 4.1, there are nine tasks [6]. Preliminary tasks of planning the assessment and gathering data on the systems and facilities are included in Tasks 1.0 (Preliminary Evaluation), 2.0 (Assessment Plan), and 3.0 (Testing and Data Gathering). The central tasks are 4.0 (Determine Stresses), 5.0 (Determine Susceptibilities) and 6.0 (Calculate Margins/Uncertainties). The approach also includes a review of the final data and possible iteration of the margin calculations, and a final report. These are Tasks 7.0(a) and 7.0(b) (Review, Evaluation), 8.0 (Revise Plans), and 9.0 (Prepare Report).

5.0 CONCLUSIONS

A numerical computer model of Maxwell's Equations V3DFD and a computer based assessment method TESLA have been described for evaluating LPS design and lightning threats to specific facilities. It is seen that detailed electromagnetic field profiles and currents may be calculated and evaluated to determine in a realistic manner safe zones for assets in and around the facility for given lightning attachment points. Further work needs to be done in establishing the probability of location of the attachment points on the LPS and also for probable attachment points on the facility in the event of "failure" of the LPS.

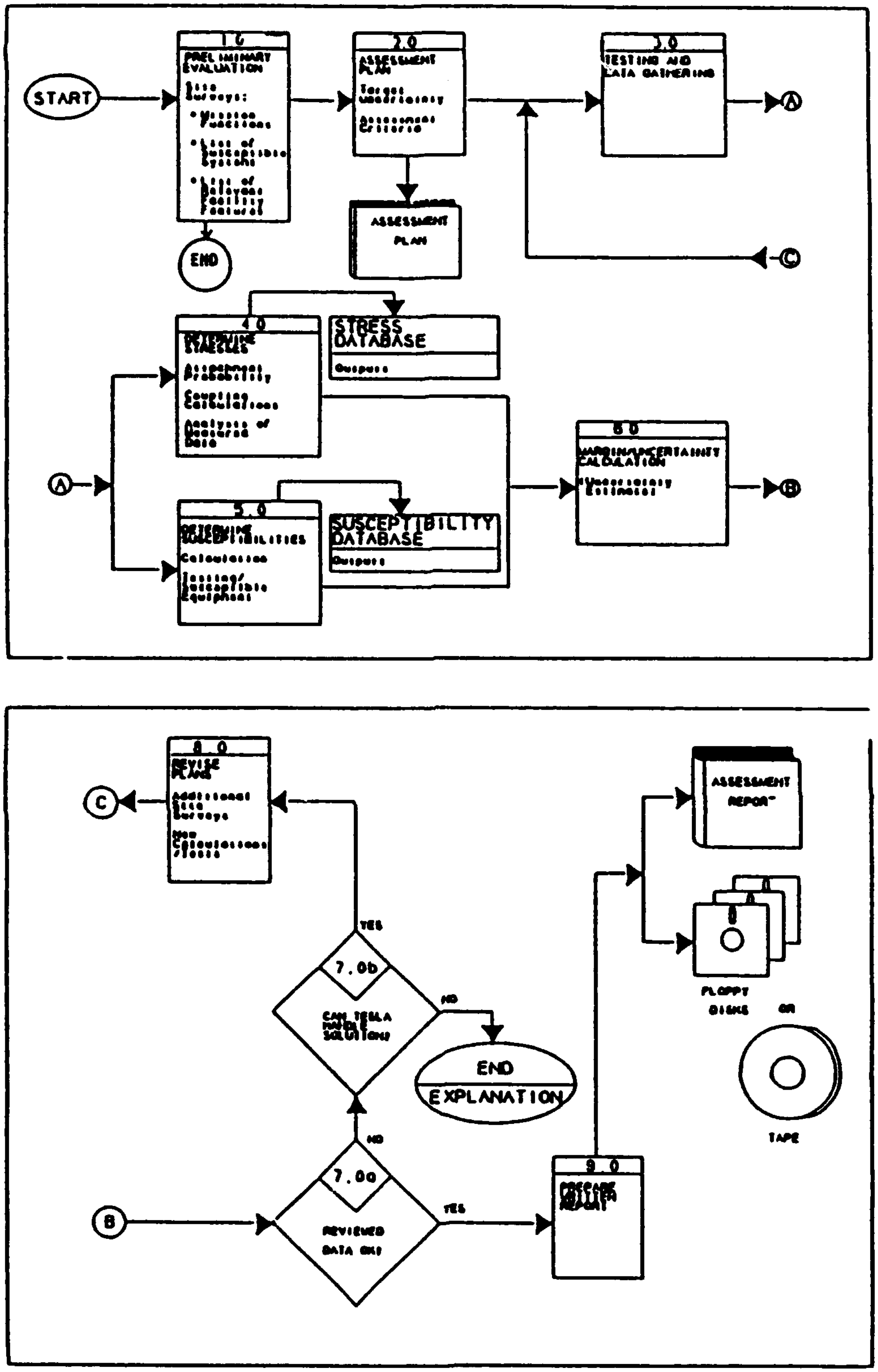


Figure 4.1 The Final Assessment Methodology for a Detailed Assessment by TESLA

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APPLICATION OF LIGHTNING DETECTION AND WARNING SYSTEMS WITHIN THE EXPLOSIVES AND BLASTING ENVIRONMENT

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ABSTRACT

Lightning has always posed a serious threat to operations involving explosives, especially within the DOD and commercial mining and construction industries. In recent years, technological advancements in communications systems and microprocessors have significantly improved the accuracy and efficiency of lightning detection and warning systems and instrumentation. These advancements have also increased the availability of highly reliable, accurate and affordable systems for use in receiving, processing and displaying realtime lightning information and data from warning instrumentation.

Access to these systems, which detect the presence of, or potential for, cloud-to-ground and a varying percentage of cloud stroke lightning, is exposing personnel to one of the most complex elements of atmospheric physics. Armed with this "scientific data", supervisors and managers are expected to make the right decision all of the time, decisions that will have a significant impact on personnel safety, productivity, and the organization's material resources. It is a fact of life that the data they are dealing with is not perfect, can be misinterpreted, and in many cases, can be unwittingly viewed as a false report. Such factors will not only reduce the effectiveness of the system in the every day environment, but also, significantly undermine user confidence which could slow response/reaction to future warnings.

The intent of this paper is to; (1) provide the reader with a basic understanding of thunderstorm/lightning meteorology, (2) review various technologies used in the detection and advance warning of lightning events; (3) address lightning effects on cables; (4) discuss methods and procedures, along with information gained by various activities who employ either detection or advance warning technology, or both, within their daily operations. Access to such information will provide current and potential users with additional insight on these issues, and hopefully, stimulate new ideas on ways such systems can be used to improve the explosives safety environment without compromising operational readiness.

1.0 Introduction

Since the last seminar in St. Louis, Missouri in 1990, there has been a significant increase in the number of organizations utilizing realtime lightning data and/or advance warning, such as Electric Field Mills (EFM), instruments to support operations and safety needs within the explosives environment.

While a significant number of commercial users has evolved, such as Amax Coal Company, Northrup, Rockwell International, and Lockheed Missiles and Space, an equally significant number of users within the Department of Defense (DOD) has also taken place. The system configuration at these activities varies between employment of only realtime detection and tracking systems, or integration with, or stand alone operation of, EFM's.

Some of the activities that utilize only realtime systems include, Redstone Arsenal, NTC Orlando, Maxwell AFB and NAS Memphis. While those integrating such data with EFM outputs include, POMFLANT, NSWC White Oak, NSWC Yorktown, and NAS Jacksonville. In some cases, there are locations that only use EFMs, such as Naval activities in Orlando, Florida, Indian Head, Maryland and Silverdale Washington.

The purpose of this paper is to provide the reader with a refresher on thunderstorm/lightning meteorology, lightning warning and detection instruments and systems, and information gained and procedures used by various activities who employ either detection or EFM technology, or both, within their daily operations. Access to such information, will provide current and potential users additional insight and stimulate new ideas on ways such systems can be used to improve the explosives safety environment, without compromising operational readiness.

2.0 Understanding Thunderstorms and Lightning

Before discussing the application of detection and warning systems, it is important that the reader gain a basic understanding of, and respect for, lightning phenomena and the threat it poses. The information below, while somewhat condensed, is intended to provide a different perspective of thunderstorms and expose the reader to new theories on thunderstorms and lightning.

While thunderstorms are considered to be the most spectacular weather phenomena, lightning by far is the most dangerous. Traveling at the speed of light, the energy of a lightning discharge can reach a magnitude of well over 200,000 amps or several tens of millions of volts. More people are killed annually by lightning than by tornadoes, hurricanes or floods.

2.1 Types of Thunderstorms

There are two types of thunderstorms, synoptic and air mass. Synoptic thunderstorms are those which are generated by major weather systems such as fronts, low pressure systems, and hurricanes. On the other hand, the air mass variety appear as singular or groups (clusters) of cells which form during the summer throughout the United States.

2.1.1 Synoptic Thunderstorms

These thunderstorms usually involve a broad area and demonstrate some consistency as to their movement and intensity. Some may be embedded in large areas of cloudiness, as with a warm front, while others will form a distinct line when associated with cold fronts. Typically, the most severe form of thunderstorm will frequently be found in a squall line, which is spawned by a fast moving cold front. These storms have been known to move at ground speeds greater than 60 mph and, in some cases, their tops may extend more than 50,000 feet into the atmosphere. It is not uncommon for these storms to produce large hail, high winds, tornadoes and flooding.

One advantage when dealing with synoptic activity is that the frequency and intensity of the storms is predicted with a high level of accuracy. Thus, adequate warning is usually provided in advance so people can take action to reduce potential for damage, or anticipate unavoidable damage.

2.1.2 Air Mass Thunderstorms

As previously noted, these storms are normally generated by the heat of the day and involve either individual or groups of cells. When addressing a group of cells, the most common types are clusters and lines. A good example of such activity is the line of thunderstorms that form along the Ohio River Valley or over the Piedmont area of the Carolinas during the Summer months.

These storms are highly predictable, especially during the Summer, when the only day to day change in patterns is storm movement, or the location where they may initially form. There are times when conditions over a certain area are enhanced by converging wind fields or synoptic systems in the upper atmosphere. When this occurs, storm activity tends to increase and involves a larger area. The biggest problem associated with these storms is that they can develop quickly and thus, create a first strike hazard with no advance warning of such an event. Therefore, it is fair to state that air mass thunderstorms represent the most serious threat to the explosives environment.

2.2 Thunderstorm Origins

A typical thunderstorm involves three stages; (1) Cumulus, 2) Mature, and 3) Dissipation. In some cases, a fourth stage, called the redevelopment stage, may also occur in various situations. The life cycle of a typical thunderstorm will vary between 1 and 2 hours. For convenience, the term "cell" is used to address individual thunderstorms.

For a cell to form, three elements are necessary; (1) moisture, (2) a lifting action, and (3) hygroscopic nuclei. Sources of moisture may be large bodies of water such as oceans, lakes, rivers, or other local sources, such as ponds and streams. In most cases, the lifting action is supplied by warm air as it rises from the earth's surface. However, other natural actions such as wind flowing up mountain slopes, or sea/land breeze regimes can also produce sufficient lift. Hydroscopic nuclei serves as a host upon which water vapor will adhere when it undergoes the process of condensation. The type of nuclei varies geographically and can include coal dust, sand, salt crystals and various forms of industrial pollutants. It is important to note that a delicate balance of these elements must be sustained during the cell's development. If any one element's influence is reduced, or becomes dominant, then the cell will normally not evolve into a thunderstorm.

2.2.1 Cumulus Stage

This stage is recognizable by the formation of puffy white clouds that form into a basic cell. The cell feeds on the warm moist air from below, and as it builds into the atmosphere, draws additional moisture and heat from the surrounding air. During this stage, all currents within the cell are upward and during the latter phases, downdrafts begin to form in the upper portion of the cell. Occasional intracloud lightning may occur near the end of this stage.

2.2.2 Mature Stage

During this stage, well defined downdraft and updraft patterns are established within the cell. As the cell builds further into the atmosphere, it will normally encounter a uniform wind field that pushes some of the associated cloud mass away from the main cell. This mass is commonly called an anvil. The altitude of the anvil's base may vary from 25,000-30,000 feet above ground level. In addition, as the cell approaches full maturity, its appearance will take on a more ominous character as the moisture content and lightning activity increases. A cell is fully matured when precipitation falls from the base and reaches the earth. This event is preceded by a release of cold air from the base of the cloud that takes place in the form of a downdraft.

As this downdraft travels downward, it comes in contact with the earth and on impact, moves horizontally outward in all directions. This event is commonly called a "first gust front". The horizontal extent of this front is greatest along the cell's axis of movement. It is not uncommon for the windfield to extend 15 miles ahead of the cell and more than 5 miles in other directions. Winds in excess of 100 knots have been recorded in more severe versions. During this phase, a significant increase in lightning activity takes place. When considering the sequence of events we have discussed to this point, it is obvious that the on-set of the first gust front is an environmental alarm that alerts us to approaching danger.

2.2.3 Dissipation Stage

During this stage, all motion within the cell is downward. Lightning is still active during the early part of this stage; however, as the rain subsides, the lightning tapers off and the wind gradually abates. Many people will disagree with such a statement, because at one time or another they have encountered situations where the wind, rain and lightning have persisted for many hours from what appeared to be one cell, or area. In a sense they are correct because such a scenario can and does occur, especially with synoptic thunderstorms. To better understand the cause of such conditions, it is important that a fourth stage of the thunderstorm process, the redevelopment cycle, be recognized.

2.2.4 Redevelopment Cycle

As the cold air within the first gust front travels outward from the cell, it is once again warmed by the earth's surface and the surrounding air, and obtains moisture from the atmosphere and other sources. The air is slowly modified and begins to rise and turn in a counterclockwise motion. This action results in a new thunderstorm cell which may evolve into a thunderstorm as the parent cell decays.

This cycle is not uncommon in an air mass situation, especially if a line or cluster is involved, or a very unstable feature such as an upper level trough is present. Personnel should be sensitive to the re-appearance of indications common to the cumulus and mature stages to recognize this event, since most of the time the associated cloud mass is disguised by residual clouds generated by the parent cell.

2.3 Thunderstorm Categories

There are only two categories of thunderstorms, normal and severe. By definition, a severe storm must produce surface wind speeds of 50 knots or greater or hail, if present, that is 3/4 inch in diameter or greater. If conditions are less than these, the storm is viewed as a normal thunderstorm. In addition, under current rules, the type of lightning or its frequency are not used in classifying storm severity.

2.4 The Lightning Profile

The atmosphere in its normal state has a positive charge, while the earth's is negative. As a thunderstorm enters the latter portion of the cumulus stage, the on-set of down drafts within the upper portion of the cloud induces a mixture of charges within the cell. As the cell builds through the freezing level and enters the early part of the mature stage, a discharge between the positive charged region in the cloud base and the negatively charged region above it takes place. This event frees electrons in the negative region which were previously immobilized by attachment to water/ice particles being carried downward within the cloud.

The freed electrons overrun the positive region along the base of the cloud, neutralizing its small positive charge, then continue their trip toward the ground, which takes 20 milliseconds. The vehicle for moving the negative charge to earth is the stepped leader, which moves from the cloud to the ground in rapid luminous steps each of which are 150 feet in length. Each leader step occurs in less than a microsecond and the time between steps is about 50 microseconds.

When the stepped leader is near ground, its large negative charge induces large amounts of positive charge beneath it on the earth and objects projecting above the earth's surface. Since opposite charges attract each other, the positive charge attempts to join the negative charge and in doing so, initiates upward going discharges. One of these discharges contacts the downward-moving leader and thereby determines the lightning strike point. When the leader initially touches ground, electrons flow to ground from the channel base and as the return stroke moves upward, large numbers of electrons flow at greater and greater heights. It is this return stroke that produces the bright visible channel.

The human eye is not fast enough to see the propagation of the return stroke or the stepped leader preceding it. To an observer, it appears that all points on the channel become bright simultaneously. The total discharge takes place in 0.5 sec., and is called a flash. Each component discharge called a "stroke", is measured in tenths of milliseconds. Usually, a flash contains 3 or 4 strokes. Often lightning appears to flicker. In such cases, the eye is detecting the individual strokes which make up the flash. Contrary to popular belief, strokes within a flash may not always originate at the point where the original discharge takes place. Parameters (distance and time) used to qualify such events varies from 3 km and 180 milliseconds, to 10 Km and 500 milliseconds, Casper [1]. Figure-1 provides an overview of such events.

2.4.1 Types of Lightning

Currently, there are only four recognized types of lightning; (1) intracloud, (2) cloud to cloud, (3) cloud to air and, (4) cloud to ground (CG). In many cases, the first three are grouped into one term "cloud strokes". The remainder of this section will primarily deal with CG lightning.

2.4.2 Bolts From the Blue

This is the most dangerous form of CG lightning, in that it will affect people who at the time of the event, think they are safe by virtue of their distance from the thunderstorm cell. In some cases, CG lightning has affected an area that is under sunny skies, and thus the term "Bolt from the Blue" was born. In most cases, the anvil that spreads from the upper portion of the thunderstorm is the source of this type of lightning. Within the anvil the typical electrical pattern is reversed in that a positive charge extends over a section of earth where the ground is still in a state of negative charge. When considering the distance from the base of the anvil to the ground, it is not unusual to see strong discharges associated with this type of lightning. There have been reports of these lightning strokes occurring up to 30 miles from the main cell, and producing currents in excess of 150 kiloamps.

3.0 Lightning Effects on Overhead and Buried Cable

Facilities manufacturing or using explosives may suffer from lightning effects even though the lightning may be several miles away and within a cloud. Induced electrical and magnetic effects from such lightning in cables can cause large voltages [2]. These over-voltages can cause many problems such as premature ignition of explosive devices used in blasting operations. Excessive sparking between cables may also cause detonation of gasses in explosives manufacturing plants. Adequate bonding and surge suppression may help to reduce these effects, but direct strikes will almost always cause some sparking.

The major sources of lightning surges in conductors are due to:

a) Ground potentials caused by nearby lightning strokes.
b) Induced effects caused by lightning current flowing on a shield.
c) Direct strokes to a wire.
d) Side-flashes to the conductor from a nearby strike.
e) A straight conductor acting as a electrical field change antenna for lightning effects.
f) A looped conductor acting as a magnetic field antenna for lightning effects.

Burying the cable does not remove lightning effects, as the cable is then an ideal ground path for the current. The lightning current may side-flash several meters to the conductor under the ground, where the distance is primarily a function of solid resistivity and the resistance of the conductor to ground.

The largest lightning voltage recorded on a transmission line reached a peak value of 5 million volts in less than two microseconds.

The resulting oscilloscope recording is shown in Figure 3 and the stroke occurred some 4 miles up the line. It is suggested that closer to the strike point, the current rate was probably of the order of 10 million volts per microsecond.

Residential 120V AC lines are found to experience peak lightning associated voltages of up to 6 kV and internal switching transients up to 3 kV. The transients will be oscillatory in nature with a fundamental frequency from a few tens of kilohertz to several megahertz with components ranging into hundreds of megahertz. They will last from 100 nanoseconds to 100 microseconds and be clamped within a few cycles. Good grounding and bonding may reduce the transients significantly.

Intracloud lightning causes a considerable number of induced effects on cables of several thousand volts and several hundred amps even though the separation distance of cable to discharge may be several miles. The main reason for such an effect is that the power, telephone, or data cable acts as an antenna. Shorter cable give rise to larger surges due to reflections at the cable ends.

Nearby cloud or air discharges, particularly if the stroke channel is directly above and parallel to a line, may cause appreciable voltages in the line. A value of 10 kV/km for an earth resistivity of 1,000 ohms m. has been calculated (Boyce, 1962). Thus, nearby cloud discharges will cause protector operation and induce substantial currents in lines. It is however, difficult to obtain data on the effects of such discharges since their location and orientation are not readily determined.

In the case of lightning strokes to ground more than about 30 kilometers from a line, the radiation component of the field is predominant. At distances exceeding several hundred kilometers, the induced voltage in the line comprises a train of waves caused by successive reflections of the radiated pulse from the ionosphere and earth. The peak voltages do not exceed a few tens of volts, and at most, they may cause some noise in unbalanced lines. Ground strokes further than 3 to 5 kilometers from a line normally induce less than a kilovolt in lines of any appreciable length, although higher voltages will occur on short, well-insulated lines. Again, the currents to ground through terminal protectors are small.

Strokes to ground at distances of between about 25 and 3,000 meters will generally induce more than 1,000 volts in overhead lines, and these, together with direct strokes to the line, are of principal importance. The maximum voltage is induced at or near a point on the line opposite the lightning stroke. A surge is propagated along the conductor in both directions, and repeated reflections occur from both ends of the line, resulting in surge durations up to several milliseconds. Both the time to crest and the time to half-value of initial surge increase with distance from the stroke, as may be seen from Figure 4. Some indication of the order of currents in a single horizontal conductor 1,000 meters or more in length above earth with zero resistivity, is given in Figure 5 for various stroke currents and distances from the stroke. The crest currents and not the voltages are given since the current is of greater importance in specifying the characteristics of protectors. On a long line, the crest currents in the traveling waves, before attenuation, will be half of the values in these figures, and the crest voltage will be the product of this current and the surge impedance of the conductor. Heavy discharges nearer than 50 or even 100 meters from the line will cause flashover of the insulators. Hence, the full currents given in Figures 4 & 5 will not always be propagated at both ends of the terminal protectors, and this means there is a voltage between the ends of the line. This voltage is plotted as a function of time in Figure 6. Since the gradient decreases rapidly with distance from the flash, the voltage difference between the ends of the line is determined mainly by the potential at the end nearest to the flash, unless the line is shorter than 300 to 400 meters. The surge impedance of a short line, due to multiple reflections, reduces very rapidly to the terminating impedance, which is normally the resistance of the earth electrode. Since an earth resistivity of 1,000 ohm m. may be considerably exceeded, currents of the order of 5 to 10 kA are possible in short lines--these are much higher than the few hundred amperes in Figure 5.

The various ways in which voltages and currents in paired and coaxial cables are caused by nearby ground flashes depend in a complex manner on several factors. If the lightning current enters a cable at some point along its length, the current will divide into two roughly equal parts on each side of the point of impact. Particularly in high ground-resistivity areas, these surge currents will flow for considerable distances in metal sheaths before being attenuated and dissipated to ground.

These currents cause a voltage drop on the internal surface of the sheath, and this appears as an impulse voltage between the sheath and the conductors. Figure 6 is based on a formula by Sunde. If breakdown occurs, part of the lightning current will flow into the conductors. Since the attenuation of the conductors/sheath circuit is much less than that of the sheath/earth circuit, the voltage between the sheath and the conductors increases with distance from the impact point, and further damage to the cable may occur several kilometers away.

In addition to the foregoing mechanism, high currents are produced in short cable conductors by the differences in the earth potentials at points (such as the ends of branching points), where protectors to earth are fitted in exactly the same way as described for open-wire lines. This occurs even though there has been no breakdown in the cable itself. This effect is more serious than for open-wire lines, since cable conductors are smaller in diameter and are more easily fused than open-wire lines. Large differences in potential between the conductors also occur at various points along a cable which has protectors fitted to some pairs only at branching points.

4.0 Detection and Warning Systems

For the detection and location of CG lightning, there are two proven approaches; 1) magnetic direction finding (MDF) [3] and, [4] time-of-arrival (TOA) [5].

4.0.1. MDF Technology

The MDF technique has been in widespread use since the late 1970s and is based on the relative induced voltages and polarities in an orthogonal loop pair of antennas. While this technology certainly represented a major advancement over the limited capabilities of past systems there are problems with site errors, Pierce [6]. More recent papers indicate that the average accuracy of a MDF network varies from 6-10 Km [7], based on the number of sensors employed and their operating baselines. There are many forms of these "flash detectors" and their accuracy will vary with design and/or the technology employed. Another form of this technology incorporates a stand-along sensor design. These systems lack sufficent accuracy to support reliable application within typical explosives operations. As noted by Wantland and Free [8], such storm trackers "measure the direction of flashes just like the networks, but analyze the waveform shapes of several strikes to estimate storm distances to within a few miles".

4.0.2 TOA Technology

For more than half a century, TOA technology, which is also used in the satellite based Global Positioning System, has by far, been considered to be the most accurate way of fixing the source of an individual spheric. The exceptional accuracy of these systems is made possible through use of accurate interstation timing of less than 1 microsecond. Papers by Bent, [5] and Lyons and Bent [9] describe basic system operations and present examples of data collected by operating TOA networks in the U.S. during the early 1980s. In addition, more recent papers by Casper [10] and independent research by Dr. M.J.G. Janssen [11], and E. Montandon [12] address accuracies of 200-600 meters or better from TOA networks and document the superiority TOA technology has over the antiquated MDF method.

4.0.3 Warning Systems

The most common and reliable technology utilized to provide advance warning of the potential for lightning is the electric field mill. This instrument is designed to constantly measure the intensity of the potential electric field, either negative or positive, between the base of the clouds and the surface of the earth. Once a predetermined alarm threshold is exceeded, the system will activate an audible and/or visual alarm.

The reliability and accuracy of these devices varies from a primary level of measurement, to what can only be defined as gadgets. The price of the latter may vary from $50 to as much as $4,000, while more reliable high resolution EFMs will cost approximately $6,000. Most designs support integration with a PC and/or remote alarm, and provide digital (RS-232) and/or analog outputs.

In the past, there has been serious concern regarding the use of these systems since many view them as being prone to false alarms, thus production orientated people are hesitant to respond to an alarm that is initiated at a preset value someone claims is ideal to optimize system application. The alarm threshold commonly used is 2,000 Volts per meter (Vm). Many scientists feel that when this level of potential is met, conditions are ideal for a lightning event. While some systems may lay claim to a substantial increase in resolution above 5,000 Vm, when such a level has been attained, in most cases any opportunity for a timely response to the threat has been all but lost, and their is a likelyhood that a lightning event has already occurred.

In most cases, the field mill's reputation for false alarms is unfair since most of the time such determinations are based on observations obtained through application of unsound procedures. For example, counting the seconds between the flash and the sound of thunder to determine the distance to the storm is no longer viewed as an acceptable method. Research has shown that in many cases, up to 40% of the thunder associated with lightning is not heard by the people who observe the event. This is usually caused by, atmospheric abnormalities such as sound focusing and distortion induced by the wind-field.

Figure 2 shows a comparison between real time lightning data and a field mill. The field mill data shows an electric field in excess of 2,000 Vm occurring within a 10 mile range (Point 1) and at least 15 minutes advance warning for a stroke that occurred at a distance of less than 5 miles (Point 2). Of particular interest are the field changes that occur when lightning strokes, both cloud and ground, take place nearby, as can be seen at points 1 and 2, and between points 3 and 4.

5.0 Data Timeliness and Display

Within this section we will discuss the impact data timeliness has on the user, and the types of displays most commonly used to view data.

5.1 Data Timeliness

With regard to time, there are basically two types of data, realtime and other than realtime (aged). Realtime lightning data will normally be delivered and displayed within a reasonable time after the event. In most cases, if the data is received within 1-minute of the actual event it is considered to be realtime. Aged data (other than realtime) may be received with an induced delay, be buffered for a period of time then sent at established time slots, or combined with other data from radar and satellites.

5.1.1 Realtime Data

Realtime data provides an overview of what is going on at the present time. When integrated with realtime data previously received, a reasonable interpretation of the scope of the activity, its projected movement and closest point of approach or time of arrival at the site can be determined with a reasonable level of credibility. Thus the user can anticipate when the threat will occur, and in some applications, what action can be taken to reduce damage to facilities and disruption of operations.

Users of realtime data must always keep in mind that various elements and processes within the atmosphere can produce significant variations in existing patterns. The thunderstorm cycle, local topography or the time of day when a system passes could produce storm intensities that are less, or more intense than, what was originally viewed.

5.1.2 Aged Data

Aged data is normally intended to provide users with a broad picture of what has already occurred within a specific time-window. In many cases subject data is meshed with similar information such as radar data and satellite imagery. It must be remembered that as the age of the data increases, there is a significant decrease in its application value. This data form is not recommended if lightning sensitive operations are conducted on a routine basis and the site experiences more than 5 thunderstorm days per year.

5.2 Data Displays

With the advent of advanced video graphics and high speed and compact processors, industry has been able to be very response to varied requirements for ways to display data, along with supporting background graphics. In general, there are two basic categories of displays: (1) Pavlovian; and, (2) hands-on.

5.2.1 Pavlovian Display

This type of display is normally connected to an on-site sensor. Basically, the function of the display involves flashing lights, bells and whistles scenario that is designed to generate a response of sorts from the user. Type of displays include red lights, flashing lights, alarms, or one of the most common, a computer based system that displays a pie shaped circle that will change color, based on the number of flashes/strokes detected within a particular slice. These displays can be effective to some extent as long as the function of the system operator is to initiate a response and the alarm thresholds and system controls are accessible so that changes can be implemented whenever changes in the activity's mission take place.

Some serious drawbacks of such displays include the inability to determine the storm's direction and speed or its stage of development involved. In addition, many times such systems are advertised as providing the user with storm severity, which is determined by counting the number of flashes that occur within a given timeframe. While this claim may inadvertently by true in some cases, there is no scientific proof to support such a claim, and as stated earlier, lightning frequency is not a consideration when determining storm severity. If it were, surely the National Weather Service recognize such a technique.

The biggest drawback of this type of display is that the user never gets a feel for patterns associated with storm activity, and is placed in a position that any action must be tied to the color pattern and/or some form of alarm device, either audio and/or visual, since no reference point is available to quality control the data before responding. This scenario can created problems that will directly impact on productivity, and reduce user confidence in the system over time. For example, follow-up evaluation of alarm actions may later be ruled as false even though only limited supporting data is available, In addition, the system operators may be forced into a position where they must wait for an alarm before any action can be taken.

5.2.2 Hands-On Displays

This type of display is designed to assist the user in monitoring the size, patterns, density and movement of thunderstorm areas. The biggest advantage gained from such an operating profile is that the user can normally gain a feel for the thunderstorm pattern and anticipate future movement and speed of the cell(s) with an adequate level of accuracy.

Naturally, the most important part of any hands-on display system is the software used to operate it. These software packages are usually menu driven, user friendly and include a basic screen display that is either generic to system users, or tailored to specifically meet both generic and unique needs. Many packages will also include added features that the operator can use to enhance and/or further manipulate the displayed data. Special purpose operating features that are common to most systems include zoom, time lapse and data looping.

Some of the more sophisticated software packages may include user programmable features that include alarm areas, movable windows, integration of electric field mills, predefined displays, alternate map setups, range and bearing determination, a cycle graphic, access to stroke details on command, and greater control of map and display features, titles and time. All of these elements further enhance the potential for accurate/effective interpretation of the data base by layman.

Graphic displays have become very popular because they usually employ a background map which depicts various landmarks, such as roads, towns, and the user's facility. The ability to view data in this form further enhances the users ability to "feel" the storm and maintain proper orientation when viewing the lightning activity as it moves closer to the user's facility.

It is important to note that most hands-on displays include a user controlled Pavlovian profile. The Pavlovian application differs when used with these displays in that its purpose is to attract the attention of the user to the system to effect data review and manipulation, rather than cause a direct response. In addition, in most cases, the system operator has extended control over alarm thresholds, the area they affect, and the type(s) of alarms employed.

6.0 Data Manipulation, Application, and Integration

This section will address the three issues stated, in a combined form, with respect to lightning detection systems and advance warning instrumentation. To help the reader gain a perspective on the various types of systems and how they may integrate with each other, Figure 8 is provided. This drawing provides an overview of a fully automated system designed for the Greater Orlando Airport Authority (GOAA). The system depicted has been installed and is currently undergoing a ninety evaluation process, the results of which will be used to determine what settings and thresholds will be used in the standard operating profile.

6.1 Detection Systems

This section will address the use of data from stand-alone systems (on-site) and data that is received from a network of sensors like those employed by the Navy in their Lightning Detection and Tracking System Networks. It cannot be overly stressed that these types of systems rely on the fact that lightning has or is occurring. Use of a detection system will not alert the user to the presence of a cell developing overhead or the threat posed by an anvil, either of which could produce a first strike at the facility. Thus, while the potential for a first stroke event to take place at a specific time and place, is slim, the decision as to whether such a risk is governed to a great extent by the nature of the operations being conducted.

For example, when conditions appear to be threatening at a training facility such as NTC Orlando, the decision, in the absence of any lightning, to move personnel indoors is based more on not having the troops get drenched, then it is on the danger lightning presents. On the other hand, if munitions are being handled, a response under similar circumstances would be borne out of concern that there is a good chance for that lightning will occur, based on the ominous appearance of the clouds.

6.1.1 Stand-Alone Systems

These systems are basically flash detectors for the most part, and their design may be as simple as a black box with a simple antenna design, to a platform mounted sensor in an open field. The more basic detectors include an alarm system within their design that is rather simple and to the point. Most detectors use an averaging method, and if designed to measure an electro-magnetic signal, are subject to local interference, site-errors and other elements that could further degrade the limited accuracy of such systems. Some include a capability to be integrated with a PC, on which various data is displayed, or a chart recorder.

For the most part, depending on the technology used, such sensors do not offer the level of accuracy sustained by networks, In addition to the lack of a reasonable level of accuracy, many of these systems, by virtue of their display profile, are Pavlovian in nature and give little room for the user to try and evaluate the data to ascertain the storm's direction of movement, its speed, intensity or the existence of a cyclic pattern.

In many applications such sensors have proven to be of some value. However, use of such systems should be limited to small scale operations that are conducted in areas where little or no thunderstorm activity takes place (less than 8 thunderstorms days per year) and only a Pavlovian application would be employed.

6.1.2 Network Data

During the past fifteen months the Department of Commerce (DOC) and NOAA have been conducting a competitive procurement under which they will obtain realtime lightning data for the contiguous 48 states and adjacent coastal areas and boarder areas. Although negotiations continue, a contract is scheduled for award sometime in September, 1992. Within the solicitation, specific note was made of the need for such data in support of ordnance and weapons related operations.

The reason for such interest in network data is obvious in that data provided by sensors designed to function as a network produce the best results with respect to lightning detection and location accuracy. In addition, the data supplied under the contract will employ TOA technology and provide a data base which will reflect individual stroke information.

Personnel who currently utilize this data are able to perform various levels of analysis, even though they are layman, For example, the user is able to ascertain not only the general patterns as they evolve, but also get a feel for the system's movement and its cyclic profile. Armed with this information, the user can make adjustments in schedules, anticipate disruptions during certain periods and, after operations are shut-down or curtailed, determine when conditions are such that a return to limited or full operation is warranted. Experience has shown that use of such data is only limited by the imagination of the user.

In addition to the above, such displays can be setup to work in a Pavlovian profile, and at any time be overridden by a human if need be. The advantage to this capability is that non-technical personnel can be used to monitor the system for alarms that are determined by supervisors and/or managers, then when an alarm is initiated, contact appropriate personnel who will further analyze the data and determine a response will be necessary.

Such systems usually have the capability to injest and display data from advanced warning systems. Typically, the actual Vm levels measured by each EFM are displayed. As discussed below, access to such data and its corrolation with realtime stroke data offer a complete overview of the lightning profile to the system operator.

6.2 Advanced Warning System (Stand-Alone)

As discussed above, there will be situations where overhead development of what appears to be convection activity would have an impact on operations. In many cases, weather patterns such as warm fronts or local convective activity, while intense at times, will not produce thunderstorms. While conditions will be similar to those viewed during activity, vertical development of the activity may be suppressed and therefore only rain will occur.

It is during threatening conditions that do not produce thunderstorms, that an advanced warning system such as an EFM, serves its most useful purpose. The fact that operations continue during conditions which would normally produce a shut-down, can result in substantial savings. Likewise, as a thunderstorm moves away from a site, noting the EFM's return to a stable profile, can facilitate a timely return to normal operations.

In addition to an advanced warning application, some users of EFMs have employed them as lightning detectors. When tied to a digital output or graphic profile, the viewed data can be used to identify the presence of nearby lightning activity (Figure 2), especially cloud strokes. However, it is important to note that with the exception of the on-site response to an exceeded threshold, data from the EFM cannot provide a profile reflecting direction of and speed, or actual location of the cell with respect to the user site.

As we can see, use of EFMs, as a detection system, has its positive and negative points. As with many instruments, initiative on the part of the end-user often produces an added application that in most cases, may be limited in scope. For example, the writer knows of some people who use EFM data to get a feel for static charge during Winter months. While this is case where the instrument is used to monitor conditions that are extremely stable conditions, rather than unstable, the bottom line is that by understanding the strengths and weaknesses of such an application, the end-user can benefit from the additional application. However, personnel should exercise caution when using any instrumentation for an application for which it was not designed. A better method by far, would be to integrate such data with other data bases, producing information that, through correlation, can produce expanded results.

7.0 Conclusions

After careful review of the information provided herein, it is obvious that only through proper planning can a potential user of lightning detection and advance warning systems select the operating profile needed to support their mission. In addition, items such as the level of control exercised by personnel who directly and indirectly use and apply the data, required accuracy, and the need to develop an effective program and system configuration that can meet the demands of existing requirements and will be flexible in responding to future changes in the activity's mission.

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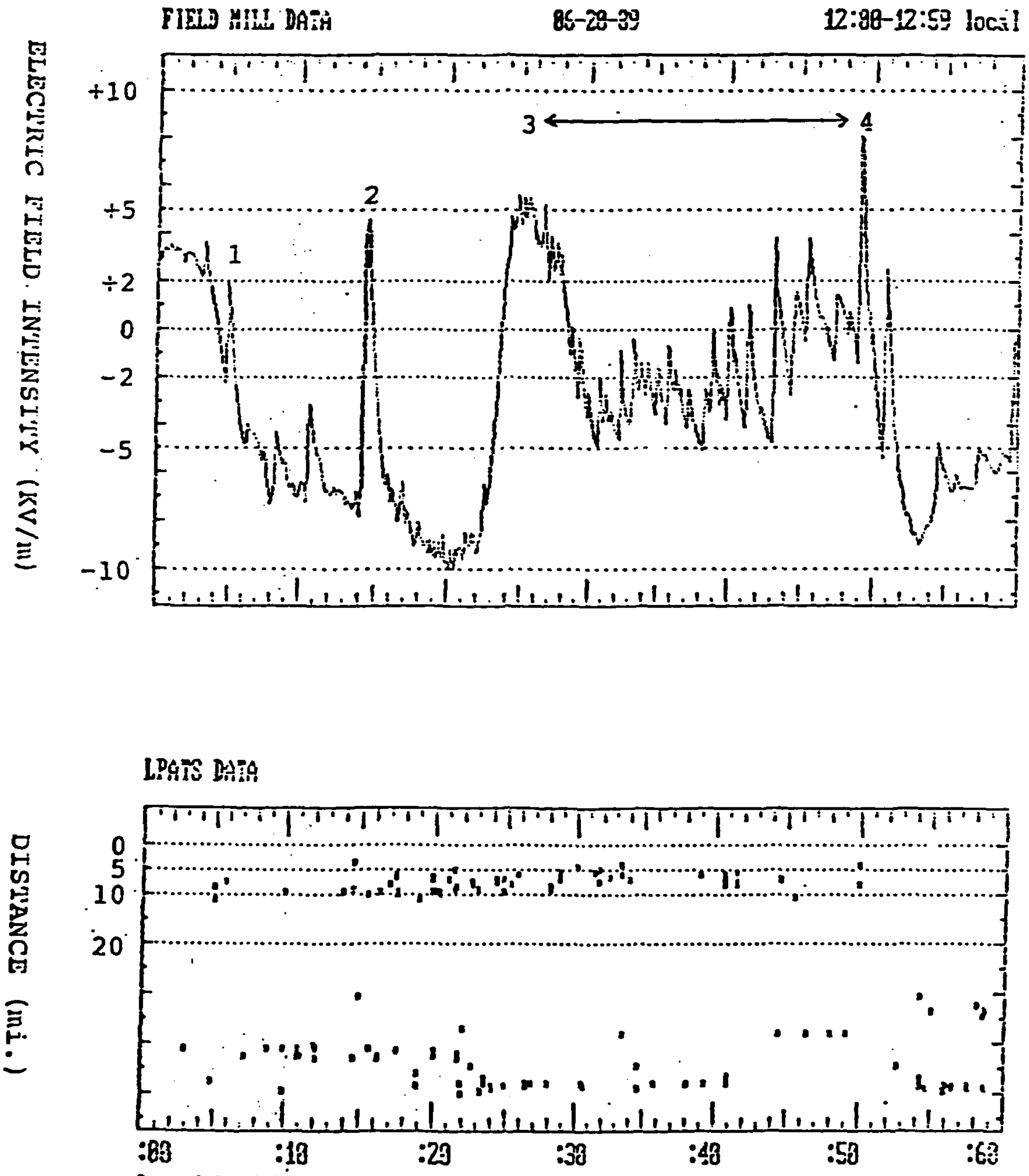
N	33.281	W	103.324	14:18:07	20-Sep-90 -67 KAmps	
N	36.437	W	106.635	14:18:08	20-Sep-90 +68 KAmps	
N	34.924	W	107.952	14:18:09	20-Sep-90 -16 KAmps	
N	29.299	W	89.490	14:18:22	20-Sep-90 -28 KAmps	
N	29.326	W	89.525	14:18:22	20-Sep-90 -23 KAmps	
N	26.085	W	80.423	14:18:22	20-Sep-90 -19 KAmps	
N	35.279	W	102.594	14:18:13	20-Sep-90 -21 KAmps	
N	26.092	W	80.422	14:18:23	20-Sep-90 -7 KAmps	
N	26.025	W	79.635	14:18:25	20-Sep-90 -21 KAmps	
N	26.009	W	79.613	14:18:25	20-Sep-90 -30 KAmps	
N	26.046	W	79.662	14:18:25	20-Sep-90 -108 KAmps	
N	25.994	W	80.728	14:18:29	20-Sep-90 -19 KAmps	
N	33.266	W	92.887	14:18:33	20-Sep-90 -46 KAmps	Three strokes in one flash.
N	33.265	W	92.886	14:18:33	20-Sep-90 -21 KAmps	
N	33.267	W	92.887	14:18:33	20-Sep-90 -21 KAmps	
N	35.519	W	102.018	14:18:21	20-Sep-90 -27 KAmps	
N	26.018	W	80.717	14:18:32	20-Sep-90 -33 KAmps	
N	26.059	W	80.713	14:18:32	20-Sep-90 -1.9 KAmps	
N	26.065	W	80.646	14:18:32	20-Sep-90 +7 KAmps	
N	26.050	W	80.713	14:18:32	20-Sep-90 -28 KAmps	
N	26.076	W	80.758	14:18:39	20-Sep-90 -49 KAmps	
N	25.519	W	80.654	14:18:39	20-Sep-90 -8 KAmps	
N	26.067	W	80.745	14:18:39	20-Sep-90 -7 KAmps	
N	26.064	W	80.746	14:18:39	20-Sep-90 -9 KAmps	
N	26.578	W	80.244	14:18:44	20-Sep-90 -35 KAmps	Eight strokes in one flash.
N	26.577	W	80.242	14:18:44	20-Sep-90 -79 KAmps	
N	26.577	W	80.244	14:18:44	20-Sep-90 -19 KAmps	
N	26.578	W	80.244	14:18:44	20-Sep-90 -18 KAmps	
N	26.578	W	80.244	14:18:44	20-Sep-90 -49 KAmps	
N	26.577	W	80.243	14:18:44	20-Sep-90 -44 KAmps	
N	26.578	W	80.244	14:18:44	20-Sep-90 -24 KAmps	
N	26.578	W	80.242	14:18:44	20-Sep-90 -12 KAmps	
N	26.576	W	80.242	14:18:44	20-Sep-90 -27 KAmps	
N	40.010	W	96.178	14:18:50	20-Sep-90 -31 KAmps	
N	35.825	W	92.639	14:18:50	20-Sep-90 +76 KAmps	
N	35.643	W	92.496	14:18:50	20-Sep-90 +108 KAmps	
N	35.576	W	92.494	14:18:51	20-Sep-90 -12 KAmps	
N	26.095	W	80.763	14:18:50	20-Sep-90 -26 KAmps	
N	33.260	W	92.879	14:19:05	20-Sep-90 -14 KAmps	
N	26.101	W	80.730	14:19:06	20-Sep-90 -52 KAmps	
N	39.974	W	96.141	14:19:07	20-Sep-90 +13 KAmps	
N	29.325	W	89.505	14:19:09	20-Sep-90 -27 KAmps	
N	26.096	W	80.491	14:19:09	20-Sep-90 -20 KAmps	
N	36.292	W	106.569	14:18:57	20-Sep-90 -32 KAmps	
N	26.015	W	80.740	14:19:11	20-Sep-90 +11 KAmps	
N	39.972	W	96.118	14:19:17	20-Sep-90 -43 KAmps	
N	26.047	W	80.724	14:19:16	20-Sep-90 -46 KAmps	
N	26.076	W	80.754	14:19:16	20-Sep-90 -41 KAmps	

Figure 1

TYPICAL ELECTRIC FIELD MILL DATA
DURING LIGHTNING ACTIVITY



2350 Commerce Park Drive N.E., Palm Bay, Florida 32905 U.S.A.
phone (407) 725-8001 FAX (407) 725-7918 TELEX 755959

FIGURE 2.

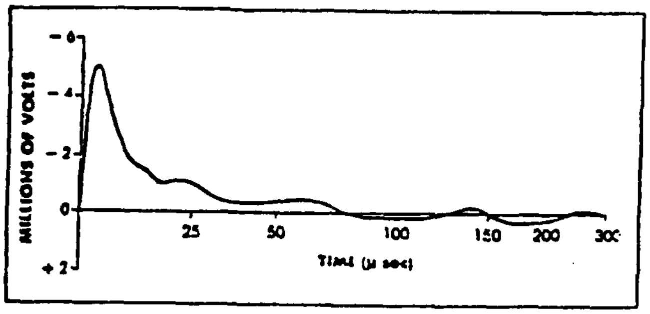


Figure 3. Cathode-ray oscillogram of highest voltage on a transmission line; 110 kV wood pole of Arkansas Power and Light Company; no ground wire.

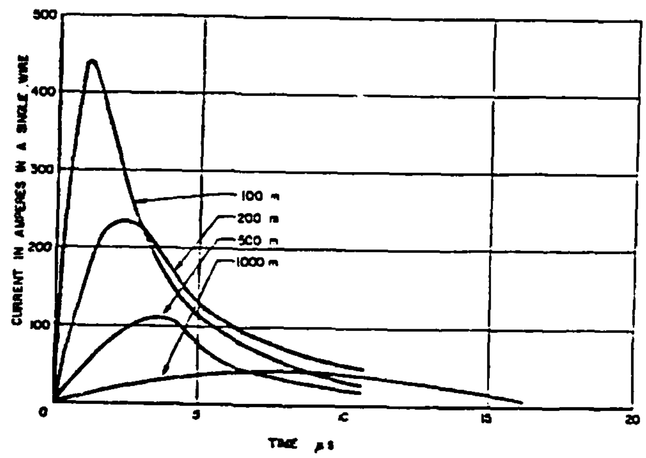


Figure 4. Current induced by a lightning stroke with a crest current of 150 kA and waveform of 5/65 μs at various distances from a line.

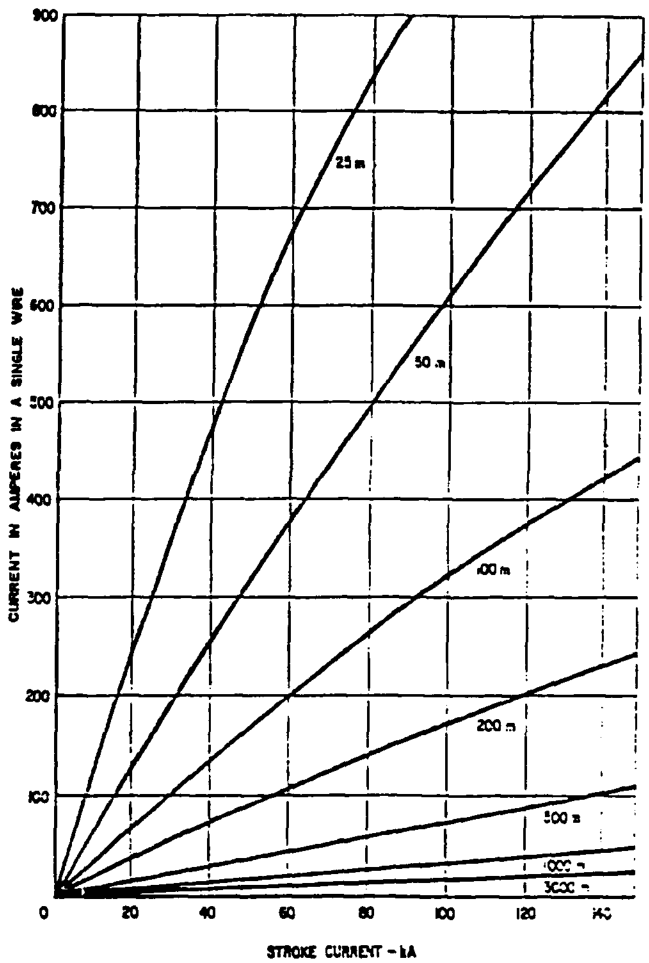


Figure 5. Current to earth at the ends of a single horizontal wire for various crest stroke currents and separating distances (zero soil resistivity).

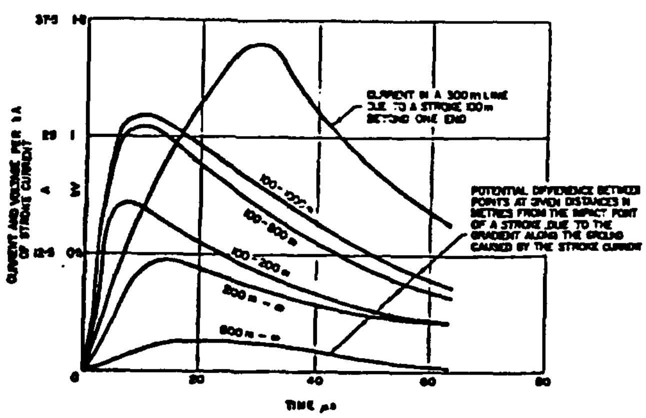


Figure 6. Voltages and currents in a horizontal conductor due to earth gradients arising from a finite each condicutivity. Ground resistivity 1,000 ohms/meter and stroke velocity 50 m μs^{-1}.

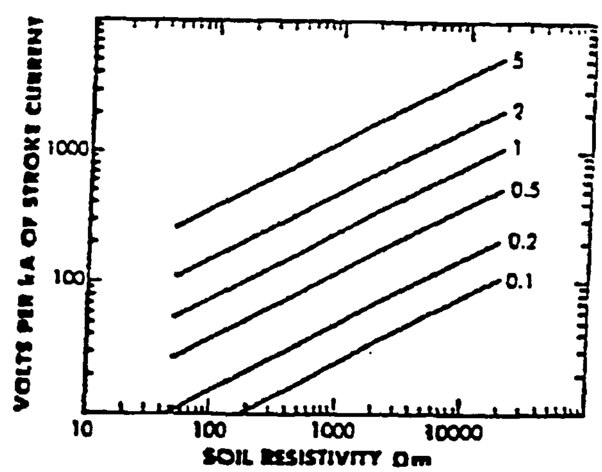
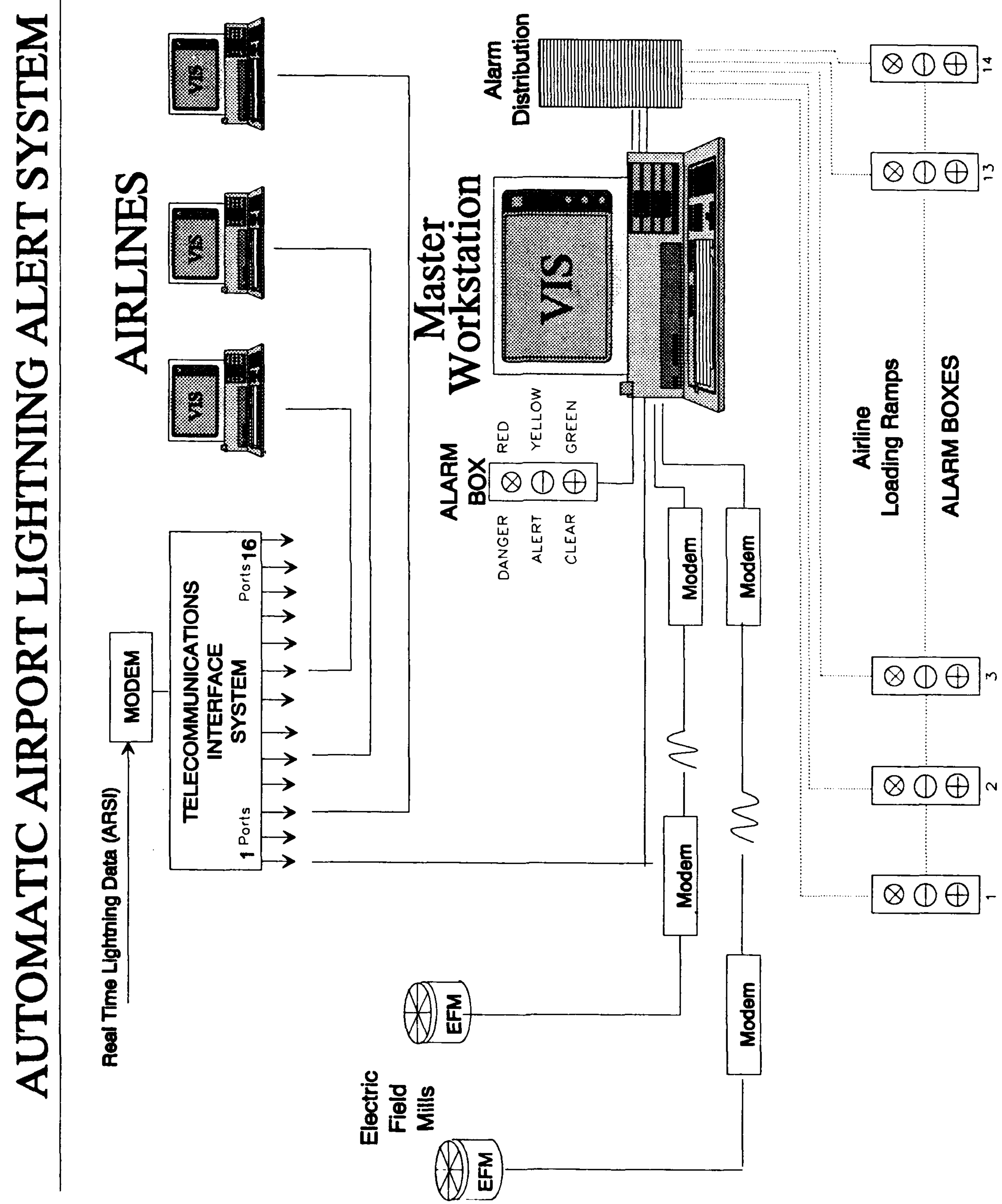


Figure 7. Crest voltage between the metal sheath and conductors at the end of the cable (the entry point of a lightning surge with a 5/65 μs waveform) for values of a sheath resistance between 0.1 and 5 ohms/kilometer $^{-1}$.

FIGURE 8


AUTOMATIC AIRPORT LIGHTNING ALERT SYSTEM
Real Time Lightning Data (ARSI)
MODEM
TELECOMMUNICATIONS INTERFACE SYSTEM
1 Ports
Ports 16
AIRLINES
VIS
VIS
VIS
Master Workstation
VIS
Alarm Distribution
ALARM BOX
RED
YELLOW
GREEN
DANGER
ALERT
CLEAR
Modem
Modem
Modem
Modem
Airline Loading Ramps
ALARM BOXES
1
2
3
13
14
EFM
EFM
Electric Field Mills

Radon Testing at Radford Army Ammunition Plant

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ABSTRACT

Radon testing of buildings in all geological areas of Radford Army Ammunition Plant showed only 11 buildings of the 511 tested had radon levels greater than 4.0 picocuries per liter of air (4.0 pCi/l). Alpha track monitors were used for 3-month screen tests of these buildings. Any buildings having a radon content greater than 4.0 pCi/l were tested for 12-months. Mitigation by air dilution reduced the radon content in 10 buildings to less than 4.0 pCi/l. Ducts are being installed in the 11th building to also reduce the radon content by air dilution.

INTRODUCTION

Radon is a radioactive gas resulting from the natural decay of uranium and thorium. You cannot see it, smell it or taste it. The earth's crust contains various amounts of U-238 and Th-232 which decay, through a number of steps, to radon 222 and 220, respectively. Both Rn-222 and Rn-220 also decay to a number of radioactive daughters. The portions of interest in the decay schemes of Rn-222 and Rn-220 are shown in Figures 1 and 2, respectively.

The only known health effect associated with long-term exposure to elevated levels of radon is an increased risk of developing lung cancer.[1] However, not everyone exposed to elevated levels of radon will develop lung cancer. In general, the risk increases as the level of radon and the length of exposure increase.

In the outdoor air, radon is diluted to such low concentrations that it is usually nothing to worry about. However, once inside an enclosed space (such as a home) radon can accumulate. Indoor levels depend on the building's construction and the concentration of radon in the underlying soil. Radon can enter the home through very small spaces, such as cracks in concrete, dirt floors, sumps, joints and hollow block walls.

Radon can also enter water in private wells and be released in a home when the water is used. Usually, radon is not a problem with large community water supplies, where it would likely be released into the outside air before the water reaches a home.

In some unusual situations, materials used in the construction of the house will release radon. For example, a home with a large stone fireplace.

Radon has always been present in the air. Concern over elevated indoor concentrations first arose in the late 1960s when homes were found in the West that had been built with materials contaminated by waste from uranium mines.[1] Since then, cases of high indoor radon levels have been found in many parts of the country. The dilemma is that no one knows which homes have a problem and which do not.

The U. S. Army is concerned about the health of its soldiers, military families and its civilian work force. The Army's radon program[2] is to (1) identify buildings containing radon levels exceeding United States Environmental Protection Agency (EPA) guidelines, (2) take appropriate steps to reduce radon levels in these buildings, (3) resurvey all buildings where mitigation has taken place and (4) ensure that newly constructed buildings are within EPA guidelines.

Radford Army Ammunition Plant is a diverse installation made up of eight major production areas. It is built beside the New River in Southwestern Virginia on old farm land. Geologically, the production areas are located on land deposited by the river as the Eastern United States was formed. The section of the plant known as Staff Village is on a limestone outcrop. Regional geologic maps refer to the general area in which the plant is located as the Pulaski Fault.

Buildings were tested for radon based on priorities established by the Army.[2] First (priority 1): hospital and living quarters. Second (priority 2): areas having 24-hours operations (operation centers, production areas, fire and security headquarters and test and evaluation facilities). Third (priority 3): all other buildings routinely inhabited.

DISCUSSION

Indoor radon levels were tested in 511 buildings during late winter and early spring in 1990 when doors and windows were generally closed. The detectors were placed in the lowest level of priority 1 buildings. Detectors in priority 2 and 3 buildings were placed in the lowest inhabited areas where minimum circulation occurred. The detectors stayed in place for 90 days. If radon was found to exceed 4.0 picocuries per liter of air (4 pCi/l) after a 90-day test period, a 1-year test period followed to substantiate the 90-day test results.

The Army chose an alpha track detector for monitoring radon. The detector (Figure 3) consists of a small strip of plastic placed in a 1 1/2-inch outside diameter plastic holder with a top containing nine 1/4-inch holes. Alpha particles released when radon decays, hit the plastic strip and make microscopic tracks. These tracks become visible when the plastic strip is immersed in an etching solution at the laboratory. The number of tracks on the strip enables the technicians to calculate the average radon concentration in the building during the testing period.

To assure that test results generated by the radon program are accurate, a quality assurance and quality control program[2] specified by the Army was followed. Detectors and data summary sheets containing only the installations name, detector's serial number and dates of placement and retrieval was the only information provided to the laboratory.

Detectors were supplied in sealed aluminum foil. The detectors were removed from the foil and placed in test locations. After the specified test period, an adhesive backed "Gold Seal" was placed over the holes in the top of the detector.

Other detectors were used to ensure accurate test results. Three percent of the detectors received were spiked samples (detectors exposed to known radon levels in an EPA radiation laboratory). Duplicate detectors were exposed at every tenth test location and located within six-inches of each other. Two detectors, referred to as field blanks, were also used from each box of detectors received. When shipping the detectors used in priority 1, 2 or 3 locations, the field blanks were removed from the aluminum foil packaging. The "Gold Seal" was immediately applied. The placement and retrieval dates were marked on the detectors using the same ink and handwriting. The field blanks were then mixed with the other detectors for shipment to the laboratory for analyses. A contractor was chosen by the Department of the Army to ensure that there was a 99.5 percent confidence in the initial measurements.

Radon testing of buildings in all geological areas of the Radford Army Ammunition Plant showed only 11 buildings of the 511 tested had radon levels greater than 4.0 pCi/l based on the 3-month and 12-month test periods. Eight of the 11 buildings with radon above 4.0 pCi/l are located on a limestone outcrop. Top soil in some of the yards is only eight-inches deep. Depending on meteorological and soil conditions (pressure, temperature, permeability, moisture, etc.) the gaseous radon diffuses into the atmosphere or buildings by ways previously stated. The location and method of building construction (concrete slab floor, cinder block walls, dirt crawl space ventilating into the occupied basement) contributed to the radon content in each structure.

Two production buildings used as control rooms had radon exceeding 4.0 pCi/l. These control rooms are essentially earth covered steel tanks with a doorway and exhaust stack. The radon content was reduced to less than 4.0 pCi/l by air dilution (running the exhaust fan continuously).

Installation of ductwork and an exhaust fan is currently underway in the 11th building having radon above 4.0 pCi/l. Testing will be done to determine if air dilution is a satisfactory method of mitigation in this building.

CONCLUSION

Mitigation of radon in buildings having a radon content of 4.0 pCi/l or higher can be accomplished by air dilution. However, air dilution is not completely satisfactory because of building heat lose and cost of electricity to run the fans. Long-term mitigation involves caulking, plastic sheet sealed over dirt crawl spaces, etc. Long-term mitigation techniques will be considered after building modifications have been completed.

REFERENCES

[1]EPA Pamphlet, "A Citizen's Guide to Radon," dated August 1986.

[2]United States Army Environmental Hygiene Agency, Technical Guide No. 164.

Figure 1

Radon 222 Decay Series

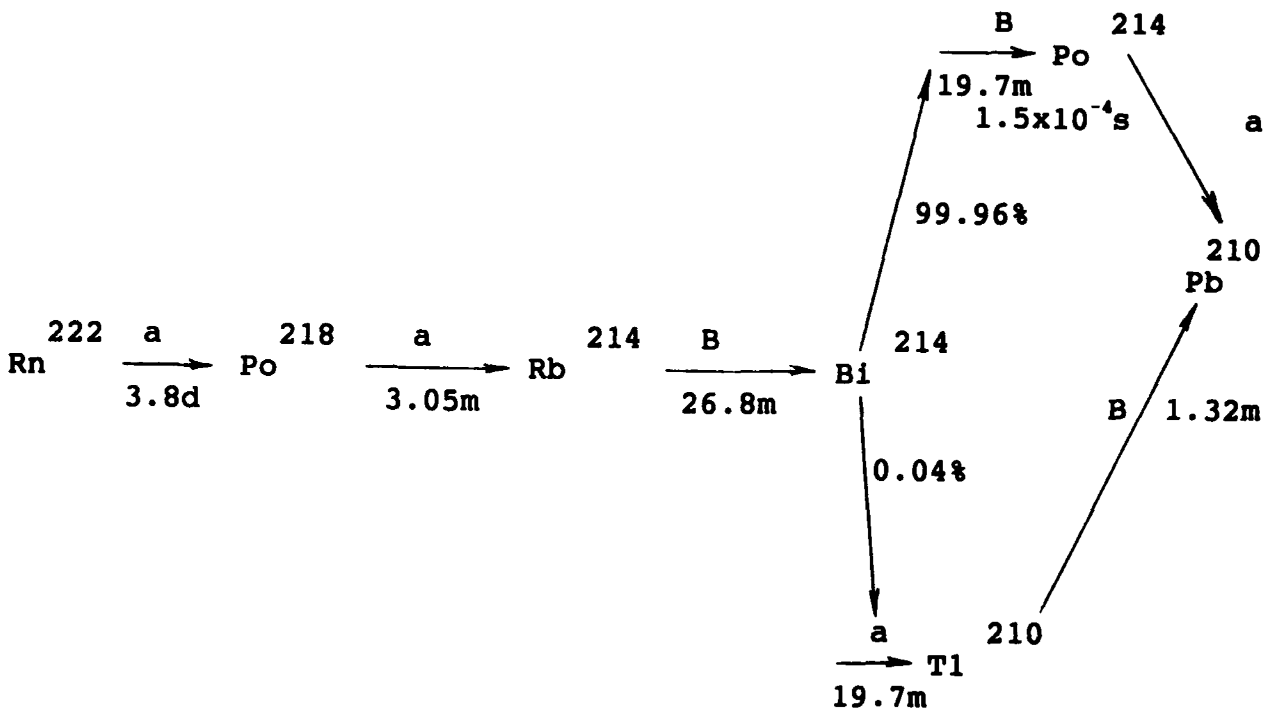
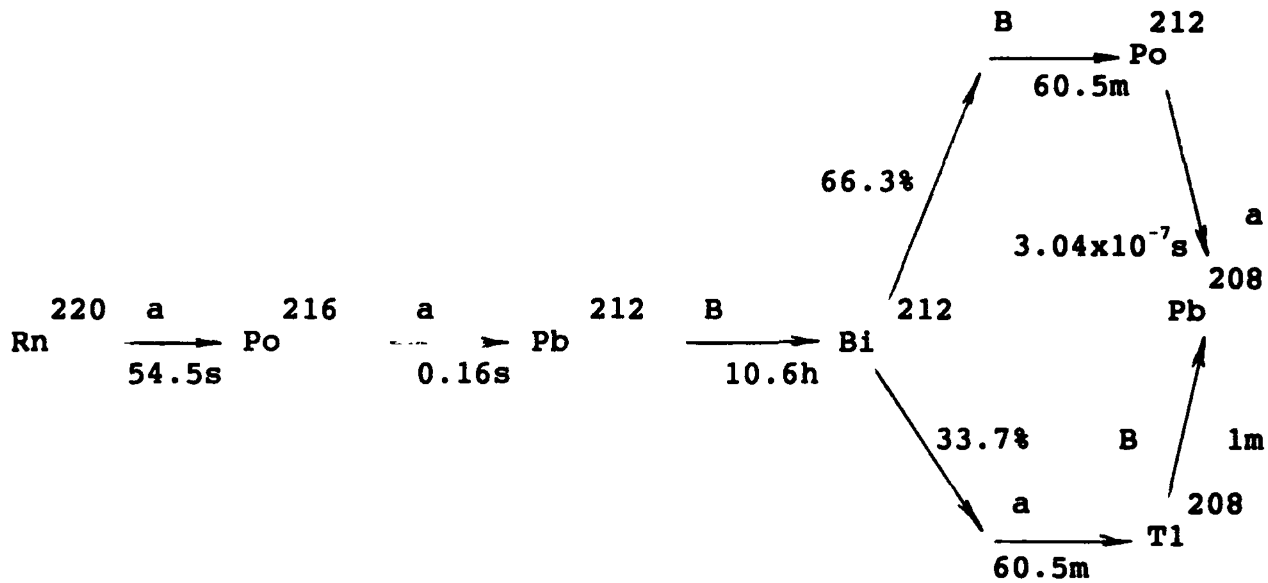


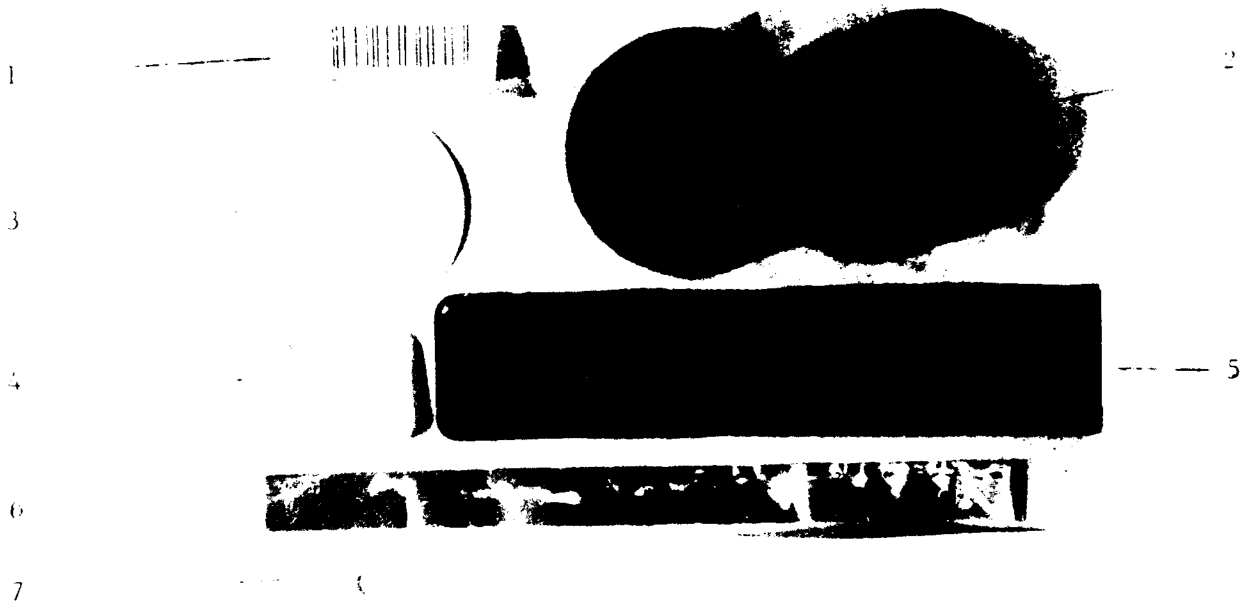
Figure 2

Thorium 220 Decay Series



Legend for figures 1 and 2

s	second	B	beta particle	Bi	bismuth
h	hour	Rn	radon	TI	thallium
d	day	Po	polonium	Pb	lead
a	alpha particle	Rb	rubidium		



Legend

1. Bar code identification label
2. Bottom and top of plastic cassette
3. Filter
4. Date label
5. Radtrak label with identification number
6. Detector strip
7. Monitor hanging strip

Figure 3

Disassembled Alpha Track Monitor

EXPLOSIVES SAFETY TRAINING FOR THE 1990s

AMMUNITION SCHOOL

U.S. ARMY DEFENSE AMMUNITION CENTER AND SCHOOL

Savanna, Illinois

DAVID W. FOULK, CHIEF

AMMUNITION SCHOOL

- PROVIDES EXPLOSIVES TRAINING DOD-WIDE
- PROVIDES UNIQUE TRAINING COURSES NOT FOUND ELSEWHERE IN THE MILITARY SERVICES OR PRIVATE INDUSTRY
- COURSES COVER COMPLETE SPAN OF LIFE-CYCLE LOGISTICS
- COURSES CAN BE TAILORED TO ANY TARGET AUDIENCE FROM ANY SERVICE
- MANY COURSES CAN BE TAUGHT ON-SITE BY MOBILE TRAINING TEAMS

PRIMARY EXPLOSIVES SAFETY COURSES

- BASICS OF NAVAL EXPLOSIVES HAZARD CONTROL
- ELECTRICAL EXPLOSIVES SAFETY FOR NAVAL FACILITIES
- EXPLOSIVES SAFETY FOR NAVAL FACILITY PLANNING
- NAVAL EXPLOSIVES SAFETY MANAGERS/SUPERVISORS ORIENTATION
- NEW PLANT COMMANDER SAFETY AND ORIENTATION
- U.S. ARMY EXPLOSIVES SAFETY COURSE
- ELECTRICAL EXPLOSIVES SAFETY FOR ARMY FACILITIES *
- EXPLOSIVES SAFETY AFLOAT *
- EXPLOSIVES SAFETY FOR FIRING RANGES *
- HAZARD ANALYSIS FOR AMMUNITION OPERATIONS *
- HAZARDOUS ORDNANCE RECOGNITION AND SAFETY *
- NAVAL AMMUNITION ACCIDENT/INCIDENT INVESTIGATION AND REPORTING *
- EXPLOSIVES SAFETY FOR DEFENSE CONTRACTORS *
- SAFETY IN INDUSTRIAL EXPLOSIVES OPERATIONS *
- CHEMICAL AGENTS SAFETY COURSE *

* UNDER DEVELOPMENT

Course: **Basics of Naval Explosives Hazard Control**

DOD Component/MACOM: **U.S. Navy/U.S. Marine Corps**

Scope: **Course content includes evaluation, classification, and control of hazards; safety in maintenance, demilitarization, transportation and various handling operations; storage compatibility, and quantity distance requirements.**

Target Audience: **Air Force/Navy/Marine Corps personnel involved with ammunition and explosives operations.**

Course: **Electrical Explosives Safety for Naval Facilities**

DOD Component/MACOM: **U.S. Navy/U.S. Marine Corps**

Scope: **Course content includes identification of of electrical hazards, grounding requirements, HERO protection and lightning protection for explosives facilities.**

Target Audience: **Engineers, technicians or safety inspectors responsible for electrical safety in explosives locations.**

Course: **Explosives Safety for Naval Facility Planning**

DOD Component/MACOM: **U.S. Navy/U.S. Marine Corps**

Scope: **Course content includes an in-depth study of DOD quantity distance standards and application of these standards in the form of a Facility Design Problems Workshop.**

Target Audience: **Air Force/Navy/Marine Corps facility planners responsible for explosives facilities at shore installations, safety department personnel responsible for review of facility site plans and individuals who fall within the review chain of typical Air Force/Navy/Marine Corps facility site plans.**

Course: **Naval Explosives Safety Managers/Supervisors Orientation**

DOD Component/MACOM: **U.S. Navy/U.S. Marine Corps**

Scope: **Course content includes characteristics of explosives and propellants; hazard classification and storage compatibility groups; explosives safety standards/quantity distance; site planning and preparation of waiver/exemption requests; malfunction investigation and explosives accident investigation; and environmental requirements.**

Target Audience: **Managerial/Supervisory personnel responsible for explosive safety in ammunition/explosive operations.**

Course: **New Plant Commanders Safety and Orientation**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **Course contents include identification of different classes of ammunition and explosives, stressing safe handling and explosives safety requirements.**

Target Audience: **Lieutenant Colonels enroute to assignments in Army Ammunition Plants**

Course: **U.S. Army Explosives Safety Course**

DOD Component/MACOM: **U.S. Army**

Scope: **Course content includes characteristics of explosives and propellants; hazard classification and storage compatibility groups; explosives safety standards/quantity distance; site planning and preparation of waiver/exemption requests; malfunction investigation and explosives accident investigation; and environmental requirements.**

Target Audience: **Army/Air Force safety interns and/or GS-09 and above safety specialists/ engineers.**

Course: **Electrical Explosives Safety for Army Facilities**

DOD Component/MACOM: **U.S. Army**

Scope: **Course content includes electrical safety considerations; hazards of electromagnetic radiation to ordnance, fuel and personnel; electrical requirements; grounding/bonding measurements; and test methodology**

Target Audience: **Army personnel involved in the design, installation, testing or inspection of electrical services, equipment, and lightning/grounding systems. Personnel should be GS-07 thru 12 or WG-06 thru 09.**

Course: **Explosives Safety Afloat**

DOD Component/MACOM: **U.S. Navy - NAVSEASYSCOM**

Scope: **Course content includes characteristics of explosives and propellants, hazard classification, storage compatibility aboard vessels, explosives mishap investigation and ordnance handling aboard vessels.**

Target Audience: **U.S. Navy active duty military, assigned to the fleet, whose duties specifically relate to evolutions involving ammunition and explosives.**

Course: **Explosives Safety for Firing Ranges**

DOD Component/MACOM: **U.S. Army**

Scope: **Course contents include characteristics of explosives and propellants, hazard classification, storage compatibility, requirements for outdoor storage, transportation, quantity-distance, ammunition handling, malfunction reporting and range safety.**

Target Audience: **Active duty military and civilian technicians responsible for range control and using unit ammunition officers and non-commissioned officers.**

Course: **Hazard Analysis for Ammunition Operations**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **Course provides training to ammunition personnel in the practical application of qualitative hazard analysis techniques. The course will include training on how to conduct and use preliminary and operating hazard analysis for ammunition operations**

Target Audience: **Personnel responsible for the development of Standing Operating Procedures (SOP's) for depot/ wholesale operations IAW AMC-R 700-107. Prospective attendees should be knowledgeable of ammunition operations at their respective installations.**

Course: **Hazardous Ordnance Recognition and Safety**

DOD Component/MACOM: **U.S. Army Corps of Engineers**

Scope: **Course content includes a basic coverage of ammunition families, their functioning, physical characteristics, means of identification and hazards. Special emphasis is placed on available reference materials and required actions upon discovering hazardous ordnance.**

Target Audience: **Corps of Engineer/contractor personnel involved in Formerly Used Defense Sites (FUDS) surveys and Remediation. It is designed for individuals with minimal ammunition expertise.**

Course: **Naval Ammunition Accident/Incident Investigation and Reporting**

DOD Component/MACOM: **U.S. NAVY**

Scope: **Course content will include standardized accident reporting procedures and methods of "Techniques For Investigation"**

Target Audience: **Navy and Marine Corps personnel involved in accident/incident investigation and reporting. Personnel should be in grade GS-07 thru 12, WG-06 thru 09, and Military equivalent rank/rate.**

Course: **Explosives Safety for Defense Contractors**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **To provide the student an understanding of the technical safety standards, procedures, and safe practices required for ammunition and explosives. The course focuses on the application of requirements in the DOD Contractors Safety Manual For Ammunition and Explosives.**

Target Audience: **Defense contractor personnel, civilian personnel GS-07 and above procurement or contract administrators, and military personnel having duties involving defense contractor development, use, or manufacture of explosives or devices containing explosives.**

Course: **Safety in Industrial Explosives Operations**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **Provides the student an understanding of the technical safety standards, procedures, and safe practices required in industrial ammunition and explosives operation; includes requirements for new construction, modification, repairs, quantity distance, and hazard classification of explosives items. Also included are various safety aspects of press, component, melt loading, and testing of explosives and ammunition.**

Target Audience: **GS-05 thru GS-12 Safety personnel, first line supervisors, and engineering personnel involved in munitions plants, ammunition depots, and proving grounds.**

Course: **Chemical Agents Safety Course**

DOD Component/MACOM: **U.S. Army/Safety**

Scope: **To provide personnel with the information and knowledge necessary for the development, implementation, and maintenance of an effective chemical safety program designed to prevent accidents resulting in personnel exposure to toxic chemical agents, or damage to property.**

Target Audience: **Safety professionals, supervisors, and operators who manage or implement chemical safety programs at DA MACOMS, subordinate headquarters or activities.**

CONVENTIONAL AMMUNITION

EXPLOSIVES SAFETY-RELATED COURSES

- AMMUNITION DEMILITARIZATION
- AMMUNITION MAINTENANCE
- ADVANCED CONVENTIONAL AMMUNITION ORIENTATION
- CONVENTIONAL AMMUNITION SURVEILLANCE
- PREPARATION OF STANDING OPERATING PROCEDURES FOR AMMUNITION & EXPLOSIVES OPERATIONS
- SPECIAL TECHNICAL AMMUNITION
- SPECIAL TECHNICAL AMMUNITION FOR LOGISTICS ASSISTANCE REPRESENTATIVES
- SURVEILLANCE OF MAINTENANCE/DEMILITARIZATION OPERATIONS
- TECHNICAL AMMUNITION

Course: **Ammunition Demilitarization**

DOD Component/MACOM: **U.S. Army**
International Military Students

Scope: **Course content includes explosives safety requirements for demilitarization/disposal of ammunition/explosives. Included is set up and detonation of "live" explosives by each student.**

Target Audience: **Ammunition Manager Interns, Wage Grade Employees and Supervisors Requiring Certification**

Course: **Ammunition Maintenance**

DOD Component/MACOM: **U.S. Army**
International Military Students

Scope: **Course content includes explosives safety requirements for ammunition maintenance projects. Students set up and operate a "live" ammunition maintenance line.**

Target Audience: **Ammunition Manager Interns,**
Wage Grade Employees and
Supervisors Requiring Certification

Course: **Advanced Conventional Ammunition Orientation**

DOD Component/MACOM: **U.S. Army**

Scope: **Course contents include safe handling procedures for ammunition and explosives and quantity distance requirements.**

Target Audience: **Ammunition Manager Interns**

Course: **Conventional Ammunition Surveillance**

DOD Component/MACOM: **U.S. Army**

Scope: **Course content includes quantity distance requirements, safety and operational requirements for ammunition storage and transportation.**

Target Audience: **Army/Air Force QASAS Interns**

Course: **Preparation of SOPs for Ammunition and Explosives Operations**

DOD Component/MACOM: **U.S. Army**

Scope: **Course content includes explosives safety requirements necessary for inclusion in SOPs, hazard analysis and environmental requirements.**

Target audience: **Personnel directly involved in the preparation or review of ammunition operation SOPs.**

Course: **Special Technical Ammunition**

DOD Component/MACOM: **U.S. Army AMC/TRADOC/FORSCOM**

Scope: **Course content includes the introduction of the different classes of ammunition and explosives, stressing safe handling and explosives safety requirements during the receipt, storage, maintenance, production, demilitarization, or issue.**

Target Audience: **Army/Air Force Non-Supervisory Wage Employees Requiring Certification**

Course: **Special Technical Ammunition For Logistics Assistance Representatives (LARS)**

DOD Component/MACOM: **U.S. Army AMCCOM**

Scope: **Course content includes introduction of the different classes of ammunition and explosives, stressing safe handling and explosives safety requirements during issue, receipt, storage, maintenance, production, and demilitarization.**

Target Audience: **AMCCOM LARS**

Course: **Surveillance of Maintenance/ Demilitarization Operations**

DOD Component/MACOM: **U.S. Army**

Scope: **Course content includes explosives safety requirements for ammunition maintenance projects and demilitarization/disposal of ammunition/explosives. Students set up and operate a "live" ammunition maintenance line and detonate "live" explosives.**

Target Audience: **Army/Air Force QASAS Interns**

Course: **Technical Ammunition Course**

DOD Component/MACOM: **U.S. Army**
AMC/TRADOC/FORSCOM

Scope: **Course content includes ammunition safe handling practices, quantity distance and explosives safety requirements for storage and transportation.**

Target Audience: **Wage Grade Employees Requiring Certification**

LOGISTICS

EXPLOSIVES SAFETY-RELATED COURSES

- AMMUNITION STORAGE
- EXPENDABLE ORDNANCE MANAGEMENT
- GENERAL TRANSPORTATION OF HAZARDOUS MATERIALS
- NAVAL MOTOR VEHICLE AND RAILCAR INSPECTION
- NAVAL MOTOR VEHICLE AND RAILCAR INSPECTION RECERTIFICATION
- TECHNICAL TRANSPORTATION OF HAZARDOUS MATERIALS
- FUNDAMENTALS OF SHIPBOARD BLOCKING AND BRACING *
- INTRODUCTION TO NAVAL AMMUNITION MANAGEMENT *

* UNDER DEVELOPMENT

Course: **Ammunition Storage**

DOD Component/MACOM: **U.S. Army**
International Military Students

Scope: **Course content includes safety principles for space utilization, storage operations and Management Informations Systems requirements.**

Target Audience: **Ammunition Manager Interns, Depot/Activity Storage Personnel at the wholesale level.**

Course: **Expendable Ordnance Management**

DOD Component/MACOM: **Naval Sea Systems Command (SEA-06)**

Scope: **Provide mid-career course in the Technical and Managerial aspects of ammunition and explosives operations at Naval facilities.**

Target Audience: **Naval Officers 0-3 to 0-5 and/or Civilians GS-11 to GS-14 currently assigned or enroute to an assignment involving EOM.**

Course: **General Transportation of Hazardous Materials**

DOD Component/MACOM: **DOD, Contractor**

Scope: **Course content includes certification requirements of Domestic and International Regulations for safe movement of ammunition/explosives. Recertification course for Technical Transportation of Hazardous Materials.**

Target Audience: **Army/Air Force employees requiring certification for transportating hazardous cargo.**

Course: **Naval Motor Vehicle and Railcar Inspection**

DOD Component/MACOM: **U.S. Navy/ U.S. Marine Corps**

Scope: **Course content includes proper packaging, compatibility, and blocking/bracing for transportation of ammunition, explosives and other related hazardous material.**

Target Audience: **Air Force/Navy/Marine Corps Motor Vehicle and Railcar Inspection Personnel**

Course: **Naval Motor Vehicle and Railcar Inspection Recertification**

DOD Component/MACOM: **U.S. Navy/ U.S. Marine Corps**

Scope: **Course content includes proper packaging, compatibility, and blocking/bracing for transportation of ammunition, explosives and other related hazardous material.**

Target Audience: **Air Force/Navy/Marine Corps Motor Vehicle and Railcar Inspection Personnel**

Course: **Technical Transportation of Hazardous Materials**

DOD Component/MACOM: **DOD & Contractors**

Scope: **Course covers the certification requirements of Domestic and International Regulations for the movement of hazardous materials in commerce.**

Target Audience: **Personnel required to certify that hazardous materials are qualified for movement.**

Course: **Fundamentals of Shipboard Blocking and Bracing**

DOD Component/MACOM: **Naval Sea Systems Command (SEA-06)**

Scope: **General and specific requirements for proper blocking, bracing, and loading of Navy and Civilian Ammunition Vessels.**

Target Audience: **Supervisory Wage Grade Personnel directly involved with daily operations of loading and unloading both U.S. Navy and Commercial Breakbulk ships with ammunition.**

Course: **Introduction to Naval Ammunition Management**

DOD Component/MACOM: **Naval Sea Systems Command (SEA-06)**

Scope: **Basics of Ammunition Logistics Management at facilities other than Naval Weapons Stations.**

Target Audience: **Naval Officers, Senior Enlisted Personnel, and Reserve Naval Officers involved in Ammunition Management.**

GUIDED MISSILE/SURETY MATERIEL EXPLOSIVES SAFETY-RELATED COURSES

- BASIC MISSILE OPERATIONAL SAFETY
- CHEMICAL HAZARD PREDICTION
- CHEMICAL HAZARD PREDICTION FOR DECISION MAKERS
- CHEMICAL SURETY MATERIEL
- CHEMICAL ACCIDENT/INCIDENT RESPONSE & ASSISTANCE
- FIRE-RADIATION AND EXPLOSIVE HAZARDS
- NUCLEAR ACCIDENT/INCIDENT RESPONSE & ASSISTANCE
- NUCLEAR ACCIDENT/INCIDENT RESPONSE & ASSISTANCE OFFICERS
- SENIOR OFFICER NUCLEAR/CHEMICAL
- TECHNICAL CHEMICAL SURETY MATERIEL
- AMMUNITION RADIATION TECHNICAL TRAINING *
- CHEMICAL AWARENESS (ARMY) *
- CHEMICAL DEMILITARIZATION/SURVEILLANCE OPERATIONS *
- CHEMICAL STOCKPILE EMERGENCY PREPAREDNESS PROGRAM ORIENTATION *
- CONVENTIONAL AMMUNITION RADIATION TRAINING *

* UNDER DEVELOPMENT

Course: **Basic Missile Operational Safety**

DOD Component/MACOM: **U.S. Army**
AMC/TRADOC/FORSCOM

Scope: **Course content includes explosives safety requirements during handling, storage, transportation and maintenance of guided missile ammunition.**

Target Audience: **Non-Supervisory Wage Grade Employees Requiring Certification**

Course: **Chemical Hazard Prediction**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **Course content is designed to provide current information on the chemical and physical properties, toxicity, and physiological effects of the toxic agents GB, VX, and HD and to provide descriptions and characteristics of toxic chemical munitions.**

Target Audience: **QASAS interns or individuals assigned to a position which requires familiarity with the calculation of downwind hazard distances for toxic chemical releases.**

Course: **Chemical Hazard Prediction for Decision Makers**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **This course will provide an overview of the data elements that affect the dispersion of chemical agents. This will provide decision makers with an increased understanding of cloud movement and agent concentration factors which will allow them to make better informed decisions.**

Target Audience: **All individuals involved in chemical surety hazard assessment and CAIRA decision making.**

Course: **Chemical Surety Materiel**

DOD Component/MACOM: **U.S. Army**

Scope: **Course content includes properties of chemical agents, chemical munitions and containers; protective clothing and safety requirements; chemical agent detection and identification; disposal and decontamination; chemical surety and Chemical Event Response and Assistance; and storage and shipment of surety agents.**

Target Audience: **QASAS Interns**

Course: **Chemical Accident/Incident Response and Assistance**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **Topics include elements of the Initial Response Force (IRF), site security, communication and reporting procedures, personnel and site decontamination, detection methods, weather and terrain effects, protective clothing, and agent chemical and physical properties.**

Target Audience: **Personnel assigned or anticipating assignment to a position that involves chemical response control duties at either an installation or staff level organization.**

Course: **Fire-Radiation and Explosive Hazards**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **Training provided includes basic Army Nuclear Weapon Design principles, an overview of explosive and radioactive material hazards, typical biological effects of exposure to ionizing radiation, and personnel protective measures to be taken against internal and external radiation hazards present at the scene of an accident involving Army Nuclear Weapons.**

Target Audience: **All fire department officers, fire fighters, law enforcement officers, civil defense and safety officials, transportation personnel, and any other personnel responsible for providing immediate emergency assistance at the scene of a fire involving nuclear weapons.**

Course: **Nuclear Accident/Incident Response and Assistance**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **This course is divided into subcourses, each of which examines a facet of nuclear accident response in detail. All aspects of response, from on-site procedures to national level actions are covered. Realistic exercises are conducted throughout the course to emphasize and reinforce the classroom training sessions. Exercise performance is monitored and constructive critiques are utilized to reiterate proper procedures.**

Target Audience: **QASAS interns and others as defined in AMCR 350-2**

Course: **Nuclear Accident/Incident Response and Assistance Officers**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **Provides information on the problems and responsibilities involved in nuclear accident response. Explosive, toxic, radioactive hazards, radiation detection, protection techniques, procedures, plans, response teams, and emergency command post functions are covered. Past accidents are analyzed with an emphasis on lessons learned.**

Target Audience: **Prospective enrollees should be assigned or have a planned assignment as a NAIRA Operations Officer, On-Scene Commander staff member, or On-Scene Commander.**

Course: **Senior Officer Nuclear/Chemical**

DOD Component/MACOM: **U.S. Army**

Scope: **Course content includes identification of typical hazards, basic handling and explosives safety standards, and quantity distance for nuclear weapons.**

Target Audience: **Senior military officers/ civilians with nuclear duties.**

Course: **Technical Chemical Surety Materiel**

DOD Component/MACOM: **U.S. Army**
AMC/TRADOC/FORSCOM

Scope: **Course content includes protective clothing, agent detection, decontamination, disposal, general safety and accident response.**

Target Audience: **Wage Grade Personnel Requiring Certification**

Course: **Ammunition Radiation Technical Training**

DOD Component/MACOM: **U.S. Army**

Scope: **This course will be divided into different subcourses each of which has specific learning objectives, such as an overview of basic atomic theory, safety requirement for handling, inspection, storage, and demilitarization of conventional ammunition containing depleted uranium (DU) or radioactive components.**

Target Audience: **Munitions handlers and first line supervisors.**

Course: **Chemical Awareness (ARMY)**

DOD Component/MACOM: **U.S. Army/AMC/USANCA**

Scope: **Basic information on chemical agents, munitions, storage, chemical event response planning, emergency notification, effects of weather and terrain on agent releases; role of the CSEPP; avoiding exposure and basic toxicity data on mustard and nerve agents.**

Target Audience: **All DOD personnel, typically chemical storage installation personnel not normally involved with the chemical program.**

Course: **Chemical Demilitarization/Surveillance Operations**

DOD Component/MACOM: **U.S Army/AMC**

Scope: **Detailed look at the operations and functions of existing and proposed chemical demilitarization plants with an emphasis on quality assurance checks and procedures.**

Target Audience: **U.S. Army QASAS and other surveillance personnel.**

Course: **Chemical Stockpile Emergency Preparedness Program Orientation**

DOD Component/MACOM: **U.S. Army/USANCA**

Scope: **Purpose of the CSEPP; Army/FEMA MOU; the Joint Steering Committee; the six subcommittees (training, automation, exercises, public affairs, planning and re-entry); Federal/state/local and installation implementation programs and their relationship to the Chemical Disposal Program.**

Target Audience: **All DOD personnel involved with or affected by the CSEPP.**

Course: **Conventional Ammunition Radiation Training**

DOD Component/MACOM: **U.S. Army/AMC**

Scope: **Course content will provide information on the radiation aspects of conventional ammunition components and associated hardware. Course will cover U^{238} (DU) associated with a variety of DU rounds and armor plating on vehicles, H^{3} and Pm^{147} found in rifle and light antitank weapon (LAW) rocket sights, Am^{241} in M438A1 detectors, and Ni^{63} identified in chemical agent monitors (CAM's) .**

Target Audience: **QASAS, munitions handlers and first line supervisors.**

DEVELOPMENT OF AN ON-LINE TEXT-BASED RETRIEVAL SYSTEM FOR THE DDESB SEMINARS ABSTRACTS

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Abstract

An automated, on-line, text-based retrieval system for papers presented at the the Department of Defense Explosives Safety Board (DDESB) Safety Seminars was developed, tested and made operational. The project consisted of several steps, including 1) preparation of abstracts, bibliographic citations and subject indexes for every paper, 2) development of an online text-based management system (TBMS), and 3) uploading the records into the database. The TBMS was used to prepare a printed volume consisting of the seminar papers abstracts and subject, corporate source, and author indexes. The printed version was distributed initially by the DDESB to selected recipients: further copies are available from the NTIS.

The online DDESB TBMS is currently accessible on a mainframe computer at The Johns Hopkins University Applied Physics Laboratory. Connection to the system may be achieved by telephone modem or network. The system permits online searching, viewing of search results, printing or results, and electronic downloading of results. The TBMS allows records to be retrieved by various search criteria including any word or combination of words appearing in the title, abstract or index, author, and any numeric identifiers associated with the citations, including report number, contract number, report date, and abstract number.

Introduction

In the late 1980's, the Department of Defense Explosives Safety Board (DDESB) recognized a need to improve access to the papers in past proceedings of its Safety Seminars. A large number of papers had been presented over the preceeding thirty years, and the only means of retrieving or locating a particular paper in the proceedings was to use the tables of contents for individual volumes. To address the need for automated access, the Chemical Propulsion Information Agency (CPIA), a division of the Johns Hopkins University's G. W. C. Whiting School of Engineering, was contracted to develop a retrieval system.

Coincident with the DDESB's recognition of its need for a retrieval system, the CPIA had recognized a need to acquire an improved means of retrieving its own archival material. The CPIA has been engaged in information retrieval since the organization's inception in 1946. The organization has developed a number of retrieval systems, both automated and manual, over the intervening years, for its extensive collection of technical papers and documents. As a result, a joint effort was intitiated to develop a state-of-the-art retrieval system that could be used for both organizations' documents.

The CPIA is a DoD Information Analysis Center residing at 10630 Little Patuxent Parkway Suite 202, Columbia MD 21044-3200, tel. 410/992-7300.

Seminar Papers

The DDESB held its Safety Seminars annually from 1959 through 1974, and biannually since 1976. In the early years of publication (starting in 1959), the DDESB seminar proceedings were organized relatively informally. In some of the earliest publications, the proceedings consisted of only minutes of seminar meetings, prefaces, welcoming addresses and introductory remarks, with no distinct or separate papers that could be catalogued separately for bibliographic purposes. The lack of discernably separate papers can make bibliographic control somewhat difficult, especially when the contents are not identified in an index. Over the years, the style of the published proceedings evolved gradually into compilations of discrete, formal papers. The variation over time of the organization of the proceedings would present a special challenge to the developers of a retrieval system.

Retrieval System Development

System Goals and Architecture

The major goal of the project was to develop a user-friendly means of locating Seminar papers by subject and by bibliographic identifiers. The project would also serve to upgrade the existing CPIA retrieval system as well, so that compatibility with the existing CPIA data structures was strongly desired. The specific system requirements identified to achieve the stated goals were as follows:

- provide on-line access to DDESB and CPIA technical papers and reports;
- permit conversion of the old CPIA subject-term-based retrieval system to a text retrieval system which would be easier to access and maintain;
- provide the means to query terms within the titles, abstracts and subject terms fields;
- permit on-line interactive viewing of the text fields of the document or paper within the DDESB or CPIA data;
- provide for output of the specific report formats to mainframe printers, local PC files, and local PC printers;
- allow multiple databases to be queried from the same on-line system.
- permit search entries into the database; and
- provide menues and help screens.

Preparation of DDESB bibliographic data

The development of the DDESB's Seminar Papers retrieval system reflected the experience of the CPIA with its own Chemical Propulsion Abstracts. The CPIA has produced printed abstracts and indexes of its document receipts annually since the late 1940s. These volumes were prepared manually until 1968, without the aid of any machine-searchable data. In 1969, CPIA implemented an automated system for retrieving its technical documents by technical subject area. The automated system also permitted the creation of title block citations and subject, corporate source, personal author, contract number, and report number indexes.

The basis for CPIA's 1969-era machine-searchable system was subject indexes together with traditional bibliographic fields. The subject index terms were prepared for each document by CPIA staff engineers and scientists and provide a specialist's identification of the document's technical content. The staff used a controlled, computer-compatible, structured vocabulary to construct hierarchical indexes which were input to a mainframe computer search system. An indexer would construct an index "stack" by first selecting from a list of general subject headings and then adding subsequent terms to focus on the specific subjects covered in the document. For example, to index a document entitled "Analysis of Composite Propellant Ignition by Electrostatic Discharge," an indexer might create the following "stack:"

..SOLID PROPELLANTS (gen)
....(see also SOLID PROPELLANTS (sp))
......composite propellant
........electrostatic discharge sensitivity
..........ignition mechanism
............workshop report
............analytical model
............confinement effect
............ESD ignition

The stacks for a given number of documents or papers could then be compiled into a single printed index organized hierarchically by subjects. Thus, a researcher interested in modelling of electrostatic discharge ignition properties of a composite solid propellant could locate the report through the use of the index. The compiled indexes were the basis of the machine-searcheable retrieval system developed for CPIA's large archive of propulsion technology documents. The computerized search system enabled both online searching and production of printed index compilations for publication. Similar capability was desired for the DDESB retrieval system, therefore DDESB records needed to be created that would accomodate the CPIA data structure.

The inconsistent condition of the DDESB Seminars' proceedings presented something of a challenge for the CPIA personnel engaged in the development of the retrieval system. As the system was intended to be automated, a consistent format was mandated for the individual records. Many of the older presentations needed to have new material created to be used as database records. These older presentations often lacked common bibliographic features such as titles, abstracts, and other bibliographic information that could be used to assist in later retrieval. The CPIA staff synthesized bibliographic data as needed to create records for input to the automated system. The fields incorporated into each document record include the following:

- Title: Title of citation;
- Corporate Source: Facility responsible for the reported work;
- DTIC Accession Number: Defense Technical Information Center number;
- Descriptive Note: e.g. "Meeting Paper;"
- Authors: The personal author, e.g., "Greenberg, P. L.;"
- Distribution/Availability Statement: e.g.,"Availability NTIS/DTIC - Approved for public release; distribution is unlimited.;"
- Abstract: Brief description of citation, generated by author or CPIA staff;
- Classification: the classification of the citation, e.g.,"U" = unclassified;
- Report Date: e.g., "Aug86;"
- Page Count: e.g., "16p;"
- Index Terms: subject terms assigned by the CPIA professional staff.

The new, textbased retrieval system developed for both DDESB and for CPIA was intended to retain many of the desirable features of the subject-index based system, with many additional enhancements. The CPIA along with specialists from the JHU Applied Physics Laboratory (APL) identified text-base management as the optimal approach to bibliographic information retrieval. A text database management system (TDBMS) stores and retrieves full textual information based upon word and phrase criteria. The developers selected InfoData's INQUIRE/Text system for application to the CPIA/DDESB retrieval project.

The INQUIRE/Text program can store and retrieve unstructured textual information ("free" text) as well as traditional structured fields. In addition, the INQUIRE/Text system can search via words and phrases "near" or in proximity to each other. These capabilities were desired in the new system, so that text fields could be constructed, such as "Title" or "Author," to permit searches of defined fields. The most common type of search expected was the adjacent search, which finds words that appear next to one another in a record. This feature adds greatly to the specificity of a search, by permitting concepts described by multiple words groups or phrases to be specified (e.g., "insensitive munitions" or "high explosives" or "rocket motor propellant").

Programming specialists from both CPIA and APL worked intensively to develop the system over a period of several years. The task included development of screens for user interface with the system, application of mainframe operating system facilities, integration of the Inquire/Text search software with the existing Script output program, creation of special programs to process input data files (which were in turn created by data-entry staff using WordPerfect© software), testing the system for both function and usability, and modifying the system as needed to achieve the optimal balance between user-friendly operation, cost, and efficiency. The system was finally made operational in October 1990.

System Description

System Access

The CPIA named its new system the Propulsion Information Retrieval System (PIRS). The means of access to the CPIA PIRS is via either personal computer connected by a high speed modem to the Johns Hopkins University Applied Physics Laboratory (JHU/APL) mainframe, using YTerm terminal emulation software or by a network such as Internet, using an IBM 3270 terminal emulator.

System Operation

The user establishes connection with the APL mainframe, supplies User ID and password in response to system prompts. The PIRS is then loaded automatically. The system presents a number of screens to the user, through which the user selects options relating to a search, enters search criteria (the "search strategy"), and prints or views the results. The interface screens are described below:

The system first introduces the user with a "banner" or "header" screen (Figure 1). The banner screen announces the PIRS system, gives contact names and phone numbers, and gives security information.

```
WELCOME TO THE CPIA
PROPULSION INFORMATION RETRIEVAL SYSTEM (PIRS)
FOR INFORMATION CONTACT
PAUL MYERS 410-992-7307

USERS WHO NEED FURTHER TECHNICAL INFORMATION OR WHO WISH TO HAVE DATA
EXTRACTED FROM RESULTING CITATIONS, SHOULD CALL TRACY D. WILSON,
CPIA'S INFORMATION ANALYSIS SECTION MANAGER, AT 410-992-7306 FOR
ASSISTANCE.

**************************WARNING********************
As a condition of obtaining CPIA services, all information received
from the CPIA that is not clearly marked for public release is
considered to be limited in distribution to only U.S. Government
agencies and their contractors; the information may also contain
technical data whose export is restricted by the Arms Export Control
Act (TITLE 22, USC Sec 2751 et seq.) or by Executive Order 12470.
Violation of these export laws is subject to severe criminal
penalties. Non compliance may result in termination of access and a
requirement to return all information obtained from CPIA.
**************************WARNING********************

PRESS ENTER TO CONTINUE
```

Figure 1. PIRS Banner Screen

Searching

The next screen that appears is the *Search* screen (Figure 2) which acts as a central control panel through which all other system functions are accessed. The search strategy may be entered in lines 1 through 6 to initiate a search.

The CPIA PIRS allows users to search for documents in a number of ways, including by technical subject and by document identifiers (i.e. report number, document author, date, etc.). The PIRS permits users, via use of set strategies, to construct very sophisticated searches in order to identify highly relevant documents. The users may create subject searches of the document title, document abstract, and of the CPIA-created subject index terms. They may construct very specific searches using Boolean logic operators (or, and, not) to connect a series of search terms. The system also offers powerful proximity search capabilities, whereby a set of search terms or words are located only if they appear adjacent to one another or in the same sentence. Another proximity operator allows for searches for a string located within a specified number of words of a second string. The *Search* screen allows for entry of inquiry terms and operators, displays search results, and lists function keys and their associated functions.

Database Selection

Because the system includes a number of separate databases, provision for selecting an individual database was established with the *Database Selection* screen (Figure 3), which allows the user to limit searches to CPIA or DDESB citations. The PIRS defaults to all databases present, unless the user selects a specific database.

```
                         PIRS SEARCH SCREEN

TYPE IN THE WORD OR WORDS TO BE SEARCHED:

1:
2:
3:
4:
5:
6:
                          LAST SET CREATED

SET NUMBER: 0

NUMBER OF DOCUMENTS:                          HITS:
DATABASE:         FIELD:

MESSAGE:

PF1 HELP                    PF5 CLEAR SCREENS      PF10 VIEW
PF2 DB/FIELD SELECTION      PF6 BROWSE TERMS       PF11 REPORT DATE
PF3 QUIT                    PF9 PRINT/DOWNLOAD     PF12 FREE ALL SETS
PF4 HISTORY
```

Figure 2. PIRS Search Screen

```
            DATABASE SELECTION

DATABASES                    SELECTION
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
CHEMICAL PROPULSION INFORMATION AGENCY (CPIA)  ->46273 RECORDS
CPIA DATABASE =  1
DEPARTMENT OF DEFENSE EXPLOSIVE SAFETY BOARD   -> 1533 RECORDS
DDESB DATABASE =  2

OTHER (TBR) = 3

SELECT DATABASE NUMBER:
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
PRESS ENTER KEY AFTER THE DATABASE IS SELECTED.
IF NO NUMBER IS SELECTED, PIRS WILL DEFAULT TO ALL DATABASES.

            PF1 SYSTEM HELP
```

Figure 3. Database Selection Screen

A user may also select individual fields for searching, if necessary, to limit the search results. The *Field Selection* screen (Figure 4) is used for this purpose.

```
                    CPIA TEXT FIELD SELECTION SCREEN

FIELDS             SELECTION   FIELDS                            SELECTION
---------------------------------------------------------------------------
TITLE              01          CORPORATE SOURCE                  09
AUTHORS            02          DESCRIPTIVE NOTE                  10
COMMENT            03          SUPPLEMENTARY NOTE                11
CONTRACT           04          DTIC ACCESSION NUMBER             12
ABSTRACT           05          DECLASSIFICATION AUDIT TRAIL      13
FILE NUMBER        06          DECLASSIFICATION EVENT/DATE       14
INDEX TERMS        07          DISTRIBUTION/AVAILABILITY         15
REPORT NUMBER      08          TITLE, ABSTRACT, & TERMS          16
---------------------------------------------------------------------------
SELECT FIELD NUMBER:
CHOOSE THE FIELD YOU WISH TO WORK WITH BY
ENTERING THE FIELD NUMBER AFTER THE COLON (:)
PRESS ENTER WHEN FINISHED (DEFAULT IS ALL FIELDS)

                    PF1 SYSTEM HELP
```

Figure 4. PIRS Field Selection Screen

<u>Printing</u>

Printed results can be obtained by using the *Print* screen (Figure 5). This screen allows the user to select one of three modes of output:

1) Print results offsite at JHU-APL in Laurel, Maryland; the printout will be mailed to the user.
2) Print locally, on PC printer attached to the user's computer; and
3) Download the results from the mainframe to a PC file.

```
PLEASE MAKE A SELECTION FROM BELOW ===> 1

    1  PRINT AT APL AND MAIL OUT (DEFAULT)
    2  PRINT LOCALLY AT PC
    3  DOWNLOAD TO PC FILE

F3 TO EXIT
```

Figure 5. Print options

<u>Viewing</u>

The *View* screen (Figure 6) allows the user to review the results of the search. Records are displayed with the most recent records appearing first. The user may view as many as 25 records. The search results are presented in the form of title block citations, including the report bibliographic data and abstract. The results may be viewed on screen during the search session.

```
COMMAND ===>              CPIA VIEW SCREEN          PRESS PF1 FOR HELP
**************************** TOP OF DATA ****************************
+*- - - - - - - - - - - - - - - - - - - - - - - - - - - - Item 1 of 16
90- 10099            No. Unknown

ARMY ENGINEER DIV HUNTSVILLE AL

EXPLOSIVE SAFETY SITING OF CORPS OF ENGINEERS STANDARD IGLOO DESIGNS.
Meeting Paper

Williams, E.            , et al.
PUB DATE: AUG.,1990, PAGES:15P
Contract(s):
Availability: NTIS/DTIC - Approved for public release; distribution is
unlimited.
This paper was presented at the Twenty-Fourth Explosives Safety Seminar, held
at Adam's Mark Hotel, St. Louis, MO on 28-30 August, 1990, Vol. II, No.
Unknown (90-0062), P 1929-1943.

Siting and design requirements for Corps of Engineers standard igloo magazines according to DoD
6055.9-STD are discussed in this paper. These standard igloos include steel arch, semicircular steel
arch, and the concrete cubicle magazine. Requirements for a structureto qulify as a standard igloo
magazine include tests of primary structural elements: earth-covered arch, rear wall, head wall, and
blast doors. The igloo siting and design verification program, the Eskimo test series, are all described
in this paper, and evaluation procedures for nonconforming hybrid magazine designs are reviewed.
```

Figure 6. PIRS View Screen

Search Term Selection

Another feature of the system is the *Browse* screen (Figure 7). This screen allows the user to enter the stem of a term of interest. PIRS will display words in the database that start with the stem, along with the number of occurances (hits) in the database. The user can select from this list up to eight words to create a search inquiry with "or" operators.

System Applications

DDESB

Seminar Papers Searches DDESB personnel can search the system to locate seminar papers in the same manner as CPIA searches. The DDESB accesses the PIRS through high-speed modem connection, and downloads are accomplished through the *Print* screen as described above. Development of a personal computer-based version of the DDESB text-based management system is anticipated for 1993.

Seminar Papers Abstracts A part of the project, CPIA used the system to produce a printed version of the DDESB Seminar Papers Abstracts. The loose-leaf volume was initally distributed to selected recipients identified by the DDESB. Subsequently, a bound version (CPIA Publication 577) was published and made available for purchase (from either CPIA or NTIS). A typical page from the publication is shown in Figure 8.

```
                    BROWSE AN INDEX SCREEN

ENTER A WORD(S) OR STEM(S) TO SEARCH ON:
(MUST be TWO characters or more)







-------------------------------------------------------------
MESSAGE:  ENTER A STEM AND PRESS ENTER
-------------------------------------------------------------
PF1 HELP                        PF3 RETURN TO THE SEARCH SCREEN
```

Figure 7. PIRS Browse Screen

<u>CPIA</u> The CPIA uses PIRS to support many of its functions as a DoD Information Analysis Center. The PIRS provides primary support to the CPIA technical staff in locating references used in responding to technical inquiries, in preparing printed literature searches and published bibliographies, identifying specialists in a particular technical area, and in locating references for technical articles and reports.

<u>Technical Inquiries</u> The Technical/Bibliographic Inquiry (TBI) Service is used by CPIA users to obtain data and information tailored to their specific needs. Users are encouraged to take advantage of the professional staff's knowledge of technology accomplishments and trends through technical inquiries. Pertinent and specific data and information are provided, along with analysis, assistance, and referral service.

<u>Literature Searches</u> Literature searches are conducted by the technical staff to locate highly relevant citations on given technical subjects. The subjects may be quite broad or very specific, and are usually selected based on a staff member's awareness of particular relevance to the interests of a segment of the propulsion or explosives communities. Literature Searches are unclassified and contain "title block" bibliographic citations and abstracts of pertinent reports as well as subject, corporate source, and author indexes. The literature searches are published and distributed to CPIA subscribers.

<u>Printed Chemical Propulsion Abstracts</u> The <u>Chemical Propulsion Abstracts</u> (CPA) is an unclassified publication containing abstracts and bibliographic citations of reports on U.S. Government-sponsored programs in chemical and electric propulsion. The abstracts cover research, development, test, and evaluation (RDT&E) of propellants and propulsion units used in missile, rocket, space, launch, and gun systems. Loose-leaf interim issues are distributed throughout the year to provide current information. A bound volume is issued annually to include all the bibliographic citations and abstracts and cumulative indexes for the year.

76-10023 Not Listed

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION BAY ST LOUIS MS NATIONAL SPACE TECHNOLOGY LAB
EFFECT OF CONFINEMENT ON PYROTECHNIC REACTION RATES AND OUTPUT ENERGY.
Meeting Paper
McKown, G. L.; Sep 76, 6P
Availability: NTIS/DTIC - Approved for public release; distribution is unlimited.
Report classification: UNCLASSIFIED.
This paper was presented at the Seventeenth Explosives Safety Seminar, held at the Regency Inn, Denver, CO on 14-16 September 1976, Vol. I, AD A036 015, (76-10001), P 357-362.

This paper discusses experimental evidence that confinement afforded by enclosures or containers may have a dramatic effect on reaction rate and output energy of deflagrating pyrotechnic materials. Tests in apparatus that represent a closed structure, self-confinement, and a vented enclosure are described. Results obtained in the form of reaction rates from measurements of temperature, pressure, heat flux, reaction duration, and fireball size are given. As yet, no definite conclusions can be drawn based on the limited data obtained to date. Additional test programs are being conducted on various vented and unvented structures.

76-10024 Not Listed

ROYAL ORDNANCE FACTORY LANCASHIRE (ENGLAND)
TRENDS IN ELECTROSTATIC PRECAUTIONS IN FILLING FACTORIES.
Meeting Paper
Donegan, D. P.; Sep 76; 21P
Availability: NTIS/DTIC - Approved for public release; distribution is unlimited.
Report classification: UNCLASSIFIED.
This paper was presented at the Seventeenth Explosives Safety Seminar, held at the Regency Inn, Denver, CO on 14-16 September 1976, Vol. I, AD A036 015, (76-10001), P 363-383.

In this paper, the techniques used to reduce electrostatic charge generation in British explosives processing facilities are discussed. The electrostatic behavior of explosive powders is also reviewed as are the concepts of electrostatically safe and safe quantities of explosives. The practice of grounding is described along with the minimum safe levels of humidity at various temperatures for various explosives. Personnel safety and the use of safe, nonconducting tools and containers are also reviewed. The four appendixes to this paper provide more detailed information on these topics.

76-10025 Not Listed

ROYAL ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT ROYAL ARSENAL EAST WOOLWICH UK
THE ROLES OF DEFLAGRATION AND EXPLOSIVENESS IN HAZARD ASSESSMENT.
Meeting Paper
Hubbard, P. J.; Lee, P. R.; Sep 76; 24P
Availability: NTIS/DTIC - Approved for public release; distribution is unlimited.
Report classification: UNCLASSIFIED.
This paper was presented at the Seventeenth Explosives Safety Seminar, held at the Regency Inn, Denver, CO on 14-16 September 1976, Vol I, AD A036 015, (76-10001), P 385-408.

This paper presents a discussion of explosiveness and deflagration and studies conducted to investigate these properties for certain explosives. Burning tube experiments and studies to examine how confinement affects explosiveness and deflagration revealed the following conclusions: 1) the velocity of deflagration increases with increasing confinement; 2) explosiveness is a function of the whole explosive system; 3) explosives have different levels of explosiveness depending on confinement which can vary depending on the point of ignition of the explosive within a munition, and 4) the most useful ways of comparing explosives are examining the velocity of deflagration, fragment patterns, and the ease of extinguishment on removal of the confinement.

76-10026 Not Listed

NAVAL WEAPONS CENTER CHINA LAKE CA
GUIDELINES FOR EVALUATING CONDUCTIVE FLOOR COATINGS.
Meeting Paper
Pritchard, G. C.; Sep 76; 13P
Availability: NTIS/DTIC - Approved for public release; distribution is unlimited.
Report classification: UNCLASSIFIED.
This paper was presented at the Seventeenth Explosives Safety Seminar, held at the Regency Inn, Denver, CO on 14-16 September 1976, Vol. I, AD A036 015, (76-10001), P 409-421.

The purpose, installation, and maintenance of conductive floor coatings are discussed in this paper. These coatings are often used when insufficient time or money prohibit the installation of a conductive floor. The criteria used for selecting a coating are listed as are the factors that can affect the resistance of the coating (e.g., frequency/method of cleaning, humidity, floor preparation). Also emphasized was the need to be aware of the compatibility of the coating with any hazardous materials involved. Two tests for this compatibility are described.

76-10027 Not Listed

PICATINNY ARSENAL DOVER NJ
SAFETY HIGHLIGHTS OF THE FIFTH QUADRIPARTITE AMMUNITION CONFERENCE.
Meeting Paper
Saffian, L. W.; Sep 76; 4P
Availability: NTIS/DTIC - Approved for public release; distribution is unlimited.
Report classification: UNCLASSIFIED.
This paper was presented at the Seventeenth Explosives Safety Seminar, held at the Regency Inn, Denver, CO on 14-16 September 1976, Vol. I, AD A036 015, (76-10001), P 423-426.

This paper provides a brief review of the Fifth Quadripartite Ammunition Conference held in Australia in October 1975. Various aspects of munitions manufacturing safety and technology were discussed at the meeting. Nine papers that were presented at the meeting are reviewed. The topics of these papers include designing safety into munitions, hazards analysis studies of a Navy bomb plant, electrostatic sensitivity test methods, nonconducting containers, and blast-resistant structures.

76-10028 Not Listed

MASON AND HANGER-SILAS MASON CO INC MIDDLETOWN IA
ELIMINATION OF BASE SEPARATION IN CAST LOADED PROJECTILES.
Meeting Paper
Place, E. A.; Sep 76; 41P
Availability: NTIS/DTIC - Approved for public release; distribution is unlimited.
Report classification: UNCLASSIFIED.
This paper was presented at the Seventeenth Explosives Safety Seminar, held at the Regency Inn, Denver, CO on 14-16 September 1976, Vol. I, AD A036 015, (76-10001), P 427-467.

This report describes techniques developed to prevent base separation in the manufacture of projectiles. The separation occurs between the explosive cast and the steel shell casing when the explosive contracts as its cools after pouring. Base separation is believed to contribute to pre-

Figure 8. A typical page from CPIA Publication 577

Project Status/Progress Report

System Development: In the fall of 1990, after transferring all old-system data to the new system, CPIA began operational use of the system. Prepared DDESB data were uploaded from 1989 through November of 1991. The PIRS has been used to provide on-line access to the document assets of both CPIA and DDESB since then. The system was used to print the bound volume of the DDESB Seminar Papers Abstracts in December, 1991. The volume, published as CPIA Publication 577, contains 1,533 citations. In 1992, CPIA began a trial period of access to the system by several Government sites.

Status: The 1,533 individual records created for the DDESB Seminar presentations are currently resident on the automated retrieval system. In addition, about 45,000 document citations from the CPIA library are retrievable on the CPIA PIRS (the CPIA maintains a collection of over 75,000 technical documents in the field of chemical propulsion and related technologies). The PIRS is operational and has proven to be a reliable, powerful, and usable search tool. New citations are being added routinely, and CPIA is using the system as stated in the project goals. The CPIA has used the system to prepare publication-ready literature searches and other documents including the Chemical Propulsion Abstracts and the DDESB Seminar Papers Abstracts. No other document collections are currently being processed into the system.

Both the CPIA and the DDESB have access to the system through standard telephone lines and 9600 bits/second modems. A number of Government organizations which block-fund CPIA have been given access to the PIRS on a trial basis. The facilities accessing the PIRS during the trial period are as follows:

- Army Missile Command, Redstone Arsenal, Alabama
- NASA Marshall Space Flight Center, Marshall Space Flight Center, Alabama
- Army Strategic Defense Command, Huntsville, Alabama
- Air Force Phillips Laboratory, Edwards AFB, California
- NASA Lewis Research Center, Cleveland, Ohio
- Naval Air Warfare Center - Weapons Division, China Lake, California
- Army Research Development and Engineering Center, Picatinny Arsenal, New Jersey
- Army Ballistic Research Laboratory, Aberdeen Proving Grounds, Maryland

During the trial access to the system by Government sites, some problems were encountered by remote users connecting through Internet. These problems have been, or are being, resolved. It is intended that all features of the system be available to all users.

A recognized standard communications software package needs to be identified that will make access more strightforward and integrate well with the search system. A commercially available package, Procomm Plus, is being considered for this purpose. The software is currently being evaluated.

Summary

The CPIA project to develop an on-line retrieval system for the DDESB Seminar Papers has been completed successfully. The resulting system is being used daily to access bibliographic records of both the DDESB and CPIA. Other Government organizations are currently establishing connections to the system and are being trained in its use.

THE EFFECTS OF ULTRAHIGH-PRESSURE WATERJET IMPACT ON HIGH EXPLOSIVES

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ABSTRACT

Alliant Techsystems tested the effects of ultrahigh-pressure waterjet impact on both PETN and TNT explosives. The pressure of the test was approximately 1 GPa (150 ksi) since this pressure generates the maximum water velocity, is the pressure limit of available equipment, and is the pressure at which water freezes at 25°C (75°F). PETN and TNT were chosen as representative of the range of explosives used in the industry. PETN is the most sensitive common secondary explosive, while TNT is a low-sensitivity explosive that makes up more than two-thirds of the military explosives used. The results of the tests show that neither PETN nor TNT reacts when impacted by waterjets at these pressures.

August 1992

INTRODUCTION

Background

Alliant Techsystems, formally the Defense Systems Group of the Honeywell Corporation, has pursued the use of waterjets on explosive materials for several years. Two other papers in this Department of Defense Explosive Safety Board Seminar deal with specific areas of our waterjet cutting experience: The first paper summarizes the parameters used for waterjet cutting of high-explosive ammunition, and the second paper summarizes the safety testing of waterjets on high explosives.

Definition of the Problem

This paper addresses the upper pressure limit of waterjet impact on high-explosive materials. As part of our safety investigations we identified several mechanisms for initiating explosives by waterjets. The most likely candidate for initiation of explosive materials was the effect of direct impact by high-velocity streams of fluid. To complete a credible safety analysis, our initial efforts were to identify other documentation in the field. Since waterjets are still an unconventional method of machining, however, there is a general lack of data on the effects of waterjets on explosives specifically. Some work does exist,[1] but at the relatively low pressure of 175 MPa (26 ksi) rather than at the 350 MPa (50 ksi) pressures that commercial waterjet equipment operates.

Approach

Because the most likely candidate for initiating the explosives was the effect of waterjet impact, we decided to use the highest possible pressure in a standard Bruceton test to establish the actual 50 percent fire point. The maximum pressure obtainable at a continuous flow was approximately 1 GPa (150 ksi). This pressure was finally agreed upon because it is the highest pressure currently available, it generates a water stream traveling at nearly the sonic limiting velocity of water—1475 m/s (4900 f/s)[2]—and it is the pressure water freezes at 25°C (75°F), a condition which creates an upper limit for any "worst case" runaway pump scenarios.

Once the pressure was chosen, the components were assembled to perform the test. A statistically large sample of 50 shots for each explosive was planned in order to prove the effects of waterjets on the explosives.

APPARATUS AND PROCEDURE

Test Setup

We investigated the three domestic vendors of high-pressure waterjets and identified only one machine that was capable of producing the necessary pressure of 1 GPa (150 ksi) for greater than two seconds. Since this ultrahigh-pressure machine was not transportable, the testing was

[1]Summers, D., and Worsey, P., *The Use of High Pressure Water Jets to Wash Out Explosives*, Proc. 6th Int. Conf. on Erosion by Liquid and Solid Impact.
[2]Hendricks, R., et al., *WASP—A Flexible FORTRAN IV Computer Code for Calculating Water and Steam Properties*, NASA Technical Note D-7391, November 1973.

performed at the Ingersoll-Rand facility in Baxter Springs, Kansas. The ultrahigh-pressure waterjet machine was fortunately located in a test cell that had 30 cm (12 in.) thick concrete walls suitable for our explosive testing.

The ultrahigh-pressure waterjet pump was actually two pumps and a large, custom-made accumulator built for this test sequence. Although the ultrahigh-pressure system (Figure 1) was capable of achieving our required pressures, the unit normally operated at much lower levels. This situation caused concerns over how long the system would survive operating at the requested pressures. Piping for the system was specially manufactured, two-component, 1.3 mm (0.05 in.) bore tubing with a 19 mm (0.75 in.) outside diameter as shown in Figure 2. Fittings for the system were standard 25 mm (1 in.) high-pressure compression fittings.

No one was allowed in the test area during pressurization due to the high pressures the system utilized. At these pressures the liquid mixture becomes a compressible material and the tubing expands enough to store a significant amount of energy. A special mixture of propylene glycol and glycerin was used as the working fluid instead of water since water would freeze if the system temperature dropped below 25°C (75°F).

A special pressure transducer was obtained and custom fittings were fabricated to provide an accurate reading of the pressures going into the test chamber. Data from this pressure transducer was recorded on a Nicolet recording oscilloscope and also displayed on a peak-holding digital readout. These recorders supplemented the existing recording device used for the normal operation of the ultrahigh-pressure pump.

As an additional safety precaution inside the concrete walls of the test cell, we constructed an explosive test chamber (Figure 3) of 13 mm (0.5 in.) steel plate and proof-tested the chamber at 200 percent surcharge. No distortion or damage was done to the chamber by the proof tests. Inside the chamber was mounted a specially made, pneumatically controlled high-pressure valve manufactured by Harwood Engineering and rated for 1 GPa (150 ksi). The valve was placed close enough to the orifice to minimize the pressure drop from piping friction but still be protected behind a steel blast shield. Pressure drop across the valve was measured by Ingersoll-Rand technicians at 68 kPa (10 psi). The system used a 0.13 mm (0.005 in.) orifice (Figure 4) for all tests in order to maintain fluid pressure in the system. Due to the ultrahigh pressures involved, diamond orifices were used and replaced when worn or damaged.

The explosive samples were set into a custom holder (Figure 5) for the actual impact shot. This holder allowed the fluid to impact the explosive and capture the liquid for later analysis by our laboratories.

Test Procedure

To perform a statistically credible test, 50 explosive samples were tested of each explosive material. The materials selected for the test were Mil-Spec pressed PETN and cast TNT explosive samples. Our other waterjet safety tests had referenced each test sequence against a cast TNT standard. We also used the same TNT reference in this test to retain traceability. The PETN was chosen since it is considered the most impact-sensitive secondary high-explosive material and, if the TNT failed to initiate at the pressures that we were attempting, the PETN might still react within that pressure range.

The explosive materials were loaded individually into the test chamber and both the chamber and the test cell sealed. Once the area was cleared of personnel, the ultrahigh-pressure system started the pressurization sequence. Several minutes later the system finally reached the maximum achievable pressure and the data recorders were activated. Some variation occurred as the system gradually degraded due to the effects of the high pressure. When the system failed to achieve the target pressure, the test was aborted and the system was dumped into a safety tank. The source of the failure was identified, corrected, and the test sequence restarted.

Once the system was at its maximum pressure, the explosive technician authorized the shot and the high-pressure valve was actuated. The system pressure lasted only a few seconds before the pressure bled down below the test levels. The remaining liquid was then dumped to the safety sump. The explosives were visually analyzed immediately after the test shots and then packaged for return transportation to our laboratories. Photographs of the samples were taken and sent for advance examination by our laboratory scientists. All liquid retained in the test holder and residual explosive materials were packaged in prepared sample bottles and sent immediately back to the laboratory for analysis. In addition to the explosive samples, virgin liquid and untouched explosive samples were also taken as control samples for laboratory comparison.

RESULTS

We successfully tested 50 of 51 samples of PETN and 51 of 53 samples of TNT at the maximum pressure of the machine. No reaction, identified either visually or by chemical analysis, occurred as a result of the action of ultrahigh-pressure fluid impact on either PETN or TNT. The actual pressures measured at the valve, as shown in Figure 6, ranged from a minimum of 0.82 GPa (120.6 ksi) to a maximum of 1.02 GPa (149.9 ksi). The average test pressure for PETN was 0.97 GPa (142.6 ksi) and for TNT was 0.94 GPa (137.6 ksi).

Of the 50 PETN tests, only one "no-test" occurred due to a dislocated target; this test was *not* counted in the total. Two of the TNT tests were invalidated due to valve problems and these were deleted from the data. We had anticipated such a problem and quickly replaced the defective valve with a standby valve.

During the tests several diamond orifices failed due to plugging by ferrous particles. These particles may have been from either piping contamination or an incipient failure of some internal pump component. One of the plumbing connections failed during the test without major incident. As we tried to pressurize the system, we found that we could not maintain pressure. The system was "dumped" and the piping inspected. The failure was easily spotted and the tubing replaced. The tubing used was a special two-part, high-pressure tubing manufactured specifically for the pressures at which we were operating. The outer part of the tubing is swaged over an inner tube forcing the inner tube into compression. The failure, as shown in Figure 7, was caused by the swaged inner liner of the tubing being extruded by the operating pressure and pushing apart the connector.

CONCLUSION

The testing of both PETN and TNT at pressures of 1 GPa (150 ksi) was successful. It demonstrated that these explosives were safe to cut with a waterjet at these pressures with a single tailed safety interval of 96 percent at a statistical confidence interval of 95 percent. The safety of these tests confirm the impact model that we developed and are presented in the second paper of these proceedings.

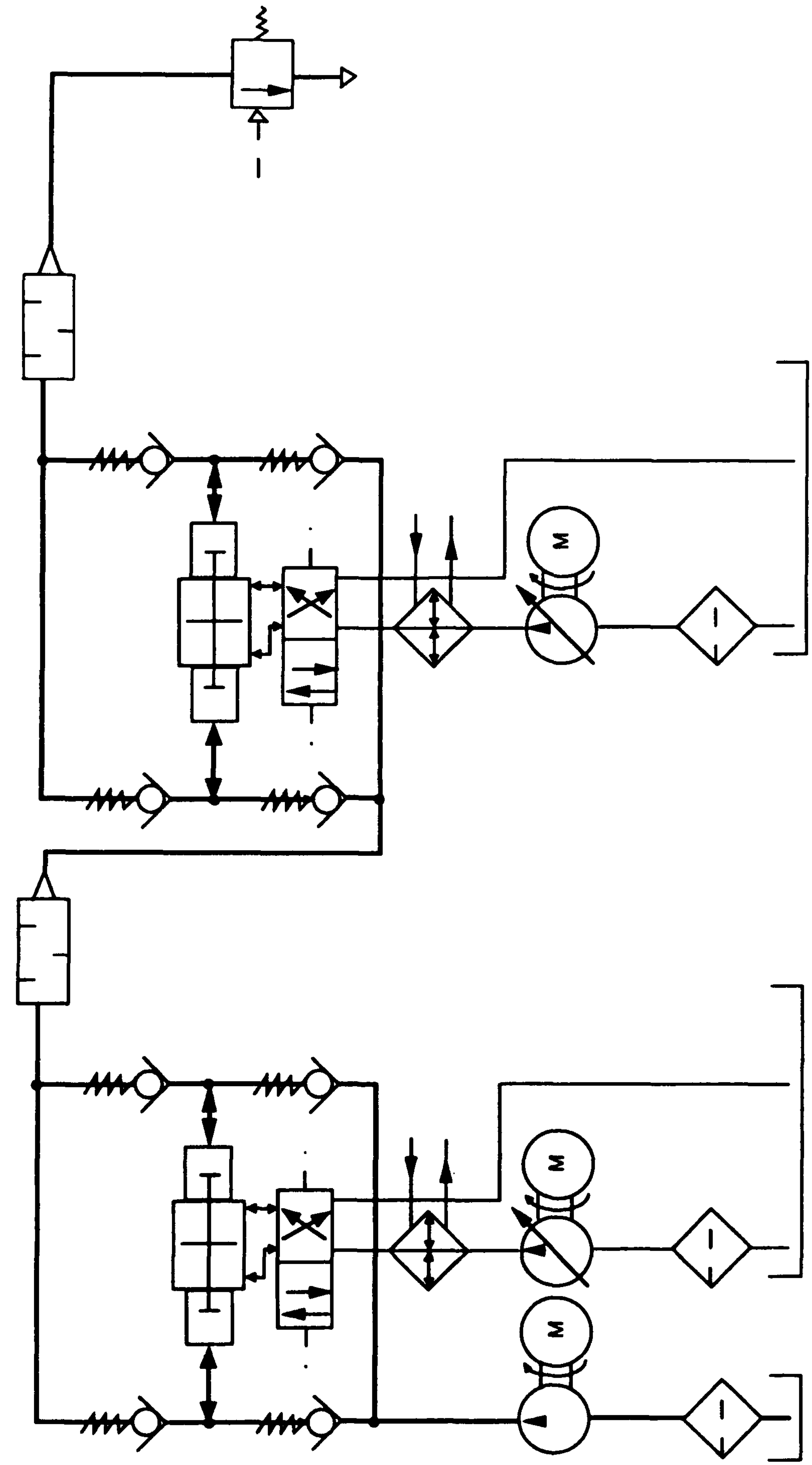

Figure 1. Ultrahigh-Pressure Waterjet Pump System Schematic

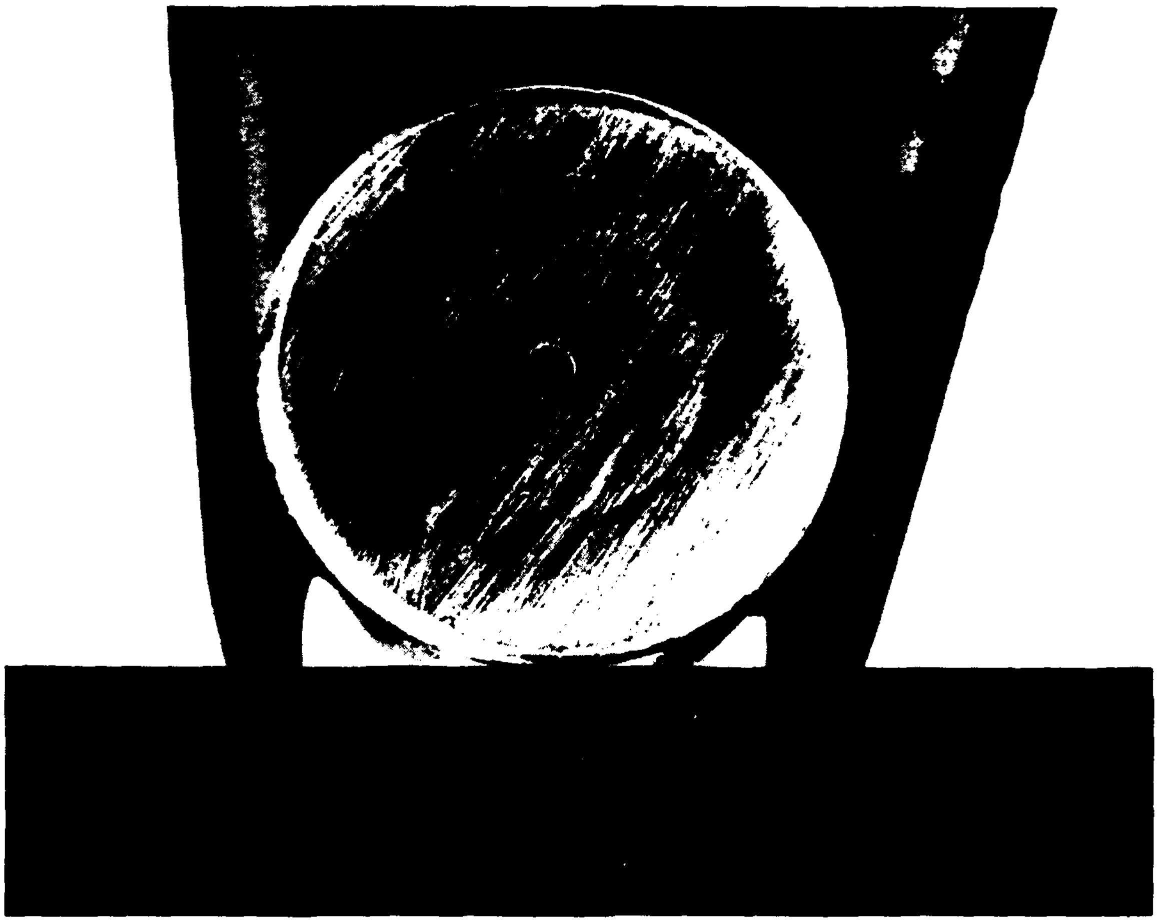

Figure 2. High Pressure Tubing

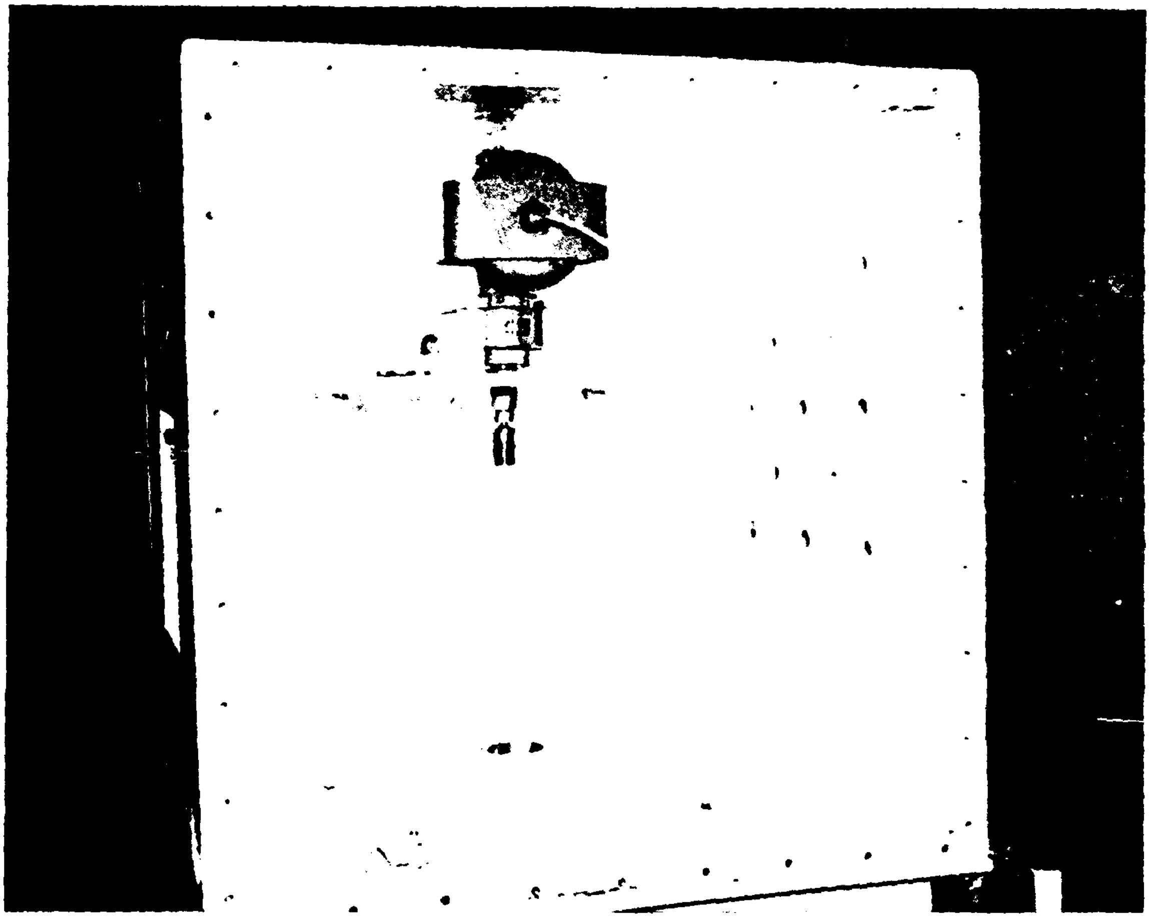

Figure 3. Explosive Test Chamber

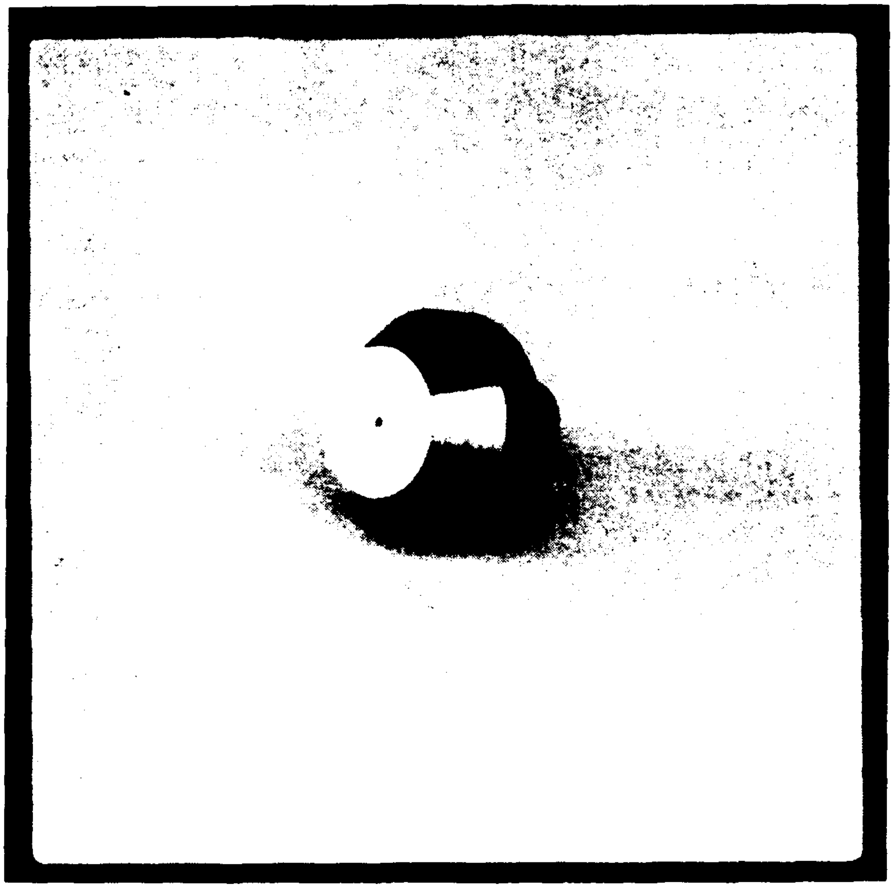

Figure 4. High Pressure Orifice

Figure 5. Explosive Sample Holder

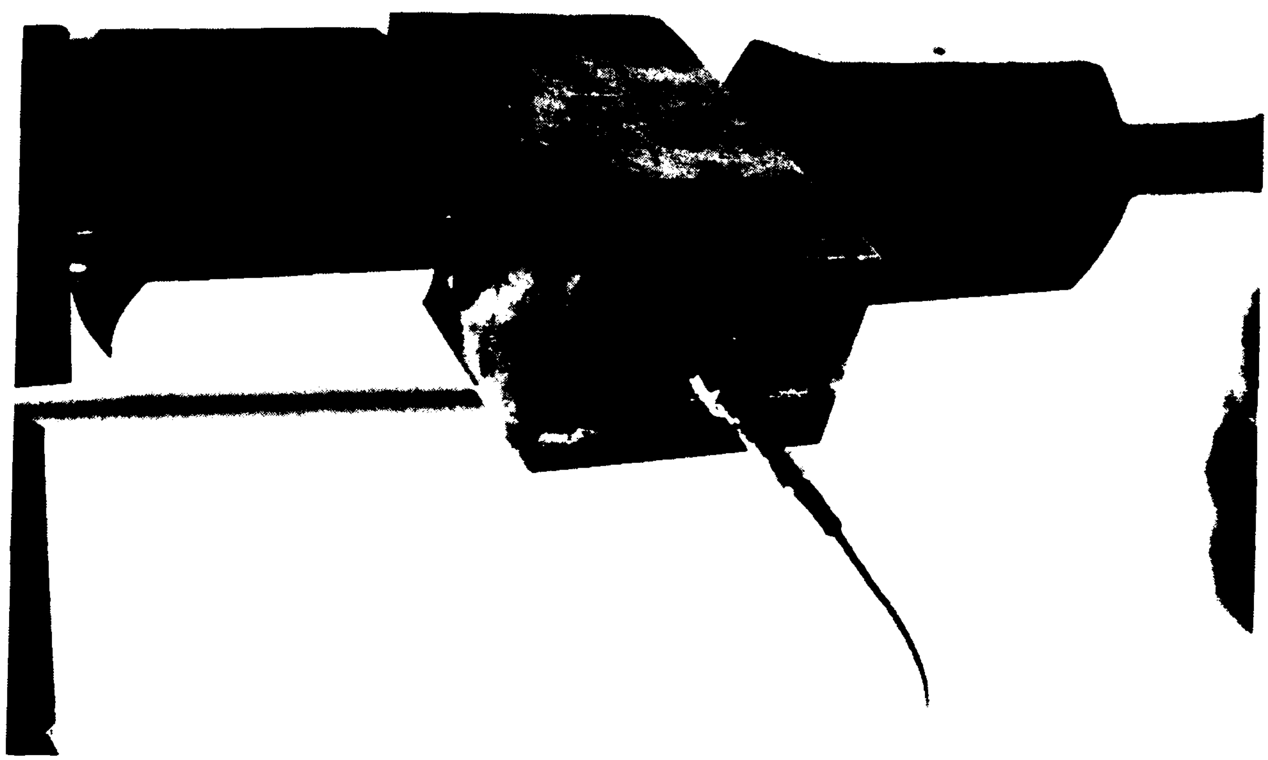

Figure 6. Ultrahigh-Pressure Transducer

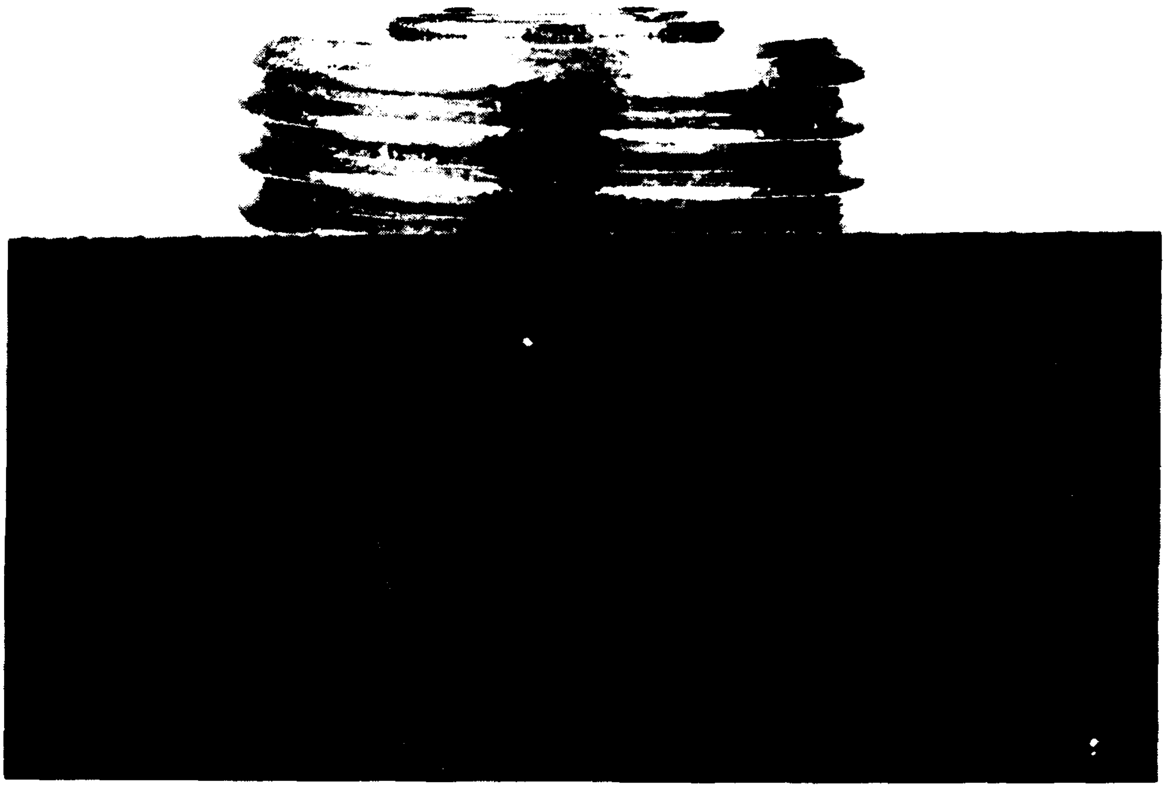

Figure 7. Tubing Failure

ADVANCED FIELD DATA ACQUISITION

TECHNIQUES FOR

CONTAMINATED SITE CHARACTERIZATION

Presented to:

25th DOD Explosive Safety Seminar
Anaheim, California

August 19, 1992

Prepared by:

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INTRODUCTION

The continual need to apply the latest technologies to enable better characterization of subsurface anomalies in conjunction with accurate mapping and locator techniques is typified by the introduction of the Ultra Sonic Range Acquisition Data System (USRADS).

The system is a complete computer based device that automates the measurement, data collection , and mapping of environmental survey data. USRADS automatically determines a surveyor's XY- position in the field using "time-of-flight" information and links this with the surveyor's instrument readings, via radio transmission, to a portable computer. USRADS analyses and presents "real time" data at the site. USRADS is interfaced with the latest field instruments for assessing and evaluating surface and subsurface anomalies, e.g. radiation, ordnance, trenches, pits, and hazardous waste surveys.

The original USRADS was developed by Oak Ridge National Laboratory (ORNL) as part of the Department of Energy's Uranium Mill Tailings Remedial Action Project. The system was developed to increase the speed and accuracy and simultaneously lower the expense of creating survey grids for geophysical surveys.

1.0 THE USRADS/UXO SYSTEM

The original USRADS system developed by ORNL uses a computer interface with a Geonics EM31 terrain conductivity meter. The USRADS operator carries a transducer in a backpack, which sends ultrasonic pulses to microphones deployed in the survey area. A microprocessor-controlled radio transmitter, also carried in the backpack, transmits terrain conductivity data to a mobile base station, where the operator's grid position, electromagnetic quadrature, and inphase readings are automatically recorded each second by a portable computer. The system was found to be accurate to 10cm up to a distance of 120 meters. After initial testing and development, a licensing agreement was signed with Chemrad Tennessee Corporation, located in Oak Ridge, Tennessee, to further develop the system for use in real-time environmental surveys.

Through agreements, EOD Technology teamed with Chemrad to through agreements to increase the instrument interfaces and application to sites contaminated with unexploded ordnance (UXO) and explosive wastes. The system has been successfully applied for characterization of such sites for the U.S. Army Corps of Engineers, Huntsville Division, and USTHAMA.

2.0 DESCRIPTION OF HARDWARE/SOFTWARE

Hardware

USRADS consists of a surveyor datapack, fifteen stationary receivers, a master receiver, custom computer interface and timing circuitry, and a portable computer. The datapack contains the interface circuitry to receive the signal from the field instrument, an ultrasonic transmitter, radio equipment, and on-board micro computer to establish bi-directional communications with the computer, and a handheld terminal for communications between the surveyor and the computer. The stationary receivers are used to determine the ultrasonic time-of-flight information from the surveyor datapack which allows the computer to calculate and plot the surveyors location each second. The master receiver provides for the radio telemetry links between the datapack and stationary receivers to the computer. The computer performs the positioning calculations, stores the location/detector data, displays the surveyor location with corresponding data in real-time, and performs in-field analysis of the USRADS survey data.

Software

The USRADS software includes routines for Setup, Survey and Analysis. Setup routines are included to check the equipment operation, to locate the stationary receivers, and to calibrate the system for ultrasonic accuracy. Setup also automatically draws the site map on the computer screen, scaling and orienting the map as required. Survey routines display the site map on the computer screen, collect, store, and plot the surveyor location and corresponding detector data once each second, in real-time. If the data for a particular location is greater than the operator specified threshold, then that location is highlighted on the computer display. In this manner, those areas exceeding the threshold criteria are determined as the survey progresses.

USRADS analyze routines are include to perform analysis if the USRADS data while in the filed immediately upon conclusion of the survey. Theses routines include numerous different types of graphical display formulas including Track Map Replay, Block Statistics, Contour and 3-D plots of the data. The Replay program generates the same display that the surveyor viewed when the survey of the property was completed, while varying the data threshold of interest. The Block Statistics routine enables the operator to select a grid block size and have the data statistically analyzed for each block (number measurements, measurement range, average and standard deviation). Utility routines are also included to convert the data tc formats compatible with the most popular software packages used for contouring routines, spreadsheets, databases, and Autocadd.

3.0 SYSTEM OPERATION

To operate USRADS, the user generally places four or more stationary receivers on the site around the area to be surveyed. Next, the location of the stationary receivers are precisely and automatically determined using the USRADS ultrasonics. Through the Setup computer routines, the computer automatically draws the survey site on screen with x,y axis oriented as specified by the user and at a scale to encompass the most distant stationary receivers. Then the surveyor, wearing the datapack (or vehicle mounted), covers the site at a constant rate in the desired pattern of survey coverage. The rest is automatic. The ultrasonic crystal pulses once each second as the data from the portable survey instrument is automatically transmitted to the computer via radio telemetry link. The corresponding ultrasonic time-of-flight information is used by the computer to determine the surveyors location. The computer plots the surveyor position on the CRT, with an indication of any locations that have detector readings which exceed a user specified threshold. During the survey, the surveyor controls the conduct of the survey through the use of the handheld terminal that is connected to the surveyor datapack. The handheld terminal reports the surveyor location or the current detector data, as desired. The surveyor can also suspend the survey, enter comments to the file, select the type of display, and terminate the survey from the handheld terminal.

3.1 USRADS Capabilities/Applications

USRADS automatically determines and maps environmental suspect locations and simultaneously logs related detector data, with comments, as desired, tied to the computer map files for subsequent review and presentation, and analysis. USRADS determines the surveyor position to ± six inches, once per second, displays the surveyors x, y, /coordinates on the handheld terminal, and allows the surveyor to enter comments to computer file from the handheld terminal. Optional configurations can log either 1, 3, or 6 channels of detector data once each second through analog, serial, or parallel interfaces to the datapack. USRADS provides automatic site map generation, real-time display of surveyor location, tracking of any corresponding detector data, and immediate availability of USRADS data for analysis in the field. USRADS can convert data to ASCII format and others, as required for use commercially available GIS/LIS analysis, data base, and presentation software.

3.2 USRADS/Radiation Surveys

Detects, measures, and maps radioactive contamination and radiation dose rates. Interfaces with most popular radiation detection devices (indoors/outdoors).

3.3 USRADS/EM31 Terrain Conductivity Surveys

Non intrusively measures and maps underground features and objects such as subterranean contours of land fill sites, locations of buried metallic objects, and location and extent of underground plumes of subsurface liquid flows up to eighteen (18) feet in depth.

3.4 USRADS/XMET 880 X-ray Florescence Surveys

Measures and maps elemental species of hazardous material pollution in surface soils such as lead, zinc, mercury, arsenic, etc. (Z number > 13).

3.5 USRADS/UXO MAGNETOMETER -

Schonstedt GA-52B and Schonstedt GA-72C/V non intrusively measure magnetic anomalies and variation accurately to a depth of five (5) feet, highly suitable for detection of unexploded ordnance and ordnance debris.

Other system options with USRADS can be readily used with up to an array of six (6) different sensor systems or a mix of sensor types depending upon the objective of the survey. Other measurement instruments such as gradiometers, vapor detectors,noise meters, and light meters can be easily interfaced with the system.

4.0 EMPLOYMENT OF USRADS/UNEXPLODED ORDNANCE SYSTEM (UX0)

The USRADS/UXO system has been deployed in the characterization of suspected Ordnance Explosive Waste (OEW) sites to determine the extent of the problem. The system has used conductivity and magnetometer instruments individually or in parallel to enable detailed analysis to be carried out.

In remediation activities it establishes an accurate cost effective "before" and "after" surface and subsurface multi-color mapped profile and has proven to be an excellent Quality Assurance/Quality Control tool. The system has adjustable threshold limits to eliminate background distinctions such as soilbearing, ferrous oxides, or small pieces of progmentation.

4.1 Typical USRADS/UXO Protocols Utilizing Portable System (2-man team)

SURVEY: A rapid initial assessment of a cleared area utilizing 5 foot sweep lanes. 3.0 acres per 8 hour day in good open flat terrain, 3.75 acres per 10 hour day, good open flat terrain.

CONFIDENCE LEVEL: Lowest because of the rapid pace of movement. This protocol will identify burial pits, burial trenches, and large ordnance items such as bombs, and large projectiles.

REMEDIATION: A slower assessment of a cleared area utilizing 5 foot sweep lanes. Two passes over the same area (cross hatch) are made. 1.5 acres per 8 hour day in good open terrain. 2.0 acres per 10 hour day in good open flat terrain.

CONFIDENCE LEVEL: Very good because of the cross hatch. This protocol will identify burial pits, burial trenches, large ordnance items such as bombs, large projectiles and smaller ordnance items such as mortars.

QC: The slowest assessment of a cleared area utilizing 5 foot sweep lanes. Three passes over the same area are made. 1.0 acres per 8 hour day in good open flat terrain. 1.25 acres per 10 hour day in good open flat terrain.

CONFIDENCE LEVEL: Highest because of the double cross hatch. This protocol will identify burial pits, burial trenches, large ordnance items such as bombs, large projectiles and smaller ordnance items such as mortars, grenades and shrapnel.

NOTE: TERRAIN MULTIPLIERS ARE USED TO FIGURE SWEEP RATES IN TERRAIN OTHER THEN THAT IDENTIFIED ABOVE.

4.2 Interpretation of Survey Results

A full data analysis of the results requires data input from historical data and knowledge of prior usage followed by closer study of specific anomalies to quantify and identify contamination type. A hazard risk analysis can also be included as part of the interpretation of the survey results.

The graphic presentation of the data consists of Track Maps, multilevel contours and a three dimensional plot with multilevel contours plotted above the three dimensional plots so that both the magnitude of the magnetic anomaly and the relative position of the anomaly in the X, Y plane can be viewed simultaneously. In addition to the graphic presentation of the data for each survey grid, the data for each area will be consolidated into a single image.
The USRADS/UXO system can be used to produce feature maps of each area during the survey.

The Feature Maps are used to document the location of landmarks or site characteristics contained within the survey areas that can aid in the interpretation of the data.

4.3 Track Maps

The color coded Track Maps document the surveyor's location and the relative magnitude (Table 1) of the signal from the survey instrument. Each dot or highlighted symbol indicates the location of a data point. The difference between the dot and a highlighted symbol is that the magnitude of the survey instrument exceeded the threshold listed at the bottom of each plot. The three-dimensional plots display the range and location of the detector signal over the entire survey area.

Signal Level	Color
0 - 299	Green
300 - 899	Blue
900 - 1199	Magenta
1200 - 1500	Yellow
1500 - Up	Red

Table 1. Track Map Color Key

4.4 Multilevel Contour and Three Dimensional Plots

Multilevel contours and the two/three-dimensional plots are provided for each of the survey grids. The multilevel contour provides a means to identify the location and relative intensity of magnetic anomalies without viewing every data point collected by the surveyor as shown by the Track Maps. The multilevel contours will be scaled to 40 feet = 1 inch or as the situation dictates and are compiled on a survey grid by survey grids basis. The two/three dimensional plots provide another means of viewing the data set for each survey grid by providing both a three-dimensional plot to illustrate the magnitude of the magnetic signal and by placing the multilevel contour above the three-dimensional plot helps identify their location in the X, Y plane.

The minimum contouring interval for the example site is selected to provide the best signal to noise ratio. For the example site the minimum contour value was selected to be 150. The contouring interval for the data set was set to be 100. The color for the different contouring levels are listed in Table 2.

Signal Level	Color
0 - 149	Black
150 - 299	Brown
300 - 449	Green
450 - 599	Blue
600 - 749	Yellow
750 - Up	Red

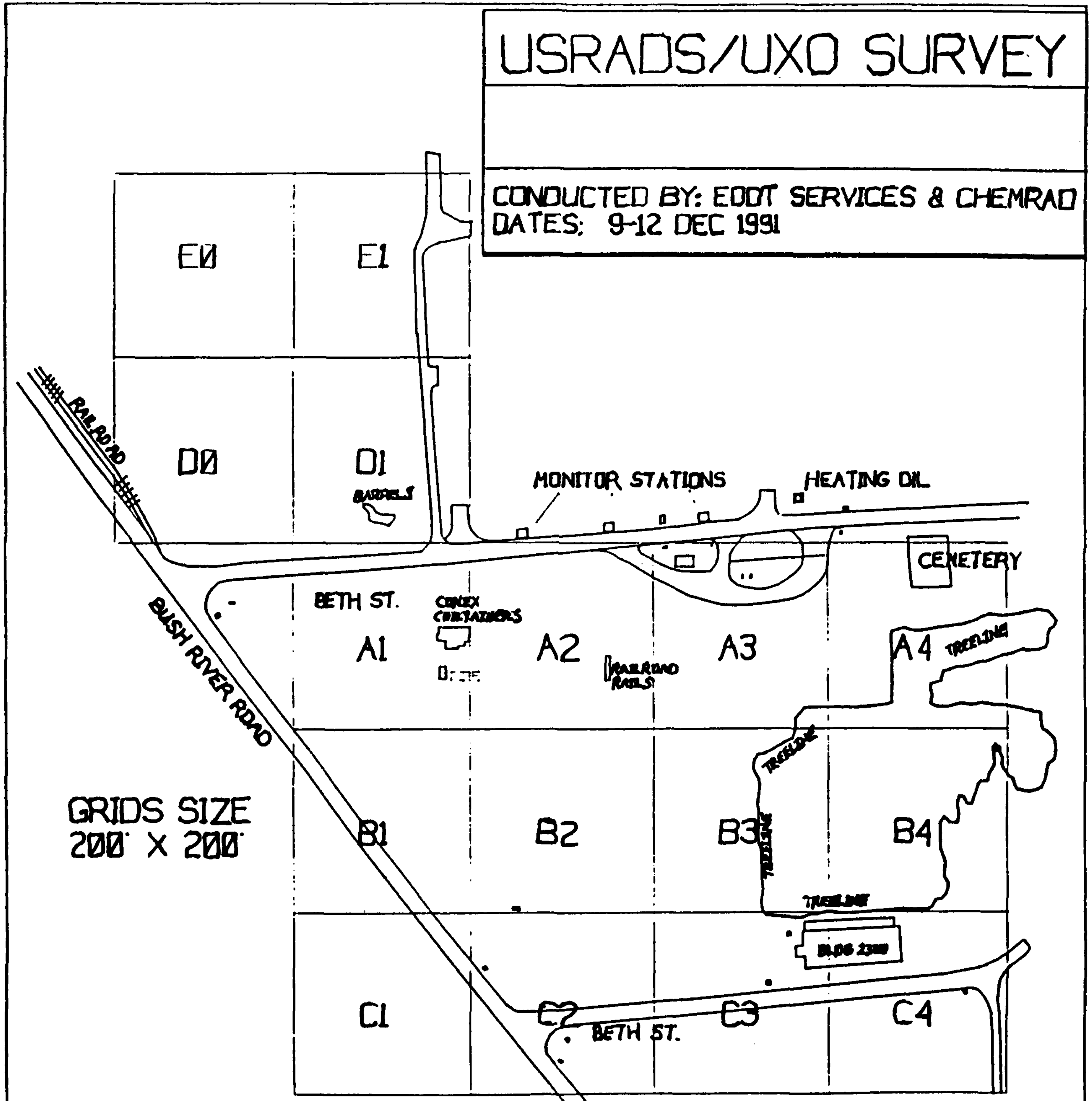
Table 2. Multilevel and 3D Color Key

4.5 Consolidated Plots

The survey data collected for the example site has been consolidated to provide an overall image for the site. The consolidated image for the site was divided into two separate images due to the shape of the site. The consolidated images are presented in both the multilevel contour format and a three-dimensional plot. The color keys for the consolidated images are the same as listed in Table 2.

4.6 Survey Key

The file names for each survey area and the survey date are contained in the example Survey Key. Also included in the Survey Key is the statistical summary for each of the survey files. The statistical summary consists of the number of data points, the minimum and maximum signal values, and the mean and standard deviation for each data set. The data offset information are the values that were added to the survey file X and Y values so that the resulting data files for a given area could be linked together to provide a comprehensive data set for the entire area. The reference column indicates the relative sensitivity of the detector by establishing common points within an area that are tested prior to each survey to document the local area background (low) and the signal generated by placing a PK nail in the area to verify the sensitivity setting between surveys in a given survey site.


USRADS/UXO SURVEY
CONDUCTED BY: EODT SERVICES & CHEMRAD
DATES: 9-12 DEC 1991
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E1
D0
D1
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RAILROAD
MONITOR STATIONS
HEATING OIL
CEMETERY
BETH ST.
CONEX CONTAINERS
A1
A2
A3
A4
RAILROAD RAILS
TREELINE
BUSH RIVER ROAD
GRIDS SIZE
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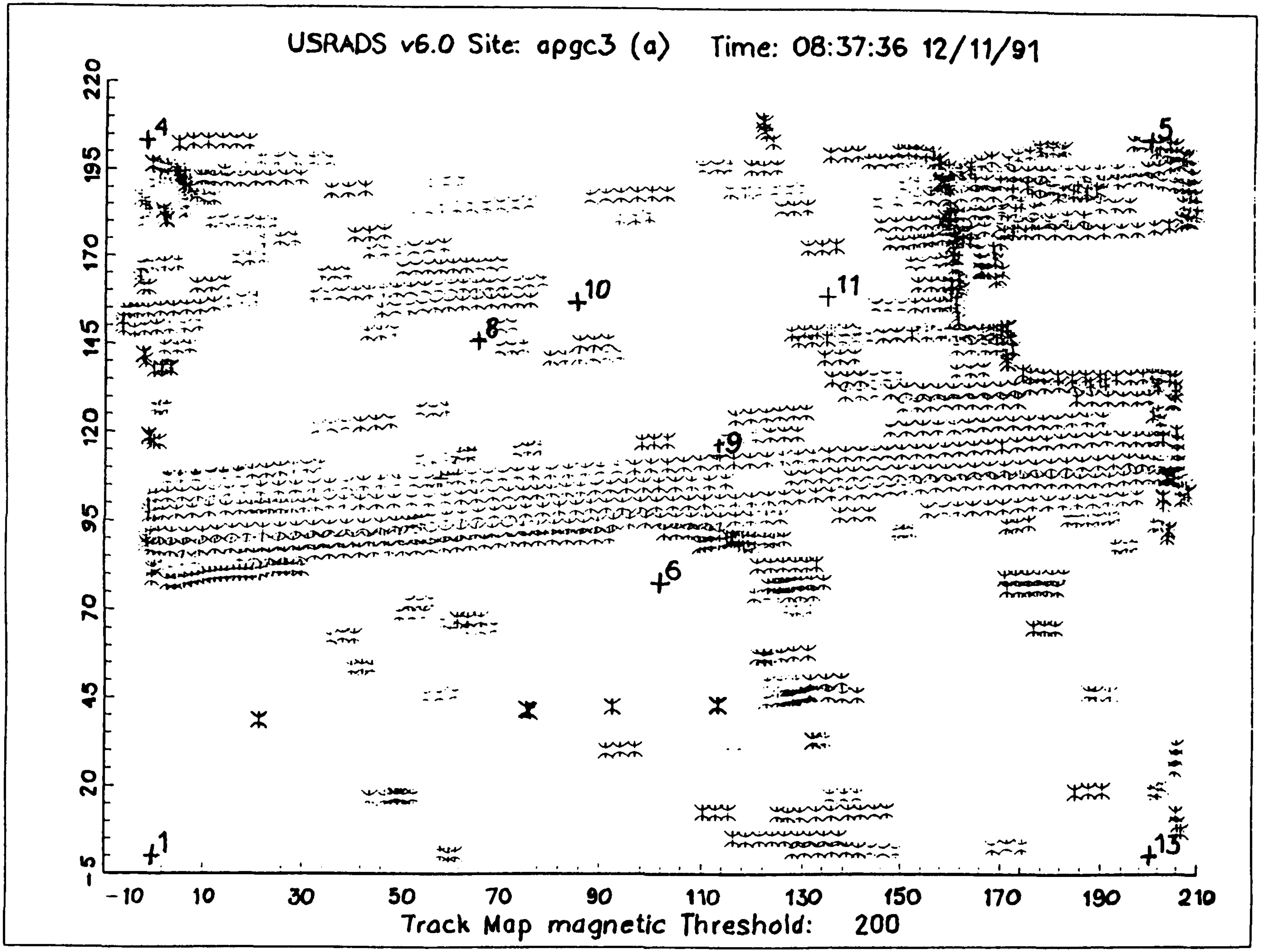
B2
B3
B4
BLDG 2300
C1
C2
C3
C4
BETH ST.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95
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-5
-10
10
30
50
70
90
110
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150
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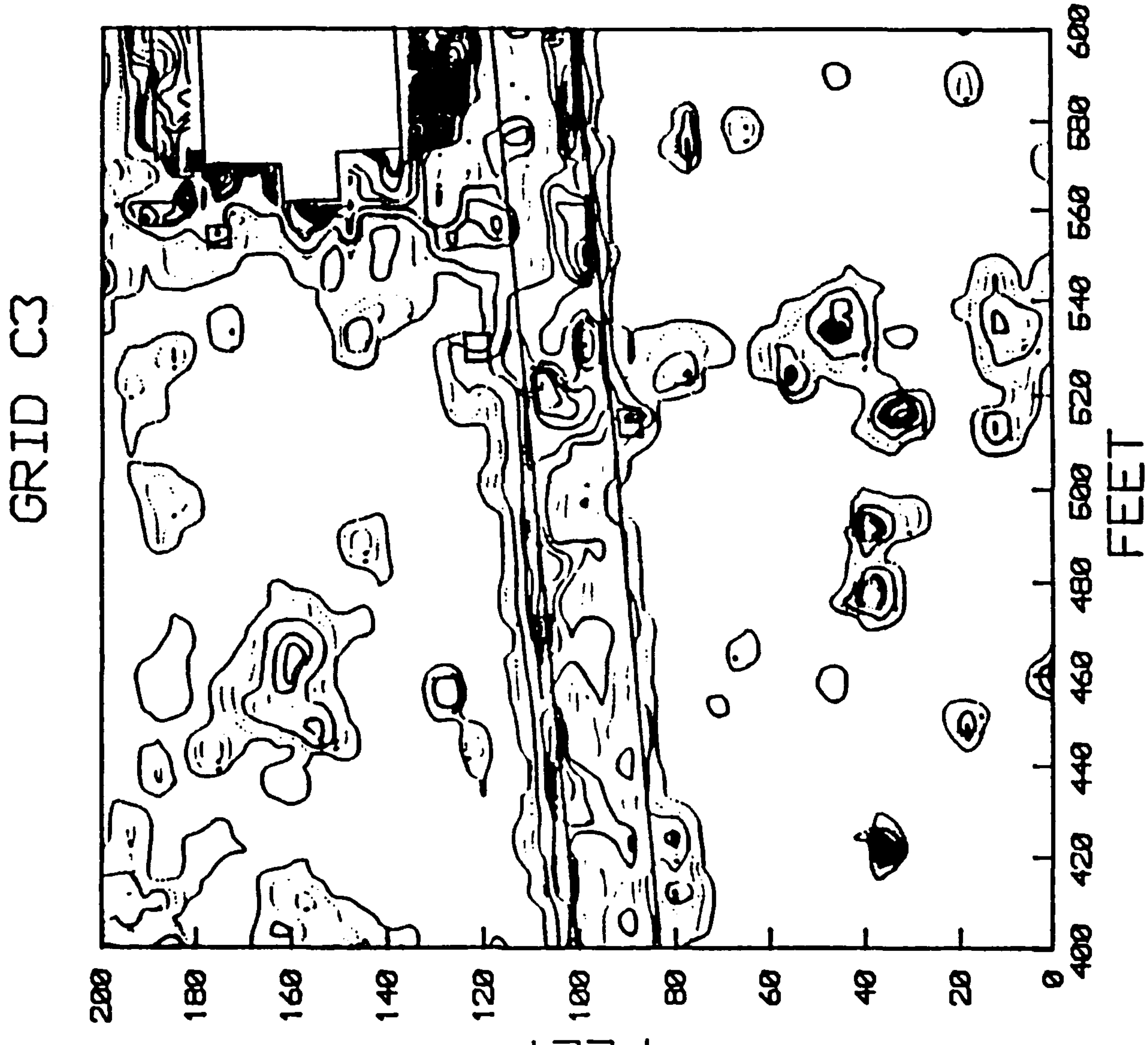
Track Map magnetic Threshold: 200
4
5
10
11
8
9
6
1
13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FEET
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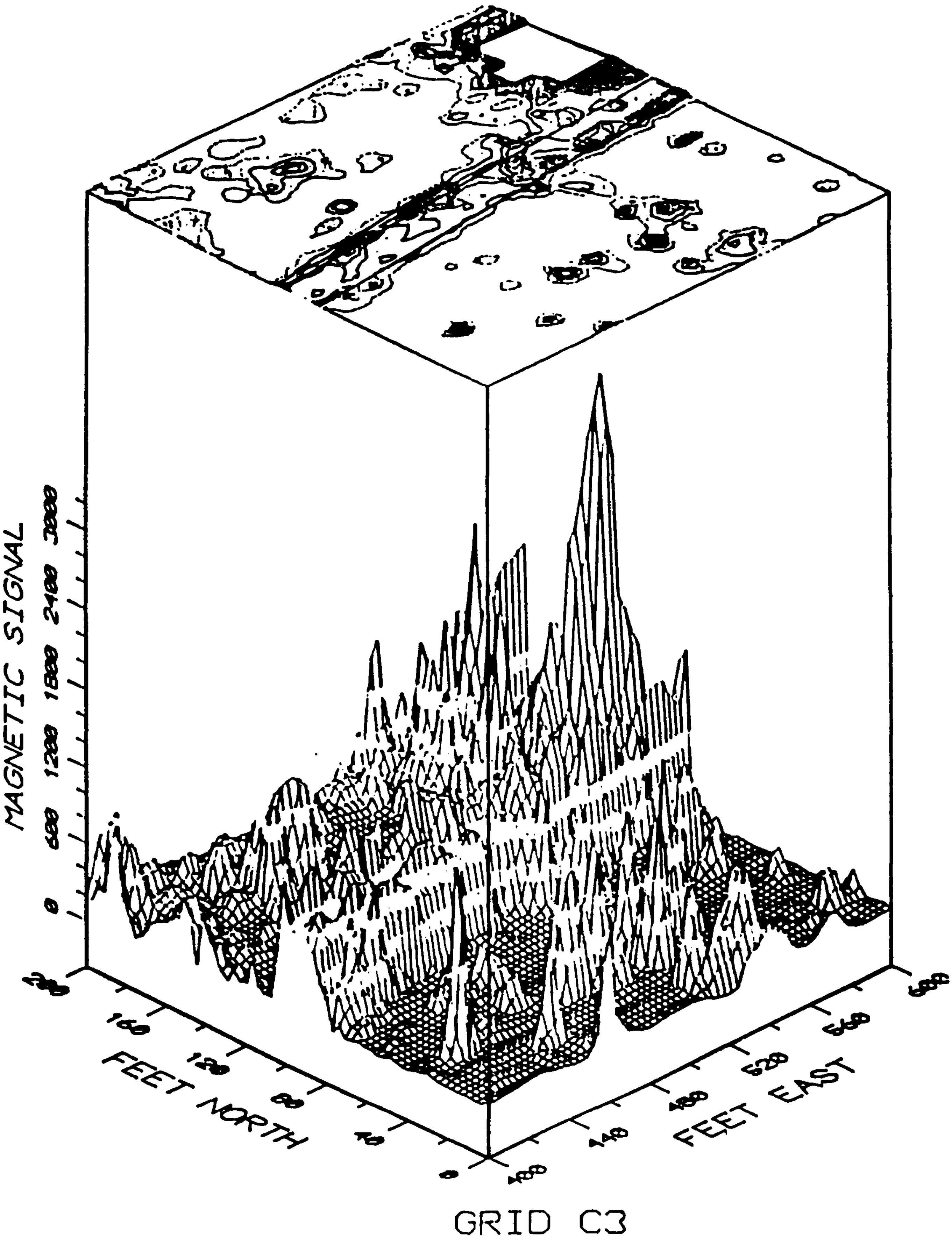

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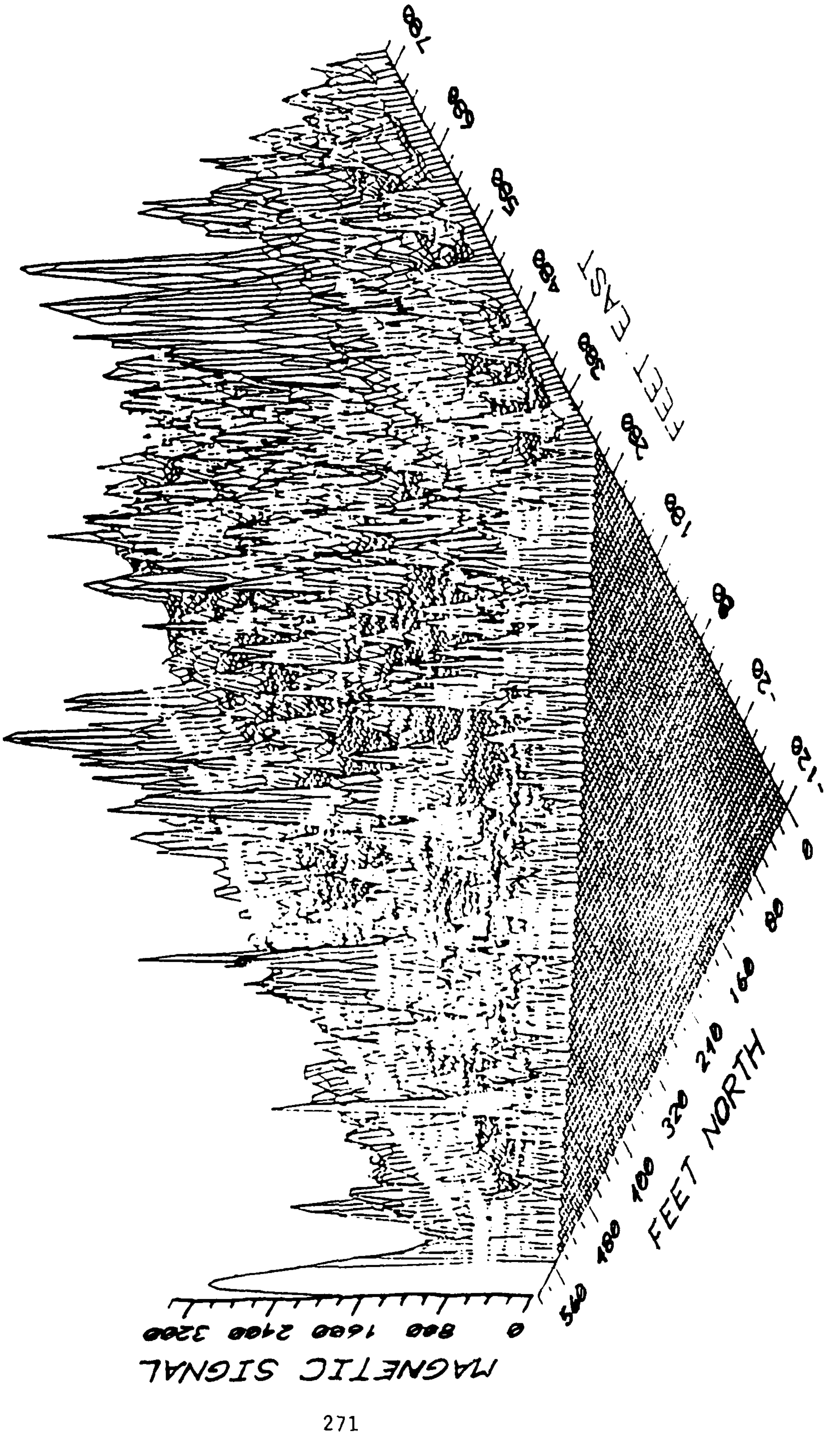

ROWS A, B, and C

5.0 CONCLUSION

USRADS offers geophysicists a number of advantages. The geophysicists in the field has the ability to monitor data as they are being collected and to refine or expand the survey coverage as required. For the interpreter the advantages include: increased spatial resolution; high data density - 3600 measurements an hour - immediately available on computer; and information on the precise location of cultural features (fences, roads, buildings, etc.) that might affect the interpretation. Theses advantages were evident in electromagnetic surveys where in two and a half hours (45 minutes survey time) including setup, take down, and some on-site analysis, 2700 quadrature and in-phase terrain conductivity measurements, were collected, and mapped.

The system operates over any terrain with good mobility, being either man portable, ATV mounted for large open areas, or robot mounted for extremely toxic environments. It offers cost advantage over current conventional methods, giving better cost control and lower cost risk.

The ability to consolidate site data through Autocadd generates a "before" and "after" action surface and subsurface profiles onto existing topographical/planimetric maps gives an accurate and permanent record and enables more detail analysis of data to be carried out, thus help to establish standards and effectiveness of remedial action. It is proven technology.

6.0 CURRENT EFFORTS AND FUTURE WORK

All field measurements involve positioning and data logging, so USRADS has many potential field applications. Currently, work is being completed for the Environmental Protection Agency to link USRADS with a portable X-ray fluorescence analyzer. USRADS offers the advantage of positioning data as well as the storing of the entire XRF spectrum for each measurement, not just the metal assays. With the whole spectrum it will be possible to reanalyze the data using different models for soil moisture, mineral content, etc. Anticipating future applications, we have made the hardware and software changes to the system as general as possible.

For initial surveys a multiple array of up to six (6) magnetometer sensors (Schonstedt GA-52B) giving a data point every foot and a rate of coverage of 10 to 15 acres per 8-hour day.

8.0 Acknowledgments

The author wishes to thank Mr. Michael Blair and Mr. Ben Redmond for their continued technical support in the development and application of the system and the sponsorship of the Department of Energy, in connection with Martin Marietta Energy Systems, Inc.

HIGH EXPLOSIVE DAMAGE ASSESSMENT MODEL ADVANCED INDUSTRIAL VERSION (HEXDAM-D+)

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ABSTRACT

HEXDAM-D+ represents the fourth industrial version of the High Explosive Damage Assessment Model. Like its predecessors this software has been designed to allow the rapid evaluation of damage experienced by each structure within a facility as a result of a primary explosion, and any accompanying secondary explosions. Its primary application is siting analysis of explosive storage and manufacturing facilities. The code can also be used to evaluate terrorism and sabotage threats to an industrial or military facility. The program has the capability to model an unlimited number of structures, and each with different dimensions and structural properties. The Parametric Analysis of Single Structures (PASS) capability allows the user to determine the influence of various important independent variables on damage to an individual structure within a facility. As with its predecessors, HEXDAM-D+ utilizes widely accepted dynamic pressure and overpressure curves to predict the pressure level at each structure location. Structure shielding based on an advanced shielding algorithm, and secondary explosion effects are calculated and damage levels are determined for each structure. HEXDAM-D+ produces output in the form of damage tables, before-damage and after-damage displays, pressure and damage contour plots, and damage-versus-distance graphs, all in color. Advanced graphical features include three-dimensional graphics in the form of oblique projections, as well as two-dimensional horizontal and vertical cross sections for overpressure, dynamic pressure, and damage contour plots. To ensure the software is usable by installation engineering, planning, and safety offices, the hardware requirements for HEXDAM-D+ have been kept at a modest level. An IBM PC-XT/AT/386/486, or compatible, with a color monitor, a dot matrix printer, and a color plotter (for hardcopy of screen graphics) are sufficient to execute HEXDAM-D+.

INTRODUCTION

The HEXDAM-D+ software represents the fourth industrial version (color added) of the High Explosive Damage Assessment Model (HEXDAM), developed by Engineering Analysis, Inc. (EAI). Like its predecessors this software has been designed to allow the rapid evaluation of damage experienced by each structure within a facility as a result of a primary explosion, and any accompanying secondary explosions. Its primary application is siting analysis of explosive storage and manufacturing facilities. The code can also be used to evaluate terrorism and sabotage threats to an industrial or military facility.

The program has the capability to model an unlimited number of structures, and each with different dimensions and structural properties. The Parametric Analysis of Single Structures (PASS) capability allows the user to determine the influence of various important independent variables on damage to an individual structure within a facility. As with its predecessors, HEXDAM-D+ utilizes widely accepted dynamic pressure and overpressure curves to predict the pressure level at each structure location. Structure shielding based on an advanced shielding algorithm, and secondary explosion effects are calculated and damage levels are determined for each structure. HEXDAM-D+ produces output in the form of damage tables, before-damage and after-damage displays, pressure and damage contour plots, and damage-versus-distance graphs, all in color. Advanced graphical features include three-dimensional graphics in the form of oblique projections, as well as two-dimensional horizontal and vertical cross sections for overpressure, dynamic pressure, and damage contour plots.

To ensure the software is usable by installation engineering, planning, and safety offices, the hardware requirements for HEXDAM-D+ have been kept at a modest level. An IBM PC-XT/AT/386/486, or compatible, with a color monitor, a dot matrix printer, and a color plotter (for hardcopy of screen graphics) are sufficient to execute HEXDAM-D+.

APPLICATIONS

HEXDAM-D+ can be used as a damage assessment tool to determine the amount of blast damage done to individual structures in a certain geographical area due to the detonation of explosives at ground-level or at a specified height above the ground. This type of information would be helpful in determining the potential for destruction of an industrial facility where significant amounts of explosives are manufactured, handled, and/or stored. Such information should also be useful in evaluating the risk represented by acts of terrorism or sabotage to any commercial building or industrial complex. Other information may be useful in determining whether structures subject to explosion (magazines, storage tanks, and fule stockpiles, etc.) received enough damage to explode, and if so, how much additional damage was done to other structures in the vicinity of the explosion.

CAPABILITIES AND LIMITATIONS

HEXDAM-D+ is a useful tool for making blast damage assessments resulting from an explosion on a localized area. Specific capabilities include:

1. Prediction of blast damages to 104 basic structures types, plus any user-defined structure types.
2. Compatibility with Vulnerability Assessment of Structurally Damaging Impulses and Pressures (VASDIP) software [1]*.
3. Prediction of blast damages to both overpressure-sensitive and dynamic pressure-sensitive structures.
4. Prediction of shielding** effects by each structure on surrounding structures based on advanced algorithm.
5. Prediction of blast damage resulting from secondary explosions triggered by the initial (primary) blast.
6. Capacity to model an unlimited number of individual structures within a facility.
7. Automatic or user-specified subdivision of structures.
8. Generation of pressure and damage contours (3-D oblique projections, 2-D horizontal and vertical cross sections).
9. Zoom feature for all graphical displays.
10. Parametric Analysis of Single Structure (PASS)

The 104 basic structure types are summarized in Table 1.

---

* Numbers in brackets refer to references cited.

** The user has the option to perform damage computations with and without shielding.

Table 1. Types of Structures Covered

1. Structural Elements (7 different types)
    a. Aluminum
    b. Asbestos
    c. Brick
    d. Concrete
    e. Glass
    f. Steel
    g. Wood
2. Composite Structures (97 different types)
    a. Bridges
    b. Buildings
        (1) Commercial/Administrative
        (2) Industrial
        (3) Residential
    c. Hangars
    d. Magazines
    e. Shelters
    f. Underground Structures
    g. Transportation Equipment
        (1) Aircraft
        (2) Railroad
        (3) Earth-moving
        (4) Naval Vessels
        (5) Vehicles
    h. Communications/Electrical Equipment
    i. Industrial Equipment
    j. Gas and Oil Storage Tanks
3. User-Defined Structures
    a. Compatible with VASDIP
    b. Unlimited Number of Choices

The HEXDAM-D+ model has certain limitations, primarily due to the amount of memory available. The following restrictions apply:

1. single primary explosion,
2. blast effects only are considered,
3. multiple reflections are not considered,
4. no terrain considerations,
5. no meteorological considerations, and
6. all structures must be on the ground.

Notice should be taken that HEXDAM-D+ has not been fully validated with all available blast data, nor has it been officially certified by any government agency. The pressure versus distance models are in general agreement with standard tables [2], and the pulse duration model compares favorably with available theory and data [3]. As shown in Figure 1, the shielding model agrees reasonably well with limited observations [4]. The secondary explosion model represents a technical concept for which insufficient data are currently available to permit rigorous validation. Because multiple shock reflections are not considered, HEXDAM-D+ cannot accurately predict damage caused by confined explosions occurring within strongly reinforced structures. For the reasons noted, good engineering judgment must be exercised in interpreting the results generated by HEXDAM-D+, especially when making critical decisions pertaining to personnel safety.

EQUIPMENT SPECIFICATIONS

The execution of HEXDAM-D+ requires the computer equipment and operating system listed in Table 2. All equipment listed is essential to the correct execution of the program.

TABLE 2. HEXDAM-D+ EQUIPMENT REQUIREMENTS

ITEM	DESCRIPTION
PROCESSING UNIT	IBM PC-XT/AT/386/486 OR COMPATIBLE
DISK DRIVE	1 HARD DISK DRIVE
PRINTER	(WITH GRAPHICS CAPABILITY)
MONITOR	MONOCHROME OR COLOR
PLOTTER	
GRAPHICS CARD	CGA, EGA, or VGA
OPERATING SYSTEM	DOS 3.2 OR LATER
RAM	MINIMUM OF 640 KILOBYTES

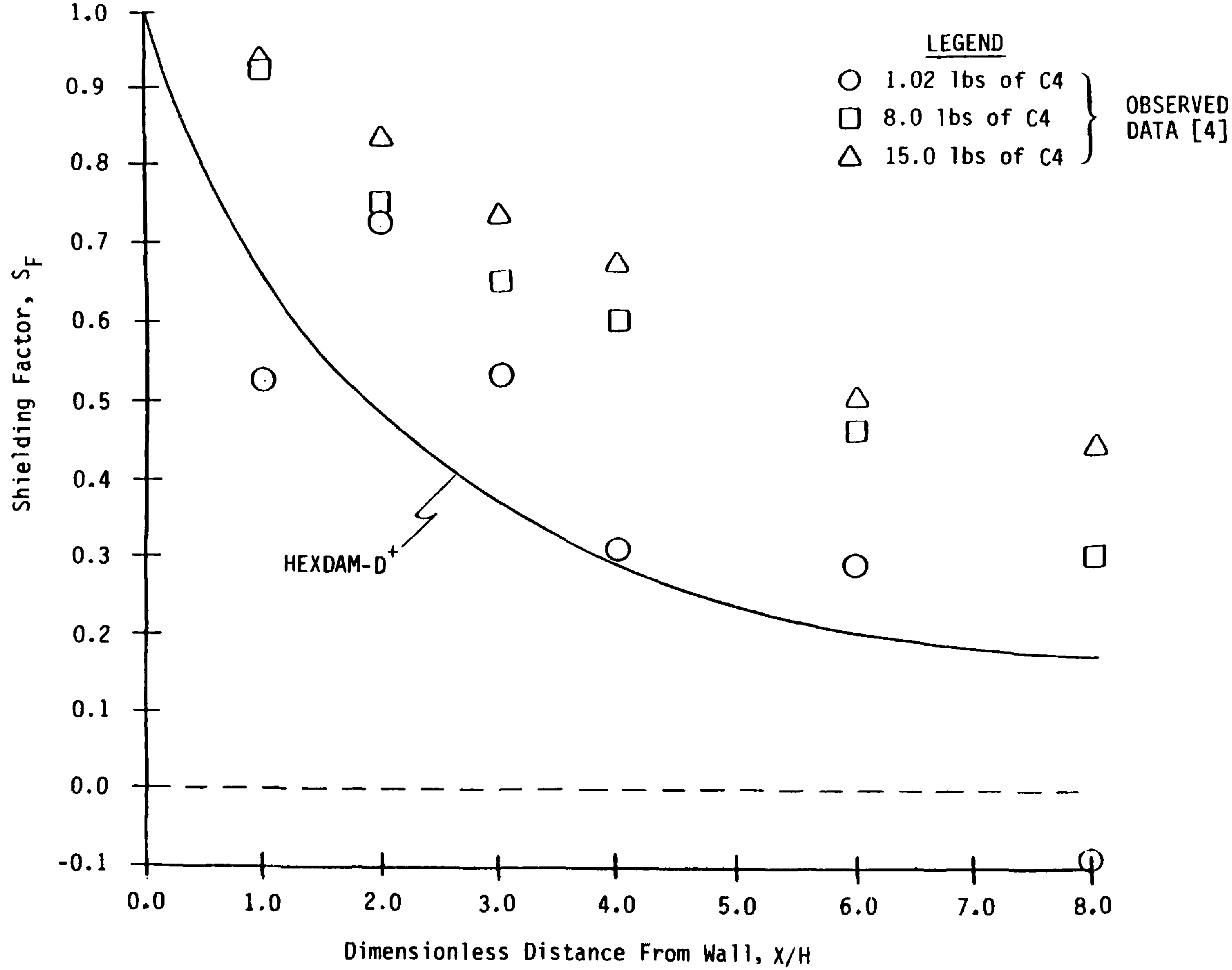


Figure 1. Shielding Factor Comparison

SOFTWARE COMPONENTS

HEXDAM-D+ software consists of three separate parts: a preprocessor (HEXDAM1), processor (HEXDAM2), and postprocessor (HEXDAM3). Each part executes independently from the others. All of the data necessary for HEXDAM-D+ are input in the preprocessor, which creates output files which are fed into the processor. Upon execution of the processor, output files are created which are fed into the postprocessor. The postprocessor generates the output data in forms of graphs, displays, contour plots, and tables.

MODES OF OPERATION

The software can be used in two modes as follows:

- o Scenario Analysis (SA)
- o Parametric Analysis of Single Structure (PASS)

In the Scenario Analysis mode, a primary explosion is specified within or about a facility consisting of one or more structures. Pressures received by each structure in the facility are calculated based on each structure's location relative to the primary explosion, as well as, any secondary explosion. The effects of structures shielding one another may also be taken into account. The damage occuring to each structure is then calculated based on the magnitude of the pressure it received and its ability to withstand the pressure. In addition to the calculations of pressures and damages occuring at the structures within the facility, the SA mode allows the user to overlay a grid (either 2-D or 3-D) over the facility and to calculate pressures which occur at these locations. In a similar manner, the SA mode allows the user to overlay a grid within specific structures in order to analyze the distribution of damage within the structures.

In addition to the Scenario Analysis capability, HEXDAM-D+ provides a second mode of operation, referred to as Parametric Analysis of Single Structure (PASS), which takes a somewhat different approach. For the PASS mode the parameters which constitute a description of the explosion (i.e., location and/or magnitude) are treated as independent variables, which are systematically varied. The pressures and damages which would occur at a single "structure-of-interest" are treated as dependent variables, which are calculated as functions of the independent variables. These calculations can be made independent of all other structures in the facility (referred to as a scenario-independent PASS), or can be made where the shielding of other structures and possible secondary explosions are taken into account (referred to as a scenario-dependent PASS).

The scenario-independent PASS involves varying the magnitude and/or location of an explosion relative to a structure-of-interest. The actual (absolute) locations of the structure and the explosion are never defined. This version of PASS is best used for answering questions such as:

> "How much damage does a given wall sustain from an explosion one foot off the ground and twenty feet away when the amount of explosive is varied from ten to one hundred pounds?"

> "What overpressures would a structure be subjected to if the location of a 100-pound explosion on the ground was varied from 10 to 100 feet away in 10-foot intervals?"

The scenario-dependent PASS mode is equivalent to performing many SA's except pressures and damages are only calculated for the structure-of-interest. This type of PASS involves varying the location and/or magnitude of an explosion within a scenario and analyzing the resulting pressures and damages predicted at the structure. Scenario-dependent PASS is useful for answering questions such as:

> "How much explosive can be safely stored in a storage area if the user wants to ensure that persons in a certain building are not harmed, if detonation somehow occurs in the storage area?"

> "Where are the most vulnerable locations outside the barriers surrounding a compound?"

> "How much damage will occur to a given building in a compound if an explosives-laden truck located at some location were to explode, where the amount of explosive in the truck is varied from 100 to 1000 pounds?"

INPUTS/OUTPUTS

The inputs and outputs to HEXDAM-D+ are dependent upon the mode of operation, Scenario Analysis, (SA), or Parametric Analysis of Single Structure (PASS).

Scenario Analysis Inputs/Outputs

The basic inputs to HEXDAM-D+ in the Scenario Analysis (SA) mode are designed to provide a description of a primary explosion and one or more structures located in the vicinity as follows:

1. Primary explosion
   a. location (including height)
   b. yield
2. Individual structures
   a. location
   b. dimensions (length, width, height)
   c. orientation
   d. structure type
      (1) 104 basic types
      (2) user-defined types
   e. explosion threshold for secondary explosions
   f. yield for secondary explosions

The basic SA outputs of HEXDAM-D+ are designed to provide descriptions (both tabular and graphical) of the structure(s), which have been exposed to the primary explosion. Such outputs include the following:

1. Before-Damage Display - Provides 3-D oblique projection in color of all structures being modeled.

2. Damage Table - For each structure provides pressure level and damage assessment.

3. After-Damage Display - Provides same 3-D oblique projection in color as Before-Damage but also indicates damage level to each structure.

4. Damage vs Distance Graph - Provides color-coded plot of damage levels to all structures versus distance from primary explosion.

5. Pressure Contours - Provides 3-D oblique projections and 2-D horizontal and vertical cross sections in color of overpressure and dynamic pressure contours.

6. Damage Contours - Provides 3-D oblique projections and 2-D horizontal and vertical cross sections in color of contour plots of damage levels to any structure.

7. Data Tables - Provides tabulation of overpressure, dynamic pressure, and/or damage level for each grid point used in contour plots.

PASS Inputs/Outputs

For a scenario-independent PASS, the basic inputs are as follows:

1. Primary explosion*
   a. ground distance from structure-of-interest
   b. height of burst
   c. slant range to structure-of-interest
   d. yield
2. Structure-of-Interest Type
   a. 104 basic types
   b. user-defined types

For a scenario-dependent PASS, the basic inputs are similar to those for a Scenario Analysis, except the structure-of-interest must also be identified. These inputs are as follows:

1. Primary explosion*
   a. X-coordinate of detonation
   b. Y-coordinate of detonation
   c. height of burst
   d. yield
2. Individual Structures
   a. location
   b. dimensions (length, width, height)
   c. orientation
   d. structure type
      (1) 104 basic types
      (2) user-defined types
   e. explosion threshold for secondary explosions
   f. yield for secondary explosions

---

* The user may vary up to three of the parameters defining the explosion. HEXDAM-D+ ensures that the combination of parameters varied is not illogical.

Regardless of the type of PASS, the user can generate up to four different plot types in the HEXDAM-D+ postprocessor. These four plot types are:

1. conventional 2-D plot - dependent variable plotted versus one independent variable

2. conventional 3-D plot - dependent variable plotted versus two independent variables

3. 2-D contour plot - dependent variable contours plotted on grid of two independent variables

4. 3-D contour plot - dependent variable iso-surfaces plotted onto grid of three independent variables

SOFTWARE PERFORMANCE

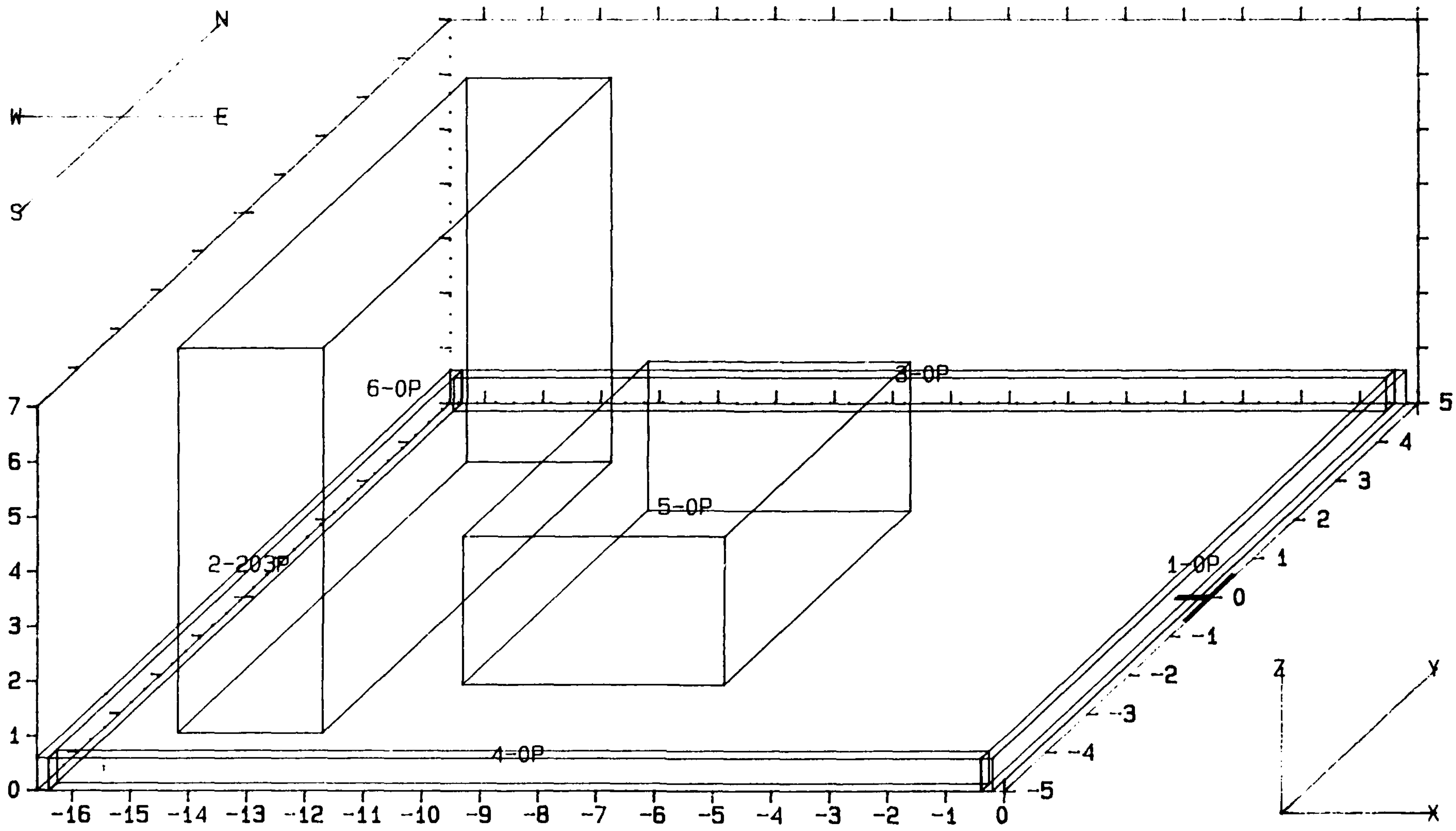
The preprocessor (HEXDAM1) calculates parameters needed by the processor (HEXDAM2), and provides before-damage graphics displays, to permit the user to verify the explosion scenario being modeled. Most of the interface between the HEXDAM-D+ software and the user is associated with the inputs required by the preprocessor. Examples of the Before-Damage Display generated by the preprocessor are presented in Figure 2 (without subdivision) and Figure 3 (with subdivision).

The HEXDAM-D+ processor (HEXDAM2) reads data files containing data preprocessed by HEXDAM1, processes the data, and writes to data files to be used by the postprocessor (HEXDAM3). Data processing by HEXDAM2 includes computation of

- overpressure and dynamic pressure,
- shielding effects,
- secondary explosions, and
- damage levels.

The only interface between the processor and the user involves the initiation of the program.

The HEXDAM-D+ postprocessor (HEXDAM3) is designed to read the data output by the processor and present the data in the form of tables and graphical displays of overpressure, dynamic pressure, and damage. The interface between the program and the user is limited to program initiation and selection of output options.

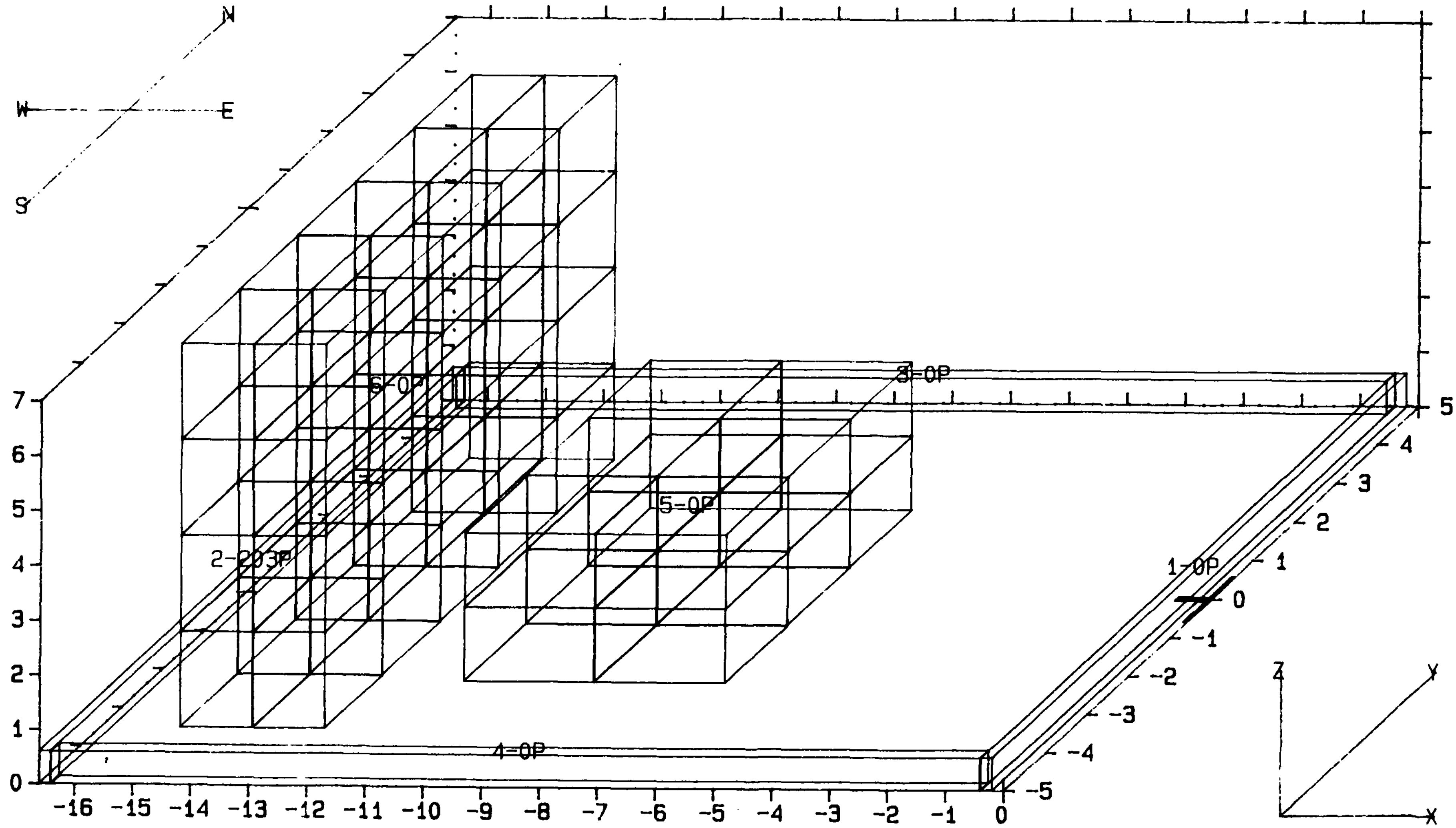


(Distances in 10's of ft)

3D Oblique Projection Before Damage (Relative to Burst)

flyer2.dat 08/13/92 15:58 Yld=1000 Lbs HoB=0.00 Ft Ah=None Av=None

Figure 2. Three-Dimensional Before-Damage Display, 0° View Angle (S-N)



(Distances in 10's of ft)

3D Oblique Projection Before Damage (Relative to Burst)

flyer2.dat 08/13/92 16:03 Yld=1000 Lbs HoB=0.00 Ft Ah=None Av=None

Figure 3. Three-Dimensional Before-Damage Display with Subdivision, 0° View Angle (S-N)

Outputs from the postprocessor are in the form of tabular data and graphical displays (both two-dimensional, and three-dimensional) of overpressure, dynamic pressure, and damage as follows:

- o Structure Damage Table
- o After-Damage Display
- o Damage-vs-Distance Graph
- o Overpressure Contour Plots
- o Dynamic Pressure Contour Plots
- o Structure Damage Contour Plots
- o Parametric Analysis of Single Structure Plots
- o Grid Description(s)
- o Data Tables

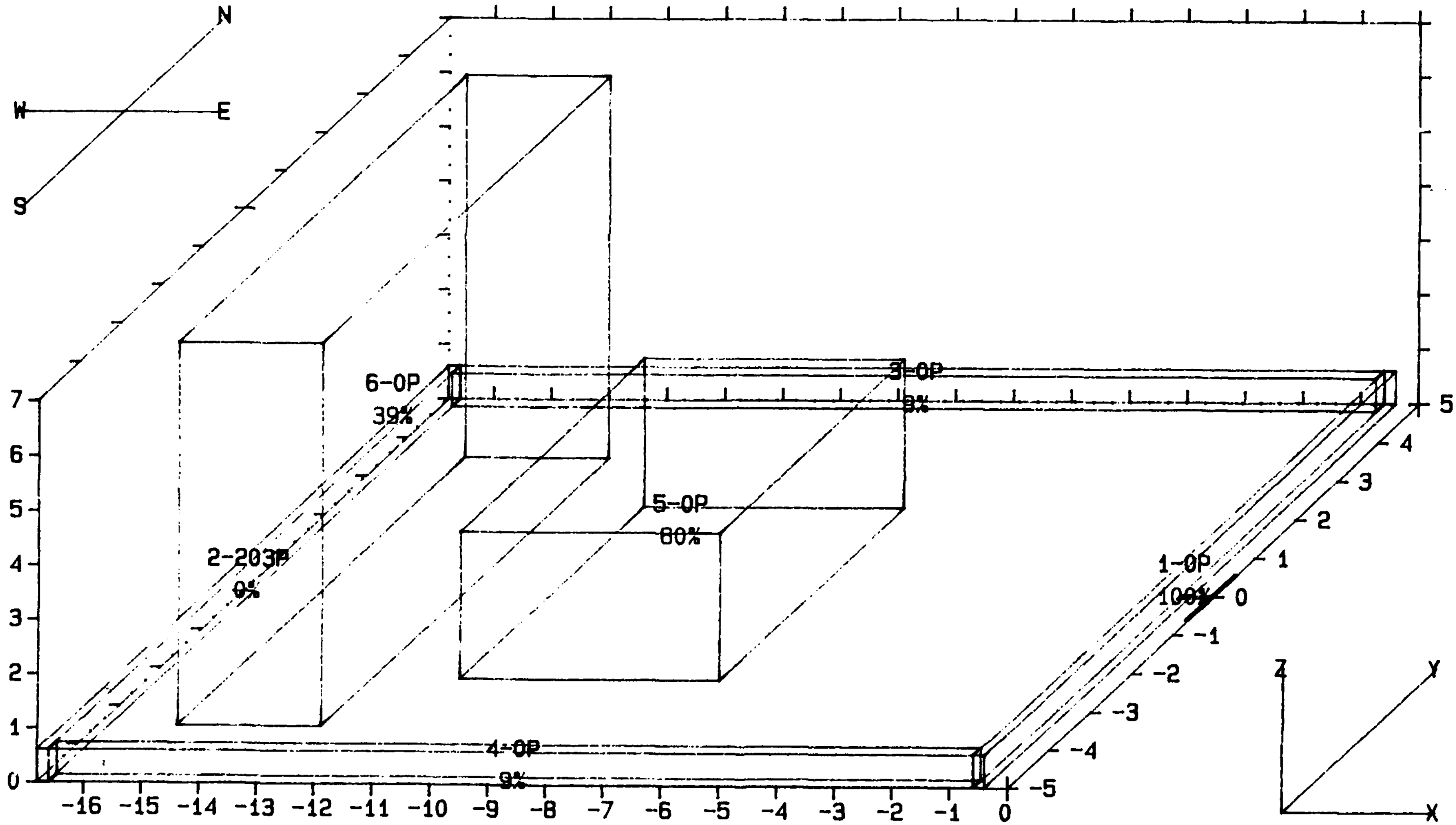
In the case of graphical displays, the user is given the option of displaying each output on the screen, generating a color copy by means of the printer or the plotter.

An example of an After-Damage Display is shown in Figure 4, corresponding to the same case as shown in the Before-Damage Display. Immediately below the label for each structure the calculated damage is displayed.

Figure 5 provides are example of the Damage-vs-Distance Graphs. By means of preprocessor inputs the user can adjust the limits for "slight", "moderate", and "severe" damage levels shown in the figure.

An example of an Overpressure Contour Plot is presented in Figure 6, while an example of a Dynamic Pressure Contour Plot is presented in Figure 7. These plots are three-dimensional oblique projections, for which four different viewing angles are available (0°, 90°, 180° and 270°). Figure 6 represents the 0° viewing angle while Figure 7 represents the 270° angle. Two-dimensional contour plots in the horizontal, vertical-lateral or vertical-longtudinal plane can also be generated for overpressure and dynamic pressure.

Examples of the two types of Structure Damage Contour Plots are presented in Figures 8 and 9. In Figure 8 the structure damage contours to the taller building on the left are displayed, with all other structures, as well as the primary detonation location, included in the plot. In Figure 9 the structure



(Distances in 10's of Ft - Percentages represent mean percent damage.)

3D Oblique Projection After Damage (Relative to Burst)

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE

Figure 4. HEXDAM-D+ Three-Dimensional After-Damage Display, 0° View Angle (S-N)

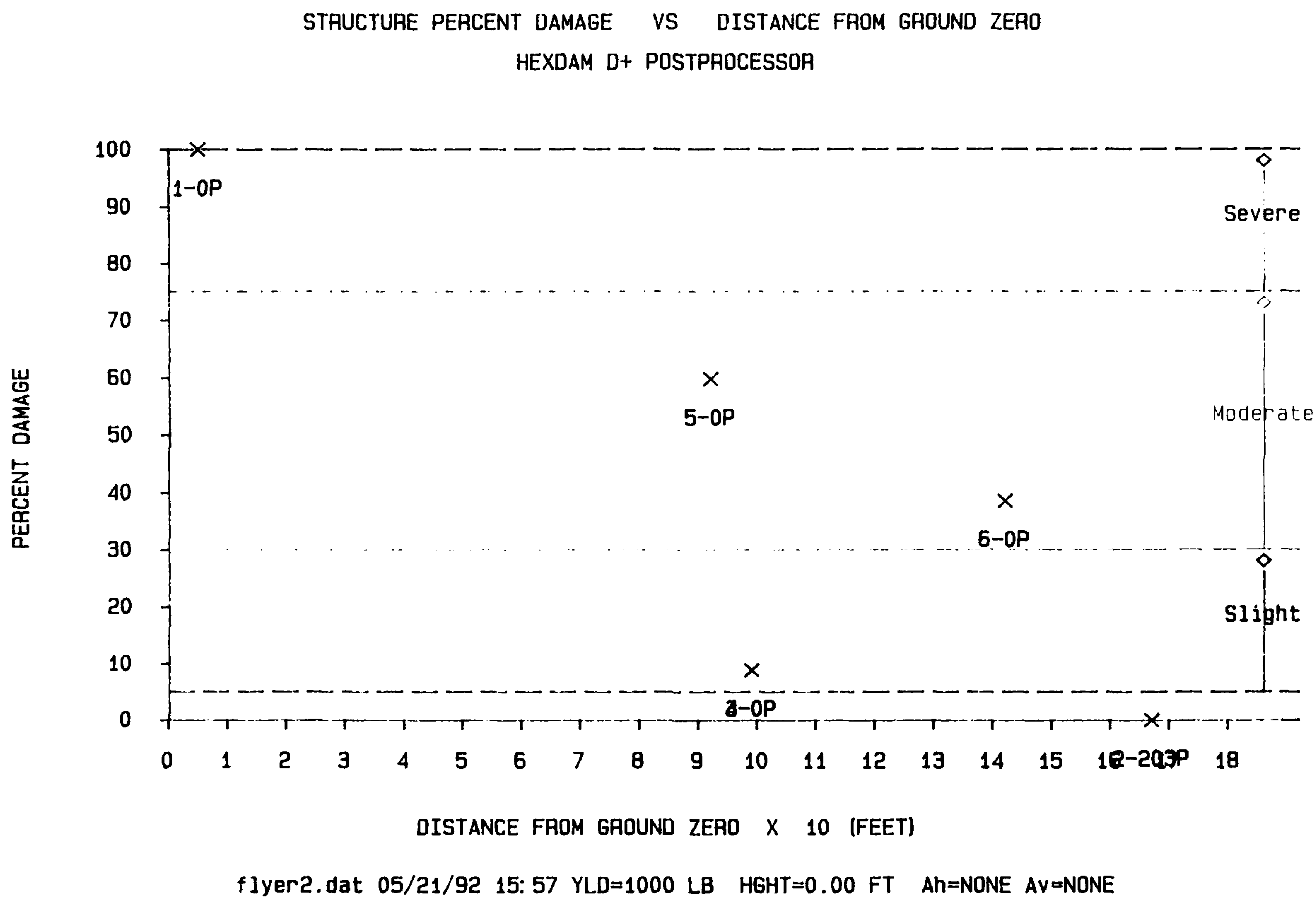
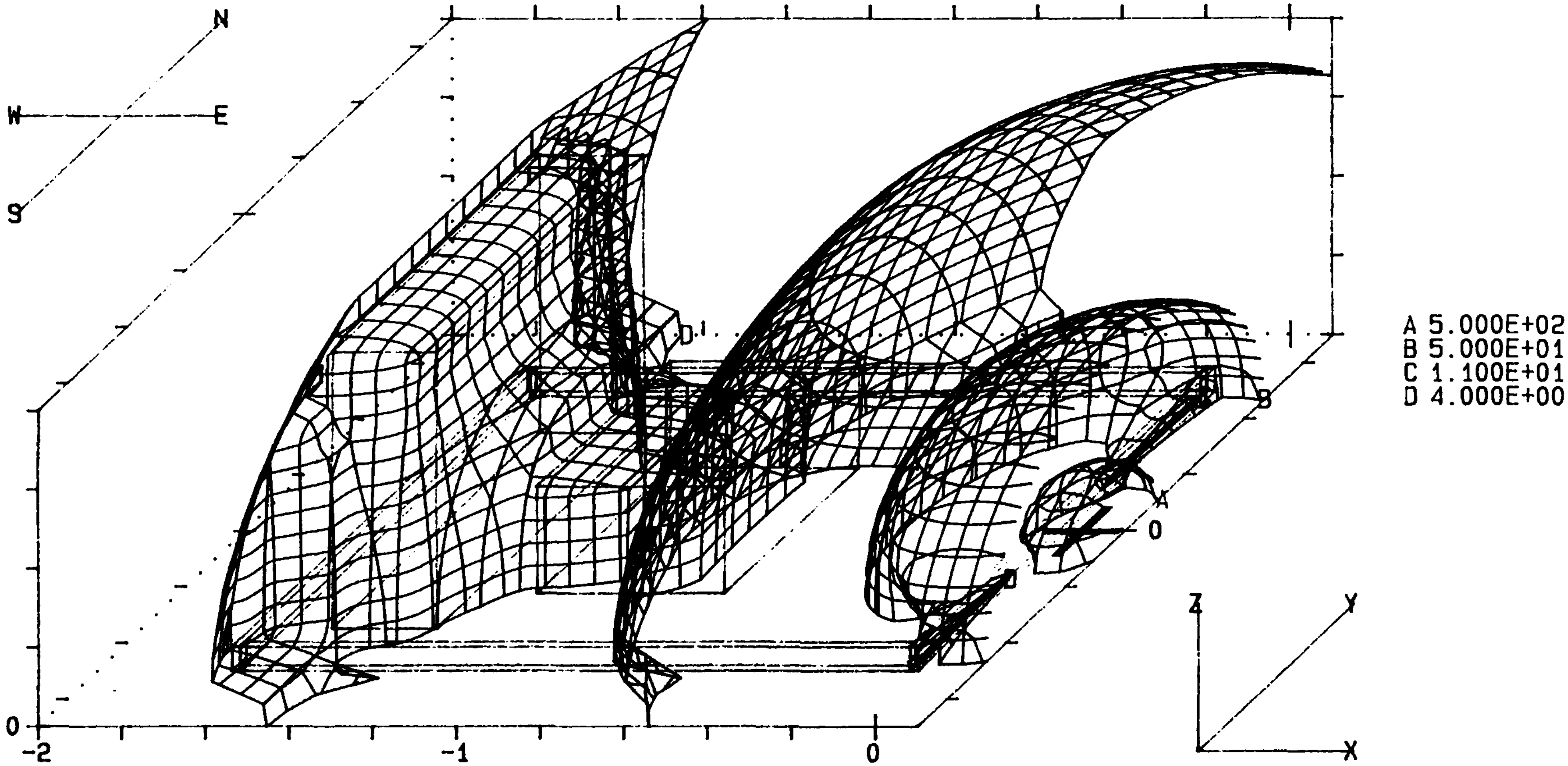


Figure 5. HEXDAM-D+ Damage VS. Distance Graph

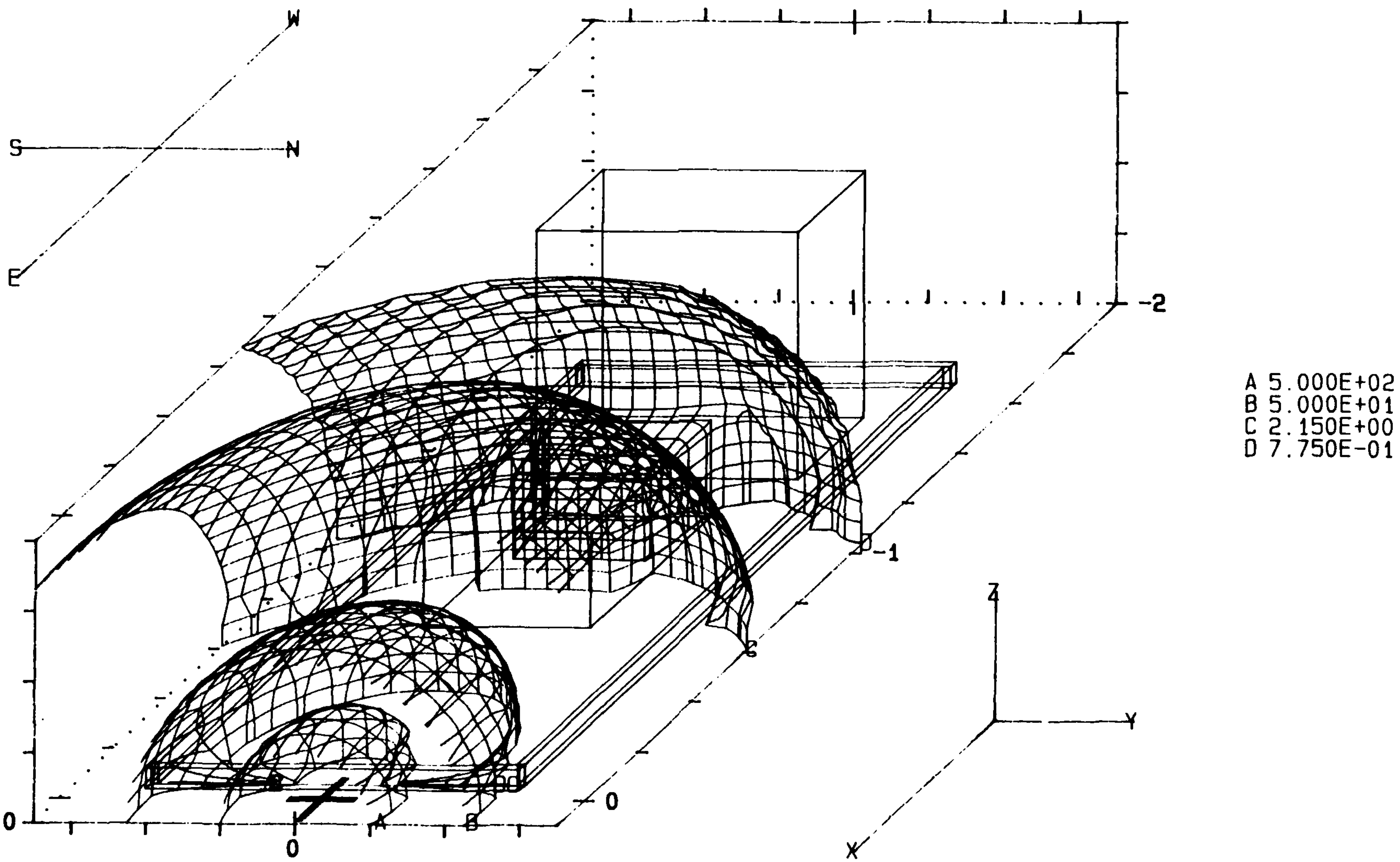


(Distances in 100's of Ft, Contours in Psi)

3D Overpressure Contour Plot

flyer2.dat 05/21/92 15:57   Yld=1000 Lbs   HoB=0.00 Ft   Ah=NONE Av=NONE

Figure 6. HEXDAM-D+ Three-Dimensional Overpressure Contour Plot, 0° View Angle (S-N)

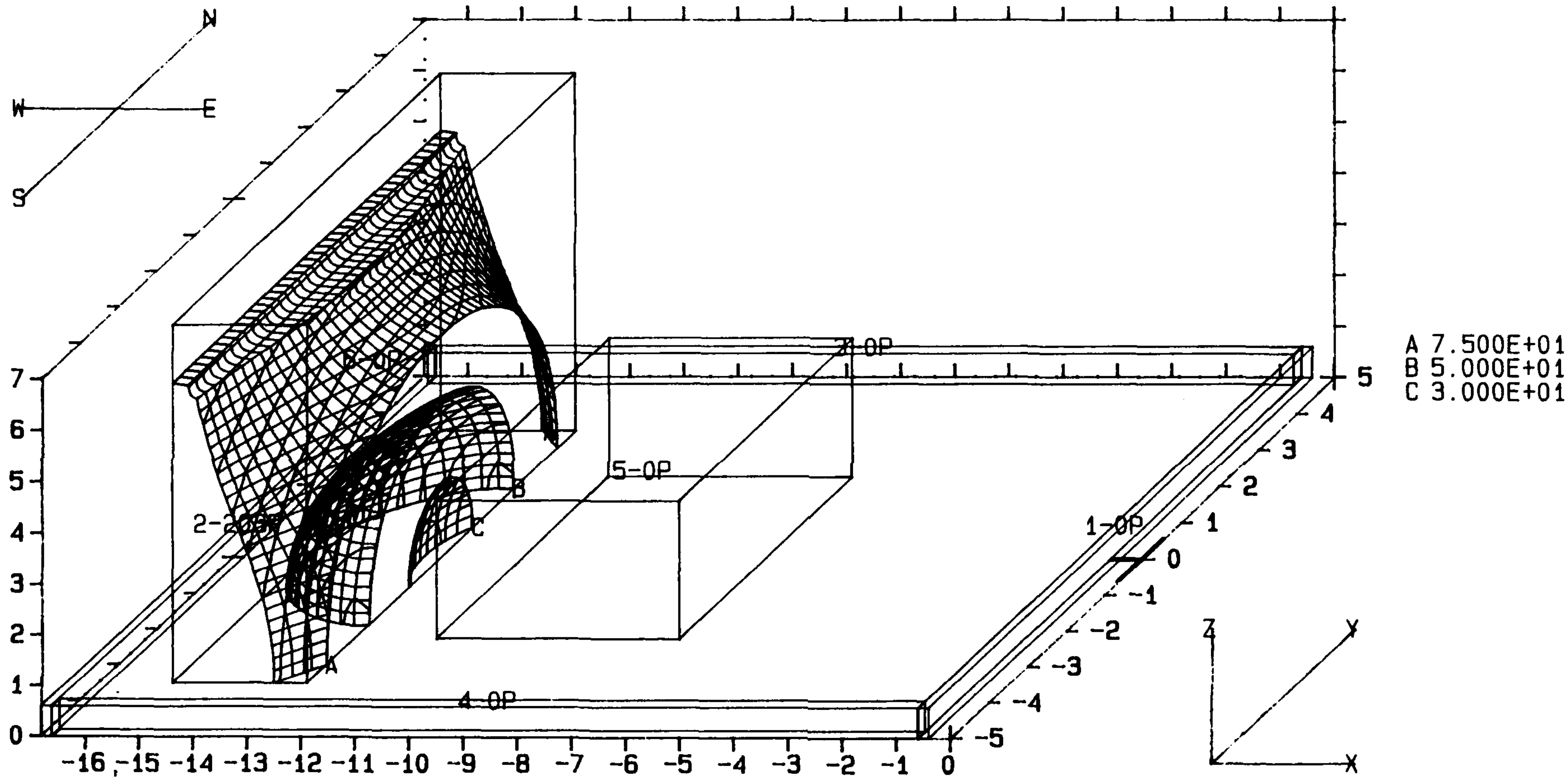


(Distances in 100's of Ft. Contours in Psi)

3D Dynamic Pressure Contour Plot

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE

Figure 7. HEXDAM-D+ Three-Dimensional Dynamic Pressure Contour Plot, 270° View Angle (E-W)

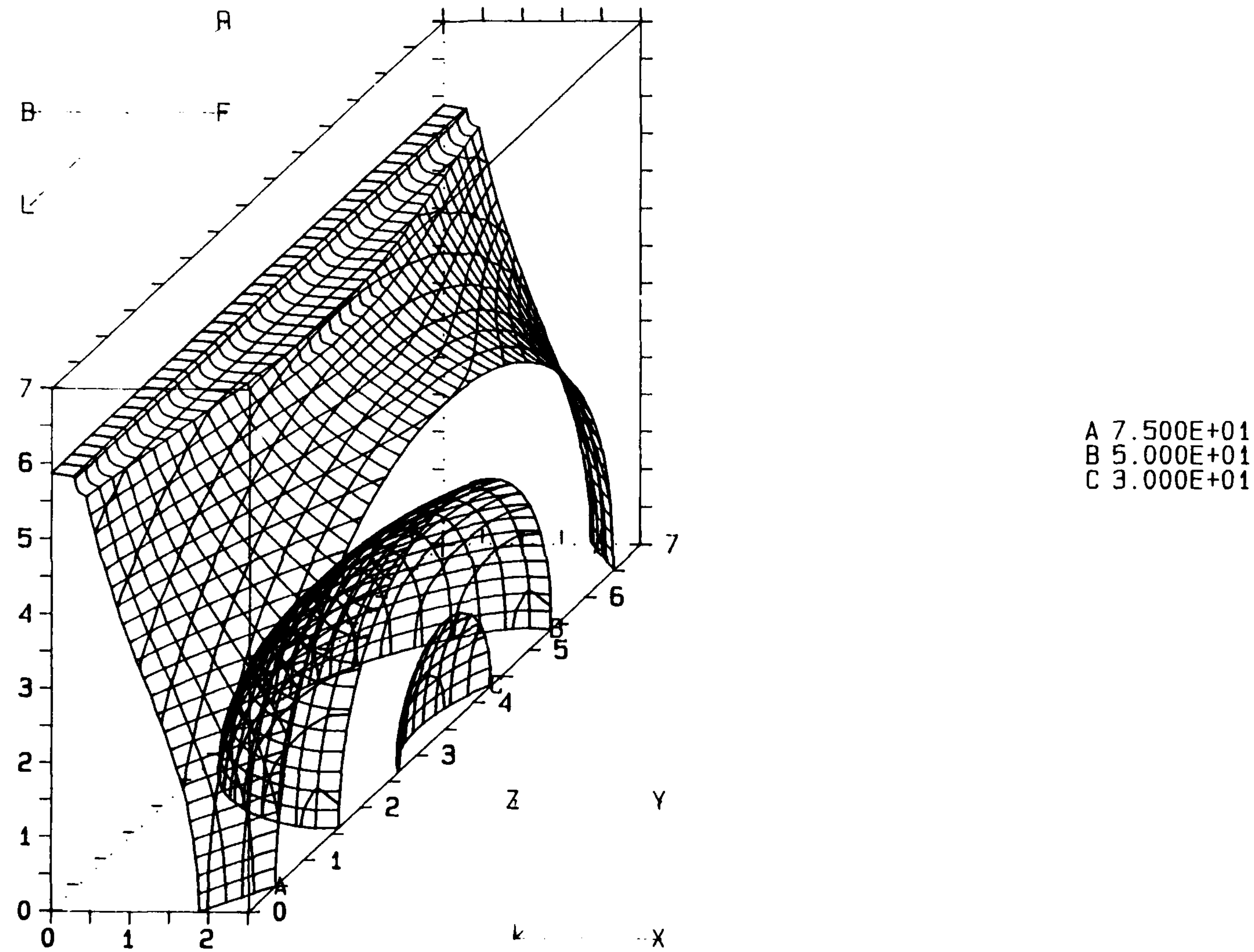


(Distances in 10's of Ft. Contours in %)

6-OP 3D Damage Contour Plot

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE

Figure 8. HEXDAM-D+ Three-Dimensional Structure Damage Contour Plot (Display relative to Blast), 0° View Angle (S-N)



(Distances in 10's of Ft, Contours in %)

6-OP 3D Damage Contour Plot

flyer2.dat 05/21/92 15:57 Yld=1000 Lbs HoB=0.00 Ft Ah=NONE Av=NONE

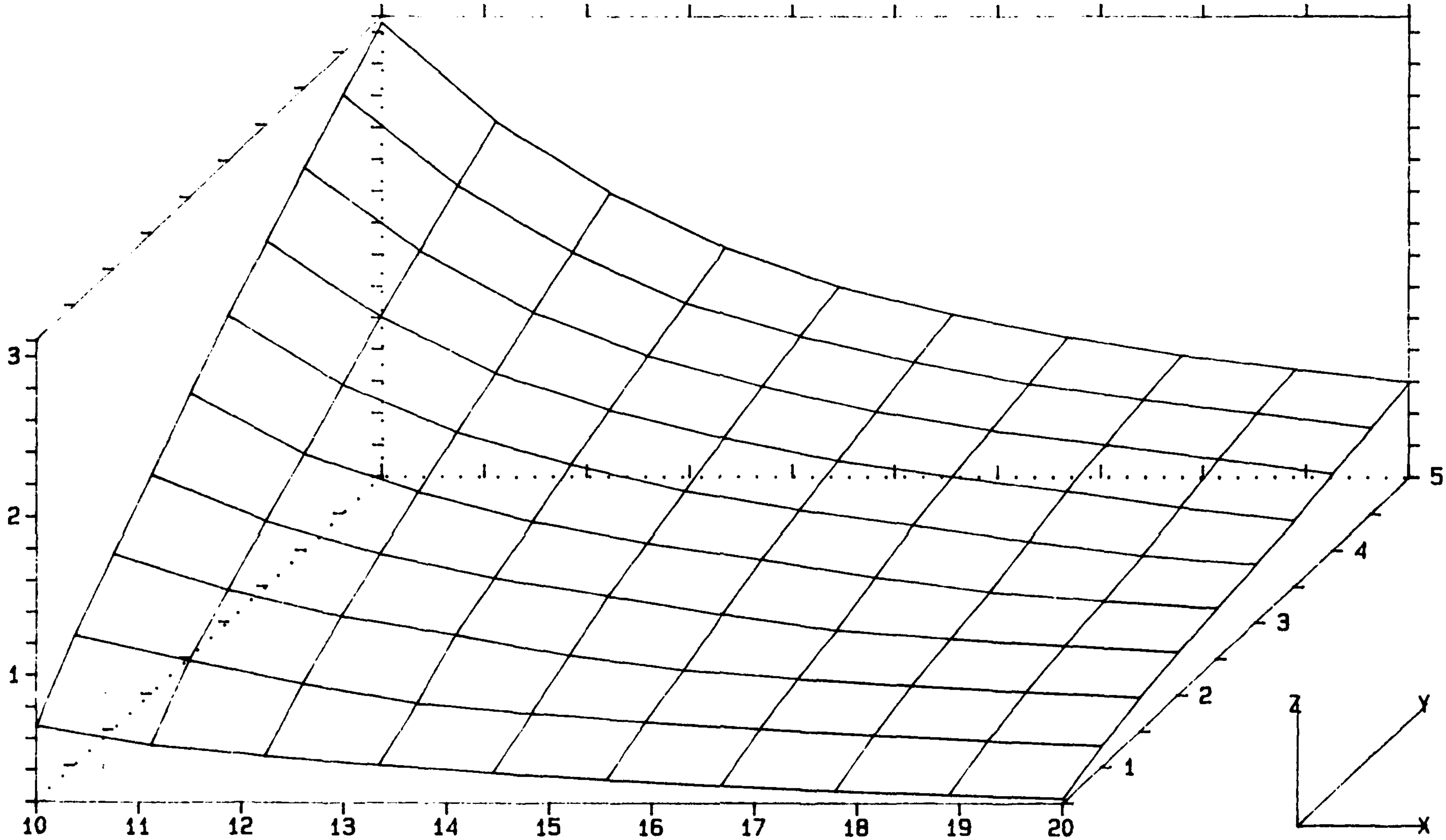
Figure 9. HEXDAM-D+ Three-Dimensional Structure Damage Contour Plot (Display independent of Blast) (L-R)

damage contours to the same building are plotted, but the other structures are omitted, as is the primary detonation.

For the Parametric Analysis of Single Structure (PASS) output, Figures 10, 11, and 12 provide examples of a conventional three-dimensional plot, a two-dimensional contour plot, and a three-dimensional contour plot, respectively. In Figure 10 the independent variables, distance and yield, are plotted on the X- and Y-axes, respectively, while the dependent variable, overpressure, is plotted on the Z-axis. In Figure 11, the independent variables, distance and height of burst, are plotted on the X- and Y-axes, respectively, forming a plane on which contours corresponding to constant values of the dependent variable, damage, are plotted. In Figure 12, the three independent variables, distance, yield, and height of burst, are plotted along the X-, Y- and Z-axes, respectively, forming a rectangular volume. Iso-surfaces of the dependent variable, overpressure, are plotted within the volume.

CONCLUSIONS

HEXDAM-D+ represents a powerful yet flexible engineering software tool for use by safety/security engineers and analysts. Because of its modest hardware requirements, it has the potential for widespread use. The ability of the software to model an unlimited number of structure represents a significant advance over its predecessors. The new shielding algorithm appears to compare reasonably well with observation. By means of the Parametric Analysis of Single Structure (PASS) feature, the effects on a specific structure-of-interest, due to a change in distance or explosive yield, can be rapidly evaluated. The use of oblique projection graphics to produce three-dimensional displays further enhances the software.

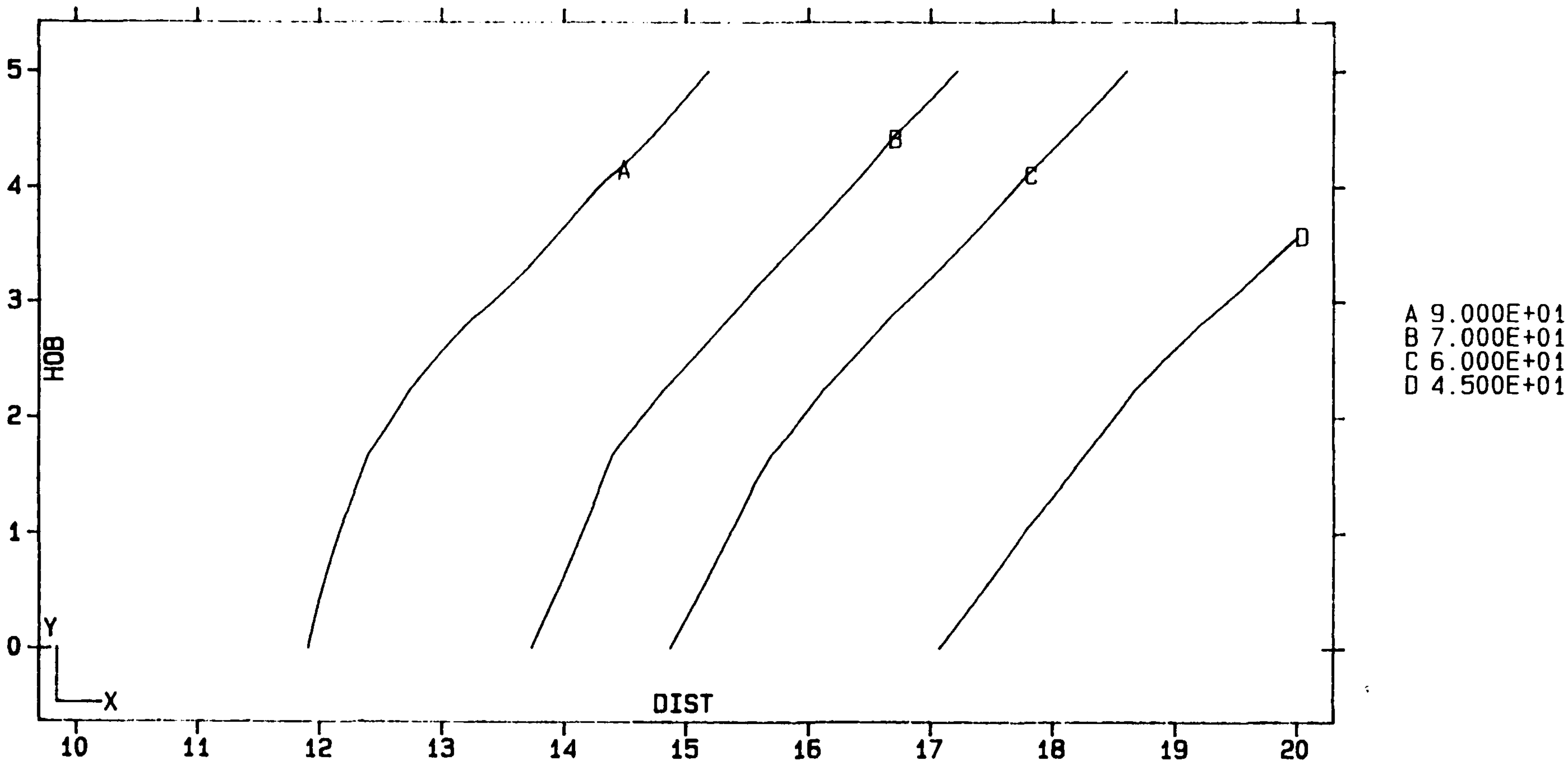


(Pressure in 10's of Psi. Yield in 1000's of Lbs. Distances in 10's of Ft)

3D Plot [X=Dist. Y=Yld. Z=OverP]. HoB= 0.000E+00

Parametric Analysis of 6-0P flyer2.dat 05/21/92 15:57 SI

Figure 10. HEXDAM-D+ PASS Three-Dimensional Plot (Conventional)

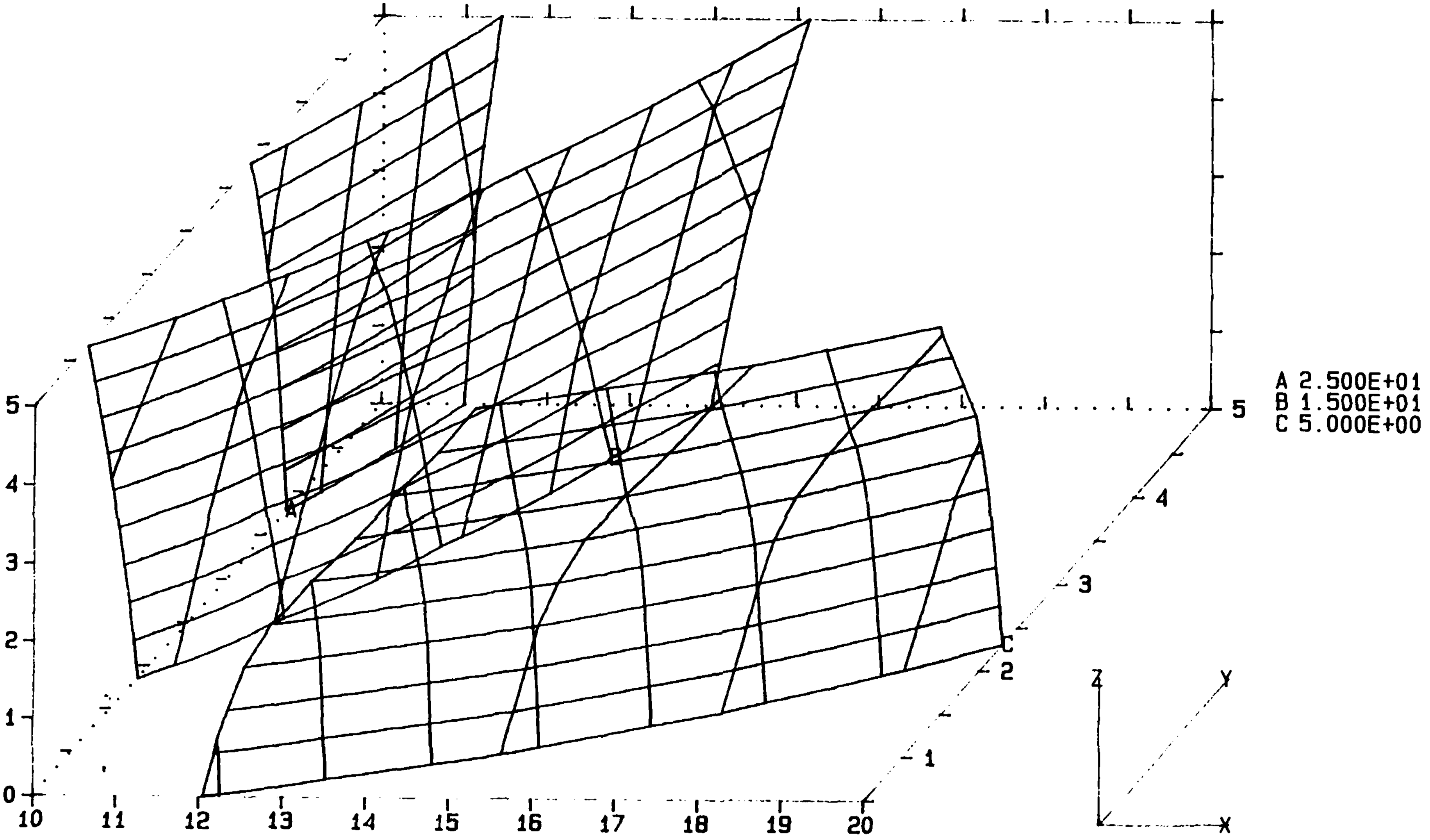


(Yield in Lbs. Distances in 10's of Ft. Contours in %)

2D Damage Contour Plot [X=Dist. Y=HoB]. Yld= 5.000E+02

Parametric Analysis of 6-OP flyer2.dat 05/21/92 15:57 SI

Figure 11. HEXDAM-D+ PASS Two-Dimensional Contour Plot



(Yield in 1000's of Lbs, Distances in 10's of Ft, Contours in Psi)

3D OverP Contour Plot [X=Dist, Y=Yld, Z=HoB]

Parametric Analysis of 6-OP flyer2.dat 05/21/92 15:57 SI

Figure 12. HEXDAM-D+ PASS Three-Dimensional Contour Plot

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4. Beyer, Mary E., "Blast Loads Behind Vertical Walls" Twenty-Second DoD Explosives Safety Seminar, Anaheim, California, 26-28 August 1986.

INVESTIGATION OF IGNITER COMPOSITION FIRE BAY 9 BUILDING G-11 LONESTAR ARMY AMMUNITION PLANT 15 MAY 1991

ROBERT A. LOYD

U.S. ARMY ARMAMENT
MUNITIONS AND CHEMICAL COMMAND

25th DEPARTMENT OF DEFENSE
EXPLOSIVES SAFETY SEMINAR
18-20 AUGUST 1992

EXECUTIVE SUMMARY

1. An explosion occurred in bay 9, building G-11, Lone Star Army Ammunition Plant (AAP), Texarkana, TX, at approximately 1417, 15 May 1991. There were no injuries or deaths. Building G-11 was being used to remotely mix 45 pounds of igniter mix. The igniter mix is used in the tracer element of the 120mm family of tank gun ammunition. All items are produced under third-party contract by Day & Zimmermann, Inc.

2. Operations prior to the explosion proceeded normally. The operator had completed one batch of igniter mix earlier in the day. He was mixing the second batch of the day and remotely dumping it onto the dial table when the incident occurred.

3. The physical evidence and examination of the videotape indicate ignition took place outside the mixing bowl on the dial table. The reaction was centered on the draw-off dial between the 11 o'clock and 2 o'clock position. This is indicated by the bending of the dial table, other physical evidence, and the high-speed videotape. This caused a hot spot between the 12 o'clock and 1 o'clock position resulting in the ignition of mix on the dial. This resulted in propagation to the remaining mix on the dial, in the collection containers, and in the mixer. The ignition may be attributable to either electrostatic discharge or friction and heat.

a. Static electricity: The most probable cause of initiation is electrostatic charge discharging between the wiper arm, collection can, and draw-off table. The addition of acetone in sufficient quantity to dissolve the chlorinated rubber and the mixing action of the duller will effectively render this normally conductive mix into a nonconductive mix. A nonconductive mix will build up a static charge due to the triboelectrification at a rate depend upon the velocity of movement of the particles. Possible discharge path would be the dial wiper in close proximity to the mixture as it fills the collection container. It would provide a discharge path that could cause ignition.

b. Friction/Heat: A secondary cause of initiation is friction and heat due to varied clearances, and foreign matter buildup on the lower surfaces of the wiper blades. Behavioral characteristics of similar mixtures containing magnesium and barium peroxide indicate these mixtures are sensitive to friction. The clearance of the dial wipers, the uneven surface on the lower edges, and rotational speed of the wipers could cause friction and heat buildup sufficient for initiation. Contamination found on the lower surfaces of the wiper arms could also change the clearance of the dial wiper arms to the draw-off table causing the potential for increased friction and heat buildup.

1. Introduction:

a. An explosion occurred in bay 9, building G-11, Lone Star AAP, Texarkana, TX, at approximately 1417, 15 May 1991. There were no injuries or deaths reported. Building G-11 was being used to remotely mix 45 pounds of igniter mix. The igniter mix is used in the tracer element of the 120mm family of tank gun ammunition. All items were produced under third-party contract by Day & Zimmermann, Inc.

b. Operations prior to the explosion proceeded with no anomalies. The operator had completed one batch of igniter mix earlier in the day. He was mixing the second batch of the day and remotely dumping it onto the dial table when the incident occurred.

c. There were no deaths or injuries, but there was major property damage to the building and equipment.

d. A video system was in use during the mixing process. Two cameras were used by the operator to monitor the operation. One camera was focused on the dial table and was mounted on the east wall of the bay. The second camera was mounted 4 feet above the mixing bowl allowing the operator to monitor the motion of the mulling wheel and the plows. The camera was attached to a high-speed video recording system and provided a videotape of the entire mixing process in the bowl.

e. The igniter mix batch was being remotely dumped when the incident occurred. The mixer door had been open approximately 30 seconds. The mulling wheel stopped rotating approximately 5 1/2 seconds before the incident.

f. The operator was preparing to stop the operation of the plow and muller wheel when the deflagration took place. The reaction was centered on the draw-off dial table between the 11 o'clock and 2 o'clock position as indicated by the bending of the dial table.

2. General History of the Igniter Composition at Lone Star AAP:

a. The igniter mix is used in the tracer element of the 120mm family of tank gun ammunition. They include: M829, APFSDS-T; M830, HEAT-MP-T; M831, TP-T; and M865, TPCSDS-T.

b. The igniter composition was first produced in March 1989. Since that time, 32 batches have been produced in building G-11. There has been one previous incident of process deflagration in bay 9, building G-11. The incident occurred on 5 September 1990. There were no injuries, but significant damage to the facilities and equipment was incurred. The incident initiated inside the mixing bowl. The mixer was in operation at the time, and the mixer door was closed. The building sustained $17,277 in damages. The exact cause of the incident was not determined.

c. The igniter composition has also been involved in at least 31 downstream process incidents occurring between 2 May 1989 and 22 May 1991. Typical examples are provided below:

(1) A process deflagration occurred during pelleting operations. It was caused by friction or spark.

(2) Two Tracer and Plug Assemblies ignited during final assembly. It was caused by friction or static discharge.

(3) Three partially assembled Tracer and Plug Assemblies and quantity of pellets ignited during final assembly. It was caused by friction.

(4) Two Tracer and Plug Assemblies ignited during consolidation of the igniter charge. It was caused by friction.

(5) A fin ruptured occurred during the consolidation of igniter composition into the Fin Assembly.

(6) A flash occurred on a conveyor belt during the transfer of a Trace and Plug Assembly.

(7) During the pressing of igniter pellets on a press, a detonation occurred.

3. Building and Equipment:

a. Building G-11 is a single-story structure 44 feet wide by 127 feet long, containing 5,588 square feet of floor area. It was constructed in 1941 as a tracer, igniter, and incendiary composition preparation building. It contains 19 cubicles separated by 12-inch thick reinforced concrete dividing walls. It has a concrete floor with hollow clay tile walls on the west, north, and east sides.

b. There is a blowout wall and roof on the south end of the building, where the mixing cubicles are located. The roof on the remainder of the building is composed of asphalt composition shingles over wood decking.

c. Cubicle 9 and adjacent corridors were insulated with foil-backed rigid insulation when temperature/humidity control equipment was installed in October 1984. The mixing cubicles, adjacent corridors, and drying cubicles are equipped with ultraviolet fire detection and ultra-high-speed deluge systems.

d. The major equipment in bay 9 consists of the following:

+ Simpson Muller Mixer
+ Remote Draw-off System for Simpson Mixer
+ Eductor System
+ Remote Charging Device for Binder Material
+ Deluge System
+ Magnesium Dumper
+ Closed Circuit Television System

4. Damage:

a. Damage to the structure consisted of the blowing off the frangible wall and roof panels of bay 9, the adjacent bays, and corridor, plus cracking the side wall on the east side of the building. There was also damage to adjacent bay roofs, frangible walls, and frangible doors. Damage to the equipment in bay 9 was heavy. The material destroyed consisted of approximately 45 pounds of igniter mix and 6 pounds of acetone.

b. The majority of the fragments consisted of fiberglass panels and rigid insulation. There were also approximately 12 pieces of metal. Most were sections of metal flashing from the roof and were located within 20 feet of the building.

c. The particle board covering the window on the west wall of the building prevented a more complete venting at that spot and channeled the pressure wave against the corridor doors.

d. The total damages were $44,972.

e. There were no deaths or injuries.

5. Weather Conditions:

a. Weather conditions at the time of the accident were:

+ Sky: 2,100 feet broken clouds
+ Temperature: 74 Degrees F
+ Relative Humidity: 70%; raining
+ Winds: South at 12 mph
+ Barometric Pressure: 29.90 inches

b. Weather conditions did not contribute to the accident.

6. Manufacture of Igniter Mix:

a. The igniter mix for the 120mm family of tank gun rounds has the following composition:

Chemical	Percent	Weight	
Barium Peroxide	79 +/- 2.0	12.0	pounds
Magnesium	13 +/- 1.0	[illegible]	grams
Chlorinated Rubber	5 +/- 0.5	340.0	grams
Charcoal Dust	2 +/- 0.3	136.0	grams
Graphite	1 +/- 0.2	68.0	grams
Acetone:		6	pounds

b. This igniter mix is prepared at Lone Star AAP using a Simpson Mix Muller. The mixture involved is created by combining three 15-pound dry mixed batches of igniter composition with a prescribed amount of acetone and mixing in the Simpson Muller Mixer until it reaches the desired consistency.

c. The mixing process proceeds as follows:

(1) A preblended mixture of the barium peroxide, magnesium, chlorinated rubber, charcoal dust, and graphite is prepared before the wet mix process takes place. These chemicals are passed through a #4 mesh screen prior to being dry blended in building G-13. Three 15-pound premix batches are then transferred to building G-11, bay 9, for the wet mix process.

(2) The three 15-pound batches are remotely dumped into a Simpson Muller Mixer. Acetone is then placed in a binder dump station, and subsequently remotely dumped into the mixer bowl.

(3) The operator then remotely starts the mixer and allows it to run until the composition reaches the desired consistency. The operator judges by viewing through the video camera at which point the mixing process is complete. The operator then remotely starts the draw-off dial and opens the mixer door. The plow then pushes the mix out the door onto the dial. The rotating wiper blades of the draw-off system push the mix into the holes in the dial plate and into stainless steel containers below. Once the mixer bowl is empty, the mixer and rotating blades are turned off, and the mixer door closed.

(4) The stainless steel containers are then lowered away from the dial and are conveyed from the bay one at a time. Each container must be removed to storage before another is allowed to be released from the dial. Once all the containers are removed, the mixing process can begin anew, or cleaning of the mixer may occur.

7. Hazardous Component Safety Data Statements (HCSDSs):

a. Information on the igniter composition as it relates to sensitivity data (friction, impact, and electrostatic discharge) and hazard data (autoignition temperature, 5-second explosive temperature, and dust) were listed as 'UNKNOWN' on the HCSDS.

b. This is critical information needed by producer of the igniter mix.

8. Military Specifications:

a. All chemicals used in the ignition mix are required to met military specifications.

b. All chemicals met the applicable military specifications.

9. Acetone:

a. The mixing of acetone and chlorinated rubber causes the development of an insoluble gelatinous substance. The material that forms will not be removed from the composition by the action of the mixer.

b. The amount of acetone added has been adjusted based on the incident history of the composition. It was increased to the present quantity as a result of the September 1990 incident. This results in a longer mixing time.

c. The use of methyl ethyl ketone (MEK) or acetone is permitted in this mix. Chlorinated rubber is more readily soluble in MEK than in acetone.

10. Mixer:

a. The mixer involved in the incident has been in service at Lone Star AAP since July 1951. It shows signs of wearing out as a result of extended service and an undetermined number of previous incidents.

b. Worn areas were discovered in the hub area of the axle assembly in the mixing bowl. A sharpened edge and an indentation in the ring were discernible. Furthermore, extensive pitting of the ring in the hub assembly was evident. The millwrights indicated they had not seen this pitting when they repaired the bowl after the September incident. The millwrights attributed this pitting to water buildup in that area. These hub anomalies could possibly cause a wobbling of the wheel and plow assembly.

11. Bowl:

a. The interior of the mixing bowl showed the presence of concentric circular grooves on the bottom of the bowl. The depth of the grooves was measured at four random locations. The depth varied from 0.007 inches to 0.015 inches. The maintenance personnel indicated that the grooves were there following the September 1990 incident. The grooves were hand-polished with emery cloth to attempt to smooth them down. It is not known if the depth of the grooves increased between September 1990 and May 1991.

b. There were marks on the side of the mixing bowl. The marks appeared from approximately the 7 o'clock to the 9 o'clock position. Eleven distinct sets of marks were visible and all had the appearance of being caused by metal to metal contact. The marks were vertically linear in arrangement. They occurred from approximately 4-8 inches above the floor of the bowl.

12. Mixing Bowl Plows:

a. Both of the plow blades were bent near the tip of the plow. It could not be determined if it was caused by the incident. However, it did not cause the incident.

b. There were differences in the thicknesses of the edges of both plow blades. This can be attributed to either normal wear or remanufacturing of the plows.

13. Muller Wheel:

a. The muller wheel was pitted and had a dent near the point where it meets the axle that links it to the plow assembly. These did not cause the accident.

b. The muller wheel stopped rotating approximately 5.5 seconds before the incident. It was determined that this was a natural stoppage due to the lowered level of mix in the bowl after the dumping action of the plows. It had no bearing on the cause of the incident.

c. A brown mark was observed that ran around the circumference of the axle at about the mid point of the axle where it connects the Muller Wheel to the plow arm assembly,. Additionally, light scoring was evident in other locations on the axle. The axle was polished after the September 1990 incident. This was judged not to have caused the incident.

14. Dial Table:

a. The remote draw-off table and associated hardware were the prototype design for all other draw-off assemblies at Lone Star AAP. This equipment was installed in October 1984.

b. There was a buildup of material found between the wiper and the dial table. This material was nonconductive. The age of the material was not known. A pitted area discovered on the dial table near the 1 o'clock position. There was a corresponding mark as well as uneven wear on the dial wiper. There was also a good signature of a reaction at this location. This would indicate a probable point of initiation.

15. Dial Wipers:

a. The four dial wipers all had uneven surfaces on the lower edges. There was misalignment of the wiper system. Viton was found on the wiper blades. The wipers were not adequately cleaned at some time prior to the incident.

b. The misalignment and uneven surfaces could cause friction between the surface of the dial table and the wiper arm.

16. Ultra-High-Speed Deluge:

a. Routine checks of the deluge system indicated that there were no problems with the deluge. The system functioned as designed during the incident.

b. The deluge system had 17 nozzles and 8 ultraviolet detectors. Several months prior to the incident, the response time of the system was checked. It was in excess of 100 milliseconds (detection to water at the nozzles). To decrease response time of the system, the water supply was looped, and a pressure tank was added. This reduced the response time to less than 70 milliseconds.

c. A review of the high-speed videotape (4.4 milliseconds per frame) revealed the deflagration (rapid burning of the mix) occurred in 5 frames or less than 25 milliseconds. The reaction time of the mix exceeds the capability of the deluge system to halt the reaction. However, the deluge system did reduce the damage done to the equipment and the structure.

17. Bonding, Grounding, and Lightning Protection:

a. The bonding and grounding was checked in November 1990. The lightning protection system was checked in August 1990. No deficiencies were noted.

b. The metal ring attached to the dial table as a splash guard was incorrectly bonded. The caulking compound used to seal the space between the two parts served as an insulator. Also, there was no evidence of bonding between the metal drop chute and the dial table.

18. Possible Causes:

a. It is plausible that the source of the ignition can be attributed to some anomaly in the mixing bowl area. The door of the mixing bowl was open at the time of the incident and this provides a path for propagation from the mixing bowl to the lower dial table. Furthermore, it was evident by examination of all components of the bowl that the potential for metal-to-metal contact from either the plows or the mixing wheel is present. However, detailed examination of the areas containing marks or grooves in the bowl, plows, or muller wheel failed to indicate a strong signature of the point of ignition/initiation. It is for this reason that the likelihood of the mixing bowl as the source of the deflagration was ruled out.

b. The physical evidence and examination of the videotape indicate ignition took place outside the mixing bowl on the dial table. The reaction was centered on the draw-off dial between the 11 o'clock and 2 o'clock position. This is indicated by the bending of the dial table, other physical, and the high speed videotape. This caused a hot spot between the 12 o'clock and 1 o'clock position resulting in the ignition of mix on he dial. This resulted in propagation to the remaining mix on the dial, in the collection containers, and in the mixer. The ignition may be attributable to either friction or electrostatics on the dial.

c. Static electricity: The mixture, under normal circumstances, when mixed dry, would be a conductive mixture with minimal possibility for static buildup due to tribo-electrification. However, the addition of acetone in sufficient quantity to dissolve the chlorinated rubber and the mixing action of the muller will effectively render this normally conductive mix into a nonconductive mix. A nonconductive mix will build up a static charge due to the triboelectrification at a rate depend upon the velocity of movement of the particles. The static charge will not effectively have the ability to bleed off because of the insulative properties of the mix. Upon dumping, free falling mixture will increase the static charge potential (become greater) until it has the ability to find a discharge path. Possible discharge path would be the dial wiper in close proximity to the mixture as it fills the collection container. It would provide a discharge path that could cause ignition. The amount of static buildup and discharge would vary day to day, mix to mix, and could possible present minimal hazards until the physical and mechanical parameters come together in the right amounts to generate the discharge rate sufficient to cause a spark.

d. Friction/Heat: Specific values for friction and impact were unknown for this mixture. However, behavioral characteristics of similar mixtures containing magnesium and barium peroxide indicate these mixtures are sensitive to friction. The clearance of the dial wipers, the uneven surface on the lower edges, and rotational speed of the wipers could cause friction and heat buildup sufficient for initiation. Contamination found on the lower surfaces of the wiper arms could also change the clearance of the dial wiper arms to the draw-off table. Again, this causes the potential for increased friction and heat buildup.

e. Other possible causes such as careless smoking, lightning, electrical short circuit, water, and electrical malfunctions were considered and discounted due to the absence of any evidence which would support such determinations.

19. Most Probable Cause:

a. The most probable cause of initiation is electrostatic charge discharging between the wiper arm, collection can, and draw-off table.

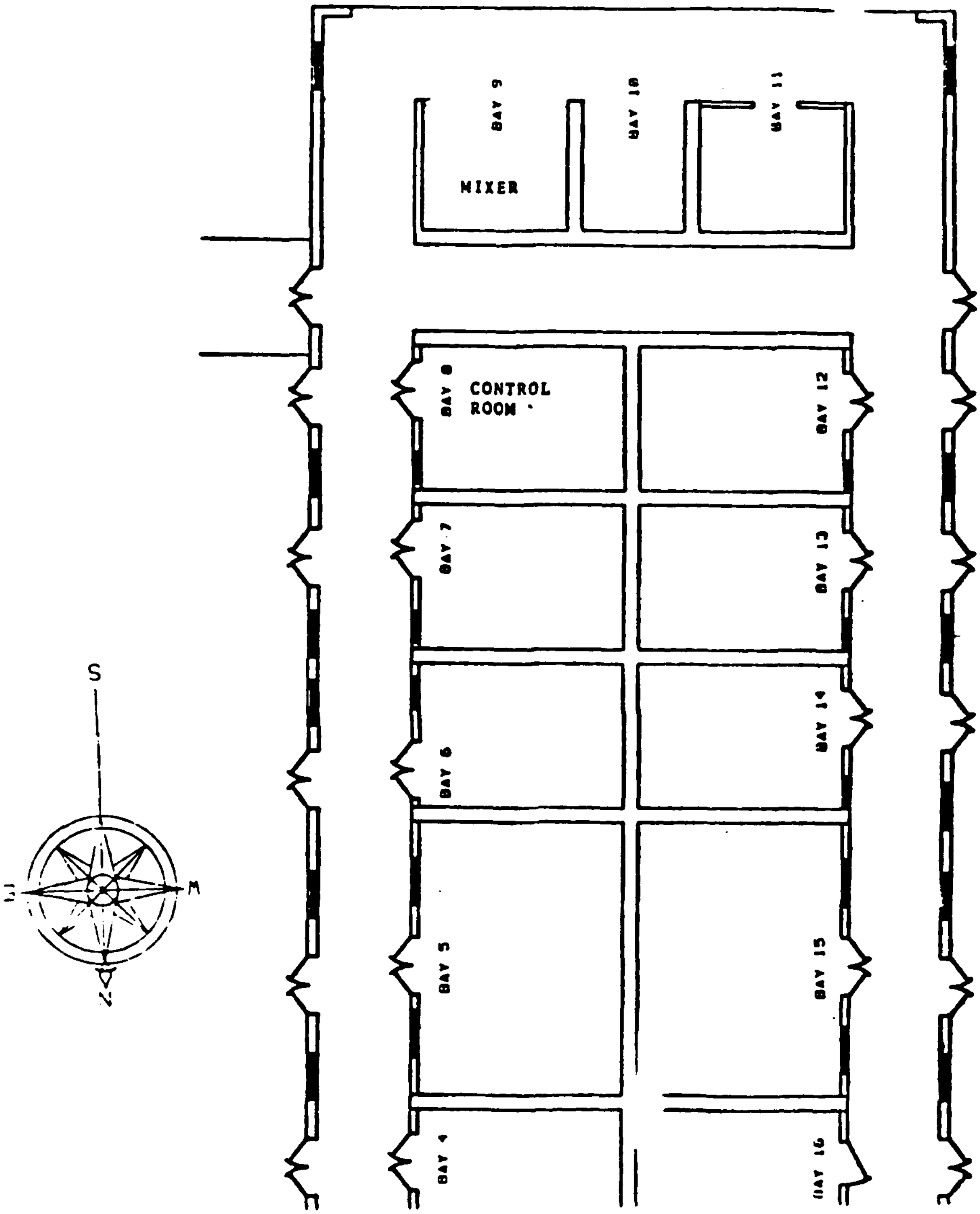
b. A secondary cause of initiation is friction and heat due to varied clearances, and foreign matter buildup on the lower surfaces of the wiper blades.

20. This report is based on the information contained in:

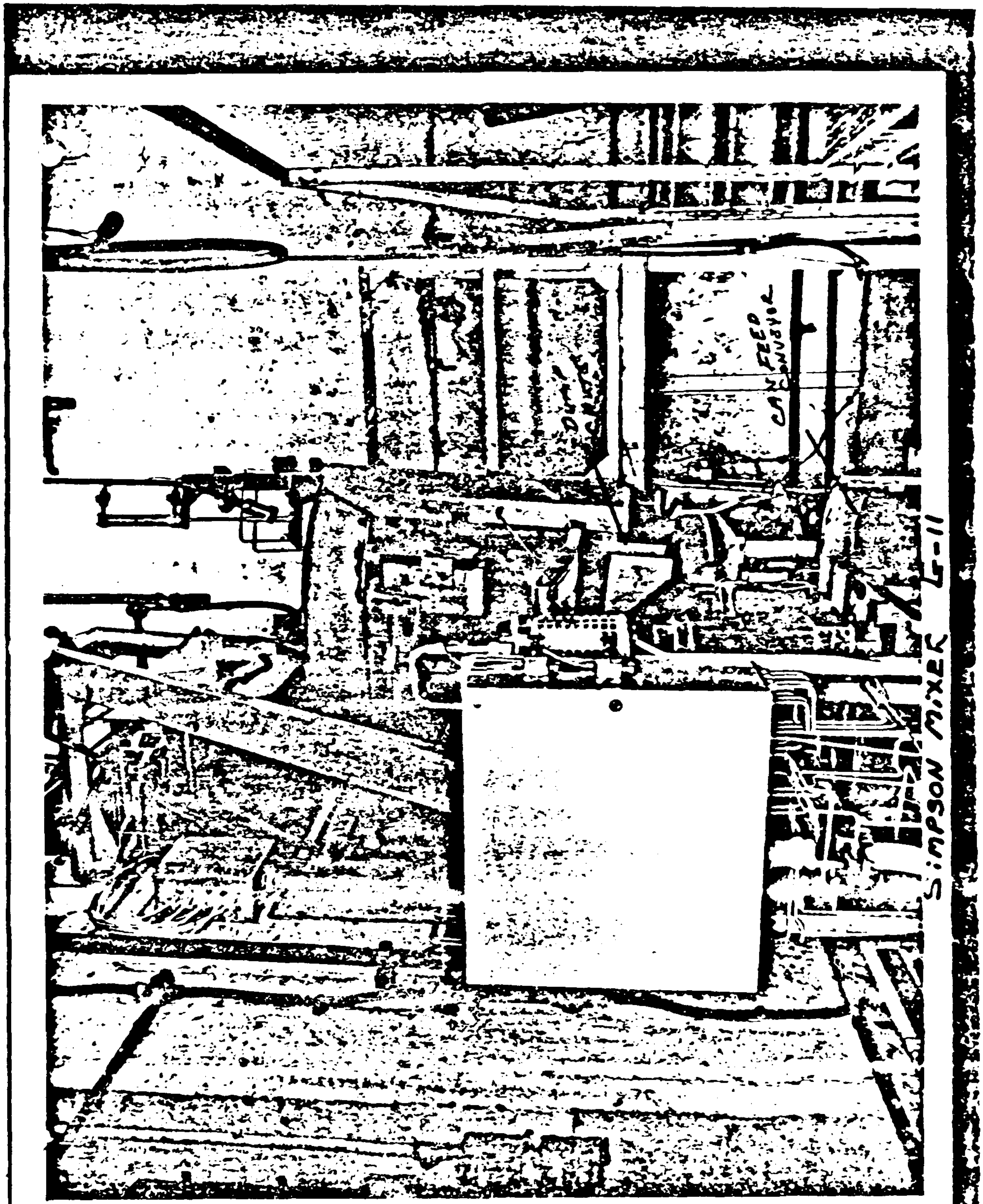
a. Report of Investigation, Building G-11, Bay 9, Lone Star Army Ammunition Plant, Texarkana, Texas, 15 May 1991. Members of the investigating team included: MAJ John Obal, Mr. Carl Morrison, Mr. Lyn Little, and Mr. Robert Loyd.

b. Outside Consultant's Report of Building G-11, Bay 9, Lone Star Army Ammunition Plant Incident dated 28 May 1991. Report was prepared by Mr. Fred McIntyre, Senior Engineer, Sverdrup Technology, Inc.

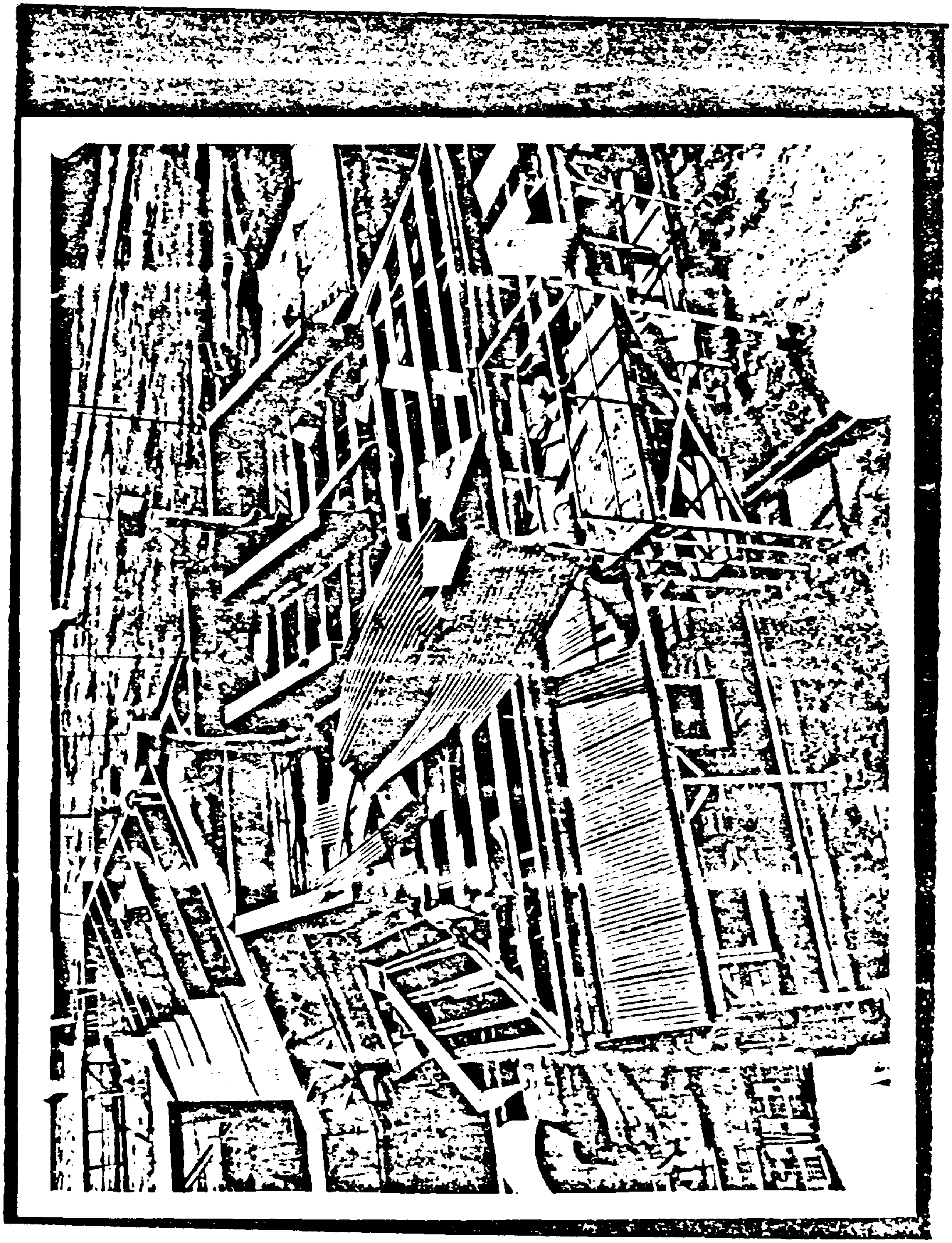
21. The author can be contacted at the U.S. Army Armament, Munitions, and Chemical Command, ATTN: AMSMC-SFP (Safety Office), Rock Island, IL 61299-6000. The telephone is commercial (309) 782-2975 or DSN 793-2975.



PARTIAL FLOOR PLAN OF BLDG G-11



Bay 9 before explosion



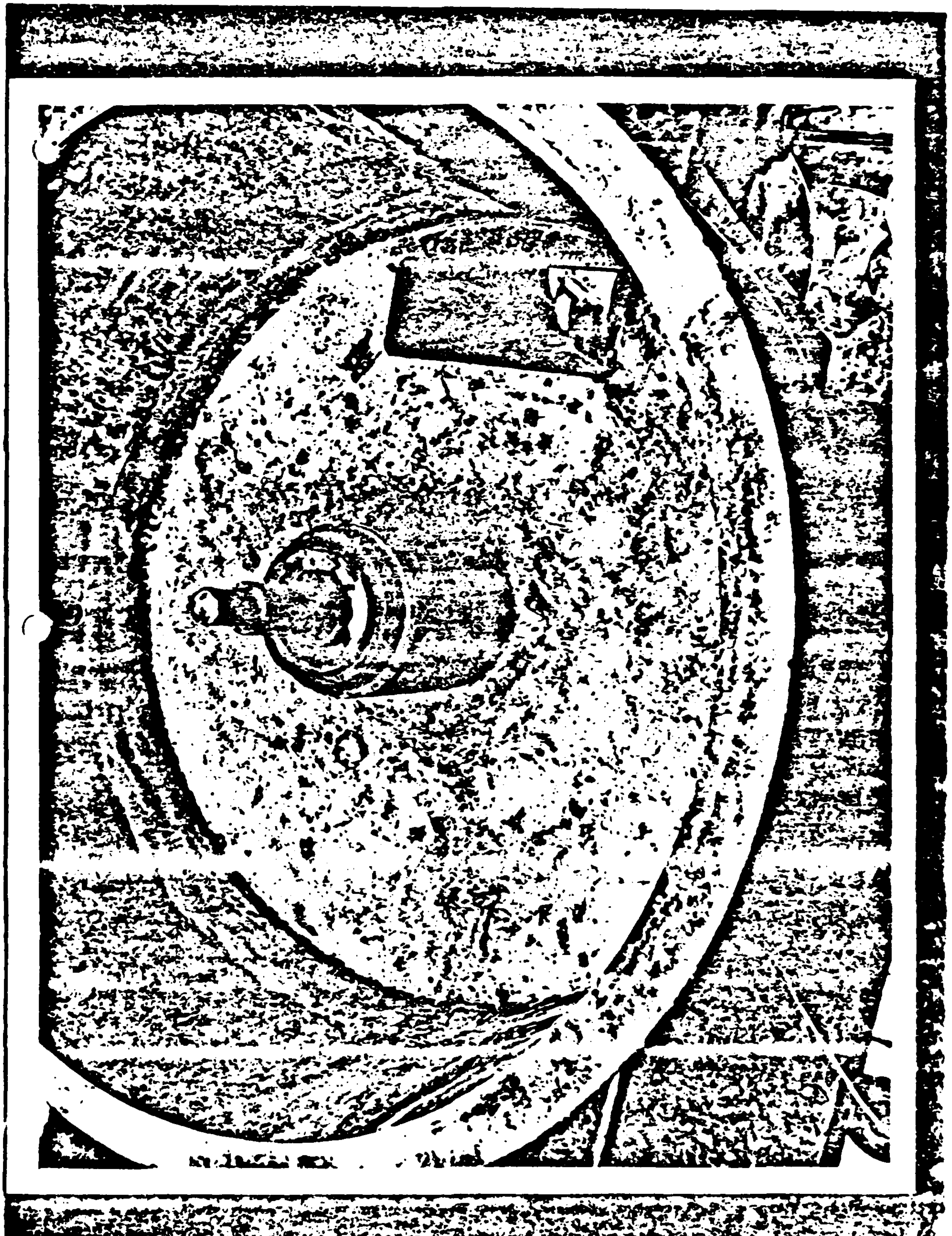
Exterior of Bldg C-11 after explosion. Bay 9 is on the right side of the three bays shown in the front of the picture.

Corridor in Front of Bay 9

Bay 9 after explosion

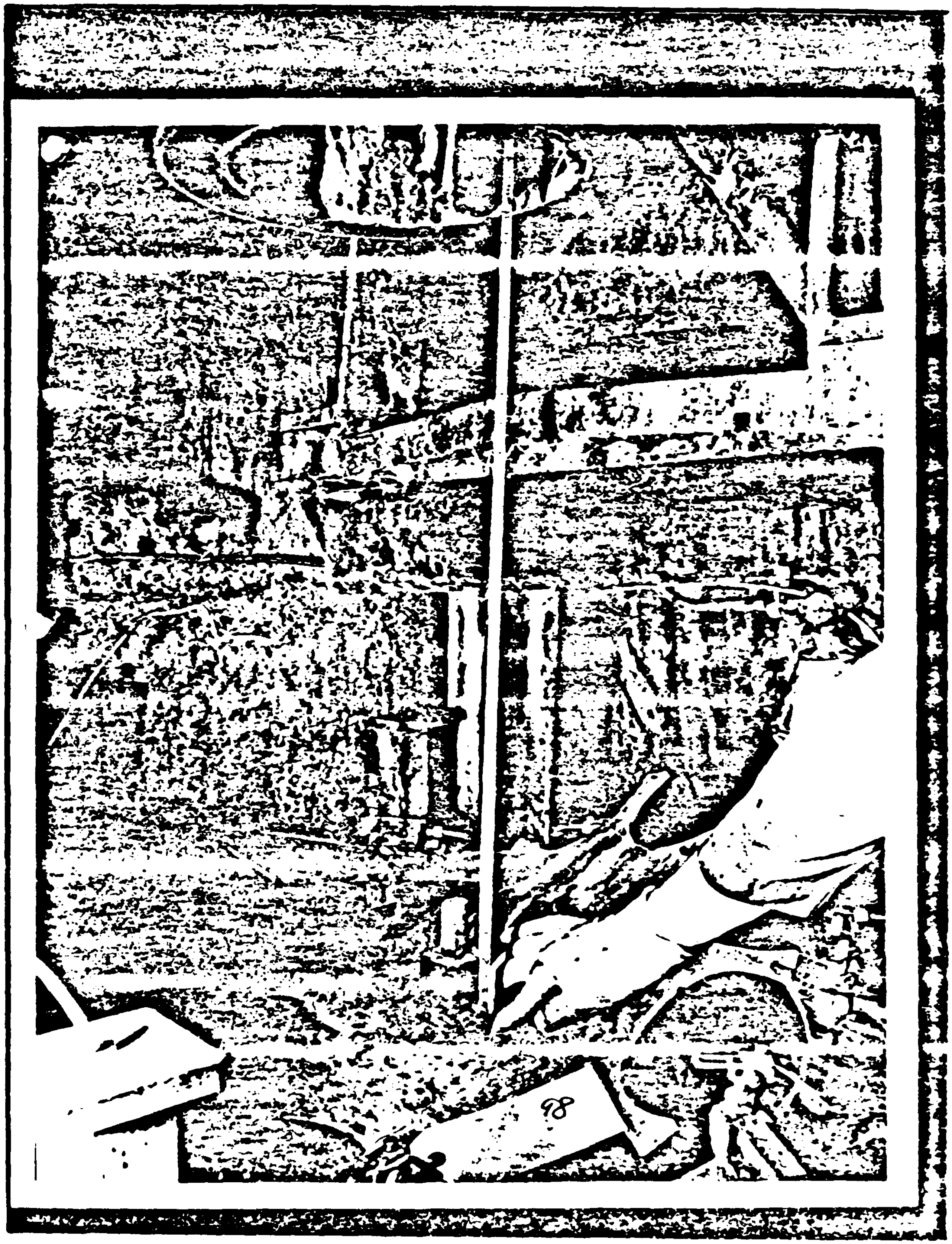
Bay 9 after the explosion.

Mix muller. Dump door/opening is at 9:00 position.

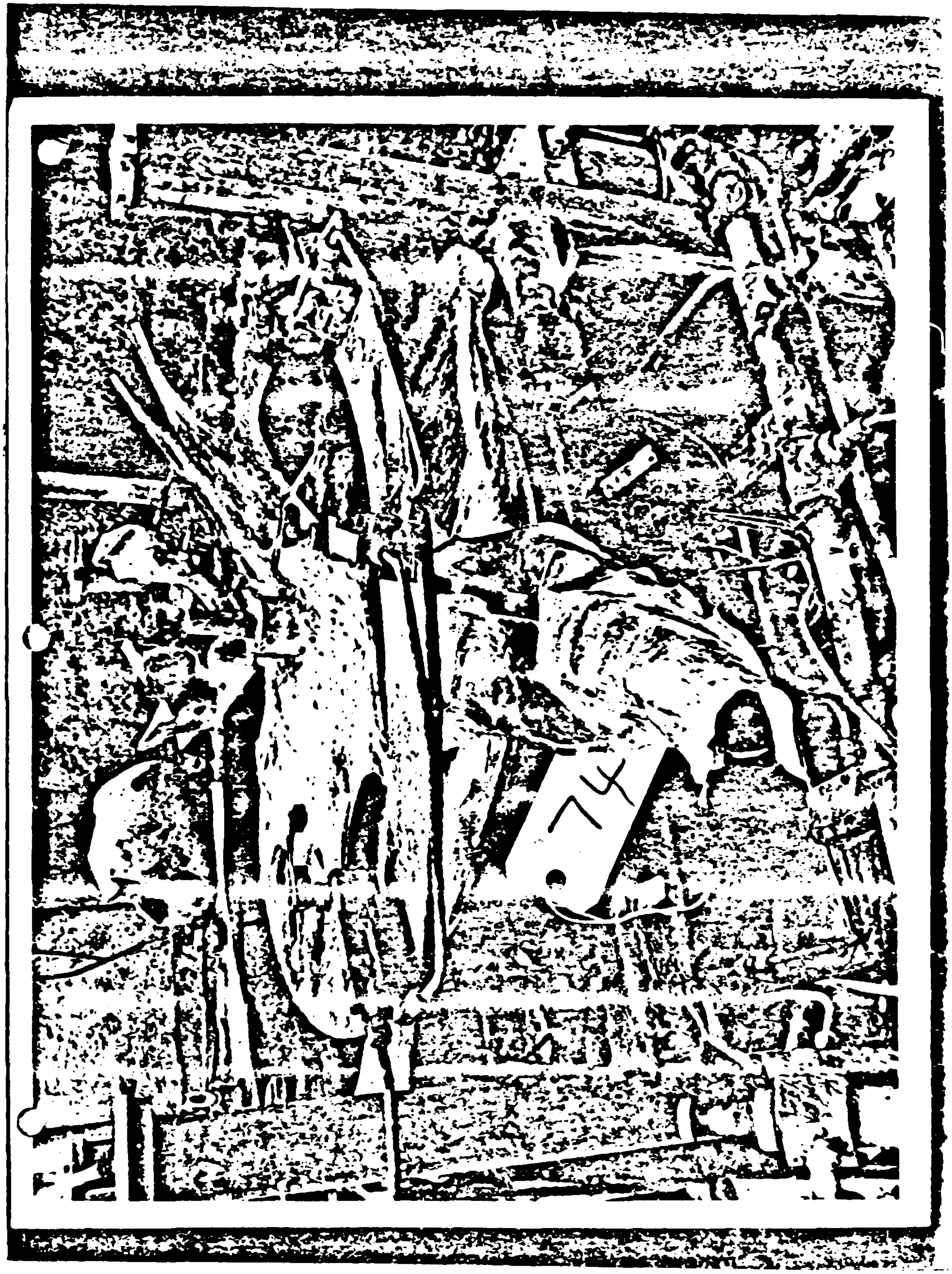


Mix muller with wheel assembly removed.

Collection chute from mixer to dial table.

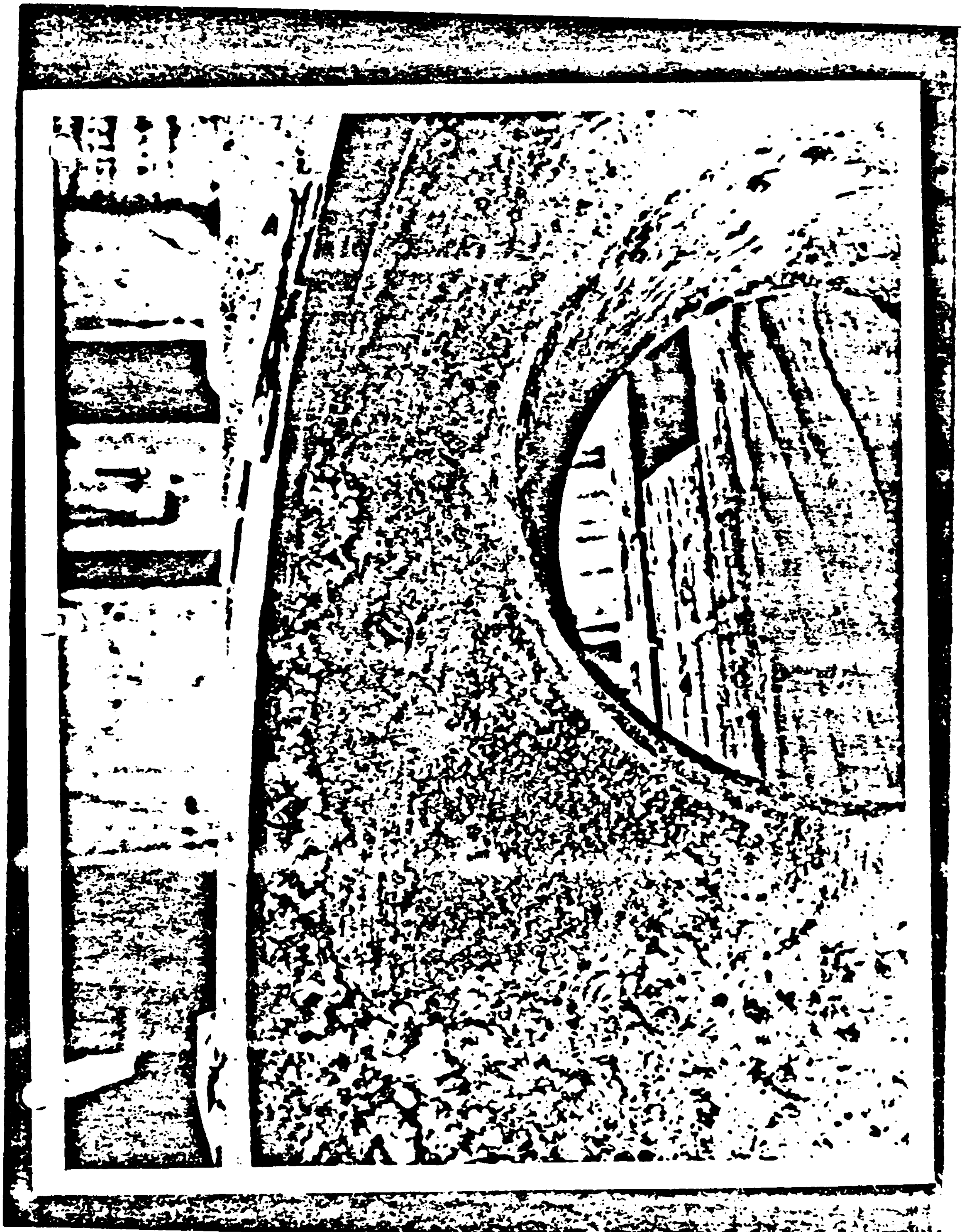


Shows the distance the igniter mix had to drop from the mixer to the dial assembly. (approximately 3.5 ft)



Dial Table

Lower Dial Assembly. Collection containers sit in the holes of the assembly.



Lower dial assembly near possible point of ignition.

Lower assembly after the explosion is in the center of the picture.

Low Cost, Combination RF and Electrostatic Ferrite Device Protection for Electroexplosive Devices

by
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Abstract: ATI has developed a series of low cost, RF protection devices that are used inside electroexplosive devices (EEDs). The first series provided only RF protection using MN 67 Ferrite Formulation manufactured into ferrite beads, baluns, and chokes. An improved Ferrite Formulation, MN 68™, provides both RF and electrostatic (ES) protection in the same types of ferrite devices. Now that ATI better understands the EED protection theories, any ferrite that meets an ATI generic specification can be used to provide the combination RF and ES protection.

ATI can provide Certified Ferrite Devices that meet the performance characteristics of devices that previously passed MIL STD 1385B field tests in a wide variety of EED applications. These measurements and certifications can be done at three points in the ferrite device production cycle. The first is on the bare ferrite device before it is wound. The second is after the ferrite device has been wound with the appropriate winding pattern to attenuate to the required RF attenuation level. The third point is after the wound ferrite device is permanently installed in the EED. ATI retains samples of each lot of ferrite devices that has passed MIL STD 1385B field testing as baseline standards for certification of subsequent production lots.

ATI has a very strong intellectual property rights position in the combination RF and ES EED protection area. The first, US Patent 4,378,738, covers MN 67 applications. The second, US Patent 5,036,768 covers MN 68™ applications and is the first of several continuation-in-part patents. Eight other US Patent Applications cover specific applications, different winding patterns, measurement methods, and applications outside of the EED areas. Overseas patent protection is in process. ATI has also applied for USA Trade Marks and Certification Marks on these devices to assure proper identification of the devices that have passed this rigorous inspection and certification procedure.

ATI first buys large lots of ferrite formulation powder in order to certify that the formulation is correct before any ferrite devices are produced. Manufacturers then produce ferrite devices solely for ATI that operate within ATI specification limits. The USA companies have a combined production capacity exceeding 50,000,000 ferrite devices per year. There is a parallel commercial winding contractor with corresponding capability. Pilot production lots as large as 25,000 bare ferrite devices have been successfully produced for and certified by ATI.

Background: For many years the potential for a simple, low cost ferrite device solution to solve the problem of inadvertent ignition of EED by stray RF energy has proved elusive. Now that the physical principles required for selecting first the ferrite formulation and then the ferrite device are understood, the technical solution has become clear and relatively simple. Prior to that understanding, many of us were on the wrong track with the selection of the ferrite formulation, the type of ferrite device required, its winding pattern, and the installation method in the EED.

New Ferrite Device Requirements: The first requirement is that there be no adhesive between the attenuating ferrite device and the EED's conductive case thereby providing good electrical contact between the two items. This contact also allows heat transfer to take place between the active ferrite and the heat radiator provided by the EED's metal case.

The second requirement is that the lead wires passing through the ferrite device must be bare and make good contact with the ferrite device. Without insulation there is no need to worry about long term insulation failure on the new generation of EEDs. Having bare lead wires allows the designer to take full advantage of the electrical properties to the ferrite to provide high impedance to incoming RF energy and to equalize the ES potential.

The third requirement is that the ferrite formulation have certain critical properties. These include:

1. A high Curie Temperature. Curie temperatures above 250^{o}C are required for EEDs without heat sinks. Several commercially available ferrite formulations have Curie Temperatures of 250^{o} or higher. ATI also has samples of these ferrites from overseas.

2. The RF attenuation starts at low frequencies. The ferrite formulation should start providing appreciable RF attenuation at frequencies no higher than 1 megahertz. Several of the newer ferrite formulations begin to be effective below 200 kilohertz. ATI is working on getting even lower actuation frequencies.

3. The ferrite devices have a DC resistance that is controlled within specified limits. If the DC resistance is too low, the EED's DC firing signal will not meet the all-fire and no-fire requirements. Prior to ATI's starting work in this area, all ferrites used for EED applications were considered to be nonconducting, or were installed with adhesives to electrically insulate them from the conductive case.

The fourth requirement is that the ferrite device must provide the correct conductor pattern. The ferrite device must be wound in such a manner to provide broad band RF protection from broadcast frequencies of one megahertz through radar frequencies in the gigahertz regions without any resonant frequencies.

Resonant frequencies would require providing additional electronic devices to protect those frequencies. These winding patterns have been demonstrated and independently verified by Franklin Research Center testing and reports. The second part of the winding pattern requirement is that it must provide sufficient RF attenuation to pass the RF attenuation specification over the entire frequency range. As an example, the ATI patented ferrite choke winding patterns are the only ones that will provide sufficient attenuation for an EED with exposed wire firing leads to pass MIL STD 1385B requirements. Improperly wound ferrite chokes will not pass MIL STD 1385B tests, and neither will single hole ferrite beads or two hole ferrite balun devices, even if they are stacked in series.

Types of Protection Provided: Once these four ferrite device requirements were met, it was determined that:

1. The wound ferrite device provided RF protection both pin-to-pin and pin-to-case over the required frequency range without any significant resonant frequencies.

2. The ferrite device provided protection against both intermittent and continuous RF energy sources.

3. One small ferrite device positioned inside the conductive case could provide all of the protection required.

4. If properly selected, the ferrite device could also provide protection against stray ES energy inadvertently initiating the EED. The ES protection was also determined to be for both pin-to-pin and pin-to-case energy inputs. The ferrite devices were also determined to be able to withstand repeated ES exposures without changing performance as some other ES protection devices do. The ferrite devices were able to survive higher ES potentials and higher power levels than other ES protective devices. The ferrite devices appear to absorb the ES energy and then bleed it out slowly in a controlled manner over large contact areas and over longer time frames.

5. The combined RF and ES protection can be provided for two wire and single wire EEDs. Examples of the two wire systems include the Mk 11 Mod 0 Electric Blasting Cap (EBC) and the Mk 20 Mod 0 Electric Squib. Both EOD Firing Line Filters are examples of one wire systems wound on MN 67 Ferrite Choke cores to provide the level of RF attenuation required for firing lines almost one mile long. The EOD firing line filters are used with the Mk 209 Mod 0 Cartridges. All of the systems listed above have been field tested to MIL STD 1385B requirements by the US Navy and are designated as HERO Safe, even though they all have exposed metal firing leads or long firing lines.

6. The ferrite protection device can be located either in the EED itself or in the firing line, if the remaining portion of

the firing line, between the ferrite device and the EED, is properly shielded. Because of the low unit cost, in most cases it is a lower cost approach to put the ferrite device in the EED and destroy it with each use, than it is to have a reusable ferrite device and shield the firing lead from the ferrite to the EED.

These results have been independently verified by Franklin Research Center reports issued over the last 14 years while this technology was slowly evolving. Within the last three years other companies have independently verified the performance of this new technology as their EEDs progressed through the R&D development process.

Levels of RF Protection Provided: Franklin Research Center determined that the Mk 11 Mod 0 EBC with MN 67 Ferrite Choke withstood 4 watts of continuously matched impedance RF energy for 5 minutes at 1 megahertz without firing (Ref. 1).

Franklin Research Center determined that the Mk 11 Mod 0 EBC with the MN 68™ Ferrite Choke in place of the MN 67 Ferrite Choke withstood 19 watts of continuously matched impedance RF energy for 5 minutes at 1 megahertz without firing (Ref 2).

As ATI better understood the requirements for combined RF & ES protection, the EED protection levels achieved have improved markedly. Franklin Research Center has not tested ATI generic ferrite formulations yet, but ATI is looking for financial assistance to test these new formulations to determine how they compare to MN™ 68 Ferrite Chokes.

New Applications for ATI Ferrite Devices: The ATI protection technologies were known to be suitable for applications using bridgewire ignition EED designs as early as 1981. Recently, ATI has been working with Thiokol Corporation to determine if the ATI protection technologies are applicable to other ignition systems such as SCB precision firing ignition devices disclosed in US 4,708,060. Thiokol is investigating using an ATI Ferrite Device in combination with the SCB for the MK 66 Igniter application. While written test reports have not been made available, verbal reports from the USN stated that the Thiokol R&D version of the Mk 66 Igniter passed MIL STD 1385B testing. As of the preparation date for this paper, the electrostatic testing has not been accomplished. One of the concerns of using the ATI Ferrite Device with the SCB was that the DC firing pulse, being only microseconds long, would be attenuated by the ATI Ferrite Device. Reproducible firing of the combination SCB device has, so far, not been a problem. Additional tests are planned by Thiokol.

Other new EED applications are in various stages of R&D development. Projects include on-board, aircraft engine fire extinguishers; electric blasting caps; cartridge actuated devices; and precision firing, ignition modules. Since ATI is only supplying the ferrite protection devices for these projects, it will be left to the developer of each of these devices to report on details of their projects. The really significant result derived from all of these projects is that the ATI technologies appear to have broad applications beyond the initial bridgewire application projects reported and referenced by FRC above and further amplified in this report.

Any new ferrite device can be manufactured by pressing the ferrite formulation using paired dies and stakes specific to each application. The die is used to produce the ferrite device's outside diameter and length. The stake is used to produce the hole pattern. Any reasonable diameter, length, and hole pattern can be produced. ATI laboratory tests using MN 68™ Ferrite Devices indicate that wound chokes as small as 3 mm in diameter and 3 mm long should be sufficient to pass MIL STD 1385B requirements. The current ferrite devices are made larger to fit the inside diameter of the EED.

Current lead time for new tooling is about 12 weeks. Another method for obtaining R&D samples is to grind down existing ferrite devices. Both the overall length and outside diameter have been successfully ground down. ATI recommends that process be left to experts to get as representative samples to production items as possible. Samples can be obtained in about 4 weeks using the specialty grinding method.

ATI Intellectual Property Rights: ATI has the following USA intellectual property rights:

1. USA Patent 4,378,738 covers all aspects of using ferrite formulation MN 67 and its devices in EED applications.

2. USA Patent 5,036,768 covers all aspects of using ferrite formulation MN 68™ and its devices in EED applications. This is the main patent for a continuing series of continuation-in-part patent applications.

3. ATI has applied for a Registered US Trade Mark on MN 68. This is official recognition that MN 68™ Ferrite Formulation is unique and can not be copied by other ferrite manufacturers, users, or suppliers.

4. ATI has applied for a Certification Mark to differentiate ATI Certified Ferrite Devices from all others. The methods of measuring these devices is patent protected, the lot certification record keeping unmatched, and the certification process unique.

Not only has ATI applied for USA intellectual property rights protection, it is also filing for selected overseas protection.

As an example, ATI's first South African Patent should issue any day. South Africa is one of the major users of explosives in the world and is undertaking a major increase in protection levels for shallow mining activities.

ATI intends to fully enforce and defend any infringements of its intellectual property rights whatsoever.

<u>ATI Patent Applications Pending</u>: ATI has the following Patent Applications pending:

1. The use of generic specification ferrite formulations for combined RF & ES Protection for all EED Applications;

2. The use of generic ferrite devices in all EED applications;

3. On-line, 100% sampling for RF and other acceptance testing of ATI protected EEDs while still on the assembly line with an optional record keeping capability;

4. Combined RF & ES protection for specific EED applications;

5. Combined RF & ES protection for bridgewire and SCB initiators applications;

6. EEDs resistant to nearby lightning strikes;

7. Multiple, combined function ferrite devices;

8. RF & ES Protection for commercial electronic equipment.

Other patent applications are in preparation as our new technologies are further developed and new applications become evident.

<u>Products and Services Available from ATI</u>: ATI can provided Certified MN 67 Ferrite Chokes as both the bare cores and properly wound and functional ferrite chokes. MN 67 Chokes that previously passed MIL STD 1385B Certification in the Mk 11 Mod 0 EBC and Mk 20 Mod 0 Electric Squib are in the baseline certification program.

The exact same devices and certifications are available for the MN 68™ Devices. ATI is encouraging all projects to use MN 68™ Ferrite Devices in place of the MN 67 versions, since the MN 68™ Ferrite Devices are in stock, are now lower cost, provide combined RF & ES protection, and provide a greater safety margin when used in EED applications compared to MN 67 versions.

ATI Certified Ferrite Devices can be provided as bare ferrite cores or correctly wound ferrite devices. ATI inspection can be performed on the bare cores, on the wound choke before insertion into the EED, or on the explosively loaded, all-up EED using a combination of RF and DC energy.

Direct engineering support, technical support, and consultation services are also available from ATI to support new design work, R&D development programs, producing ferrite devices for specific applications, providing samples for evaluation among others.

Production Quantities & Certification Available: The largest lot that ATI has purchased and certified is 25,000 units of bare ferrite devices. The low quantities are not limited by capacity of any manufacturer or qualified ferrite formulation, but primarily because the current development programs are small and require the lower numbers to complete the project.

Early in the development cycle for the ferrite devices, ATI decided not to be limited to one ferrite formulation supplier or ferrite device manufacturer. It was difficult, time consuming, and costly to get multiple suppliers when the market was very small. Having multiple, qualified sources will pay off as the number of applications and quantities of ferrite devices required increase. With multiple, qualified sources, competition will tend to keep prices lower and delivery dates shorter.

ATI has already made the investment for the production tooling required to produce ferrite cores to NAVSEA 5206533 drawing requirements. For ferrite devices similar to NAVSEA 5206533, the combined estimated production capacity is 50,000,000 devices per year. That yearly capacity could be increased, if required, with as little as one year notice.

The unit cost goal of $0.28 each for the bare core quantities of 1,000,000 per year currently appear achievable. Also, ATI is already investigating ways to lower the unit cost. Since MN 68™ Devices have such large safety margins, it may be possible to:

1. Decrease the length of the bare core

2. Decrease the diameter of the bare core

3. Loosen dimensional tolerances on the bare core

4. Simplify the design by changing the hole pattern and progressing to a cylindrical design.

In-house ATI Projects: ATI is conducting a number of in-house, internally funded efforts to:

1. Provide automatic winding of the ferrite devices to lower the unit price of the wound ferrite chokes

2. Provide winding patterns to minimize or eliminate welds or solder joints in the wound EED firing leads

3. Provide complete assemblies including firing leads, wound ferrite device and initiation mechanism ready for insertion into the EED.

Summary: ATI has expanded their technology to include the use of MN™ 68 Ferrite Devices as a combined RF and ES protection improved replacement for the MN 67 Ferrite Devices previously reported. ATI has developed a generic specification to provide combined RF and ES protection for EEDs using any ferrite formulation meeting those requirements. ATI can provide certified ferrite devices that have the same performance as those previously passing MIL STD 1385B field testing. ATI has extensive intellectual property rights in this combined protection area including issued patents, patent applications, trade marks and certification marks for their ferrite devices.

References:

1. J. Heffron, "RF and Electrostatic Testing of Detonators" Franklin Research Center Technical Report F-C5067 December 1979

2. J. Stuart, "Tests on RF-Protected Blasting Caps Mark 11 Mod 0" Franklin Research Center Final Report P247 October 1990

Operation Desert Sweep
The Restoration of Kuwait

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Abstract: This paper will provide the reader an insight into the magnitude of Ordnance and Explosive Waste (OEW) that is present in the US sector of Kuwait and how it is being detected, detonated or rendered safe, and disposed. Techniques and technologies that are being employed to ensure maximum safety and quality will be highlighted throughout this paper.

Operation Desert Sweep
The Restoration of Kuwait

In August 1990, Iraq invaded Kuwait. Then, as the United Nations coalition forces massed along the Saudi border in what was called Operation Desert Shield, Iraq dug in, laid mines and stockpiled hugh caches of munitions. When efforts to negotiate a peaceful settlement failed, Desert Storm was unleashed. For days, the Iraqi positions were bombarded in the most prolific aerial campaign in history. Then the land battle was joined, and in 100 hours Kuwait was free. The war was over, but a lethal battleground remained.

The Gulf War freed left the Kuwait countryside with enormous environmental restoration problems. Cashes of munitions, shells and other ordnance were left throughout the country. Oil wells were burning uncontrolled. Leaking oil created lakes of tar in the desert. The country's infrastructure was severely damaged - as road networks, utilities, housing, entire cities were destroyed. Damaged military hardware was scattered across the country, still filled with ordnance and POL (petroleum, oil and lubricants). Bunkers littered with all types of ordnance were dug throughout Kuwait. Hundreds of kilometers of minefields had been laid across the country, some covered by shifting sand and leaking oil.

When the Gulf conflict ended, the Kuwait Government divided the country (about the size of New Jersey) into six sectors and began negotiating Explosive Ordnance Disposal (EOD) contracts with six different counties, rewarding some of the coalition partners that helped oust Iraq. Later a seventh sector for Turkey was added.

The US designated sector is reportedly the heaviest contaminated area of the seven sectors, partly because it was subjected to the most intense aerial attacks of the war. American B-52s alone dropped over 800 tons of munitions during 527 interdiction missions against the Iraqi forces. Thousands of these munitions were cluster bombs which had a very high dud rate. In addition, unexploded ordnance (UXO) from more than a dozen countries is spread over the land.

The US sector also includes three major oil fields - Al Wafra, Um Gudair, and Al Burgan. In addition, there is a military airbase (Al Jaber) which was heavily targeted during the war, and over 150 km of minefields which were laid across the landscape. Finally, there are heavy contamination sites from unexploded ordnance in the central and southwestern areas.

In April 1991, CMS began negotiations with the Kuwait Ministry of Defense (KMOD). In October 1991, CMS was awarded a $134 million contract. The contract was divided into two phases: A four month mobilization phase provided time for build up of equipment, personnel and housing. An eighteen month performance phase covers the execution of the work, which includes: 1. Locating and clearing unexploded ordnance, 2. Removing war damaged military vehicles, and 3. Demolishing bunkers and reclaiming the land.

During the mobilization phase, CMS undertook a massive international effort to rebuild an infrastructure for use in country - living quarters, medical services, transportation, telephone, FAXes, copy machines, computers, etc. Experienced, trained and certified personnel were positioned to staff the more than 500-man team. The movement of $24 million worth of equipment from several countries, including Austria, US, and Germany, was a huge logistical challenge. Obtaining permits and other licensing requirements from the Kuwait MOD was complicated by the disarray of the country after the war. Despite all these road blocks, CMS successfully mobilized the personnel, equipment and materials within the required 4 month period.

One of the first tasks accomplished in Kuwait was the establishment of a support base of operations. CMS secured the Al Habdan Towers located along the coastline of Kuwait in the city of Fahaheel. This bombed-out multitower facility was completely renovated and refurnished. The facility houses all the American technicians working in Kuwait, and has office space for the CMS Program Office as well. The facility also has a large dining facility, recreation room, pool, tennis courts, and laundry facilities. Adjacent to the Towers is the CMS Motor Pool and maintenance facility.

The CMS EOD project, dubbed "Operation Desert Sweep", is staffed in Fahaheel, Kuwait and CMS headquarters in Tampa, Florida. The majority of CMS employees are former U.S. military personnel and are therefore comfortable with large scale EOD operations. As an example, the Deputy Director of Explosive Ordnance Disposal Operations is the former commandant of the EOD training school at Indian Head, Maryland.

After successful mobilization, CMS entered into the performance phase of the contract. The first step in the performance phase was to specify the requirements for the remediation operations. CMS divided the US sector into 36 smaller, more manageable subsectors. A thorough and detailed survey and reconnaissance was conducted on each subsector to identify the type, location and condition of UXO, mines, vehicles, trenches and bunkers.

During the survey and reconnaissance phase, EOD teams went into each subsector and gathered essential information on the contaminates found. The teams used Global Positioning Systems (GPS) to precisely record the position of ordnance and other contaminations. A CMS proprietary software system called Minefield and Ordnance Recovery System (MORS) was used to collate the data collected during the reconnaissance. Through the use of MORS, the data is archived and can be used to create very accurate maps showing the location of the items. The data in MORS, when combined with information such as vehicle and personnel availability, is used to plan, manage and conduct clearance operations. The MORS data is also essential in performing Quality Assurance for clearance operations.

Following proven military practices and procedures, CMS then disposes of ordnance, removes damaged equipment and restores the Kuwait desert to normalcy. Throughout the entire performance phase, CMS' own Quality Assurance Teams ensures the operations are being conducted safely and that clearance was accomplished to predetermined levels.

One of the major tasks facing the CMS EOD teams is the removal and disposal of approximately 150 kilometers of minefields containing over 750,000 anti-personnel and anti-tank mines from twenty different countries. The clearing of mines and ordnance is very dangerous; therefore, safety if foremost in all clearance operations. For example, the latest and most advanced Austrian Schiebel mine detector is in use. This device is capable of detecting mines with very little metal content. New techniques are also evaluated, such as an ingenious mine cruncher. Where technology has not caught up to a particular requirement, innovative techniques are used to safely and successfully accomplish a clearance task.

One of the innovative techniques used in the disposal of anti-personnel mines is the use of a specially adapted excavator. The excavator has been armored and the bucket has been replaced with a specially designed rake which is used to detonate the smaller anti-personnel mines. After a tract is cleared, the CMS QA team certifies that the area is clean and safe.

In addition to the minefields, the Iraqis left seven immense underground ammo supply sites containing thousands of tons of Iraqi ordnance which must be removed. Furthermore, there were heavily fortified bunkers and trenches, which were used for ordnance storage, vehicle fighting positions and command posts. These bunkers must be reclaimed.

More than a dozen countries took part in the air and ground war. Therefore, it is difficult to imagine the variety of shells, rounds, grenades etc that litter the country side. For the most part, this ordnance is rendered safe and transported to a location in a remote area. The munitions are placed in a ditch; C4 blocks are placed around the UXO; covered with dirt and then imploded. Ordnance which can not be safely moved is destroyed in place. The munitions found in containers in the ASPs is turned over to the KMOD. The CMS QA team then inspects the area for cleared munitions.

The war damaged military equipment posses a difficult removal problem. The vehicle's ammunition stores and POL are still on board and must be removed first. Some of this equipment is buried in sand or standing in oil. After the vehicle is rendered safe, it is transported using heavy equipment and flatbed trucks to a holding area for later disposal by the KMOD. The CMS QA team and KMOD inspects the area for contaminates.

Professionalism and safety permeate the CMS operations. CMS personnel working on this project are all highly skilled professionals with emphasis on EOD disposal. All CMS EOD technicians are graduates of the US Naval EOD School in Indian Head, Maryland. They have has extensive service in a US military EOD unit with hands-on experience and demonstrated leadership skills. Although already trained in EOD techniques, all EOD personnel are recertified through our training program. The CMS certification program is an eighty hour program combining classroom teaching with field exercises. No technicians are sent into the desert without adequate training and safety indoctrination.

CMS has established a Test and Evaluation group to continuously research new and innovative technologies, such as robotics, and remote sensing devices which can be applied to clearance operations. CMS also assists the Kuwait Government with public awareness programs. Finally, all CMS personnel are educated on Kuwait customs and culture before they enter the country.

To give the reader an idea of the enormous task that CMS has undertaken, the following program status, as of 26 JULY 1992 (5 months into the performance phase of the contract), is provided:
Tons of Ordnance Destroyed: 4,326
Tons of Ordnance Removed: 1,504
Mines Destroyed: 131,754
Vehicles Removed: 1,406
Sectors Cleared and QA'd: 12 (KMOD), 17 (CMS)

In summary, Operation Desert Sweep is an unprecedented EOD and site restoration program. CMS has successfully met the challenge and is not only meeting the requirements but is performing ahead of schedule. CMS is proud to participate with the government of Kuwait in this humanitarian operation.

A BRIEF HISTORY OF LIGHTNING PROTECTION

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ABSTRACT

Over the past several years considerable interest has been given by various agencies of the federal government to lightning protection. The lightning protection systems and underlying principles used today have evolved slowly over the 200 plus years Ben Franklin invented the first lightning rod. As knowledge of the lightning phenomenon expands, these principles and systems will continue to evolve. This paper presents a very brief history of this evolution.

BRIEF HISTORY

There has recently been much Department of Defense interest in lightning protection systems. Most of this attention has centered on the adequate safeguarding of conventional and nuclear weapons from the effects of a lightning strike. Some attention has also been given to the use of systems designed to dissipate or prevent lightning. This particular concept has actually been around since Ben Franklin first proposed it in the 1700s.

Most people know of Ben Franklin's kite experiment, but less well-known is the fact that this experiment was the result of his active experimentation with what was then known as "electrical fluid." By extensive experimentation, Franklin had observed that static electricity could be conducted away from a charged sphere by a nearby sharp, iron needle. Noticing the physical similarities between this static electricity and lightning, he wrote the following in 1749." The electrical fluid agrees with lightning in these particulars:

1) Giving light
2) Color of the light
3) Crooked direction
4) Swift motion
5) Being conducted by metals
6) Crack or noise in exploding
7) Subsisting in water or ice
8) Rending bodies it passes through
9) Destroying animals
10) Melting metals
11) Firing flammable substances
12) Sulphureous smell

Franklin further wrote "The electrical fluid is attracted by points. We do not know if this property is in lightning. But since they agree in all particulars wherein we can already compare them is it not probable they agree likewise in this? Let the experiment be made." Whereupon in 1750 he flew a kite in a thunderstorm and produced a spark to his hand from a metal key tied to the string. Having proved lightning is a form of electricity, he suggested that thunderstorms could be discharged by elevated, pointed iron rods connected to earth in the same manner as a sharp iron needle conducts electricity away from a charged sphere. After a few trials he proposed another concept for lightning rods. He suggested that if the rods did not discharge the thunderstorm, one of them might intercept a stroke and conduct it safely to earth, thereby protecting the building. Franklin never pursued this second theory and recommended that all rods have sharp points to prevent lightning. It is interesting to note that Franklin's rods were simply long iron rods driven about 3 feet into the ground, stapled to the end of a house and projected 6 or 8 feet above the ridge. Given the average height of houses back then this would make the rod 35' to 40' long (Fig.1). In comparison, modern rods are rarely over 10" long and are connected to cables for grounding purposes.

Almost immediately a disagreement arose in England over the use of sharp rods. King George III equipped his palace with blunt rods in the belief that "sharpened rods might attract lightning and thus promote the mischief that it was hoped to prevent." Controversy continued until by 1878 lightning protection practices were so diverse that the British Meteorological Society (BMS) called an international meeting of engineers and scientists to review existing knowledge and to formulate general rules for the erection of lightning rods. The report issued in 1881 covered current American practices, among them was Joseph Henry's advice that the upper part of the rod should be terminated in a single point, the cone of which should be encased with platinum not less than 1/20" in thickness." Another American advocated the use of cast iron caps on chimneys and other protuberances. The formal position of the report on sharpened rods was the following equivocation: "...it seems best to separate the double functions of the point...beveling it off so that if a disruptive discharge does take place, the full conducting power of the rod may be ready to receive it... At the same time we suggest that at one foot below the extreme top of the upper terminal that there be firmly attached...a copper ring bearing 3 or 4 copper needles, each 6 inches long.." Needless to say, these recommendations did nothing to end the controversy over the best method to protect against lightning.

In 1901, the British Lightning Research Committee was formed to again address the issue. Oddly, this committee devoted little time to the shape of the upper part of rods. Instead it gave more attention to down conductors, the problem of making better contact with the earth, and the area of protection. In a classic bit of equivocation, the committee seemingly endorsed a cone of protection where the base of the protected cone has a radius equal to the height of the rod above ground when it wrote "though this may be sufficiently correct for practical purposes, it cannot always be relied on." Other cones of protection, such as 1:1 3/4 and 1:2, where flatly rejected. Sir Oliver Lodge was a major contributor to the report issued by this committee. Among the ideas that he mentioned in the report and which still form the basis of modern protection are the following:

1) The effect of down conductor self induction needs to be accounted for.

2) Lightning will distribute itself over "such conductors as may be present" with little regard to resistance.

3) Lightning finds "no great difficulty" in traveling great distances through air or any "other medium of rather better conductivity."

4) It prefers to move in a straight line and that "sharp turns bends, or spiral windings in conductors" may lead to side flashes.

Much progress was made, but the configuration of rods remained predictably diverse.

In America in 1904 the National Fire Protection Association (NFPA) adopted the first edition of NFPA #78, The National Lightning Protection Code. This was the first American national concensus standard. While not specifically addressing point discharge controversy, its advent paralleled the rapidly growing electrical industry. Miles and miles of overhead lines were being strung. Metallic conductors installed to bring electricity into buildings also brought lightning. The lightning induced power outage thus came into being. Surge arresters were developed as knowledge of lightning protection struggled to keep up with technology.

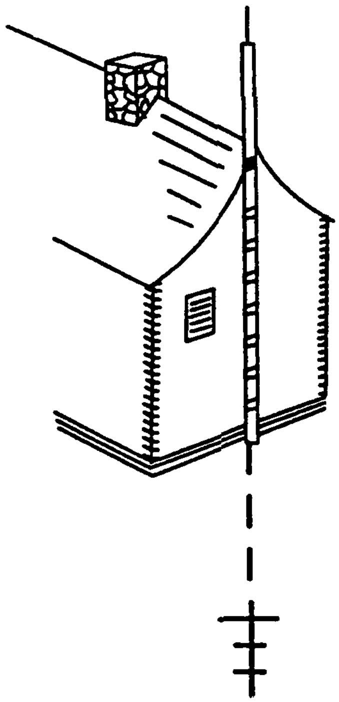
Beginning in 1926, the US government became interested in lightning protection. In the summer of that year, lightning initiated a devastating series of explosions at the Lake Denmark munitions depot in New Jersey. Over a million pounds of explosives were detonated and 19 lives were tragically lost. This catastrophy resulted in the formation of the DOD Explosives Safety Board which still functions today with the charter to oversee and provide guidance and regulations to insure the safety of all US titled munitions. From 1941 through the second world war, much effort was expended protecting arsenals, defense plants, munitions dumps, and related government facilities. The basis of this protection was NFPA #78.

In the late 1970s, a new "zone of protection" concept was introduced - the rolling ball concept. Experience had shown that traditional straight line "cones of protection" from the tip of the lightning rod to some distance on the ground could not always be depended upon to provide full protection. The rolling ball concept has proven to be effective because lightning advances from cloud to earth in discrete distances or steps of about 150 ft. Only when a downward stroke reaches a distance of about 150' above the earth will it be positively attracted to a point to be struck. This concept of area of protection is easiest to understand by visualizing a weightless ball (or sphere) with a 150 ft radius rolling over the surface of the earth and up and over all projections above the earth's surface (Fig 2). Anything touched by the ball is susceptible to being struck by lightning, while all objects not touched by virtue of the ball being lifted over them by higher objects are protected.

Presently, some of the more interesting (and DOD pertinent) research is being conducted by Mr Marvin Morris of Sandia National Laboratories in Albuquerque, NM. By using modern instrumentation and rocket-triggered lightning, Mr Morris and his associates have been able to measure the voltage, electric, and magnetic fields generated inside an earth covered munitions igloo during a lightning strike. Current densities in the various paths to ground were also measured. This research has turned up some surprising data which may eventually change lightning protection on DOD munitions facilities. Electric and magnetic fields were measured below harmful levels while voltage levels were low enough to permit a minimum 12 inch separation from walls and metal masses without causing a flash over. One of the most interesting findings was that most of the current from the lightning stroke was conducted through the structure re-bar system to the floor and foundation and then to earth. A very small percentage of current actually passed through the down conductors to the ground rods and earth. This, of course, is because the massive re-bar system in a typical igloo has much less inductance than the down conductors. A very significant discovery is that rise time (the amount of time it takes the lightning induced impulses to reach maximum value) is 3 times faster (.3 micro seconds) than previously thought. This has implications in DOD munitions maintenance and inspection building where a faster rise time can more easily induce current into weapons open for maintenance. This research is continuing and hopefully will result in DOD components being able to spend their lightning protection design and maintenance money more wisely.

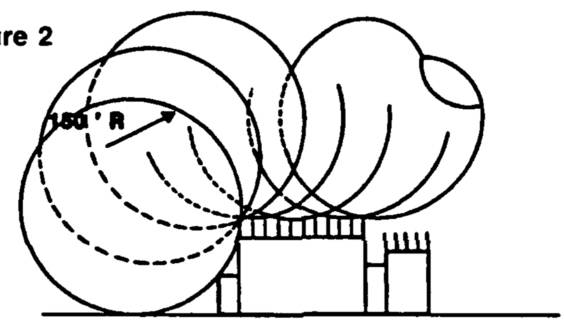
But what about the controversy of sharp points either attracting lightning on bleeding the charge from a cloud? It is now well known that sharpened rods do not sufficiently dissipate electrical charges in active thunderclouds overhead, nor do they attract lightning. Nature is full of these point discharge sources which disprove the dissipation/attraction theory. A pine forest has literally millions of point discharge sources (pine needles) yet lightning does strike it and at a rate well within statistical bounds. Notwithstanding this and other scientific data, systems are still being sold today based on their ability to prevent lightning strikes. In the late 1980s, the Federal Aviation Administration (FAA) installed lightning dissipation systems at the Orlando and Tampa airports for the

Figure 1



BEN FRANKLIN'S LIGHTNING ROD
(ADAPTED FROM LIGHTNING PROTECTION INSTITUTE STUDY COURSE)

Figure 2



ROLLING BALL CONCEPT OF AREA PROTECTION
(ADAPTED FROM NFPA #78)

purpose of testing the effectiveness of these systems. The systems were monitored closely for 2 years. In 1991, the FAA gave Congressional testimony that these systems were not anymore effective against lightning than conventional systems. In other words, they did not prevent lightning strikes. This is ironic since the inventor of the lightning rod, Ben Franklin, invented it for the purpose of slowly and silently drawing "the electric fire from the cloud."

CONCLUSION

As we move into the 21st century lightning protection will become more important. Many of the technological devices commonplace today are more susceptible to lightning damage that their "low tech" predecessors. Smaller, faster, more sensitive computers and composite materials for aircraft are examples of technologies which will challenge modern lightning research. Today's rapidly changing technologies and the attending research will surely effect how DOD operates. It appears that the history of lightning protection has just begun.

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A Geographic Information System (GIS)
for Explosives Facility Siting Analysis

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Abstract

Barricades, related facilities, segmented clear zones, waivers, and exemptions are just some of the problems faced daily by explosives siting analysts. The number of explosives locations in close proximity to operational and support facilities makes site selection one of the most critical issues relating to explosives safety. Yet, there is seldom time using conventional methods to examine all of the relevant options.

The use of Geographic Information Systems (GIS) has grown substantially in the last several years as the technology has matured to the point where it is relatively user-friendly, affordable, and accessible. The application of a GIS to the problem of explosives facility siting analysis has resulted in increased productivity, decreased errors, and the ability to detect problems that humans alone might overlook.

Introduction

Anyone who has attempted to analyze a site plan with a ruler and a calculator can testify that it is a process which begs to be automated. Not only is it tedious and error prone, but often the entire process must be repeated when the slightest change is introduced. Additionally, there is paperwork to type and revise with endless columns of figures that must be checked and rechecked. Many would agree that it is a task for which the computer is well suited. The question is how should it be applied?

The Air Force Explosives Hazard Reduction (EHR) Program Office at Eglin AFB, FL has been tasked to perform an EHR survey of several US overseas bases, the majority of the work to be performed by a small team of contractors from ISA with experience in explosives siting. Because of the magnitude of the effort and the pace of the schedule, the team also included a programmer to automate as much of the task as possible. The first EHR survey was recently completed, and the results of the experience and some of the lessons learned are presented herein.

The purpose of the EHR survey is to:

- Identify and quantify threats and operational restrictions posed by the presence of our own munitions stocks.
- Provide recommended approaches to reduce or mitigate these threats and restrictions.
- Recommend initiatives for inclusion in the EHR program.

Because ISA was not tasked to develop hardware or software systems for general use, tools and systems were applied that were on hand at the time. Other systems were not considered because of the time and expense of acquisition and training. Accordingly, these discussions will be presented in as general terms as possible so as to benefit those with different requirements. It should be emphasized that this was not a normal life cycle software development project taking years, but an on-the-fly effort where the software necessary to perform a certain task was usually started and finished on the day before it was needed. This quick turnaround sometimes led to false starts and blind alleys, but also to a kind of synergism between user and programmer that resulted in innovative solutions to complex problems. It also led to the realization that it takes less effort to automate many tasks than it normally takes to perform them even once.

Background

A GIS is an information system that is designed to work with geographically referenced data. It can be thought of as a higher order map which includes both a spatially referenced database and a set of operations for manipulating it at computer speeds.

The target hardware was an Apple® Macintosh™ running a MapGrafix™ computer-aided mapping system linked to a 4th Dimension™ database. The team utilized four Macintosh™ computers ranging from the SE to the IIfx. All were equipped with large screen monitors to facilitate working with maps and large spreadsheets of data. Output devices included an "E"-size HP pen plotter, three laser printers and a small portable ink-jet printer for field operations. Paper maps were digitized with the aid of a Kurta "E"-size digitizing tablet.

Custom programming was added to MapGrafix™ in the Pascal language and to 4th Dimension™ in its scripting language. Over an eight month period approximately 10,000 lines of code were written to enhance and customize the GIS, and another 5,000 were written for the database.

The Pascal code automates the process of digitizing base maps by providing templates for standard explosives enclosures and other facilities. It can automatically produce a report with the distances and exposures between every potential explosion site (PES) and all respective exposed sites (ES) within a user defined distance. If barricades have been digitized, the report will also show if a particular building pair is barricaded or not, and notes the identifiers (IDs) of the barricades involved.

The database code streamlines the data entry of information pertaining to individual base facilities, waivers and exemptions, and separation criteria tables. It automates the calculation of quantity distance (QD) and provides searches for finding the problem facilities. Information is output to the map which automatically creates clear zones around the selected facilities. Lists of building pair (PES-ES) data can be exported for inclusion in reports, and AF Form 943's can be printed on a laser printer. The system can also generate an assessment of risk to each facility from all nearby potential explosion sites. The risk assessment, at this point, is based on computed separation factor and a table of estimated damage by structure type. The computed separation factor is given by the distance between the PES and the ES divided by the sited net explosive weight (NEW) raised to the one third power.

Computerization

All tasks performed with the aid of a computer can be divided into three stages: input, process, and output. Input or data entry, in this context, is an extremely technical process which requires knowledge and experience relating to explosives siting. The old saying, "Garbage in, garbage out" applies, and only careful attention to detail can prevent small errors from being magnified by the computer. The team found a small, but significant number of errors in the source data which could be located by cross referencing and looking for inconsistencies.

Processing is the part where all of the data has been input and automatic algorithms are being applieu to produce results. Processing, usually the smallest portion of the task, is the most exciting part, since after weeks of entering and cross checking data, you can sit back for a few hours while the computer does all the work for you. This is what the general public thinks of when they think of data processing. Perhaps it is because of those early cartoons that depicted men in white lab coats with their feet up on desks in front of a giant mainframe, and a sign that reads "don't bother to think."

Output, of course, is traditionally the part where the computer produces reams of paper copy which is printed in neat rows and columns, bundled into boxes, delivered to the customer, and stored in some closet never to be seen again. For this reason, there is usually some kind of post-processing designed to reduce the results down and summarize them into some form with which humans can cope.

Collecting the Data

The first step in computerized site plan analysis is data collection. In our case it involved obtaining paper copies of base maps at a scale of 1:600 (1"=50') and 1:5000 (1"=416'). Copies of facilities development plans for future construction and five year capital improvement programs were also obtained. In addition we acquired lists and locations for electro-magnetic radiation hazards, explosive safety quantity-distance maps, and aircraft parking maps. In order to classify and compute QD for each facility we requested and received listings of the real property inventory detail lists, facility data records from munitions branch CAS-B records, and copies of all current and pending site plans, exemptions, waivers, and deviations. Other data of interest include: "As Built" drawings, bench mark coordinates, USAF Definitive Drawings, drawings identifying barricades by type, and a regional location map.

All totalled, this can amount to some thirty pounds of paper which must be forced into the computer against its will. Right about now, some people usually ask why this mountain of information can't be provided in electronic form. These are usually people who have never been involved with transferring information from one computer system to another. Here is a somewhat facetious test to illustrate the point. Suppose you call the safety office at the base you are about to survey and ask for all of the above information in electronic form, will the person on the other end of the line be more likely to: A) Ask what format diskettes would you like that on? B) Request a stock number. Or C) laugh in your face. If you answered B or C, you have your feet firmly planted on the ground. If you answered A you may have a problem distinguishing reality and should consider a career in politics.

Digitizing the Maps

When some people hear the phrase "digitizing maps", they think that we are talking about scanning with a flat-bed or sheet-feeding scanner because that has become a relatively common process due to desk-top-publishing. What we are really talking about though, is taping the paper maps to what looks like a large draftsman's table and clicking on the endpoints of lines with a small hand held puck equipped with cross hairs. It is a process similar to solving a child's puzzle called connect-the-dots. This is the normal method in the GIS world, but it is seldom seen outside of it, and as a result outsiders are somewhat confused by it. They are often appalled by its labor intensive nature and the fact that it seems like a low-tech solution. The situation is complicated by the fact that there are now services to which you can send your maps, and they will be scanned and "auto-traced." If you do your furniture shopping at K-Mart, you will probably be really happy with an auto-traced map, because when you pick it up, you find that you still have to put it together.

Since one of the goals of the system is to automatically determine the orientation and exposures of PES to ES pairs, buildings must be digitized in a specific way. Buildings are entered as a series of corner points with lines connecting them for walls. We arbitrarily chose to enter them in clockwise order with the front left corner entered first. This is important since the blast and fragment hazard is different for the front, side, and rear of many explosives facilities. All of the standard building types are entered with a computerized template mechanism that ensures that they are drawn in a consistent manner that the computer can later break apart into component pieces of front, side, rear, door, blast deflector, and so on. As a part of the process, the buildings are given IDs which serve as the computer's link between the database and the drawing.

Creating the Database

There are four files of data that must be set up before the automated analysis process can begin. They are the facility file, the facility type file, the separation criteria file, and the waivers and exemptions file. The facility file contains all of the information about a particular facility referenced by building number, and is entered from scratch for each base surveyed. The facility type file contains a list of building types organized by categories, and may require updating to include local facility types not previously encountered. The separation criteria file is a table organized in rows and columns containing a separation factor and minimum distance entry from every PES facility type to every facility type. Its current size is around 12,000 entries, but it is expected to grow to around 30,000. The waivers and exemptions file contains a list of potential explosion sources and exposures affected by the waiver or exemption. A database might contain as much as 20,000 kilobytes (20 MB) of data.

Turning the Crank

Once the data has been collected and entered and the maps have been digitized and linked with the database, we can finally make the computer begin to pay for itself by applying algorithms to the data to automate the processes that were formerly done by hand. These algorithms are the real focus of this paper, since without them the GIS system would be only marginally useful. Therefore, it is necessary to examine them in some detail, and in somewhat technical language.

We begin with the fundamental problem of determining the distance between two facilities. Since the Greeks, it has been known that the distance between two points P_0 and P_1 in the Cartesian plane is given by:

Formula 1. $$d = \sqrt{(X_1-X_0)^2+(Y_1-Y_0)^2}$$

However, representing buildings as points does not yield the required accuracy for explosives site planning purposes. We must instead represent them as the line segments between the corner points of the outer walls. This implies there are an infinite number of distances between two buildings depending on where you measure. In the simplest case, we are only interested in the shortest distance since that will be the one which drives our requirements. A little thought will convince you that the shortest distance (or equal in the case of parallel walls) is always between a corner point of one building and a point on the wall of the other building. So if we have a formula to find the distance between a point and an line segment, we can simply take the minimum of all the distances between all of the corners in one building and all of the walls in the other and vice versa. Since we are dealing with line segments and not lines, we must use parametric equations.

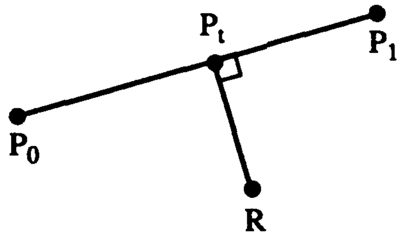


Figure 1.

The parametric affine equation of a line is given by:

Formula 2. $P_t = P_0 + t\,v$

Where v is the vector from P_0 to P_1, R is a point not on the line, and t is a parameter which varies from 0 to 1. Since the minimum distance occurs where the line from R to P_t is perpendicular to v, we can set the dot products of the two vectors equal to zero and solve for t.

Formula 3. $t = \frac{(R - P_0) \bullet v}{v \bullet v}$

If t is in the interval 0 to 1 then the perpendicular intersects the line segment and we can plug t back into Formula 2, solve for P_t and the distance is then given by $|R - P_t|$. On the other hand, if t is negative, the distance is $|R - P_0|$, and if t is greater than one, the distance is $|R - P_1|$.

The problem of finding distances between buildings is further complicated when one or both of the structures has a segmented clear zone. Segmented clear zones are the result of structural differences between the front, side, and rear of explosives enclosures. Explosives siting criteria, therefore, distinguishes between the required inhabited building distance (IBD) for a standard igloo, for example, by orientation, with the front sector being the most restrictive. This will be discussed in more detail later in the paper.

The parametric affine equation of a line is also useful for solving the problem of the intersection of two line segments. This is necessary when determining if a barricade falls between two buildings, and is also used for clipping a polygon to remove the portion falling on one side of a line. (Polygon clipping is a problem which occurs in computer graphics and detailed algorithms can be found in the textbooks of that field.) *Figure 2* shows the intersection of two line segments at a point P_t which is unknown:

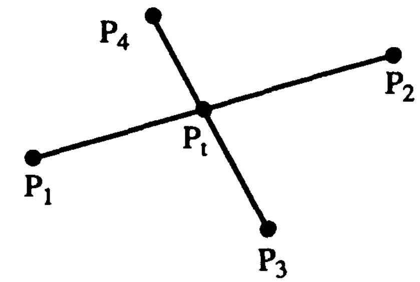


Figure 2.

Formula 4.1 $P_t = P_1 + tv$
Formula 4.2 $P_s = P_3 + sw$

Where v is the vector from P_1 to P_2, w is the vector from P_3 to P_4, and s and t are parameters which vary from 0 to 1. Since P_s and P_t are equal at the point of intersection, we can break the two vector equations into their scalar components and solve simultaneous eqations to eliminate the unknown in s giving:

Formula 4.3 $$t = \frac{Y_w(X_3-Y_1)-Y_w(Y_3-Y_1)}{Y_wX_v-X_wY_v}$$

Where the subscripts indicate from which vector or point (points are considered position vectors) the scalar components were derived. We then apply t to *Formula 4.1* to give the point of intersection. Astute readers will have noticed that the denominator of *Formula 4.3* is the determinant of the matrix of v and w corresponding to the vector cross product, and is zero only when the two are parallel. This must be checked first before applying the division.

Applying the Math

Armed with these two simple procedures for determining distance and intersection, we are now able to take on the task of determining the distances between two buildings with segmented clear zones and possible barricades in between. In contrast with the relatively simple mathematics presented above, the water now gets both deeper and murkier.

A simple case involving a segmented clear zone is illustrated below involving a hardened aircraft shelter (HAS) and another building. The HAS projects a clear zone in a 30° cone coming out of the front with the vertex placed so that the sides of the angles pass through the intersection of the door and side walls. Since the side of the cone passes through other building, there is both a front and side exposure, and we need to measure the distance of both.

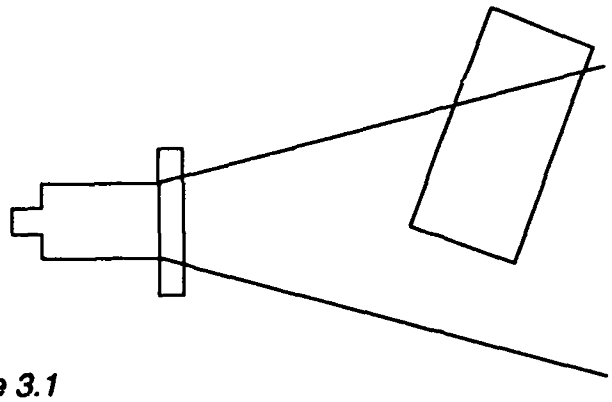


Figure 3.1

This is most easily accomplished by slicing the exposed building into two parts and applying our procedure for computing distances to each of the respective parts in turn. The distance measured from the front of the HAS is:

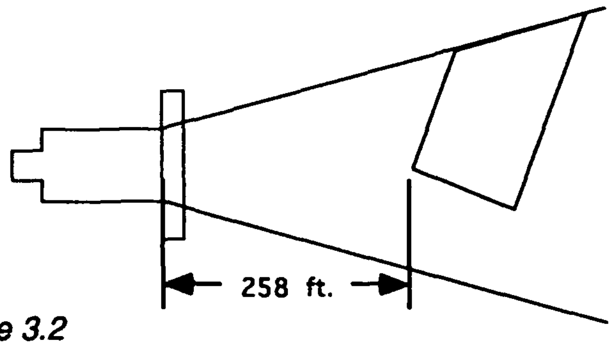


Figure 3.2

The distance measured from the side of the HAS is:

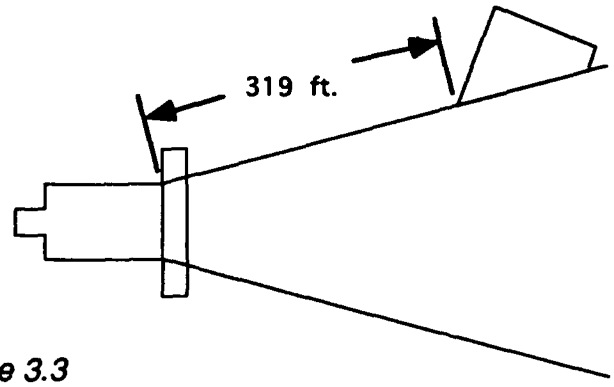


Figure 3.3

In order to go about slicing (or clipping) an arbitrary closed polygon with a line we must first develop a method for determining if a point is to the left or right of a vector.

Given two points P_0, P_1, and a point R just as in *Figure 2* we begin with the following general equation of a line:

Formula 5 $aY - bX - c = 0$
where $a = X_1 - X_0$, $b = Y_1 - Y_0$, and $c = aY_0 - bX_0$

Changing to inequalities, we find that $aY_R - bX_R - c < 0$ when the point R is to the right and > 0 when it is to the left (where left and right are as if you were standing on point P_0 looking toward P_1.) Of course, if $aY_R - bX_R - c = 0$ the point is on the line.

Clipping then, involves considering each point of the polygon in turn, keeping it if it is on the side we want, and removing it if not. Each time that we change from one side of the clip line to the other, we must compute the intersection of the current polygon side with the clip line, and retain that point.

Finding Barricades

Given that we have two buildings represented by polygons, we add a third polygon, possibly between the two, possibly not, which will represent a barricade. We wish to determine if any point on building A can connect to any point on building B without intersecting a barricade wall. While a general solution to this problem is not known to me, a rough approximation that works in almost all real world cases is as follows: Apply the intersection test to each line joining the corner points of A with the corner points of B, and every barricade wall. If any line fails to intersect at least one barricade wall, then the barricade does not completely protect A from B or vice versa.

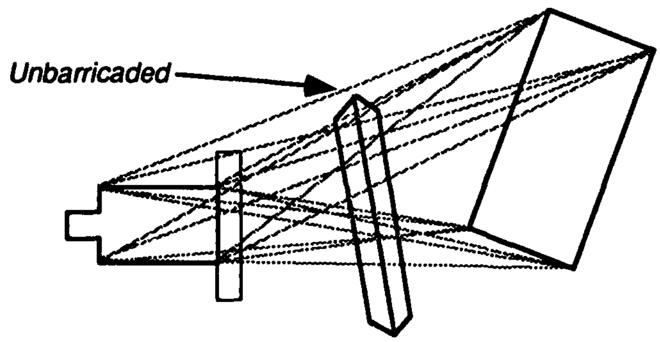


Figure 4

This procedure can be extended easily to handle multiple barricades, but it should be noted that limits must be placed on the distance that a barricade can be from a PES or ES because the effectiveness of a barricade diminishes rapidly with distance. The method can sometimes fail to detect small openings between multiple barricades. However, since that would constitute a design flaw in the barricade, it is assumed to be a rare occurrence. Barricade detection can add significantly to the processing time, since where there is one barricade, there are usually several hundred. Unless some optimization is applied to the process, it can easily take days of computer time. One optimization would be to keep list of barricades that are near enough to each building to be considered a candidate.

There are cases where we wish to know if one particular side of a building is barricaded, rather than considering the building as a whole. These are the same buildings that have segmented clear zones and require separate distance measurements, and so are handled by the same method of clipping the exposed building to the required arc and running the barricade test on the remaining portion.

Determining Exposure Faces

US Department of Defense Standard 6055.9 chapter 10, paragraph C2 states that *"A particular face of an ES is deemed to be threatened by a PES face when both of these faces lie within the arc of the threat or hazard of the other."* Figure 5 shows two standard earth-covered magazines (igloos) whose front faces do not lie within the 120° front cones of the other, but which will have front distances output by our compute distance procedure, since some of the building will lie within the cone.

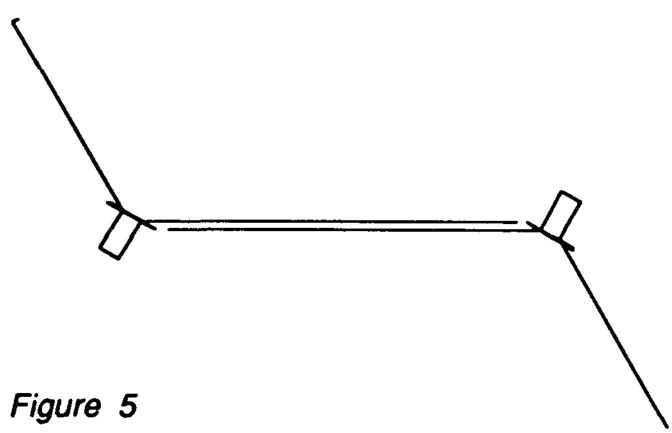


Figure 5

What is needed is to enhance our compute distance procedure for segmented clear zones to determine which faces are exposed, if the other building also has a segmented clear zone. Then we must compute the distances and exposed faces from the other building back to the first and eliminate distances to faces not within the arc of the other.

Determining which faces are exposed can be accomplished fairly easily for buildings that have a convex shape; that is, any building whose sides never face each other. After computing the distance from a particular segmented clear zone sector, we take the remaining part of the exposed building that lies within its arc and consider it one wall at a time. Beginning with the front wall and going clockwise around the structure, (since that is how we have standardized our digitizing process) we apply the procedure for determining if a point is to the left of a line. If either of the two endpoints of the source wall of the PES are to the left of the ES front wall (standing at the front left corner and looking along the door), then the source wall can be seen from the exposed wall, and the ES side is therefore considered an exposed face. The process continues around the ES until all sides have been considered.

After this process has been applied for each sector of the PES, and the ES faces exposed to each have been recorded, the roles of the PES and ES are reversed and the process is repeated until the exposed faces of each have been determined. Both lists are then checked against the other to eliminate distances to exposed faces that do not lie within the arc of the threat of the other.

It should be noted that all of the above algorithms have been simplified to the point where it is possible to explain them in simple English, and much work is needed to convert them into working procedures in any computer language. For instance, we have ignored the fact that the threat arc for the front of a hardened aircraft shelter is different when it is considered as a PES from what it is considered as an ES.

Priming the Database

After determining the distances and exposures, and noting the presence of barricades between each PES/ES pair, we then consider how this information can be processed for use in the explosives site planning analysis. One of the obstacles to the process is the problem of information overload. The computer obediently produces tens of thousands of lines of output which we must sort through to find the (hopefully) few hundred cases in which we are interested. Accordingly, the first step in analyzing our initial output is to transfer it to a database program.

In this process, data generated from the map is combined with data from other files to create records which completely describe the relationship between the building pairs. As the data is read into the **PES/ES** database file, the facility number of each is checked against the previously entered **Facility** file and the **Facility Type** of each is noted. The PES and ES Facility Types are used as indexes for the row and column of a table called the **Separation Criteria** file which contains the quantity-distance criteria derived from US Air Force and DoD standards. The table contains the **Separation Factor** (K-Factor or Q-Factor) for hazard class/division 1.1 munitions, the minimum allowable distance, and a field which contains note numbers of notes which detail exceptions and amplifications for this particular type pair. Note numbers are prefixed by a plus (+) sign if the note contains information which could result in the Separation Factor being increased or the minimum distance being decreased. The file contains separate entries for barricaded and unbarricaded building pair types. The Separation Criteria file is further broken out by exposure if a particular Facility Type has different criteria for each side.

Once we have the Separation Factor and minimum required distance, we can compute the factors which are the heart of our analytic capability, **Required Distance** and **Maximum Allowable NEW**. We use the formula: distance equals Separation Factor times Net Explosive Weight raised to the one third power. This formula gives the required separation distance for a particular Separation Factor and explosive weight. We also compute the maximum allowable NEW for a given actual distance and Separation Factor by the formula: NEW equals Actual Distance divided by the Separation Factor the quantity cubed. For multiple exposures, we compute the results of all, and use the most restrictive. In other words, we use the maximum allowable NEW which is smallest, or the required distance which is largest. It should be noted that the procedure is slightly more complex when dealing with so-called **Incremental Distance** criteria which are not smooth exponential curves, but the result is the same.

After computing the maximum allowable NEW and required distance, we must check to see if the actual distance is less than the required minimum distance. If it is, the maximum allowable NEW is set to zero, meaning that if the two building do not meet minimum separation requirements, then you cannot store explosives in the PES. If the actual distance is greater than or equal to the required minimum, and there is no Separation Factor criteria in the table (represented by a zero value), then a maximum allowable NEW by type is used from the Facility Type file.

The maximum allowable NEW that has been computed thus far applies to only one PES/ES pair. In order to find the true maximum for a particular PES, we must examine the maximums to each of the exposed sites, and take the smallest value. The facility number of the ES which yielded the smallest maximum allowable NEW is noted in the PES Facility record as the **Limiting Factor**. This information can be useful when we are seeking solutions to criteria violations.

Sorting out the Problems

The actual computerized analysis begins with a **Multi-Problem Facility Search**. This is a search applied to the entire database which produces a list of facilities that cause a criteria violation for more than one PES. This allows the analysts to concentrate their efforts on the worst problems first. On the initial run, it will often reveal data entry errors and problems with the criteria data or how it is applied, as well as legitimate violations. The results of the search can be output as a PES/ES building pair list sorted by ES so that you can go down the list and quickly determine what the problem is.

After you have pared the list down to mostly legitimate problems, you may wish to run a **Problem Facility Search**. This search will select all of the PES/ES building pair records in which the actual distance is less than the required distance, the computed maximum allowable NEW is less than the current sited NEW, or the building pair is waived or exempted. This produces a master list of all the potential problems, sorted by PES, that should be examined by the analyst.

Armed with a list of potential problems, the next step is to examine each by PES using the **PES/ES worksheet**. This is a spreadsheet-like screen which includes the Facility record data for the PES, and the PES/ES building pair data to each of the exposed sites. Changing a field like the PES's **Sited NEW** results in an immediate recalculation of required distances and maximum allowable NEW. The worksheet includes buttons for common preprogrammed searches, including special geometric searches for buildings with segmented clear zones, to reduce the PES/ES list to only those within a specified clear zone. There are also buttons and menu items for sorting, printing, performing user specified searches, and exporting the list to spreadsheets and other database programs.

When the analyst has a question about where a particular result came from, the **Detail Record** for that PES/ES pair is used. The Detail Record allows the user to view most of the information about the PES, the ES, and their relationship on one screen. One button on this screen allows the user to review the criteria table data used in the computations, and to read any notes that are associated with the entry. If necessary, the computed results may be overridden and the record locked from future automatic updates.

Linking with the Map

All of the database screens described above include the capability to display the selected facilities on the map with the press of a button. This allows for better visualization of the problem, and provides a sanity check on the computer's calculations. In addition, buttons allow the user to select facilities on the map and display their database records. Therefore, the two-way link allows the database and map to act as if they were one program, while each maintains the capability to function separately.

One of the most important links between the database and the map is the capability to generate clear zones around selected facilities. Although it is possible to generate clear zones without the database, from within the map program itself, it is a cumbersome process when it involves multiple facilities of different types and net explosive weights. By using the database's searching and selecting capability, in combination with the built-in separation criteria tables, clear zones can be generated from each specified PES to a particular ES type. This allows the user to quickly determine where possible areas are for siting a new facility.

Choosing a Site for New Facilities

Once the candidate areas for the new site have been outlined by the clear zones of surrounding facilities, the user may create a new facility with the map template mechanism, choosing from any of the standard munitions enclosure types, and customizing it with dimensions from the "As-Built" drawings. A clear zone may also be grouped with the new building, if desired, and they can be rotated and moved to a position and orientation that fits. If multiple facilities are being sited, they can be created all at once, by specifying the number in each row and column, and their side-to-side and front-to-back separation distance.

After a site has been chosen and the new facilities have been placed, the procedure to compute distances and exposures can be invoked for the surrounding facilities, and new records will be created in the database. After some additional information about the new facilities is entered, Air Force Form 943's may be printed for inclusion in a explosives site plan approval package.

Summing up the Capabilities

The hazard reduction and explosives site planning analysis capabilities of this software makes it possible for a person with the proper background and training to perform tasks at a speed and level of accuracy that would be impossible to accomplish by manual methods alone. The task, however, is still difficult, exacting, and time consuming, and human insight remains the ultimate quality control. Those of you who rely on your knowledge and experience in this area for a livelihood need have no fears of being replaced. Instead, look to the computer to supplement and focus your talents on areas where they be most productively applied, and to allow you the time to consider creative solutions by removing the burden of tedious measurements and calculation.

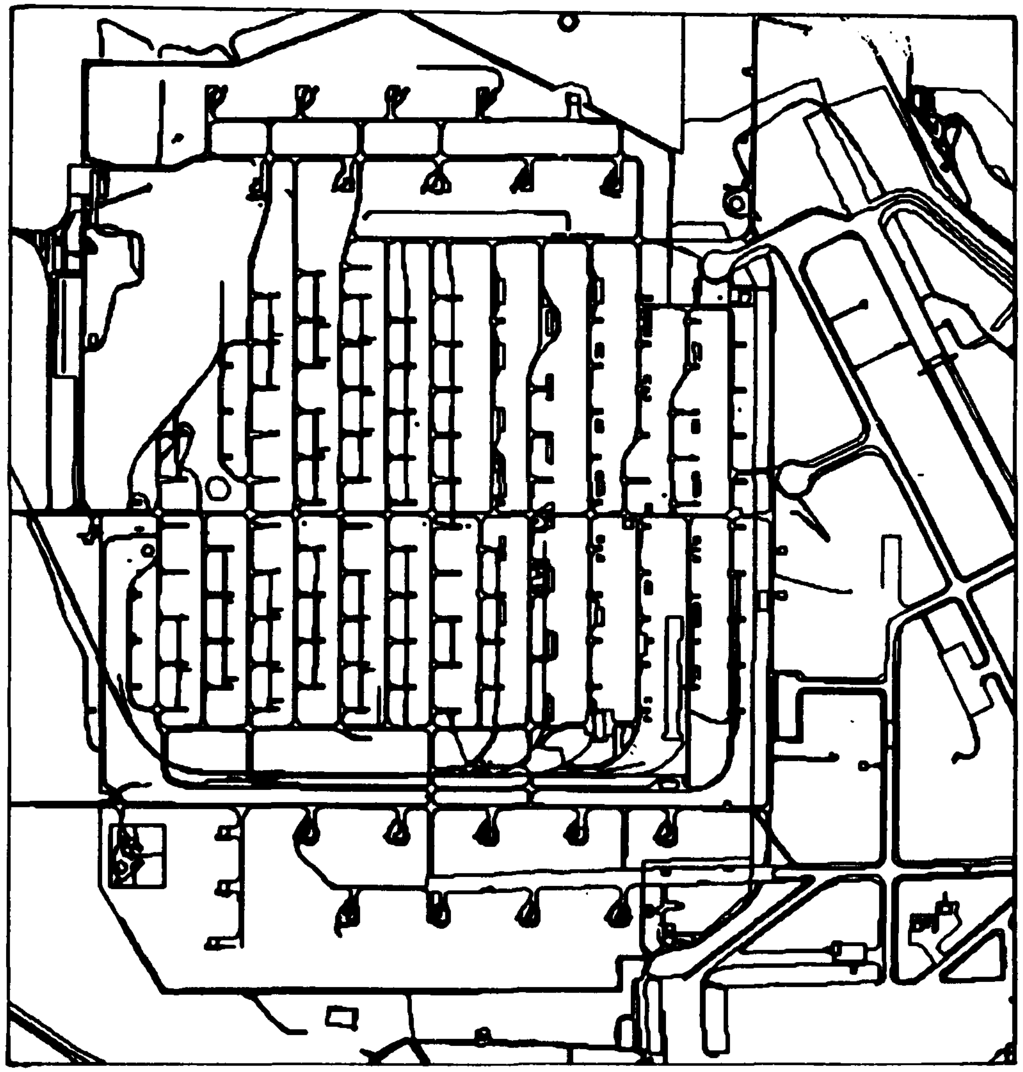
AUTOMATED SITE PLANNING

EXPLOSIVE ORDNANCE LAND USE PLANNING AID (EOPA)

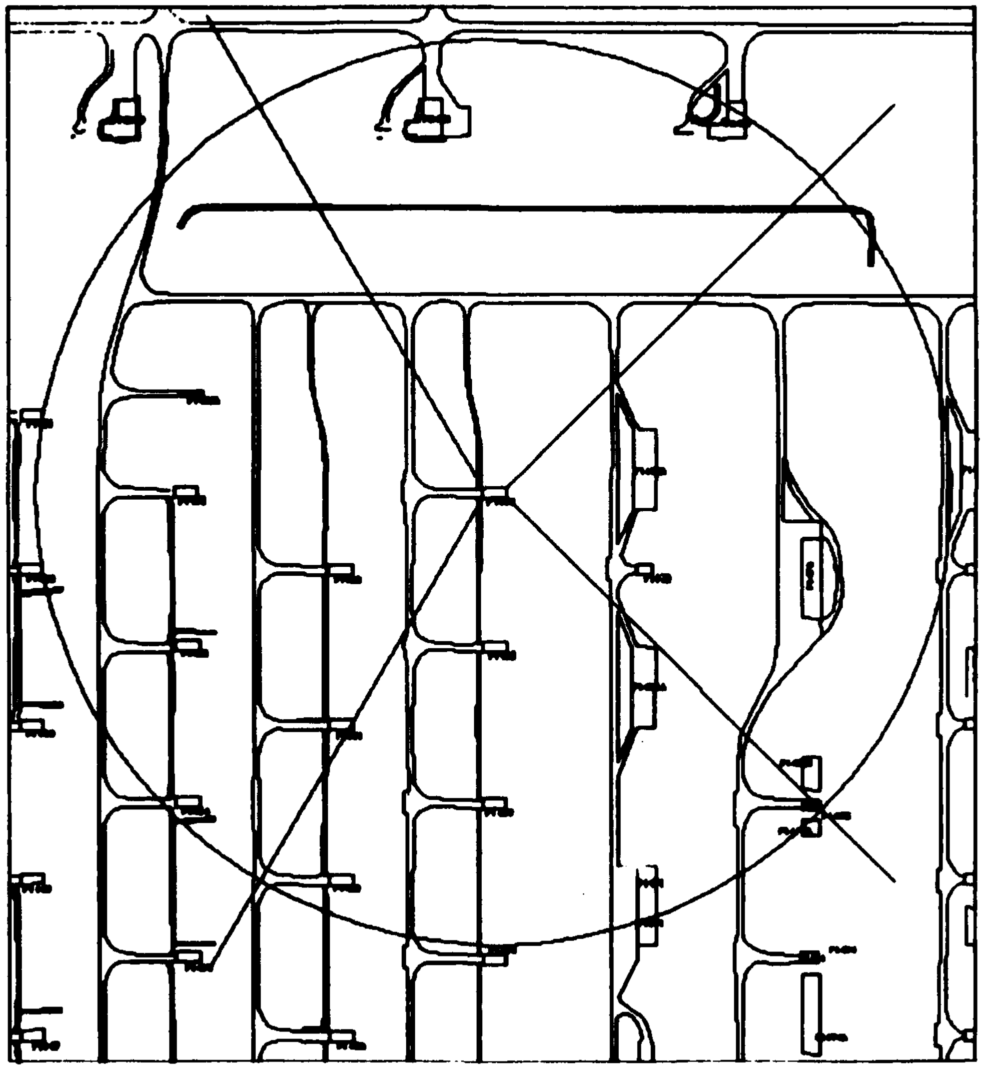
Developed For Hill Air Force Base, Utah

TOM YONKMAN
SAIC

DISPLAY DIGITAL BASE MAP

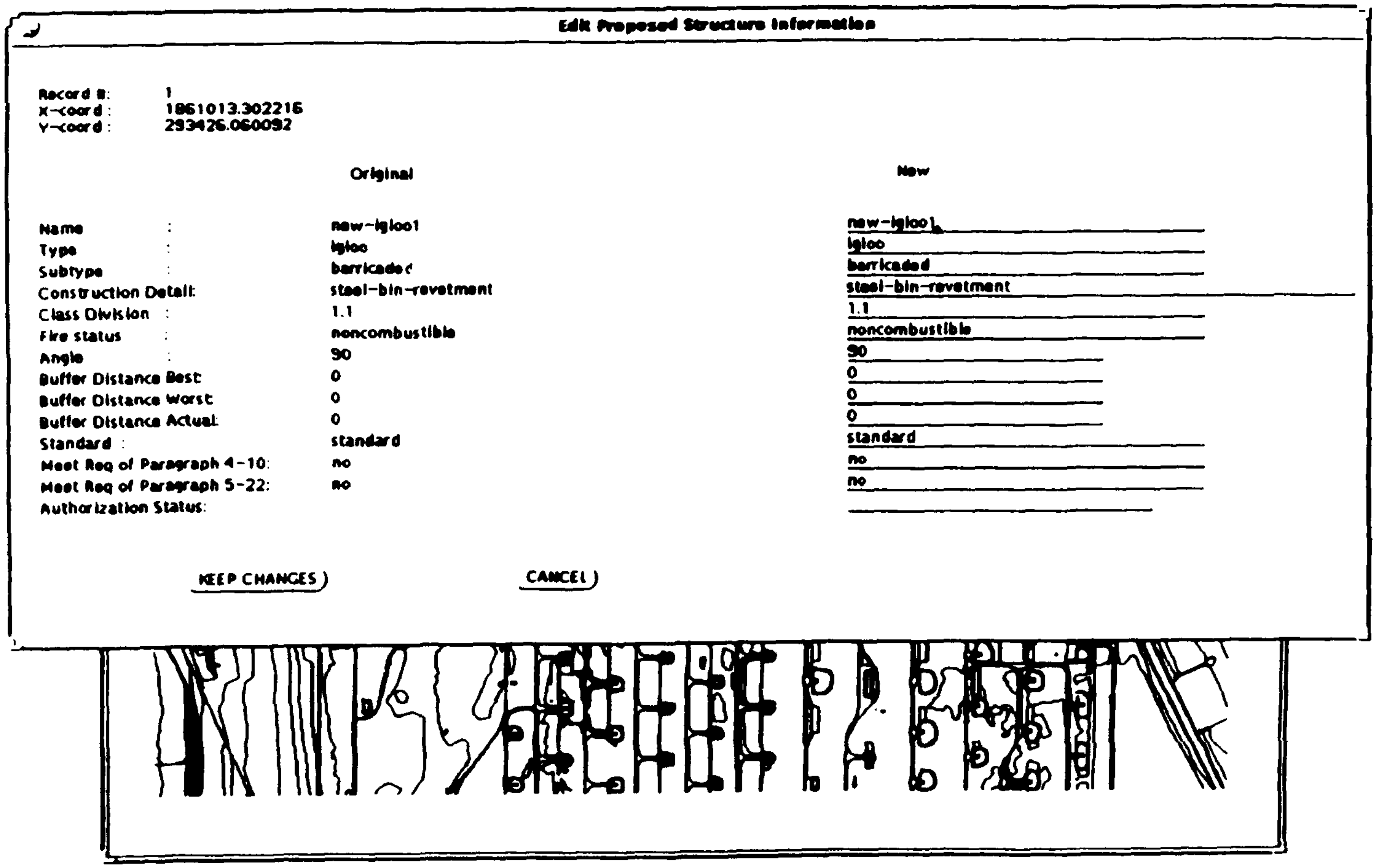


SHOW EXPOSURE LINES

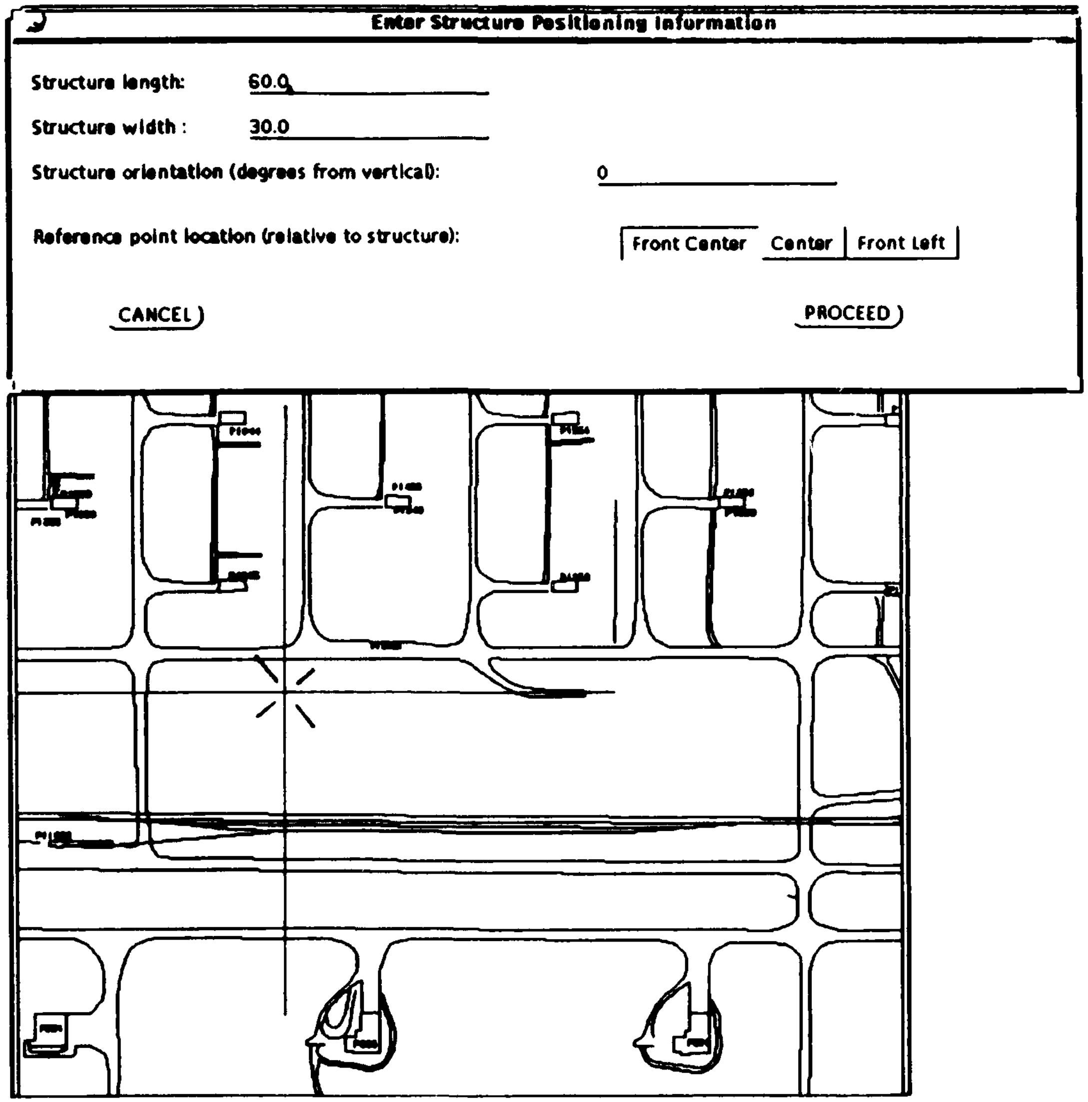


EDIT STRUCTURE DATA

Edit Information needed for Site Verification



NEW STRUCTURE PLACEMENT



SAIC

PROPOSED SITE EVALUATION

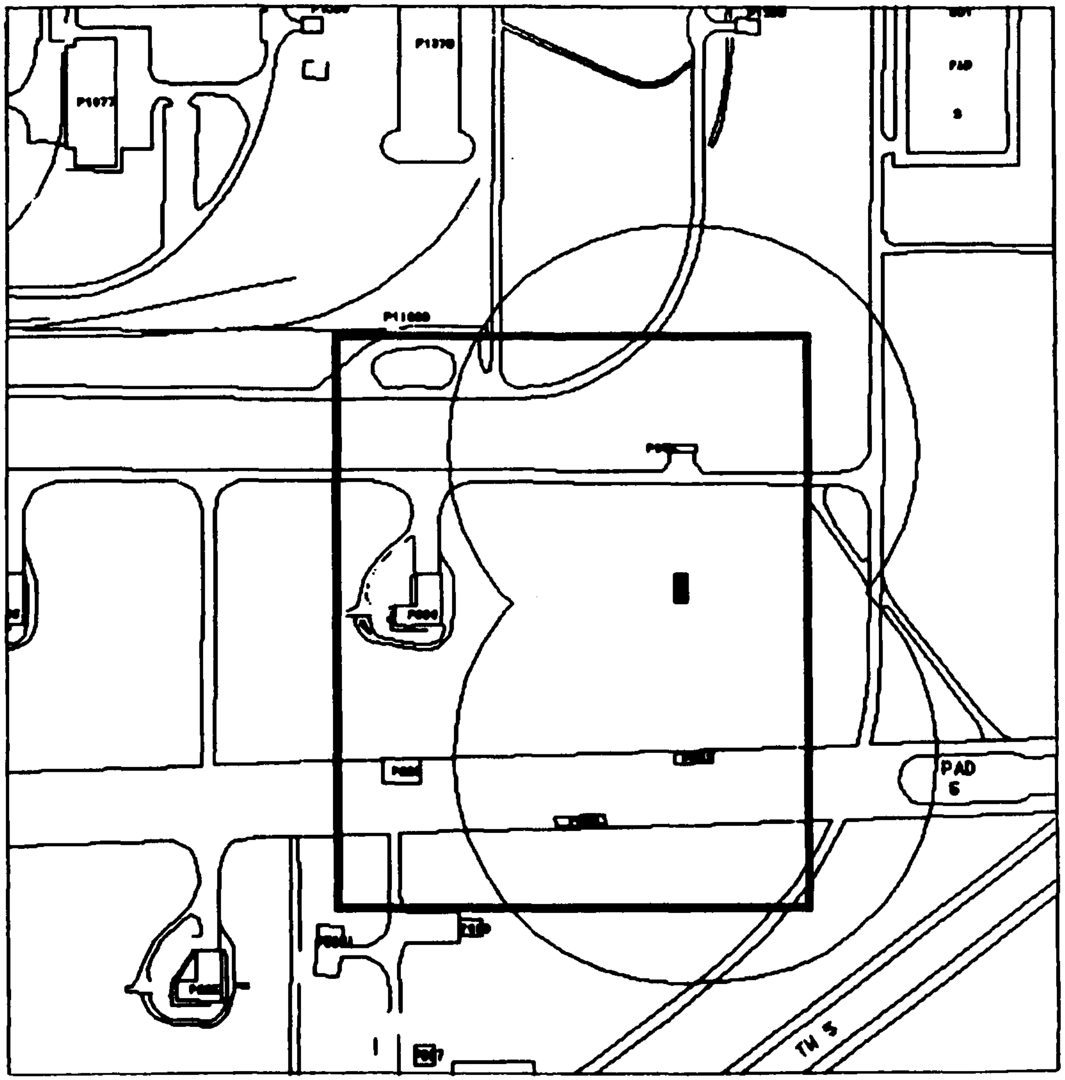
- Site Planning Regulations and Site Planner Expertise are incorporated via an Expert System

- Data on the Proposed Structure and on all nearby Existing Structures are taken into consideration.

- If proposed site does NOT comply with regulations, Recommendations are made:

- Either Explosive Material Reduction and Relocation of the Proposed Site are possible Recommendations.

GRAPHICAL SITING RECOMMENDATION



RECOMMENDATION FOR BETTER SITING

new-igloo1	conflict		
p1451	ok		
p1444	conflict	400000	307308

AUDIT TRAIL

History for ES/PES pair (passenger_load_unload_area, 4), (barricaded igloo, 1):

Row Note History

The row designation for ES (passenger_load_unload_area, 4) has been changed from 26 to 34 according to note 45.

Reason:

Building 4 is a structure where passengers assemble.

Explanation:

Note 45 states that a passenger load/unload area that consists of an area where passengers assemble such as a terminal building should be treated as an inhabited building.

PRINT FORM 333

REVISION NUMBER	EXPLOSIVES AUTHORIZATION FOR SITED MUNITIONS FACILITY	SITE PLAN NUMBER	ORGANIZATION	FACILITY NUMBER
		1		z0001

I FACILITY DESCRIPTION

A. TYPE / CONSTRUCTION / STANDARD/NON-STANDARD / AF DEFINITIVE DWG NUMBER [illegible]	F. NUMBER OF ROOMS / BAY
B. TYPE HEATING [illegible]	G. NUMBER OF EXITS
C. TYPE OF ELECTRICAL FIXTURES	H. EXTENT AND TYPE OF BARRICADING Earth cover
D. LIGHTNING PROTECTION	I. DESIGN PURPOSE (Maintenance, X-Ray, Storage, etc.)
E. DIVIDING WALLS (Number / Size)	J. SPECIAL FEATURES (Overhead Crane, Hoist, etc.) [illegible]

II COMPUTATIONAL DATA

NEAREST TARGET THAT REQUIRES A	TARGET IDENTIFICATION B	FROM (PES) C	TO (ES)	K FACTOR D	DISTANCE E	CL / DIV 1.1 F	CLASS / DIVISION 1.2 (04) G	(08) H	(12) I	(18) J	CL / DIV 1.3 K	CL / DIV 1.4 L	OTHER M
MAGAZINE DISTANCE	[illegible]	1	3	2 5	1273'	132046424	Phys-Cap	Phys-Cap	500000	500000	16503467	Phys-Cap	
INTRALINE DISTANCE	[illegible]	4	33	18	874'	114635	Phys-Cap	Phys-Cap	500000	0	5341020	Phys-Cap	
PTR DISTANCE	[illegible]	3	28	24/30	516'	9956	Phys-Cap	Phys-Cap	0	0	1099104	Phys-Cap	
IBD DISTANCE	p1424	4	34	35/50	979'	21903	Phys-Cap	Phys-Cap	0	0	7506509	Phys-Cap	
OTHER													
OTHER													

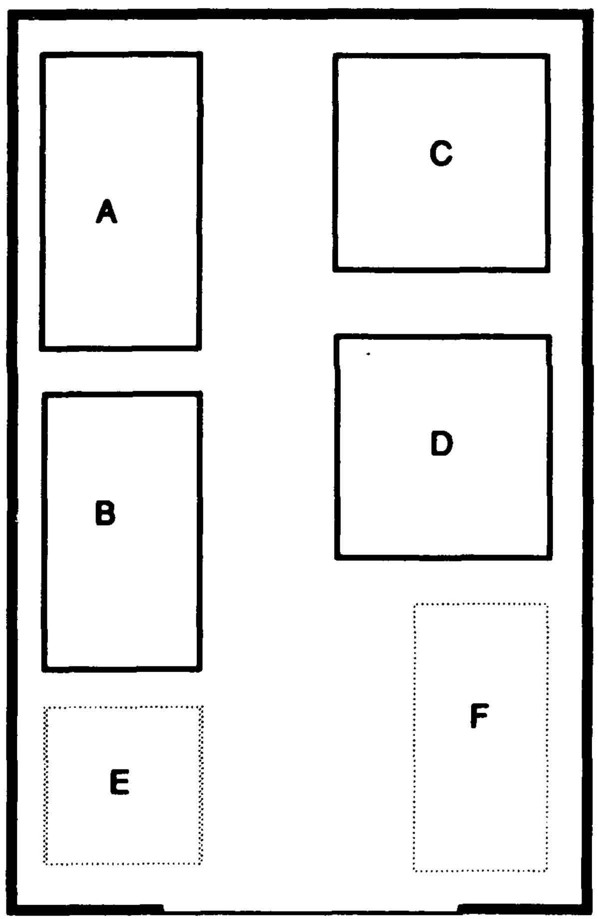
III AUTHORIZATION

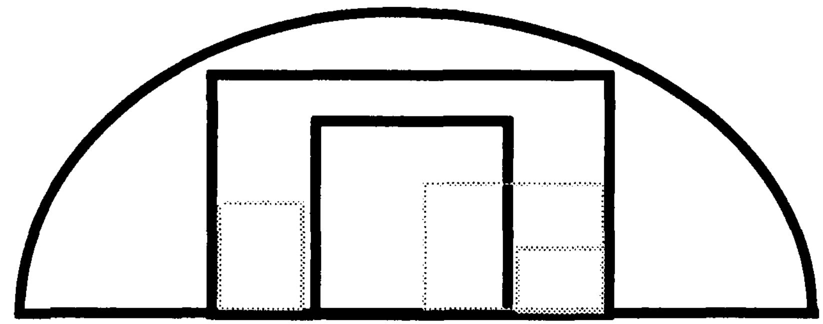
REMARKS	CL / DIV 1.1 A	CLASS / DIVISION 1.2 (04) B	(08) C	(12) D	(18) E	CL / DIV 1.3 F	CL / DIV 1.4 G	OTHER H
This is [illegible] the placement of the 5 [illegible] in the remarks section	9959	Phys Cap	Phys Cap	0	0	1099104	Phys Cap	

AFLC FORM 333, APR 89 PREVIOUS EDITION OBSOLETE

Science Applications International Corporation

VIEWING STRUCTURE CONTENTS





Construction - Reinforced Concrete Dirt Cover

DIMENSIONS - 70 FT X 35 FT X 15 FT
TOTAL VOLUME - 36750 CUBIC FEET
OCCUPIED VOLUME - 26,000 CUBIC FEET

TOTAL WEIGHT - 55,000 LBS
OCCUPIED WEIGHT - 31,500 LBS
EXPLOSIVE WEIGHT - 40,000 LBS (MAX)
OCCUPIED EXPLOSIVE WEIGHT - 25,000 LBS

ENVIRONMENT - +45 TO +95 DEGREES F

A- MM STAGE 1 IGNITER P/N 12345678-5
B - MM STAGE 3 IGNITER P/N 98765432-1
C - PCKR STAGE 1 IGNITER P/N 6574831-2
D - PCKR STAGE 2 IGNITER P/N 1928374-1

E OR F - ANY NEW ITEM

THE INTERRELATIONSHIPS BETWEEN QUALIFICATION, INSENSITIVE MUNITIONS AND HAZARD CLASSIFICATION TESTING OF EXPLOSIVES (HIGH EXPLOSIVES, PROPELLANTS AND PYROTECHNICS)

by

Dr. Richard E. Bowen
Dr. Jerry M. Ward
Mr. Edward A. Daugherty

Abstract

Within the U.S. and NATO communities, the terms and concepts of hazard classification, safety, Insensitive Munitions (IM) and qualification testing of all types of explosives including high explosives, propellants and pyrotechnics have caused confusion. It is the intent of this paper to clarify how the each of these terms are related and the testing that they entail. The similarities and differences between test protocols and requirements will be highlighted.

In addition to the terms and test requirements, this paper will give the reader an indication of when to conduct the testing within the framework of the acquisition cycle.

Background

As the basis from which to start the technical discussion of testing requirements, one must understand the origin of the requirements. Much of the recent efforts in the areas of hazard classification and explosives qualification trickeled down from international sources: the hazard classification guidelines of the United Nations Orange Book (Recommendations on the Transport of Dangerous Goods, Tests and Criteria) and the United State's adoption of Standardization Agreements (STANAGs) developed by two NATO Groups; AC/258 Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives and AC/310 Group for the Safety and Suitability for Service of Munitions and Explosives. In the body of the paper, reference will be made to the appropriate NATO STANAGs of those two Groups.

The requirements for hazard classification, qualification and IM testing deal with substances and articles which in some documentation are referred to as explosives and munitions. For consistency in this paper, the terms explosives and munitions will be used unless a distinct need is indicated to do otherwise.

For clarity, the definitions of "**Qualified**" and "**Final (or Type) Qualified**" explosives are stated below. These definitions have been excerpted from NATO STANAG 4170.

> ***Qualified Explosive***: *An explosive is qualified when it has been assessed by the National Authority and adjudged to possess properties which make it safe and suitable for consideration for use in a particular role (e.g. as a main charge filling, a booster, propellant, gun propellant, illuminant pyrotechnic, etc.). This is an intermediate stage leading to:*
>
> ***Final (or Type) Qualification***: *Final (or Type) Qualification relates to the use of the explosive in a specific application or weapon system. Final Qualification is given when the explosive has been assessed as part of the design of the specific weapon, and shown to be safe and suitable for military operations or training use in that role.*

Hazard Classification

In general, Hazard Classification of explosives and munitions is required throughout NATO and UN Nations for purposes of providing safety in transportation and storage. Data are developed by agreed test protocols which are then assessed to agreed criteria. The items are categorized as:

- 1.1 (Mass Detonating)
- 1.2 (Non Mass Detonating/Fragment Producing)
- 1.3 (Mass Fire)
- 1.4 (Moderate Fire)
- 1.5 (Very Insensitive Explosive Substance with a Mass Explosion Hazard)
- 1.6 (Extremely Insensitive Detonating Substances, and Articles, Extremely Insensitive)

It is the latter two categories which often causes confusion with personnel involved in Insensitive Munitions (IM) and Insensitive High Explosives (IHE) efforts.

Hazard Classification is governed by national, United Nations and NATO documentation. In the United States, the document is titled "Department of Defense Explosives Hazard Classification Procedures" and is used by all services (TB 700-2, NAVSEAINST 8020.8 and TO 11A-1-47) and the Department of Defense Explosives Safety Board (DDESB). Internationally Hazard Classification is governed by the UN Orange Book "Recommendations on the Transport of Dangerous Goods, Tests and Criteria." The test series of the UN Orange Book are referenced in STANAG 4123 (AC/258) "Methods to Determine and Classify the Hazards of Ammunition."

Hazard classification testing is performed at the end of the development process on the final munition design to be released to production. Testing is done in the transportation or storage configuration.

Insensitive Munitions

Insensitive Munitions efforts originated in the United States with the US Navy as the principal proponent. The US Navy interest was primarily focused on improving the survivability of ships when exposed to munitions reactions initiated by combat induced environments. National safety programs historically assessed a munitions vulnerability to environmental forces produced during the normal logistic cycle and by reasonably forecasted accident scenarios.

In 1987, the three U.S. Services signed a Joint Memorandum of Agreement to make all services munitions insensitive using the least sensitive explosive materials which will meet operational requirements. Mechanical means may be utilized to augment the insenstiive material when needed to reduce the reaction violence or protect the munition from the initiation source. The emphasis of the each Services IM Program varies due to mission requirements. While the Navy emphasis is on ship survivability, the Army is concentrating on armored vehicles such as the Bradley Fighting Vehicle and the Air Force on air base survivability. Each service under the multi-service agreement has formal implementing documentation. A multi-service test document, MIL-STD-2105 Revision B, is currently in staffing. This document identifies basic and optional safety and IM test protocols. Attempts have been made to standardize these tests with NATO and UN Hazard Classification test protocols. The document is also written so that the individual weapon program manager can tailor a hazard assessment test program to meet the life cycle environmental exposure of the particular munition.

Several NATO nations and indeed NATO, within the AC/310 Group, are developing individual Insensitive Munitions programs. National programs will no doubt vary in goals and test requirements due to the various national military defense postures and needs. The NATO program needs to address some core considerations and tests with options to suit individual national and service needs.

Internationally, NATO AC/310 is addressing IM in draft STANAG 4439 stating the overall policy and program; and in test STANAGs on classes of munitions (air launched, surface launched, etc.) and specific hazard tests (Bullet Impact, Fast Cook-off, etc.). Again, attempts are being made to standardize when possible.

The Development to Production Process

Testing for insensitive munitions and safety is performed on weapon design and explosive formulation iterations and is intended to verify the substance or article meets certain specified requirements. Design is affected and design changes are retested to verify the ability to meet requirements. Final Qualification and Insensitive Munitions criteria are only fulfilled when the testing is conducted on the most vulnerable configuration of the final design as determined by a hazard analysis.

Before discussing individual test requirements for explosives and munitions, let us discuss the normal procedure of munitions design efforts from development through production with a look at what happens at various milestones and where Qualification, Insensitive Munitions and Hazard Classification considerations enter the process. (See Figure 1)

Within the development process, the first step is Basic Research and Development. Generally, at this point in time, the emphasis is on synthesizing new explosive molecules such as the relatively recent development of CL-20. These are the building blocks of future formulations. Certainly in characterizing these new materials, some safety data are generated to rule out materials of extreme sensitivity, toxicity, etc.

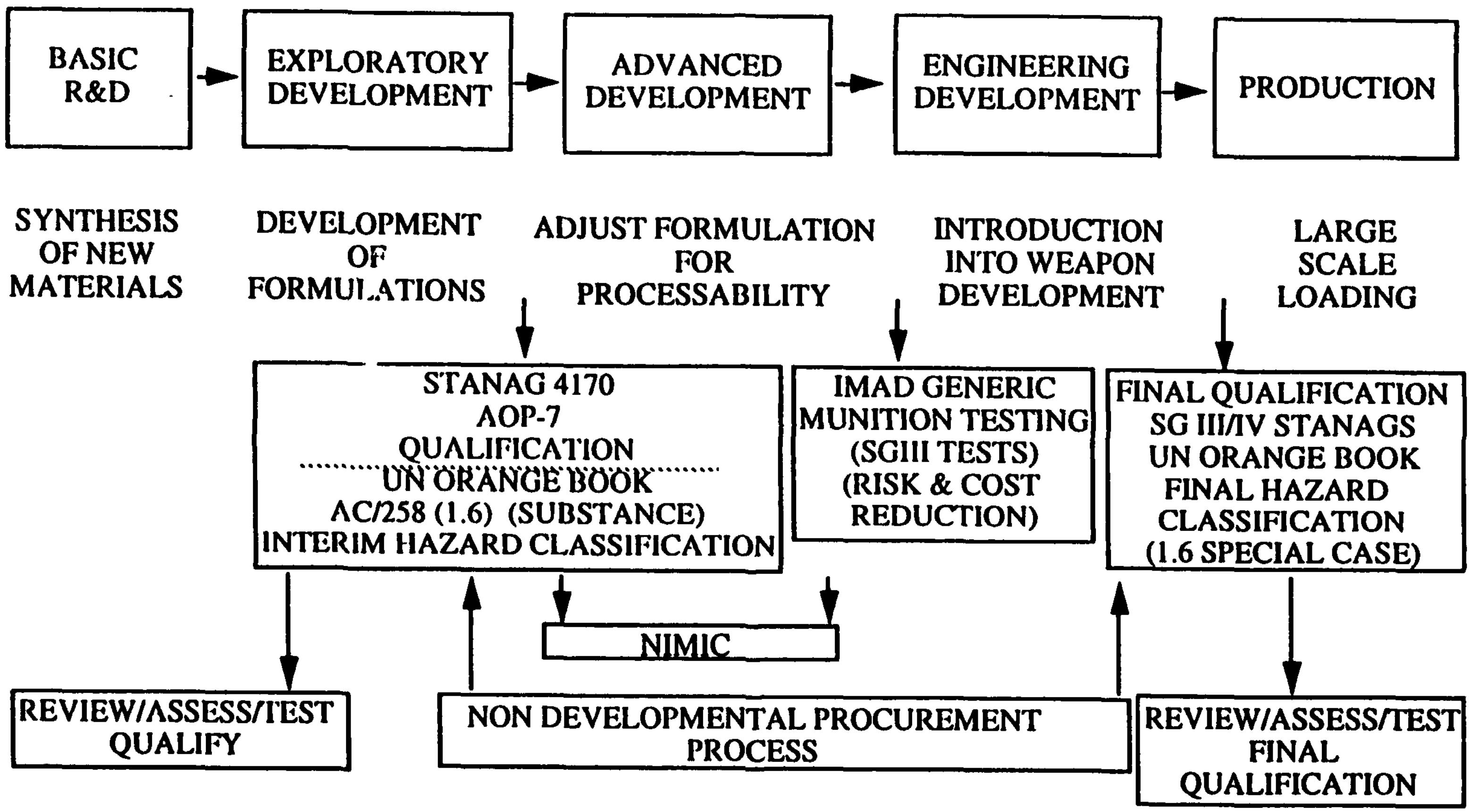
Moving on to the Exploratory Development phase, new materials or different combinations of older materials are used in the development of new formulations. In this process many undesirable features of the basic material (e.g. sensitivity) can be rendered acceptable by proper formulation efforts. It is the formulation which will be further improved for actual use in a munition. Again, basic safety test data on the materials will be collected.

When the formulation has matured, through experimentation, it may be considered ready for Advanced Development where the properties of the formulation are adjusted for processability. In some instances to achieve optimum viscosity, cure times, or other parameters, sufficient changes in the formulation may need to be made.

It is at the completion of this phase the Qualification tests of STANAG 4170 are conducted. Testing of certain critical sensitivity characteristics will have been repeated perhaps several times until the optimized formulation for safety, insensitive munitions and performance is reached. Should a 1.6 EIDS Hazard Classification be sought, the test series 7 of the UN Orange Book as referenced in STANAG 4123 (AC/258) will be conducted.

Within the United States, many of our new formulations, especially high explosives and to some degree propellants, are tested in generic hardware, such as within the U.S. Navy

DEVELOPMENT TO PRODUCTION PROCESS



Insensitive Munitions Advanced Development (IMAD) Program, just prior to entering Engineering Development.

These generic units undergo safety, vulnerability and performance tests. The generic units have been designed to simulate weapon configurations such as penetrator and fragmenting warheads. The results of this testing provides weapon designers with data they can use in their designs reducing the risk, cost and time to deployment of the actual system.

With the known safety and performance characteristics from the qualification test series on the explosive formulation and the generic warhead data, an informed selection can be made to introduce the material into a munitions development program. As the marriage of the material and munition progresses, the safety and IM tests of MIL-STD-2105 and the NATO AC/310 Subgroup IV STANAGs are conducted to verify that the munition design meets set requirements. The tests are conducted on the final production design. In instances where design iterations are required to meet requirements, retesting of the redesign is necessary.

Upon satisfactory completion of Engineering Development, the explosives and munitions are submitted for Approval for Production. All of the testing which was conducted during Engineering Development is documented and a data package forwarded to the appropriate Service authority requesting release of the explosive, as used in the munition, for production and operational use. Approval constitutes Final (or Type) Qualification.

Final Hazard Classification requests are also submitted after having completed testing in accordance with National documents, STANAG 4123 and the U.N. Orange Book (Transportation).

Explosive Materials Testing

Figure 2 lists a variety of explosive tests, both mandatory and optional for Qualification, Hazard Classification and EIDS certification. The test requirements of STANAG 4170 are referenced. The United States has ratified STANAG 4170 and is in the process of circulating a draft of MIL-STD-1751A to serve as the tri-Service, U.S. implementing document for STANAG 4170. When the military standard is adopted, the STANAG 4170 test requirements will be the U.S. standard. The requirements of STANAG 4123 and the U.N. Orange Book for Hazard Classifications 1.1 through 1.5 as well as the special category for 1.6 EIDS are also detailed in Figure 2.

FIGURE 2 EXPLOSIVES QUALIFICATION REQUIREMENTS	QUALIFICATION STANAG 4170	HAZARD CLASSIFCATION 1.6 (EIDS) STANAG 4123/UN ORANGE BOOK	HAZARD CLASSIFCATION 1.1 - 1.5 STANAG 4123/UN ORANGE BOOK
Impact Sensitivity	Mandatory	Test Series 3	Test Series 3
Friction Sensitivity	Mandatory	Test Series 3	Test Series 3
Electrostatic Sensitivity	Mandatory		
Gap Sensitivity	Mandatory	Test Series 7	Test Series 1 & 2
Cap Sensitivity	Mandatory	Test Series 7	Test Series 5
Critical Diameter	Mandatory		
Self Heating (DTA/DSC)	Mandatory		
Thermal Stability	Mandatory	Test Series 3	Test Series 3
Ignition & Unconfined Burning	Mandatory		Test Series 1 & 2
Toxicity Evaluation	Mandatory		
Detonation Velocity	Mandatory		
Min. Pressure Vapor Phase Transition	Mandatory *		
Flash Point	Mandatory *		*
Detonability	Mandatory *		
Small Scale Cook Off	Optional		
Growth	Optional		
Exudation	Optional		
Hot Wire Ignition	Optional		
Susan Impact	Optional	Test Series 7	
Small Scale Burn		Test Series 3	Test Series 3
Friability		Test Series 7 **	
Bullet Impact (Single)		Test Series 7	
External Fire		Test Series 7	
Slow Cook Off		Test Series 7	
Single Package Test			Test Series 6 ***
Propagation Stack (Packages)			Test Series 6 ***
External Fire (Packages)			Test Series 6 ***

Notice that for explosives alone, not in packaging, with the exception of the small scale burn requirement, all tests for Hazard Classification 1.1 to 1.5 are contained within the requirements for explosives Qualification.

EIDS Hazard Classification requirements are in addition to explosives Qualification requirements. To satisfy EIDS requirements, the explosives must pass small scale vulnerability tests in addition to basic safety and performance tests. Consideration should be given, anytime an explosive is proposed for EIDS certification, to use tests for the common data needs which will preclude redundant testing.

Munitions Testing

The requirements for Final (or Type) Qualification, Hazard Classification, Safety and Insensitive Munitions testing also overlap in several areas. But at the same time, there are subtle differences between the test parameters for the same types of tests, and the pass/fail criteria are different in many instances. Most relate back to the differences between the purposes of the tests; Hazard Classification for transportation/storage configurations and Insensitive Munitions (Final Qualification) testing for combat and logistics scenarios and configurations.

Figure 3 defines the Final (or Type) Qualification test requirements from STANAG 4170 as ratified by the United States. These tests also serve as the baseline Insensitive Munitions tests. Tests are generally performed on the most vulnerable life cycle configuration of the item. This testing also provides data required for Safety and Insensitive Munitions compliance verification. There are seven (7) tests listed as core tests. These tests must be performed unless rationale is provided to the proper authority that the test environment does not represent a plausible life cycle exposure. Prior to performing these tests, the explosive must be Qualified.

The figure also contains the test requirements for Final Hazard Classification for munitions and the special Hazard Classification 1.6. The Hazard Classification test series are conducted on packaged munitions. To make the tests interchangeable, Final Qualification tests would need to be done on the packaged configuration. In some instances, this may be the most vulnerable munitions configuration based on life cycle analysis.

The external fire test may be conducted with jet fuel as required by the Final Qualification test specification, MIL-STD-2105A. The Sympathetic Detonation test may also be considered acceptable in lieu of the Propagation Stack Test. Further, if in these two tests, a single item exhibits a "mild" reaction, multiple unit tests may not be required.

****

FIGURE 3
U.S. MUNITION (ARTICLE) TESTS

TEST	FINAL TYPE QUALIFICATION STANAG 4170	HAZARD CLASSIFICATION STANAG 4123/UN ORANGE BOOK	
		1.6****	1.1 - 1.4***
FAST COOK OFF (FUEL FIRE)	MANDATORY **		
EXTERNAL FIRE		MANDATORY	MANDATORY *
SLOW COOK OFF*****	MANDATORY	MANDATORY	
BULLET IMPACT (MULTIPLE)	MANDATORY	MANDATORY	
SINGLE PACKAGE TEST			MANDATORY
SYMPATHETIC DETONATION	MANDATORY **		
PROPAGATION STACK TEST		MANDATORY	MANDATORY *
FRAGMENT IMPACT	MANDATORY		
SHAPED CHARGE JET*****	OPTIONAL (HAZARD ANALYSIS)		
SHAPED CHARGE SPALL*****	OPTIONAL (HAZARD ANALYSIS)		
REQUISITE FOR SUBSTANCES	QUALIFIED PER STANAG 4170	EIDS PER STANAG 4123	

* Mild reaction in single item tests may negate need for multiple unit test.

** May be acceptable as Test Series 7 test if conducted in transport configuration.

*** Test Series 6

**** Test Series 7

***** Required unless determined not to be a credible threat by analysis.

****

Figure 4 shows the passing criteria for Final Qualification/ Insensitive Munitions and Hazard Classification 1.6. With the exception of the Bullet Impact and Fuel Fire (Bonfire) tests, the passing criteria are essentially the same. For Bullet Impact, the Insensitive Munitions acceptance criteria are more stringent, "burning only", than the EIDS criteria of "reaction less than detonation." For the Fuel Fire, the Insensitive Munitions acceptance criteria is less stringent "burning only" than the EIDS Article criteria of no "Division 1.1, 1.2 or 1.3 reaction."

****

FIGURE 4
U.S. CRITERIA
MUNITIONS (ARTICLES)

	FINAL (TYPE) QUALIFICATION INSENSITIVE MUNITIONS	HAZARD CLASSIFICATION 1.6
BULLET IMPACT	BURNING MAXIMUM	
SLOW COOK OFF	BURNING MAXIMUM	
* FAST COOK OFF	BURNING MAXIMUM	LESS THAN DETONATION
EXTERNAL FIRE		BURNING MAXIMUM
FRAGMENT IMPACT	BURNING MAXIMUM	ANY RESPONSE THAT DOES NOT CLASSIFY ITEM AS 1.1, 1.2, 1.3
**SYMPATHETIC DETONATION	NO DETONATION PROPAGATION	
PROPAGATION TEST		NO DETONATION PROPAGATION
SHAPED CHARGE JET	NO DETONATION PROPAGATION	
SHAPED CHARGE JET SPALL	NO PERSISTENT BURNING	

* MAY BE ACCEPTABLE AS EQUIVALENT TO EXTERNAL FIRE TESTS FOR HAZARD CLASSIFICATION 1.6 IF PERFORMED IN PACKAGED CONFIGURATION

** MAY BE ACCEPTABLE AS EQUIVALENT TO PROPAGATION TEST FOR HAZARD CLASSIFICATION 1.6 IF PERFORMEND IN PACKAGED CONFIGURATION

....

Conclusions which can be drawn from this chart in combination with the previous one:

(1) Acceptance as a 1.6 Article does not necessarily mean that the munition is an Insensitive Munition.

(2) An Insensitive Munitions is not a 1.6 Article unless it is filled with an EIDS.

(3) An Insensitive Munitions Article containing a 1.1 Mass Detonating substance could be classified as a 1.2 Article (Fragmentation Hazard). Smaller items could be classified as 1.4.

Recommendations

The following recommendations are offered:

If the Hazard Classification 1.6 is desired, because of the requirements for the use of an EIDS and the stringent test acceptance criteria, this decision should be made early in the design effort to have the most impact on weapon design.

With regard to testing of substances, the test requirements of STANAG 4170 and STANAG 4123 Test Series 3 and 7 need to be standardized as much as possible.

The same direction should be pursued in the standardization of STANAG 4123 Test Series 7 and the United States Insensitive Munitions tests.

The benefits of achieving standardization include:

The redundant tests are eliminated.

The risk to the weapon developer is reduced.

Less testing translates into greater affordability.

Development costs are minimized.

More consistent testing will develop a stable data base from which to base STANAG requirements.

Standardization among Nations will increase the interoperability of weapons, especially important in the reduced budget environment.

And, the overall safety of weapons and their suitability for service will be increased to the benefit of all.

EXPLOSIVE CHARGES SAFETY TESTS

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ABSTRACT

This paper describes several simulating tests of explosive charges subjected to some environmental stimulations. The simulating tests are designed according to environmental conditions in the battlefield. It is well known that oil-wood fire cook-off, bullet and fragment impact, shock wave sympathetic detonation and shaped charge jet penetration is the most dangerous stimuli to munitions. Therefore, the informations obtained by means of simulating tests may be used to assess and compare the vulnerability of various candidate explosives for munitions. In this paper we reported the experimental pictures and results of three explosives: TNT, Comp.B and TATB.

1. INTRADUCTION

As we knew, the Desert Storm (Gulf War) was a modern war. The fire was very violent, the environmental conditions were very harsh. Under the harsh terms of modern war the main charge explosives in the bomb and warhead could undergo some dangerous stimuli, such as oil-wood fire cook-off, bullet and hot fragment impact, shock wave sympathetic detonation and shaped charge jet penetration. These environmental stimnli are serious threat to survivability of munitions in the battlefield. If the main explosive charges were poor vulnerability they would produce violent reactions: deflagration or detonation, and would make an accidental explosion. In order to prevent from the accidental explosion it is necessary that the vulnerability(1-4) of candidate main explosive is tested under simulating practice conditions. Thus we designed four kinds of simulating test according to the harsh terms in the battlefield. That is oil-wood fire fast cook-off test, 7.62mm caliber bullet impact test, shock wave sympathetic detonation test and shaped charge jet penetration test. The testing results may be used to assess and compare the vulnerability of various candidate explosives, and to select the low vulnerability explosives as the munitions of modern ordances.

2. SIMULATING TESTS

(1) Fire Fast Cook-off Test

This test is designed to simulate the stimulus of the oil-wood fire to munitions in the battlefield. The test set-up (5-7) is shown in Figure 1(a). Its fire flame source consisted of a certain size and quantity of lumbers which drenched with kerosene. Its flame temperature-time history was measured by means of thermocouple (Figure 1(b)). Duration of flame was about 8 min. The candidate explosive charges were loaded in a metal case (Figure 2) which was made of 45# steel tuble and sealed at both ends by threaded caps. During testing the interval (i.e. cook-off time) from ignition of fire flame source to explosion (or detonation) of candidate explosive was measured by timer. After test the metal case or its fragments were recovered. Its fracture scenario was an evidence to assess cook-off reaction and vulnerability of the candidate explosive.

(2) Bullet Impact Test

This test is designed to simulate the stimulus of bullets or hot fragments to munition in the battlefield. The test set-up (2, 4, 6) is shown in Figure 3. The candidate explosive charges were loaded in the metal case (Figure 2). Bullet caliber was 7.62mm, it was fired by an automatic rifle at distance 30m. Bullet velocity was 741m/s. During testing the candidate explosive charges may produce the phenomena: smoke, ignition, combustion, deflagration or detonation. After test the metal case or its fragments were recovered. Its fracture scenario was an evidence to assess reaction and vulnerability of the candidate explosive.

(3) Shock Wave Sympathetic Detonation Test

The Large Scale Gap Test (7, 8) is used to simulate the shock wave stimulus to munition in the battlefield. The test set-up is shown in Figure 4. The donor was RDX/W (95/5) explosive, pressed in a cylinder $\Phi 40 \times 30$mm, density 1.675 ± 0.005 g/cm^3. Attenuator (or barrier) material was Ly-12 model of aluminium alloy, its diameter 40mm, several thicknesses. The candidate explosive (i.e. receptor) was pressed or cast in cylinder $\Phi 40 \times 90$mm. Witness plate (80mm diameter $\times$ 30mm thick) was steel A_3. The criterion for receptor to produce detonation (GO) is punching a clear dent in the steel witness plate. The critical thickness of barrier (the 50 percent point for sample detonation) was determined by means of Optimum seeking Method (0.618) to change the thichness of barrier. This critical thickness is a standard for assessing the relative shock wave sensitivity of candidate explosive.

(4) Shaped Charge Jet Penetration Test

This test is designed to simulate the metal jet stimulus to munition in the battlefield. The test assembly is shown in Figure 5. The shaped charge was RDX/W (95/5) explosive. pressed in a cylinder $\Phi 40 \times$ 66mm, density $1.680 \pm 0.005 g/cm^3$, copper liner with apex angle 60° and wall thickness 0.75mm. Its metal jet could penetrate 150 ± 6mm of steel 45# at the stand-off 72mm. The candidate explesive (receptor) was pressed or cast in a cylinder 40mm diameter × 90mm long. The criterion for sample detonation is punching a clear dent in the steel witness plate. The critical thickness of steel barrier (the 50 percent point for sample detonation) was determined by Optimum Seeking Method (0.618) to change the thickness of steel barrier. This critical thickness is a standard for assessing the relative metal jet sensitivity of candidate explosive.

Otherwise, the jet sensitivity of candidate explosive may be also expressed by quantity V_j^2d. Where, V_j the jet velocity penetrated xmm steel plate after, d the jet diameter corresponded to V_j. After penetrating various thicknesses of steel plate the velocity V_j and its diameter d of the metal jet were measured by a 2MV flash X-ray system. The results are listed in Table 5. According to these data we obtained the following fit formulas:

$$V_j = 33.6X^{-0.491} \qquad (1)$$

$$d = 2.36 - 0.01X \qquad (2)$$

Where $X \in [30, 110]$ mm

Therefore, if X is given V_j and d may be calculated with above fit formulas (1) and (2), respectively.

3. RESULTS AND DISCUSSION

We have already done above four simulating tests to three explosives: TNT, Comp.B and TATB. Their results are listed in Tables 1, 2, 3 and 4, respectively.

The results listed in Table 1 and Figure 6 indicated that TATB is very insensitive to fire fast cook-off stimulus, only combustion and no deflagration and detonation, its metal case was only ruptured in the lids. Comp.B is very sensitive to this stimulus, produced the violent reaction (detonation), its metal case was fractured at all. Although TNT could resist the long cook-off time (360S) and the high temperatures

(620℃) it produced deflagration and its metal case was ruptured wholly. Therefore, their insensitivity to cook- off stimulus is ranked as follows:

TATB > TNT > Comp. B

The results listed in Table 2 and Figure 7 indicated that, undergone the bullet impact stimulus, TATB was no reaction, its metal case was not ruptured. Comp. B burned partly and a lid of its metal case was ruptured. TNT burned out and the lids of its metal case were ruptured at all. Therefore, their insensitivity to bullet impact stimulus is ranked as follows:

TATB> Comp. B > TNT

The data of shock wave and jet sensitivities for three explosives tested are listed in Tables 3 and 4, respectively. It is well known that increasing the thickness of barrier decreases the intensity of shock wave and metal jet to enter the receptor explosive. Thus the more the thickness, the more the sensitivity. Analysed the critical thickness data(i.e. the 50% probability point for receptor detonation), their both insensitivities to stimuli of shock wave and metal jet for three explosives tested are ranked as follows:

Insensitivity to shock wave stimulus

TATB > Comp. B > TNT

G50. 28.0mm 41.0mm 42.5mm

Insensitivity to metal jet stimulus

TATB > Comp. B > TNT

X50. 47.5mm 88.3mm 97.2mm

The jet sensitivity of explasives is also expressed by quantity V_j^2d.

Because V_j^2d is of the nature of force-power, the more the quantity, the more the insensitivity. So the rank for three explosives tested is the same as above one:

	TATB	>	Comp. B	>	TNT
V_j^2d	47.6		20.6		18.1

All in all, above ranks indicated that the jet sensitivity for explosive covered by steel plate corresponds to its shock wave sensitivity. This result supports the jet penetration bow wave shock initiation mechanism for covered explosives (9, 10).

4. CONCLUSIONS

(1) The testing results showed that the four simulating tests, i.e. oil-wood fire fast cook-off test, 7.62mm caliber bullet impact test, shock wave sympathetic detonation test (Large Scale Gap Test) and shaped charge jet penetration test, are virtual for comparing and assessing the low vulnerability of candidate explosives. The results are applicable to explosive hazard and vulnerability analysis and modern weapon munition design.

(2) The results of this paper demonstrated that TATB is very insensitive to fire fast cook-off, bullet impact, shock wave sympathetic detonation and metal jet penetration stimuli. Thus it is a type low vulnerability explosive and may be used as a standard of comparison. To fast cook-off stimlus TNT deflagrated, Comp. B detonated. To bullet, shock wave and metal jet stimuli, TNT is all more sensitive than comp. B.

5. AKNOWLEDGEMENTS

The authors wish to thank Engineers Hou Shixuan and Tang Bin for

helpful assisstance in the experiments to measure the jet velocity and its diameter by flask x-ray system.

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TABLE 1 Fire Fast Cook-off Test Results

Explosive	Density g/cm3	TMD* %	Cook-off Time S	Cook-off temperature ℃	Fracture scenario of metal case (Fig.6)	Cook-off Reaction
TNT(pressed)	1.58	96	360	620	Ruptured into block	Deflagration
Comp.B(cast)	1.69	97	240	470	Fractured into pieces	Detonation
TATB(pressed)	1.73	90	300	590	Ruptured in lids	Combustion

* TMD——Therotical Maximum Denoity

TABLE 2 Bullet Impact Test Results

Explosive	Density g/cm3	TMD %	Bullet Caliber mm	Bullet velocity m/s	Fracture scenario of metal case (Fig.7)	type Reaction
TNT(pressed)	1.58	96	7.62	741	Ruptured in lids	Combustion
Comp.B(cast)	1.69	97	7.62	741	Ruptared in a lid	Part combustion
TATB(pressed)	1.73	90	7.62	741	Not ruptured	No reaction

TABLE 3 Large Scale Gap Test Results

Explosive	Density g/cm^3	TMD %	Gap Material	Critical Gap Thickness G50 mm
TNT(pressed)	1.58	96	Ly-12Al	42.5
Comp.B(cast)	1.69	97	Ly-12Al	41.0
TATB(pressed)	1.73	90	Ly-12Al	28.0

TABLE 4 Jet Sensitivity Test Results

Explosive	Density g/cm^3 (TMD %)	Critical Jet Characteristics *			
		X50 mm	Vj mm/μs	d mm	$V^2_j d$ $mm^3/\mu s^2$
TNT(pressed)	1.58 (96)	97.2	3.6	1.4	18.1
Comp.B(cast)	1.69 (97)	88.3	3.7	1.5	20.5
TATB(pressed)	1.73 (90)	47.5	5.0	1.9	47.5

* X50—Seel Plate thickness, Vj—Jet Velocity
d—Jet Diameter

TABLE 5 Velocity and Diameter of the Jet by Flash X-rays

Steel Plate Thickness mm	30	50	70	90	110
Jet Velocity Vj mm/μs	6.3	4.8	4.5	3.6	3.3
Jet Diameter d mm	2.1	1.8	1.5	1.5	1.2

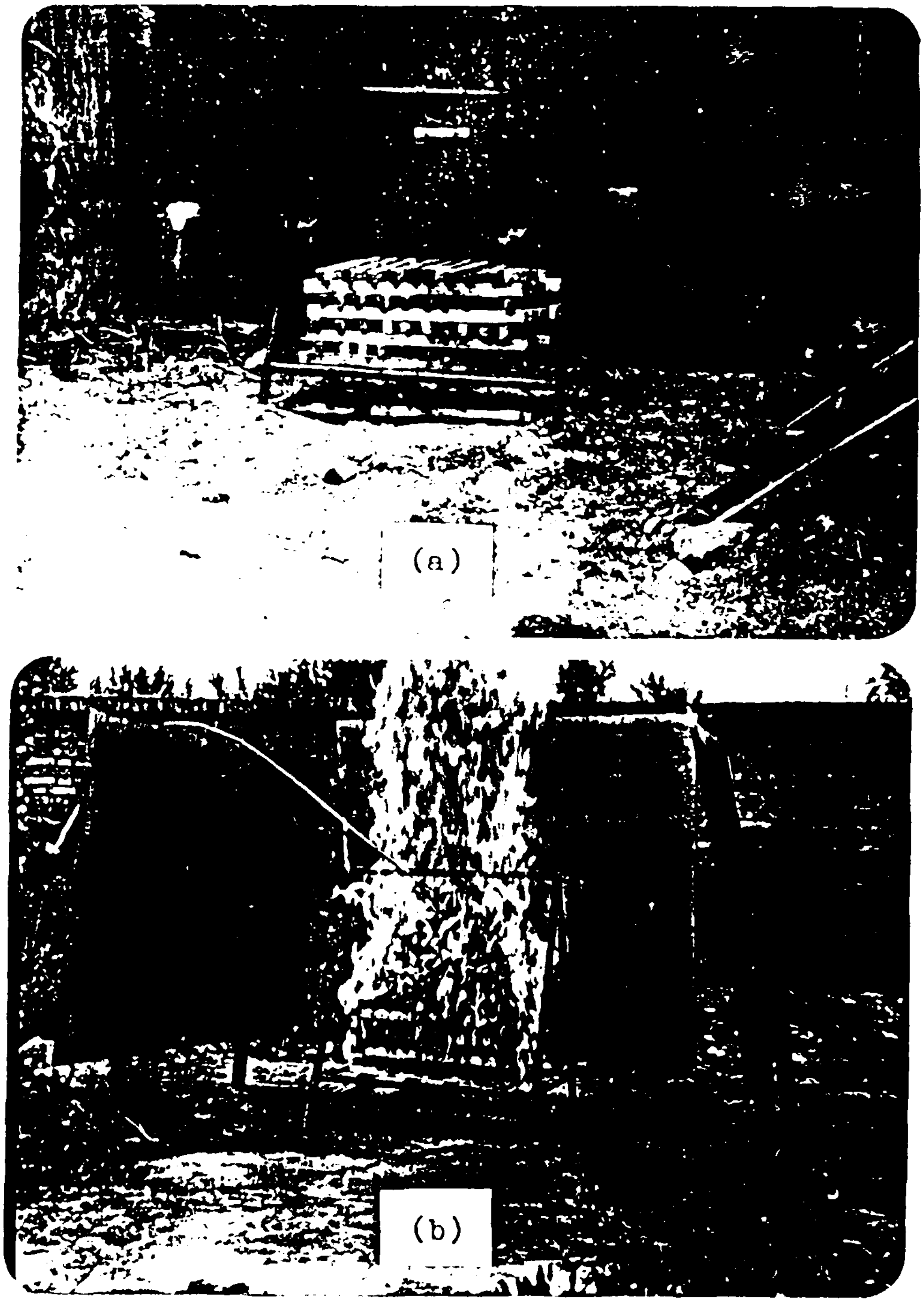

Figure 1 (a) Cook-off Test Set-up

(b) Flame Temperature Measurement

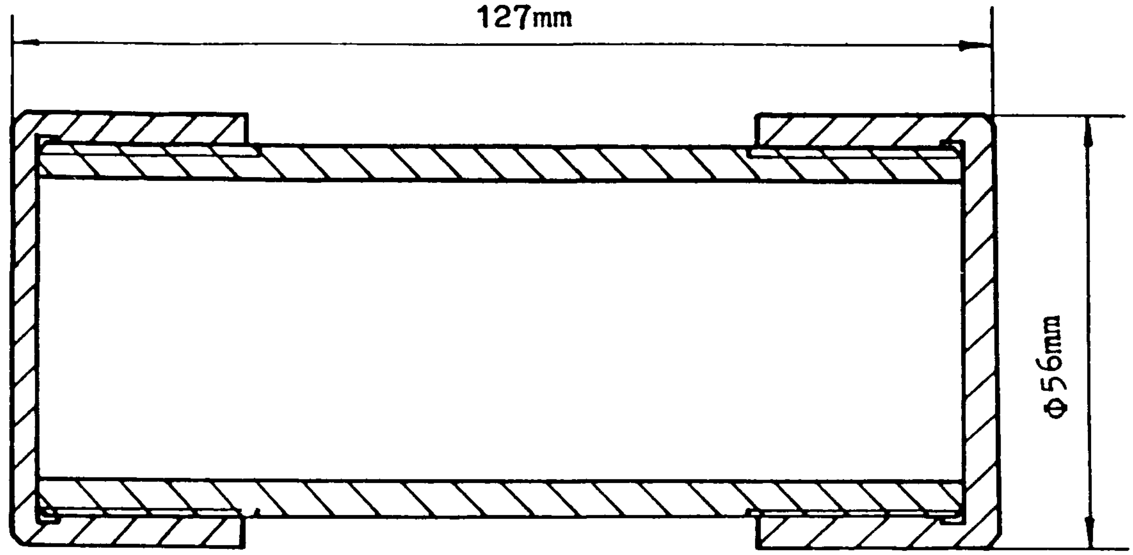

Figure 2 Metal Case

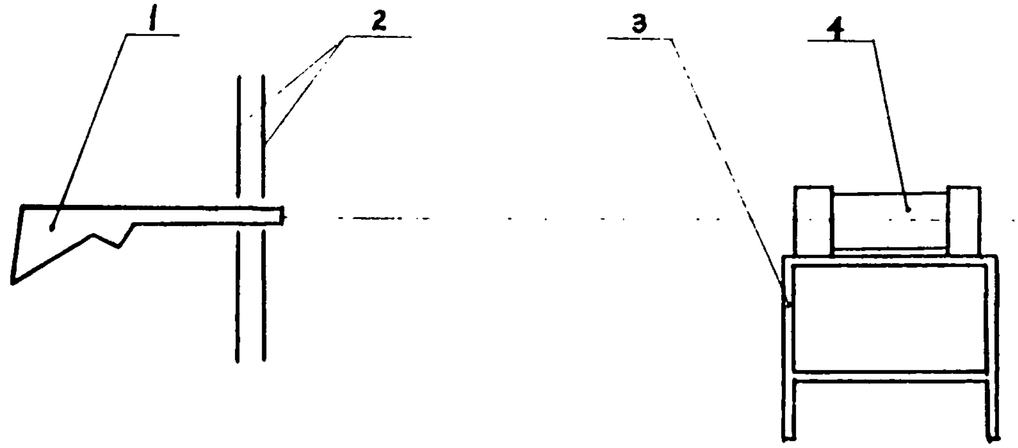

Figure 3 Bullet Impact Test Set-up

1—Rifle 2—Steel plate prevented

3—support 4—Metal case

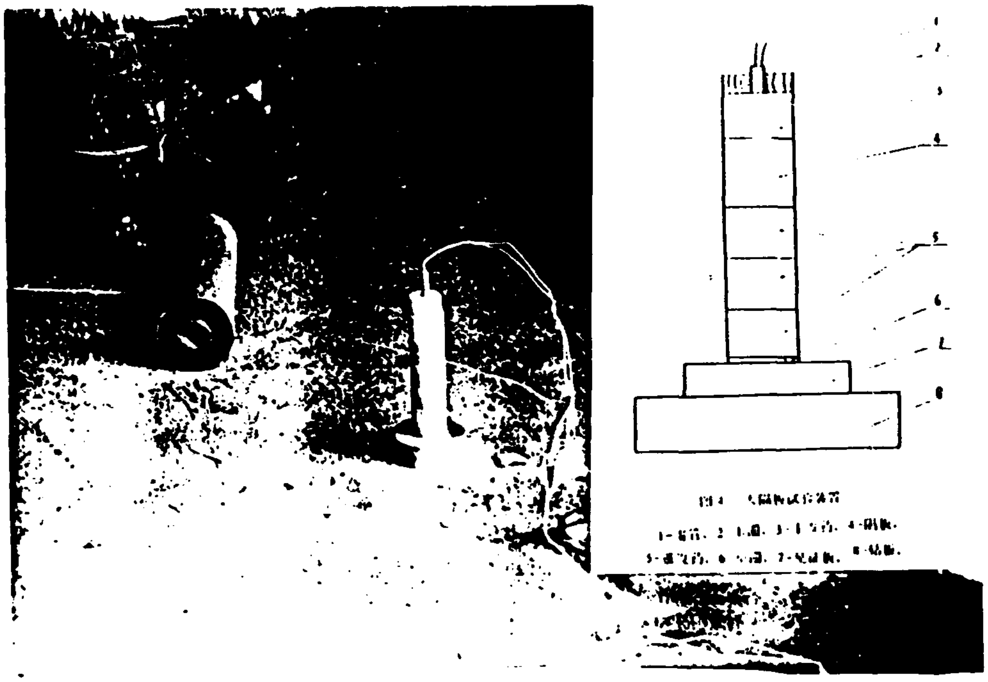

Figure 4 Large Scale Gap Test Set-up

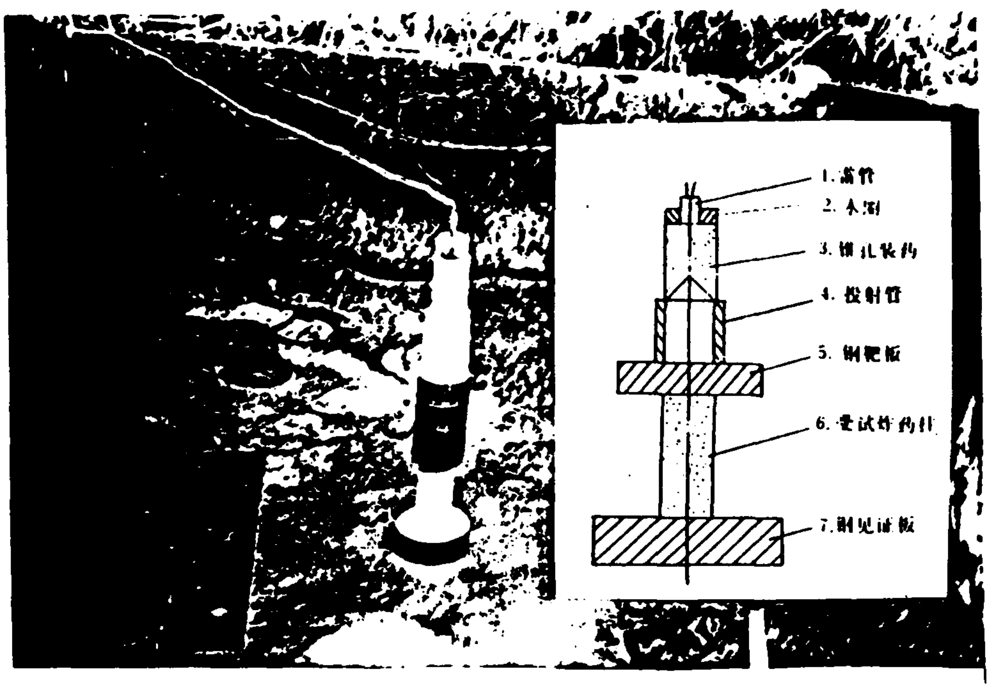

Figure 5 Metal Jet Penetration Set-up

Figure 6 Fracture Scenario of Metal Case After Cook-off Test

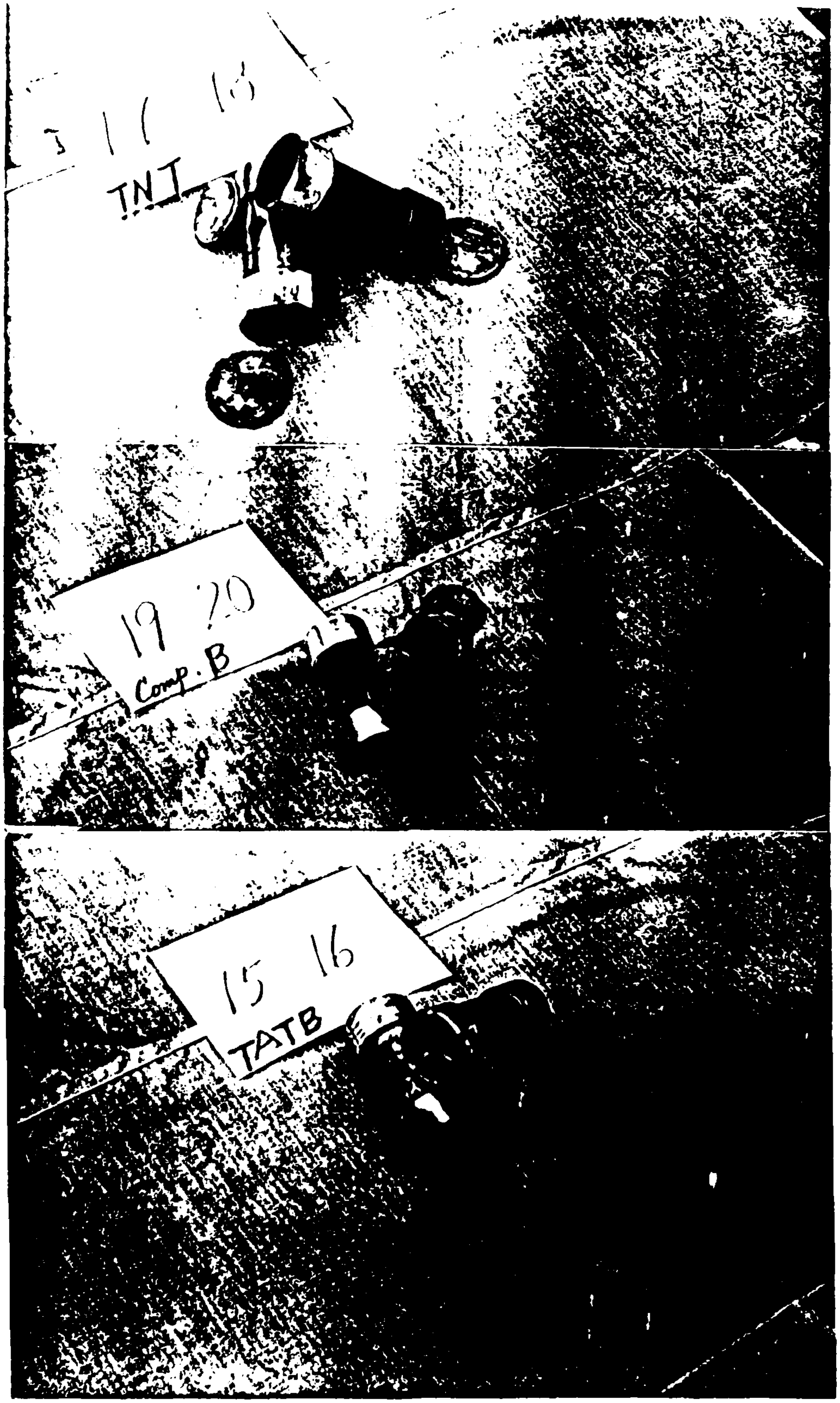

Figure 7 Fracture Scenario of Metal Case After Bullet Impact Test

THE EXPLOSIVE COMPONENT WATER GAP TEST

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ABSTRACT

In the safety assessment of munitions, the explosives used must be identified. In addition to national legislation and regulatory requirements, the safety and suitability of the explosives for use by military services is assessed according to STANAG 4170 before selection and incorporation into the munition.

Explosive components used in fuzing systems normally contain explosives which are more sensitive than main charge explosives. Small changes of loading conditions involving e.g. pressure-density and/or confinement can radically alter their performance and characteristics, which can affect their safety. Therefore it is essential that these effects are thoroughly assessed during development and, if necessary, in production.

The Explosive Component Water Gap Test (ECWGT) has been developed to assist in this assessment. It is described and the associated documents listed. It is intended to extend the test method to cover cord- and tube-shaped explosive components as well as ignition transfer elements.

AIM

1. The aim of this paper is give the background to, and explain the conduct of the explosive component water gap test, a means of testing the shock sensitiveness of explosive components cheaply and in a reproducible manner.

BACKGROUND

2. The NATO AC 310, Sub-group II is responsible for developing the philosophy for fuze safety and the test regimes for fuzes within NATO. One of the many successes of this group over the last few years is to publish the test described in this paper as a NATO standardisation agreement or STANAG. At this stage tribute must be paid to the primary author of this paper, Dr Bartels, who until he retired last year was working for BICT in Germany.

DESIGN REQUIREMENTS

3. For any of you not familiar with NATO standardisation agreements or STANAGs for short, the main one on fuzing systems is STANAG 4187 [1]. Among other requirements this STANAG demands that explosives and explosive compositions for fuzing systems shall be assessed and qualified in their design role so that the munition is safe and remains so under the specified conditions of storage and use. As a precondition the safety and suitability of the explosives for use by military service must be assessed, in addition to national legislation requirements, according to STANAG 4170 [2].

4. Explosive components used in fuzing systems normally contain explosives which are more sensitive than main charge explosives. The safety hazard created by primary explosives and comparable compositions, normally only loaded in detonators and other initiators, can be eliminated by a shutter in a fuze safety and arming device. As a result the need to endorse the related design safety requirements of STANAG 4187 should be sufficient for these very sensitive components.

5. Only those explosives qualified in accordance with the requirements of STANAG 4170 as acceptable expulsion charges and lead or booster explosives, are permitted to be in a position leading to the initiation of a high explosive main charge without an interrupter being present. They shall not be altered during their lifetime (manufacture to target sequence) by any means likely to increase their sensitiveness beyond that for which the material was qualified and at which it is customarily used.

EXPLOSIVE CHARACTERISTICS AND ASSESSMENT

6. The characteristics of explosive materials are changed when contained, pressed or associated with other materials in an explosive component. Even small changes involving for example pressure-density and/or confinement can radically alter their performance and characteristics, and which can ultimately affect their safety. To assess the effects of these changes and to identify the safety relevant data of lead and booster compositions used for qualification as well as for pilot lot acceptance tests, development testing for the characterisation and safety appraisal of these components should be standardized. Until now the criteria used by individual nations to qualify or accept lead and booster components have not be collated, readily available nor well documented. This often has delayed the acceptance of these components by other nations, hindered interoperability and wasted time and money for re-characterisation. This lack of a standard led to the promulgation of STANAG 4363 "Fuzing Systems, Development Testing for the Assessment of Lead and Booster Components" [3].

7. The STANAG is the covering document for the Allied Ordnance Publication 21 (AOP-21) [4], which contains a detailed description of the different applicable test methods and procedures. The agreement stated the responsibility of the developing nation for conducting testing as well as for providing copies of the relevant design characteristics, safety analyses and the reports of trials conducted. It confirms the requirements concerning the stability and compatibility of the incorporated explosives, regulates changes to the agreed assessment procedures detailed in AOP-21 and describes the documentation of a safety statement in combination with a data sheet.

8. The AOP describes the test procedures and test item configuration and states the information required before and after testing, required test conditions and acceptance criteria for development testing of lead and booster explosive components used in fuzing systems in either interrupted or non-interrupted explosive trains. To ensure the validity of the tests it is vital that the detailed specification of the component and explosive filling are made available from the design authority concerned. The components under test should be manufactured to approved (frozen) drawings and taken randomly. In case of specification changes affecting safety the components would have to be re-tested.

9. The safety of these components within a fuzing system depends principally on their thermal stability and sensitiveness to shock stimuli. Thermal stability testing is conducted at the system level with the component incorporated in its respective fuzing system. The shock sensitiveness can be determined before it is selected for

a specific use. For lead or booster components not exceeding 15 mm in diameter the explosive component water gap test (ECWGT) is a suitable test.

10. The Explosive Component Water Gap Test. The test, the equipment is shown in Figure 1, involves subjecting lead or booster components to a series of selected shockwave stimuli which are generated by a standardised explosive donor and attenuated by a column of distilled or deionised water. A witness rod is used to assess whether or not the lead or booster has reacted.

11. By conducting a series of Bruceton Tests the "no go" value is determined and the measured water gap value is converted to the relative shock pressure. The test results represent the effects of the explosive loading, its confinement and pressing density. A detailed test procedure including a set of drawings for the test equipment, a data sheet format as well as examples for calculation and filling up and a table for conversion of ECWGT results (mm water gap to shock pressure) are contained in AOP-21, Annex B [4]. An example of a completed ECWGT data sheet is at Annex A.

12. A component will be considered suitably insensitive to shock to enable its use in future uninterrupted explosive trains if its "no-go" level is less than or equal to 28 mm of water corresponding to a shock pressure level of 10.7 kbar. This level derives from a pellet of "NATO-tetryl" compacted to a density of 1.55 g/cc and qualified in accordance to STANAG 4170 [2].

13. The shock sensitiveness of components with diameters greater than 15 mm may be assessed by conducting a gap test on the explosive material provided that it has been manufactured to the same pressing density. The gap test is used to assess the effects of a particular environment on a component by conducting the gap test on a sample of the components before submitting similar components to the environment and then a gap test. This will show whether the shock sensitivity has been adversely affected. Such an environment could be the thermal shock test.

14. Characterisation Test. This test should be conducted to confirm the applicability of the lead or booster component for its intended role within a fuzing system. The ECWGT represents a suitable test procedure. For characterisation, a modified Bruceton Test [5] provides the mean value of shock sensitiveness and its standard deviation. The test therefore provides evidence towards determining the applicability of that component to fulfil a particular requirement in the explosive train.

15. Reporting Data Sheet. Nations which develop lead and booster explosive components shall provide the detailed results of any safety and characterisation tests that have been conducted. These results shall be available to other National Safety Approving Authorities as a part of the safety statement. When requested by NATO countries procuring these components, nations shall provide a data sheet defining the specific component including:

> Nomenclature and dimensions, identification including drawing and specification numbers, a drawing, general background data, Qualification/Assessment status, material data, safety and characterisation results, additional remarks including Compatibility Statement.

SUMMARY AND FORECAST

16. The explosive component water gap test is simple and cheap to conduct, it lends itself to statistical analyses. I believe it is a valuable test and would also be a very useful one for manufacturers as a quality control test during batch production of such components. It can also assist in determining the causes of system failures using data based on previous component tests.

17. Test development is not standing still. Its use to test cord and tube shaped explosive components as well as igniting cord components is being investigated. Tests are currently being performed in France, Germany and the UK on pyrotechnic cords. Once these test haves been completed successfully then the modified test procedure will be included in AOP 21 [4].

References:

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[3]	STANAG 4363	Fuzing Systems - Development Testing for the Assessment of Lead and Booster Components
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[5]	W J Dixon & F Massey Jr	An Introduction to Statistical Analysis New York, McGraw-Hill,(1951), pg 279-287

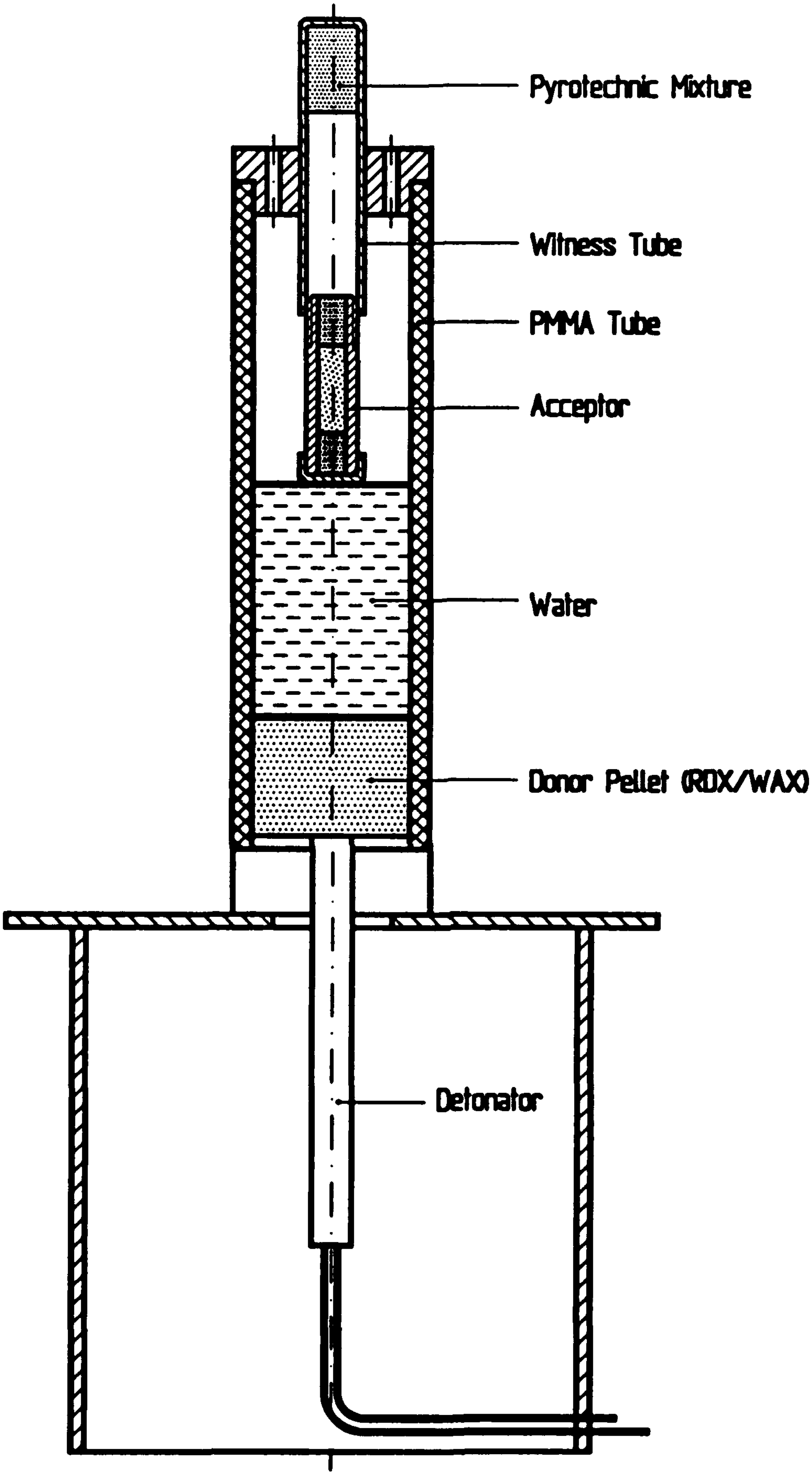


Fig. 1 Ignition Component
Water Gap Test

Explosive Component Water Gap Test (ECWGT)

Explosive Component (EC) : Booster XYZ **EC Data sheet No. :**

Lot No. : 123 **Manufacturer :** An explosives company

Explosive Filling : SS C 8042 (Tetryl) **Filling Weight :** 3.15 g **Loading Density :** 1.58 gcm^{-3}

Acceptor Orientation : Bottom of case in contact with water gap

Legend : - = no Reaction, x = Explosion

	Characterization - Test																				Safety - Test				
Water Gap / Trial No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
H_0 = 22 mm															x				x						
H_1 = 23 mm		x				x		x		x		x		-		x		-		-					
H_2 = 24 mm	-		x		-		-		-		-		-				-								
H_3 = 25 mm				-																	-	-	-	-	
H_4 = mm																									
H_5 = mm																									

H_0 = minimum water gap

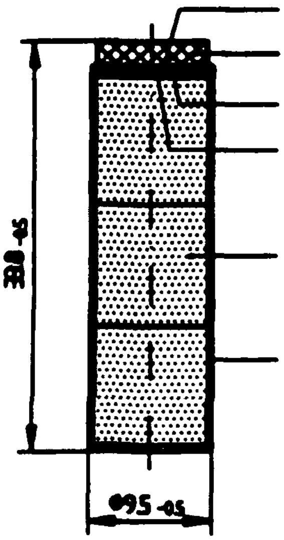
Calculation

H (mm)	i	n^+	n^-	$i \cdot n^{\pm}$	$i^2 \cdot n^{\pm}$
22	0	2	0	0	0
23	1	6	3	6	6
24	2	1	7	2	4
25	3	0	1	–	–
	4				
	5				
Σ		N^+ = 9	N^- = 11	A = 8	B = 10

$\Sigma n^+ \leq \Sigma n^-$, use n^+

$\Sigma n^+ > \Sigma n^-$, use n^-

Drawing :



Median $M_{50} = H_0 + \frac{A}{N} \pm 0.5^{**}$ $22 + \frac{8}{9} + 0.5$

Standard Deviation $S = 0.05 + 1.6 \frac{(N \cdot B - A^2)}{N^2}$

** if using N^+ add 0.5
if using N^- subtract 0.5 $S = 0.05 + 1.6 \frac{90-64}{81}$

Median : 23.4 mm Water Gap, equivalent to a pressure of approximately 15 kbar

Standard Deviation : 0.56 mm Water Gap

HIGH TEMPERATURE/SOLAR EFFECTS TESTING ON VARIOUS MUNITIONS

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ABSTRACT

The Persian Gulf War produced concerns about the safety and survivability of ammunition being stored in the desert of Southwest Asia (SWA). The temperatures and solar intensity in SWA were reported to be greater than expected. The ammunition was being stockpiled in the only environment available: on the sand and exposed to high temperatures and long daily periods of solar loading. The U.S. Army Combat Systems Test Activity (CSTA) at Aberdeen Proving Ground is addressing these safety concerns by conducting a test program in support of Operation Desert Storm to determine the effects of high temperatures and intense solar loading on various types of ammunition.

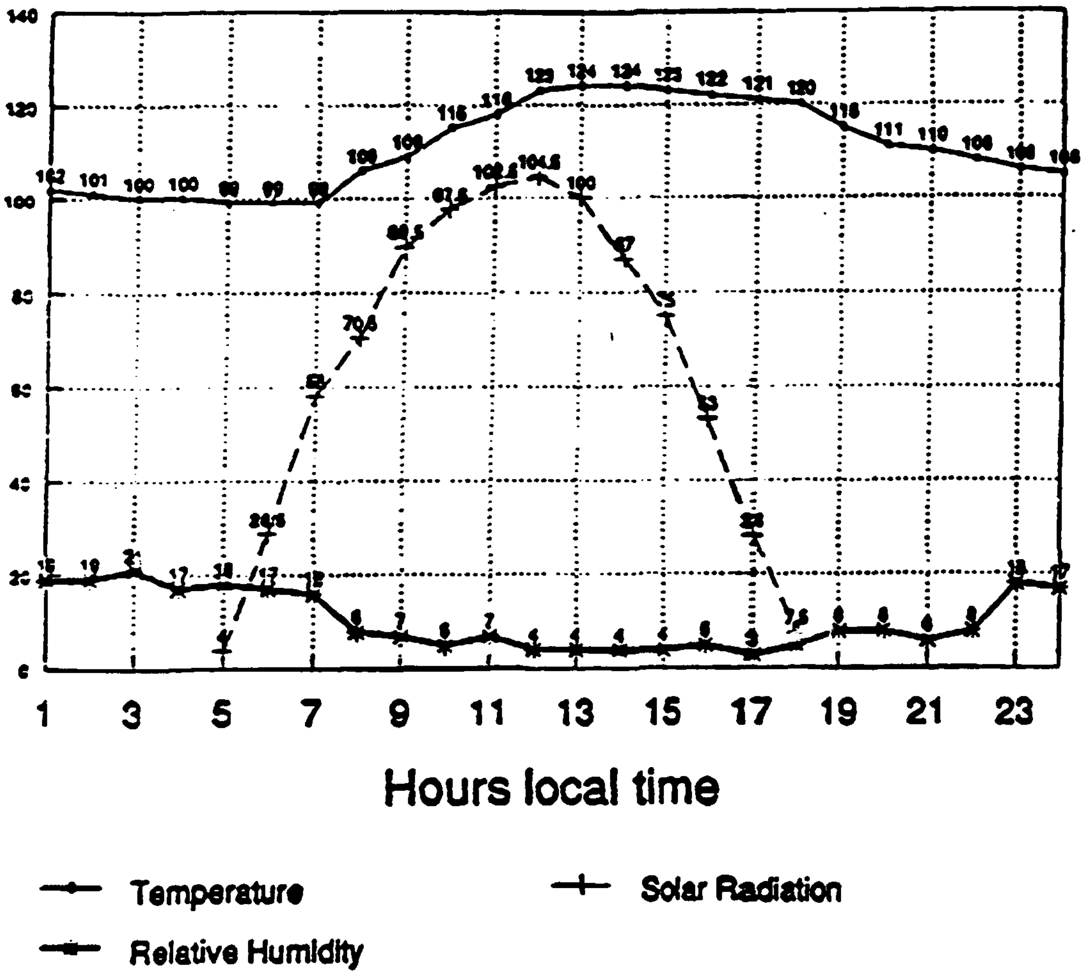
The program involves subjecting ammunition to a diurnal cycle simulating the severe temperature, relative humidity, and solar radiation conditions measured during Saudi Arabian summer days. The test items are placed in solar chambers on a bed of sand and exposed for 30-, 60-, and 90-days. Following conditioning, a variety of laboratory and ballistic tests are performed to assess safety and performance.

INTRODUCTION

Exposure of propellants and explosives to high temperatures results in both shortening of useful life and degradation of safety and performance. In an attempt to determine the impact on munitions exposed to the extreme SWA summer, the Predictive Technology Branch at Picatinny Arsenal established the High Temperature Test Program. CSTA was requested to conduct the test in two phases. The first phase was conducted from May 1991 until April 1992 and involved 10 types of ammunition ranging from 60-mm cartridges to 8-inch projectiles. The second phase began in June 1992 and also involves 10 ammunition types including fuzes and anti-tank rockets.

The test requires the utilization of three unique solar chambers, two of which were constructed specifically for the test, to simulate exposure to the SWA desert environment. The diurnal cycle used for this test was developed by Predictive Technology engineers based on actual daily information obtained by the Air Force in Southwest Asia from 1984 to 1989. The diurnal cycle (Figure 1) contains temperature, humidity and solar radiation parameters that represent a worst-case SWA summer day. The diurnal cycle developed was very similar to that of MIL-STD-810E except that the solar loading was slightly lower while temperatures were slightly higher.

Southwest Asia Profile
Temperature, Solar Radiation
Relative Humidity



Radiation X 10
Temp in degree F, Radiation in W/m^2
Relative Humidity in %

FIGURE 1. Temperature, solar radiation, and relative humidity Southwest Asia profile. Test items were conditioned to this diurnal cycle for 30-, 60-, and 90-day intervals.

TEST ITEMS

The test items used for the High Temperature program and their packaging are as follows:

PHASE I

Cartridge, 60-mm: HE, M720. Each cartridge was in its individual fiber container with eight cartridges per metal can.

Cartridge, 105-mm: HE, M1. Each cartridge was packed in a fiber container with two cartridges per wooden box.

Cartridge, 105-mm: HEAT-T, M456A2. Each cartridge was packed in a metal container with a plastic sleeve surrounding the projectile and a fiber liner around the cartridge case.

Cartridge, 120-mm: APFSDS-T, M829. Each cartridge was packed in a metal container with a foam liner.

Cartridge, 120-mm: APFSDS-T, M829A1. Packaging same as the M829.

Cartridge, 120-mm: HEAT-MP-T, M830. Packaging same as the M829.

Charge, Propelling, 155-mm: M203A1. Each charge was packed in a metal container with a fiber liner.

Projectile, 155-mm: HE, M483A1. Projectiles were unpalletized.

Charge, Propelling, 8-inch: M188A1. Packaging the same as the M203A1.

Projectile, 8-inch: HE, RA, M650. Projectiles were unpalletized.

PHASE II

Fuze, Proximity: M728. Fuzes were packaged eight per metal can.

Fuze, Point Detonating: M739. Packaging same as the M728.

Rocket, 66-mm: HEAT, M72A2. Rockets were packaged in their launchers.

Cartridge, 81-mm: HE, M821. Each cartridge was packaged in a plastic monopack with three cartridges per metal can.

Cartridge, 84-mm: M136 (AT4). Cartridges were packaged in their launchers.

Cartridge, 105-mm: APFSDS-T, M833. Each cartridge was packed in a metal container with a foam liner

Cartridge, 120-mm: HEAT-MP-T, M830. Each cartridge was packed in a metal container with a foam liner.

Charge, Propelling, 155-mm: M4A2. Each charge was packed in a metal container with a fiber liner.

Projectile, 155-mm: Extended Range, DP, M864. Projectiles were unpalletized.

Projectile, 155-mm: AT, M718A1. Projectiles were unpalletized.

TEST CHAMBERS/INSTRUMENTATION

Three chambers are required to simultaneously accommodate all of the ammunition. Combined, the three chambers provide approximately 540 square feet of test area. The two chamber lamp types used are 400 watt lucalox and 1000 watt mercury-vapor with roughly 60% of the lamps in each chamber being the mercury-vapor type. Each lamp is individually controlled and the entire light bank can be raised and lowered to adjust the solar intensity. In addition to solar intensity, both temperature and air flow distribution were measured in each chamber prior to testing. To further simulate the SWA desert environment, the floor of each chamber was covered with sand.

Two rounds of each type were instrumented with thermocouples at locations on the outside and inside of the packaging as well as numerous locations on the outside of the round and in the propellant and explosive (Figure 2). The intent was to gather as much response data as possible to determine not only the maximum surface temperatures but also to be able to determine the heat transfer characteristics within the rounds themselves.

The chamber temperature is controlled using a calibrated micro-processor-multi-looped controller utilizing a type T thermocouple. The internal chamber temperature is maintained within ± 2.2 ^{o}C (± 4 ^{o}F) throughout the cycle and is measured and recorded at four locations within each chamber. During cycling, the relative humidity is not controlled within ± 5 percent; however, the chamber relative humidity is monitored and recorded. The solar radiation levels are controlled and monitored using a calibrated pyranometer located in the center of each chamber and maintained within ± 47 W/m^2 (± 14 Btu/ft^2/h) during cycling. These analog signal inputs (temperature (both chamber and ammunition), relative humidity, and solar irradiance (voltage)) are recorded using Doric 245 data loggers and MEMTEC 2500 digital recorders. Data is recorded every 30 minutes during cycling.

SAFETY CONSIDERATIONS

Due to the high ammunition temperatures expected on this test, several safety precautions were taken. Initially inert rounds of each type were thermocoupled, subjected to the actual test profile, and the temperature data recorded. This was done to identify maximum temperatures that the different

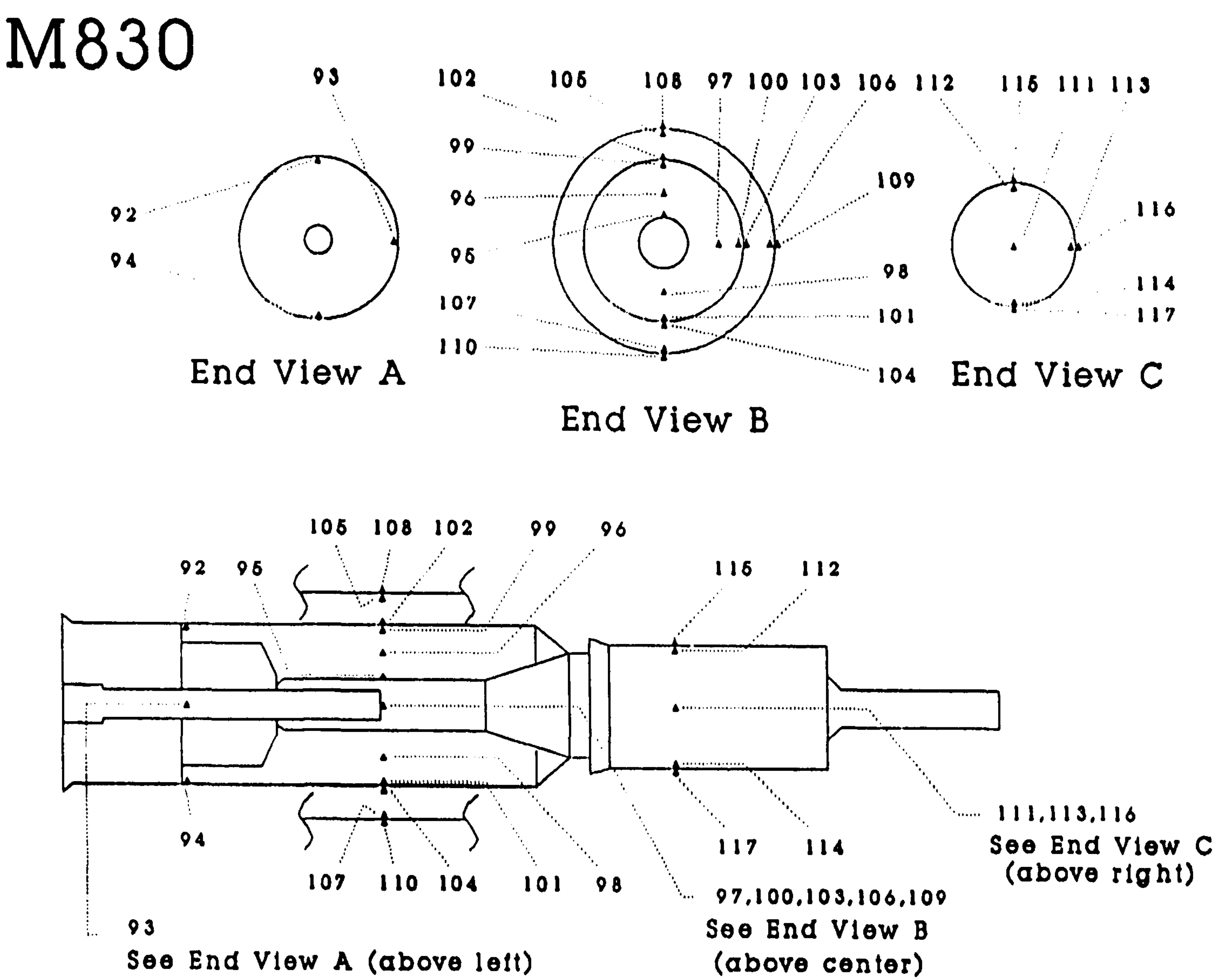


FIGURE 2. Thermocouple location diagram for the M830 cartridge. Thermocouple locations are similar for the other rounds.

areas of the round will reach at stabilization. These temperatures were then compared to the munitions explosive characteristics to determine if there was a potential hazard. Only after the hazard possibilities were assessed did testing on live ammunition take place.

Another safety precaution was linked to the internal temperature of the explosive in specific rounds of ammunition. A thermocouple placed in the high explosive filler (just inside the body wall of these rounds) was hooked to a safety device which would automatically shut down the chamber (temperature and lights) when the critical temperature of 78 ^{o}C (172 ^{o}F) was measured. This temperature was chosen because it is slightly below the melting point for the explosives.

TEST PROCEDURE

The program requires the ammunition to be subjected to 90 continuous days of the temperature-humidity-solar profile. For Phase I, all of the test items except for the M720, M483A1, and M650 were placed horizontally on the sand bed and positioned in one row of one high. The M650 and M483A1 were placed standing on their bases while the M720 rounds were placed vertically, base up, in their metal cans. For Phase II, the fuzes and the M821 were placed vertically in their metal cans while the rest of the items, including the projectiles, were placed horizontally in the chamber. Figure 3 shows the test item setup in the solar chamber. During the test, occasional chamber problems or power interrupts occur which can not be avoided. Once the chambers are brought back on line, the ammunition is re-stabilized to the temperatures that had been measured inside the rounds prior to the downtime, and then test restarted from that point with the time adjusted accordingly.

As a means of determining the aging effects of this environment on the ammunition, the test plans dictated that each type of round be divided into three groups: control rounds (no testing); laboratory rounds (those exposed then subjected to laboratory analysis; and ballistic rounds (those exposed and then fired). The control rounds are further divided into laboratory and ballistic rounds. Certain quantities of each type (laboratory and ballistic) are then removed from the environment at the 30-, 60-, and 90-day intervals of the test to evaluate the cumulative effects of the environment. The laboratory rounds are disassembled and various tests are conducted to determine the chemical composition and sensitivity of the propellant and explosive to see if any changes are occurring. Once the results of the chemical analysis verify that the rounds should be safe to fire, the ballistic tests are conducted for safety and performance.

RESULTS

As expected, different rounds reached different temperatures due to the size of the round, its packaging, and its orientation within the chamber. The following table provides a listing of the highest temperatures measured

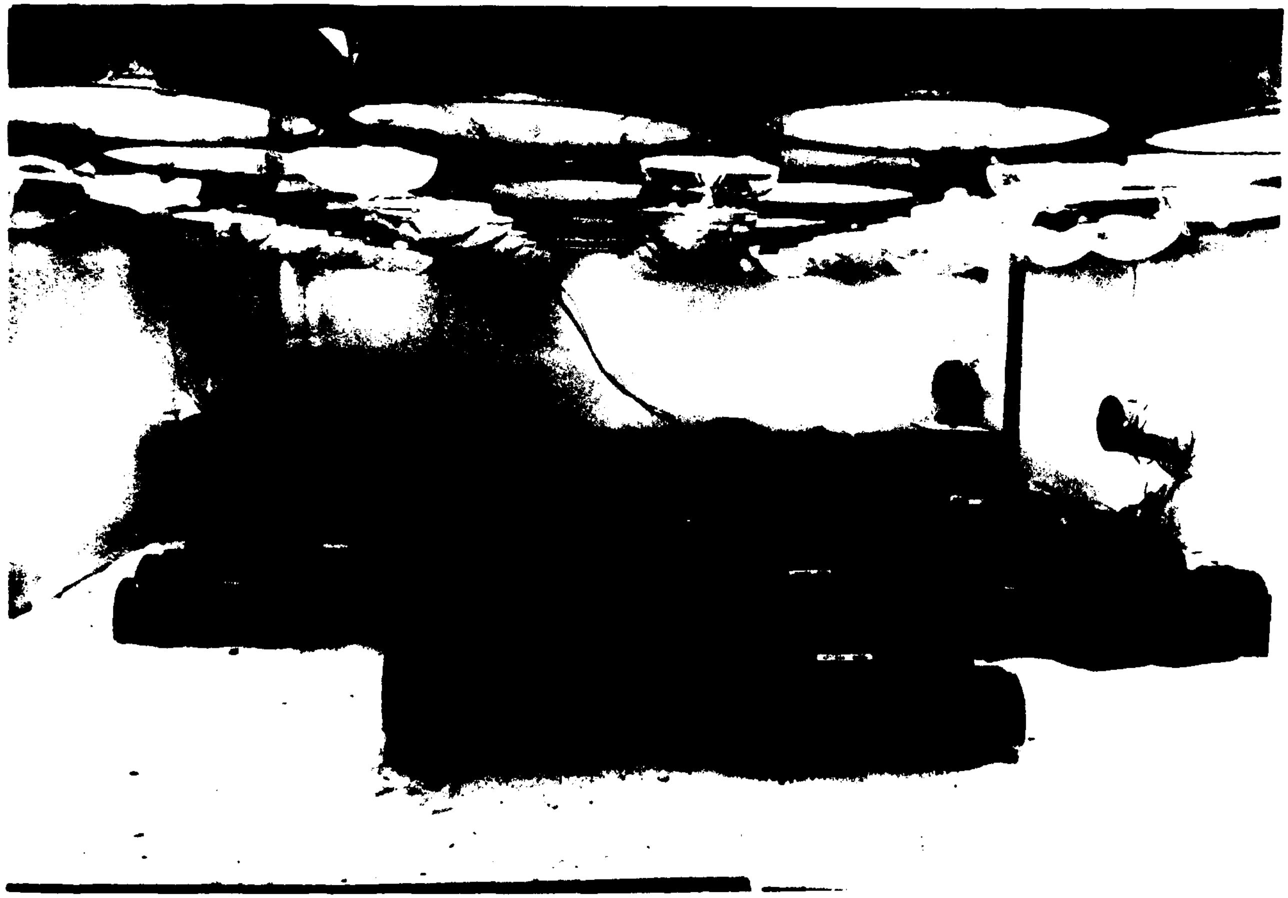


FIGURE 3. Test Items as loaded in the solar conditioning chamber. The solar spectrum is achieved using the Lucalox (larger) lamps and the Mercury Vapor lamps.

within some of the rounds during Phase I of the test. All temperatures are in degrees Fahrenheit.

ROUND TYPE	CONTAINER OUTER SURFACE	ROUND OUTER SURFACE	CORE HIGH EXPLOSIVE	CORE PROPELLANT
M830	205	192	170	180
M829	198	182	NA	155
M456A2	182	164	155	157
M188A1	191	165	NA	145
M203A1	182	169	NA	150
M650	NA	154	148	NA
M483A1	NA	147	148	NA

Laboratory and ballistic results from Phase I are currently being analyzed by the Predictive Technology Branch. Comparisons are being made to acceptance data for the particular lot in question of each round type. If the effect of the high temperature environment produces a noticeable degradation in either chemical or physical properties, then the test results, staggered at 0, 30, 60, and 90 day intervals, should be in the form of a trend. Analysis of this data can be used to predict if and when items will be adversely affected, and to what degree. Thermocouple data is also under analysis to determine how various packaging environments affect the different types of ammunition. Phase II solar conditioning should be completed in Oct 92 with all laboratory and ballistic tests completed by Jan 93.

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INHABITED BUILDING DISTANCE CRITERIA AND MODERN CONSTRUCTION

BY

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AND
WILLIAM H. ZEHRT, JR.[1]

ABSTRACT

The current Inhabited Building Distance (IBD) criteria as defined by DoD 6055.9-STD is based predominately on observations, experimental work, and opinion during the period 1945 through 1969. During the last 20 years, great advances have been made in our knowledge and understanding of blast effects phenomena. During the same period, design and construction technology have changed significantly. Modern residential and commercial structures are much lighter and more flexible than the structures on which present IBD criteria are based.

In this paper, the development of IBD criteria is reviewed, and its applicability to modern construction is evaluated. Particular attention is paid to an evaluation of probable damage and risk to modern residential structures and lightweight commercial structures, such as pre-engineered buildings, sited at IBD distances.

1.0 BACKGROUND

The Department of Defense Explosives Safety Board (DDESB) publishes and maintains criteria and defines separation distances between explosive sources and various target or receiver facilities. The selection of a separation distance between donor and various classes of receivers has been evolutionary in nature and has been based predominantly on observations, experimental work and opinion during the period from 1945 through 1969. The criteria for separation distances are based on DDESB level military service opinion and judgment of acceptable damage and injury at various distances from donors.

The available technical data, social, political and legal environment that existed when the current criteria were selected are significantly different than those existing in the world today. Of particular concern is the potential for property damage and injury to the public in general at inhabited building distances (IBD). These distances apply at the boundary of military installations or storage areas where uncontrolled residential and commercial development must be accepted.

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According to the Department of Defense Ammunition and Explosives Safety Standards, DoD 6055.9-STD, at IBD, ". . . Unstrengthened buildings can be expected to sustain structural damage up to about 5 percent of replacement cost. Personnel are provided a high degree of protection from death or serious injury, with injuries that do occur principally being caused by glass breakage and building debris. . . ." [1] This damage criteria was established based on a limited section of the data base of structure types commonly constructed in the 1940-1960 period, wood frame residential construction.

The last 20 years has seen great advances in our knowledge of blast effects phenomena. Well documented experimental work and modern computer aided analysis procedures have resolved many of the technical uncertainties that existed when the present IBD criteria were established. We have also seen significant changes in design and construction technology. Modern residential and commercial structures are much lighter, are more flexible, and make greater application of glass as an exterior cladding material. The suitability of the stated damage criteria at IBD is not clear for such modern construction.

This paper is based on the results of a report prepared under the direction of the DDESB. In that report, the possible consequences of presently specified inhabited building distance criteria were evaluated, particularly as they related to modern construction. The evaluation was accomplished in four steps:

a. The historical development of IBD criteria was reviewed and discussed.

b. The empirical and analytical data used to develop the current IBD damage criteria was reviewed, and its applicability to modern construction was evaluated.

c. A cost model was prepared which compared the damage and repair costs for residences constructed during the 1945-1969 era with expected damage and repair costs for modern residential construction located at IBD.

d. Probable damage to structures other than residential construction located at IBD was evaluated. This phase of the report concentrated on modern commercial and public structures particularly susceptible to damage from blast overpressures. Examples were provided on the performance of modern pre-engineered metal buildings, a structure type proliferating rapidly in public buildings.

2.0 ORIGIN OF DoD INHABITED BUILDING DISTANCE CRITERIA

The American Table of Distances (ATD), published in 1910, provided the first industry guidelines for the siting of stores of explosives in the United States. The ATD established separation distances between explosives and inhabited buildings and public railroads. In 1914, the scope of the document was expanded to include separation distances for public highways.

The separation distances provided in the ATD were developed through a limited quantitative analysis of observed damage information obtained from previous explosive accidents. A detailed tabulation and description of these accidents are provided in Assheton's "History of Explosions on which the American Table of Distances Was Based", published in 1930.

The ATD is the source of most U.S building code siting criteria for explosive storage. It is important to note that the minimum separation distances provided in the ATD were not based upon providing absolute safety. Instead, an "acceptable" level of damage and risk was assumed. The level of protection which would be provided at separation distances was described ". . . as preventing serious risk to life and limb and as preventing substantial building damage." [2] Separation distances were developed based upon the assumption that ". . . personnel within a building will not be seriously injured if that building does not experience substantial damage." [3]

A significant feature of the separation distances provided in the ATD was the credit given for the barricading of explosives. At that time, it was believed that intervening barricades would not only reduce debris, but would also attenuate blast overpressure at any given distance by at least 50 percent. As a result, the document, while providing separation distances for barricaded explosives only, recommended that these distances be doubled for unbarricaded explosives.

Public safety concerns following the Lake Denmark accident on 10 July 1926 prompted Congress to establish the forerunner of today's DDESB. On 3 March 1928, this body recommended to Congress that the explosive safety laws of New Jersey, which were based on ATD criteria, be adapted for use by the Armed Forces. The inhabited building distances provided in the resulting regulations remained essentially unchanged through the end of World War II.

During the 1940's, an extensive reappraisal of ATD criteria was conducted by the Army-Navy Explosives Safety Board (ANESB). In a paper prepared by Colonel Clark S. Robinson and published on 1 July 1945, a critical analysis was made of the American Table of Distances siting criteria. In this report, additional data were presented and analyzed for 66 explosions which had occurred since the initial publication of the American Table of Distances. Although no recommendations were given for new criteria, Colonel Robinson concluded that ". . . the American Table of Distances on the unbarricaded basis gives unnecessarily great distances for small quantities of explosives, but for large quantities it is grossly inadequate. . . The safety distances prescribed by the British War Office recognize this situation and, (where great concentrations are involved) require from 3 to 4 times the distance required in this country." [4]

In addition, Colonel Robinson raised the first significant doubt of the credit given to barricades in the ATD. In his report, he stated that ". . . it is now generally recognized that, except in very special circumstances, barricades around the explosive are of no effect in reducing the maximum distance at which structural damage occurs." [5]

As a result of questions raised by Colonel Robinson, an intensive effort was undertaken by the ANESB to review ATD criteria and, if needed, to develop new, more accurate criteria. On 1 July 1948, Dr. Ralph Ilsley, a member of the Board, issued a report entitled, "Reappraisal of the American Table of Distances and Recommended Bases for Discussion, Modification, and Final Approval of Minimum Risk Distances for Handling and Storing Military Explosives and Ammunition".

In his report Dr. Ilsley recommended "that the minimum distance for which the magnitude of the hazard from explosions - structural damage, flying glass, and missiles - can be accepted is represented by a risk factor of 50. (Distance from explosion in feet = 50 $W^{1/3}$. W = weight of explosives in lbs.)" Dr. Ilsley recommended that this "risk factor" be applied to residences and houses which are inhabited by families, to public highways, and to public railroads. He also recommended that the following increased "risk factors" be applied: "For above ground magazines of hollow tile construction, the risk factor shall be 85. For large storage reservoirs with wooden roofs, the risk factor shall be 200. For hangars the risk factor shall be 200. Buildings where people are accustomed to gather and which have a relatively large glass exposure - schools, hospitals, factories, railroad stations, churches, etc., - shall not be located between distances represented by risk factors of 50 and 100 unless suitable interior screens are placed in back of the windows to reduce the flying glass hazard." [6] Dr. Ilsley's report, along with results of additional full-scale tests conducted during the 1940's, prompted the renamed Armed Service Explosives Safety Board (ASESB) to recommend a revision to the DoD application of ATD criteria in April 1950.

The 1950 revision incorporated Dr. Ilsley's recommendation that increased quantity-distance criteria be used for certain high risk structures to ensure that they and their occupants receive comparable levels of protection. The revision provided the following discussion of siting requirements for high risk structures.

> The inhabited building distances recommended in Table No. 1 [which were based on an IBD distance of $50W^{1/3}$] give little protection from the hazard of flying glass in schools, hospitals, and factories unless windows have safety glass or adequate interior screens; and unless of a substantial construction give insufficient protection from structural damage to large buildings such as churches, theaters, railroad stations, assembly halls; and insufficient protection to hollow tile magazines, storehouses, and large oil or water storage reservoirs with exposed wooden roofs, or to airplane hangars. If because of their occupancy or vulnerability a reasonable degree of protection, comparable to that of dwellings and other

buildings, is desired for the structures indicated below, the distances must be changed as follows:

(1) School, hospitals, and factories - $d = 100\ W^{1/3}$ (unless provided with safety glass or interior screens)

(2) Large churches, theatres, railroad stations, and assembly halls - $d = 100\ W^{1/3}$

(3) Hollow tile magazines and storehouses - $d = 85\ W^{1/3}$

(4) Large oil or water storage tanks with exposed wooden roofs - $d = 200\ W^{1/3}$

(5) Large airplane hangars - $d = 200\ W^{1/3}$ [7]

The 1950 revision was accepted by the Air Force and the Navy with the added stipulation that a constant, minimum distance of 1235' be required for unbarricaded explosives to provide protection from fragments. The Army, however, disagreed with the validity of the recommendations and resisted any change from ATD criteria.

The disagreement between the military services on IBD criteria continued until 1955. On 11 October 1955, Colonel Ronald B. Currens, Chairman of the ASESB, exercised his right to decide issues on which the services could not reach unanimous agreement and issued a memorandum in which he required that the ATD be used to provide IBD protection for unbarricaded explosive concentrations. In addition, the memorandum required that no constant distance be specified to provide IBD protection for missiles.

On 7 December 1956, the first quantity-distance standard for the Department of Defense (DoD 4145.17) was published. This standard differed substantially from the 1950 criteria as implemented by the Navy and Air Force. Among changes, the minimum fragment distance of 1235' for unbarricaded explosives was dropped. Instead, inhabited building distances reverted to previous ATD criteria. Unbarricaded inhabited building distances were once again given as twice those required for barricaded explosives. In addition, a minimum explosive weight of 50 pounds was introduced. This minimum weight resulted in a minimum inhabited building distance of about 150' for barricaded explosives and 300' for unbarricaded explosives.

The 1956 criteria also deleted any distinction between different types of inhabited buildings. As a result, residences, churches, schools, factories, and other structures were all allowed to be sited at the same IBD requirements. The assessment of risk for different types of structures, as developed by Dr. Ilsley, was abandoned.

On 11 March 1966, a revision to the 1956 DoD explosive safety criteria, DoD 4145.23, was issued. This revision continued to use ATD criteria to credit barricades with reducing both blast and fragment hazards at inhabited building distances.

During the 1960's, there was increasing concern among members of the ASESB that barricades were not as effective in reducing blast overpressures as was assumed in the ATD. In response to this concern, the Board funded an extensive study to address the effectiveness of barricades issue.

On 12 July 1966, the ASESB was presented with a detailed analysis of the effectiveness of barricades in reducing blast overpressures at inhabited building distances. [8] The analysis concluded (as had earlier work) that at inhabited building distances, a typical barricade would not provide any reduction in blast overpressures. Missile hazards were not addressed in the analysis. Since the 1966 revision of DoD explosive safety criteria credited barricades with reducing blast overpressures at inhabited building distances, it was apparent that at least a portion of the IBD requirements was in error.

Despite the evidence that barricades would not reduce blast overpressures at IBD's, the 1969 revision, DoD 4145.27M. continued to give them the same credit as had been allowed in previous standards. During this time, there was serious disagreement among members of the ASESB as to what new standards should take the place of the ATD criteria. Members were unsure if IBD's should be based on ATD barricaded distances, ATD unbarricaded distances, or some new criteria.

In order to resolve this issue, the ASESB established its own working group in 1969 and gave it the mission of recommending new quantity-distance standards for unbarricaded explosives. It reported its findings to the ASESB on 28 February 1969.

In their recommendations, the group proposed extensive changes to the inhabited building distances given in the 1969 explosives safety document. They returned to Dr. Ilsley's 1948 recommendation that special IBD criteria be developed for structures particularly vulnerable to blast overpressures. In their report, the group stated that ". . . Consideration should be given to a specific analysis of buildings with large expanses of window glass, large unsupported roof structures, and certain wall construction that is particularly vulnerable to blast overpressure; and the distance requirements should be increased in these instances so that a comparable degree of protection limiting structural damage and risk to personnel to levels expected for more standard construction at inhabited building distance is achieved. . .". [9] "Standard" construction here is either the widely applied "residential construction" or the ill-defined "substantial construction".

On 10 June 1969, the following IBD criteria were recommended for adoption by the Board "in the event barricades are proved ineffective":

a. A fixed minimum distance of 865' for up to 10,000 pounds of unbarricaded explosives to mitigate fragmentation hazards,

b. IBD of 40 $W^{1/3}$ from 0 to 10,000 pounds for barricaded explosives,

c. IBD of 40 $W^{1/3}$ from 10,000 to 100,000 pounds (barricaded or unbarricaded explosives),

d. IBD increasing from 40 $W^{1/3}$ to 50 $W^{1/3}$ for 100,000 to 250,000 pounds (barricaded or unbarricaded explosives),

e. IBD of 50 $W^{1/3}$ for 250,000 to 500,000 pounds (barricaded or unbarricaded explosives). [10]

As can be seen, the 1969 ASESB proposal deleted the working group's recommendation that comparable levels of protection be provided to higher risk structures. In discussions leading up to this decision, several Board members expressed concern that the acceptance of siting for consistent risk would have a very detrimental impact on the siting of explosives at military installations. To avoid such problems, it was decided that inhabited building distances would be the same regardless of the vulnerability of the receptor structure to blast overpressures. In addition, the IBD selected was the lower limit of all the possible choices.

Following further review, all of the Board's IBD recommendations except the fixed minimum fragment distance of 865' were included in Interim Change 1-5 to the 1969 criteria. As a result of this change, there was a significant relaxation of IBD safety criteria for blast overpressures. Unbarricaded IBD distances based upon overpressure for weights less than 100,000 pounds were reduced from 70 $W^{1/3}$ to 40 $W^{1/3}$ or by more than 40 percent. For weights exceeding 250,000 pounds, the new IBD criteria required a minimum separation distance of 50 $W^{1/3}$ while the old criteria for unbarricaded explosives had required a minimum separation distance of 70 $W^{1/3}$.

The 1974 revision to DoD explosive safety criteria incorporated Interim change 1-5. In addition, this revision substantially strengthened fragmentation safety requirements. Interim Change 1 to the 1974 document, issued on 26 November 1975, established 1250' as a "default" minimum distance for protection from both primary fragments and building debris.

Since the 1974 revision, no changes have been made to IBD distances for protection from overpressures. The "default" IBD fragmentation distance has, however, been reduced for explosive quantities of 100 pounds or less. For these quantities, the minimum IBD distance for protection from fragments is now 670'. For explosive quantities in excess of 100 pounds, the "default" minimum distance of 1250' remains in effect. As a result, minimum IBD distances for protection from fragments will control for explosive weights of up to 30,000 pounds while IBD distances for protection from overpressures will control thereafter.

The general evolution of IBD criteria is shown in Table 2.1. In this table, inhabited building distances from the American Table of Distances (ATD), from Dr. Ilsley's 1948 recommendation, and from the current safety document, DoD 6055.9-STD are compared and contrasted.

TYPE OF CONSTRUCTION	ATD	ILSLEY RECOM.	DoD 6055.9
Residential Construction:			
- Barricaded	35	50	40-50
- Unbarricaded	70	50	40-50
Buildings with Many People and Large Glass Exposure:			
- Barricaded	35	50-100*	40-50
- Unbarricaded	70	50-100*	40-50
Large Storage Reservoirs with Wooden Roofs and Hangars:			
	N/A	200	40-50

* Use scaled distance of 100 $W^{1/3}$ unless suitable interior screens are placed behind windows to reduce flying glass hazard.

Table 2.1 - Comparison of IBD scaled distances based on overpressure.

3.0 DAMAGE TO RESIDENTIAL STRUCTURES AT INHABITED BUILDING DISTANCES

In this portion of the report, expected damage and repair costs will be developed for older and modern residential construction damaged at inhabited building distances. The analysis will include a comparison of the expected damage and repair costs to those assumed by present IBD criteria.

3.1 "House Damage Assessment" by C. Wilton and B.L. Gabrielson, 1972 [11]

In this extensive and well documented report, the results of numerous studies on damage to residential structures from air blast loadings were compiled. These studies had been conducted over the previous 21 years. They included data on the response of residential structures to both conventional and nuclear detonations. Tests included in this compilation were sponsored by several government agencies including the Defense Nuclear Agency, the Atomic Energy Commission, the DDESB, and the Civil Defense Preparedness Agency.

Four of the houses discussed in the report were located either at or within a few percent of their present inhabited building distance based on overpressure. As expected, the windows facing the blast loading were destroyed in each of these houses with some of the side and rear windows also damaged. In addition, each house reported some damage to window casings with two houses also reporting damage to front and interior doors.

Plaster cracking was reported in all of the houses with extensive plaster damage reported in some rooms. Roof rafters were damaged in three of the houses with one house reporting one broken rafter and the other two houses each reporting seven broken rafters.

It should be noted that the test houses were constructed of a higher grade of lumber than is normally used on modern residential construction. These houses employed No. 2 lumber while wood graded as No. 3 or lower is normally used in modern construction. Interestingly, the broken rafters tended to fail along knots on the tension side, near the central portion of the member. Lumber used on modern residential construction would normally have more knots and other defects than No. 2 lumber, and therefore, one would expect more of these rafters to fail under blast loading.

It is also important to remember that standard dressed sizes for dimensions less than 6" have decreased since the referenced testing was conducted. In the early 1970's, standard dressed sizes for dry lumber were reduced from the nominal dimension less 3/8" to the nominal dimension less 1/2" for dimensions less than 6". Therefore, a nominal 2 x 4 previously required to have a minimum standard dressed size of 1-5/8" x 3-5/8" is now only required to be 1-1/2" x 3-1/2". In terms of section properties, this change results in a reduction in moment capacity for a 2 x 4 of approximately 17 percent. For this reason, modern 2 x 4's will have a lower capacity than the older 2 x 4's used in the test houses.

3.2 "Blast Damage Assessment Procedures for Common Construction Categories" by Southwest Research Institute, 1987 [12]

The information provided in this report was developed to assist the Navy in assessing the vulnerability of its facilities to terrorist attack. The report was based on a maximum external surface explosion of 4,000 pounds of TNT. Included in this effort was the development of pressure-impulse (P-I) diagrams for various structure types.

P-I diagrams represent the dynamic response of different types of structural elements when exposed to a given overpressure and impulse. These diagrams must be developed for each structural element or system. They consist of one asymptote defining the response of the element to pressure load and another for impulse load. These two limiting responses are connected by a transition region where both impulse and pressure influence response. Using these diagrams, one can quickly estimate the expected level of damage to a structure subjected to a given overpressure and impulse.

One limitation of this method is that under very long duration pressure loads, the resistance of a structure will tend to degrade. This effect has been well documented in many nuclear tests and simulations and has led to the use of vulnerability parameters that account for such degradation. The effect would be more pronounced as the donor becomes very large, i.e. a million pounds or more. We will ignore this effect in this section of our report.

Among P-I diagrams developed for this report is one for wood walls. The percentage damage curves on this diagram were largely developed using data from the "House Damage Assessment" report discussed in the previous section. In order to illustrate changes in residential construction, the P-I diagram has been modified in Figure 3.1 to represent the wall of a typical residential structure constructed prior to 1970. For this wall, 2 x 4 studs eight feet in length are spaced at 16", 3/4" wood diagonal sheathing is used, and the interior wall is assumed to be 3/8" plaster over 3/8" wood lath.

In comparison, Figure 3.2 provides the P-I diagram for the wall of a typical modern residential structure. For this wall, 2 x 4 studs eight feet in length are again spaced at 16", but the exterior of the house is assumed to be 1/2" insulating board sheathing covered by vinyl siding. This represents a typical exterior cladding in modern residential construction. The interior walls are assumed to be 1/2" gypsum board.

Through comparing Figures 3.1 and 3.2, it is apparent that modern residential construction will suffer significantly more damage under blast loading than older construction. In order to provide some frame of reference, a data point has been provided for each curve. This data point represents the pressure and impulse at the IBD overpressure distance for 4,000 pounds TNT.

There are two reasons for this increased damage. In older structures, the studs and diagonal sheathing act as a composite section under blast loadings, while the studs and insulating board used in modern construction will respond independently. In addition, as we have mentioned, modern wood wall studs have a reduced section.

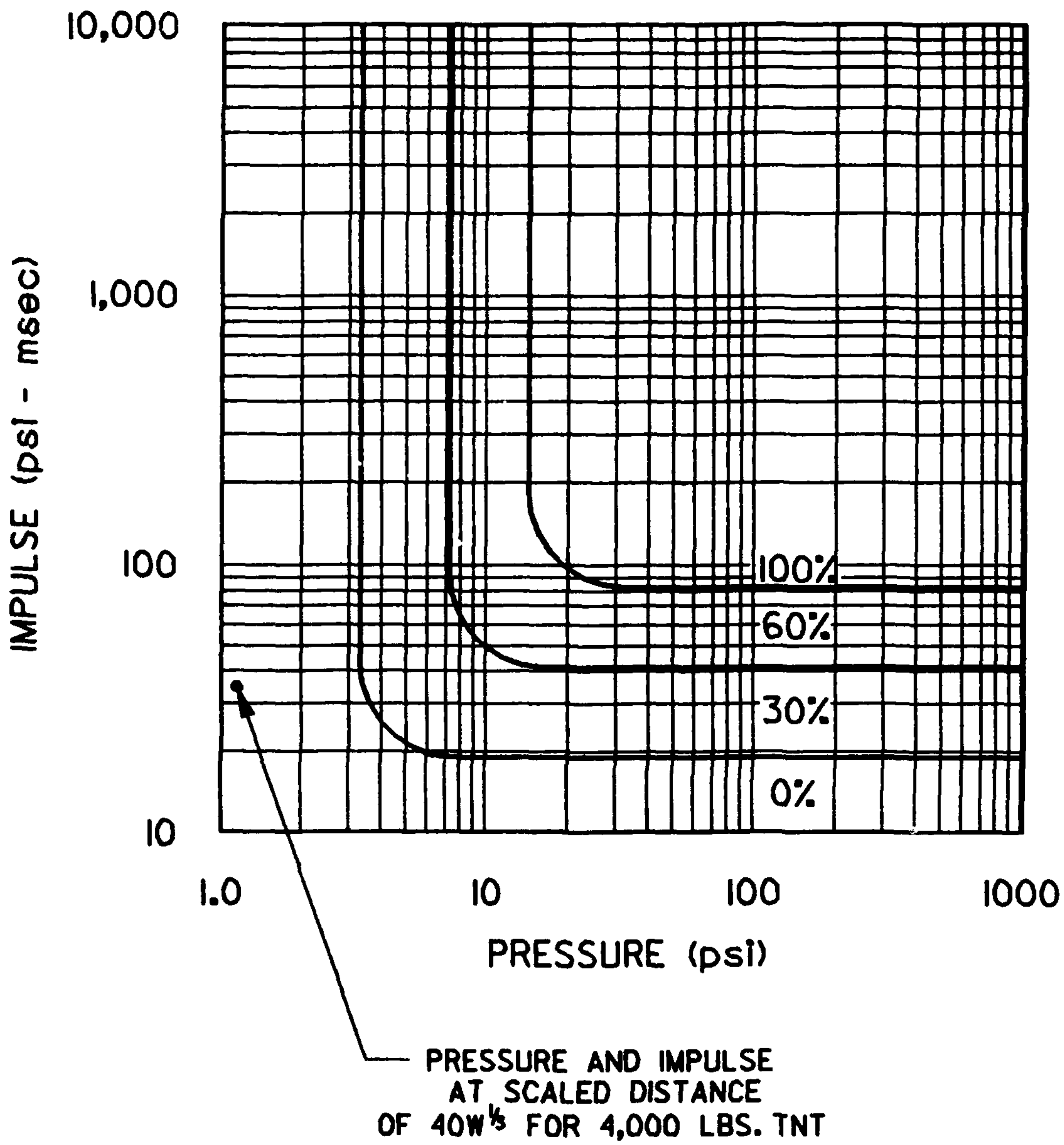

Figure 3.1 - Pressure-Impulse Diagram for older residential wall construction (Curves separate different percentages of structural damage).

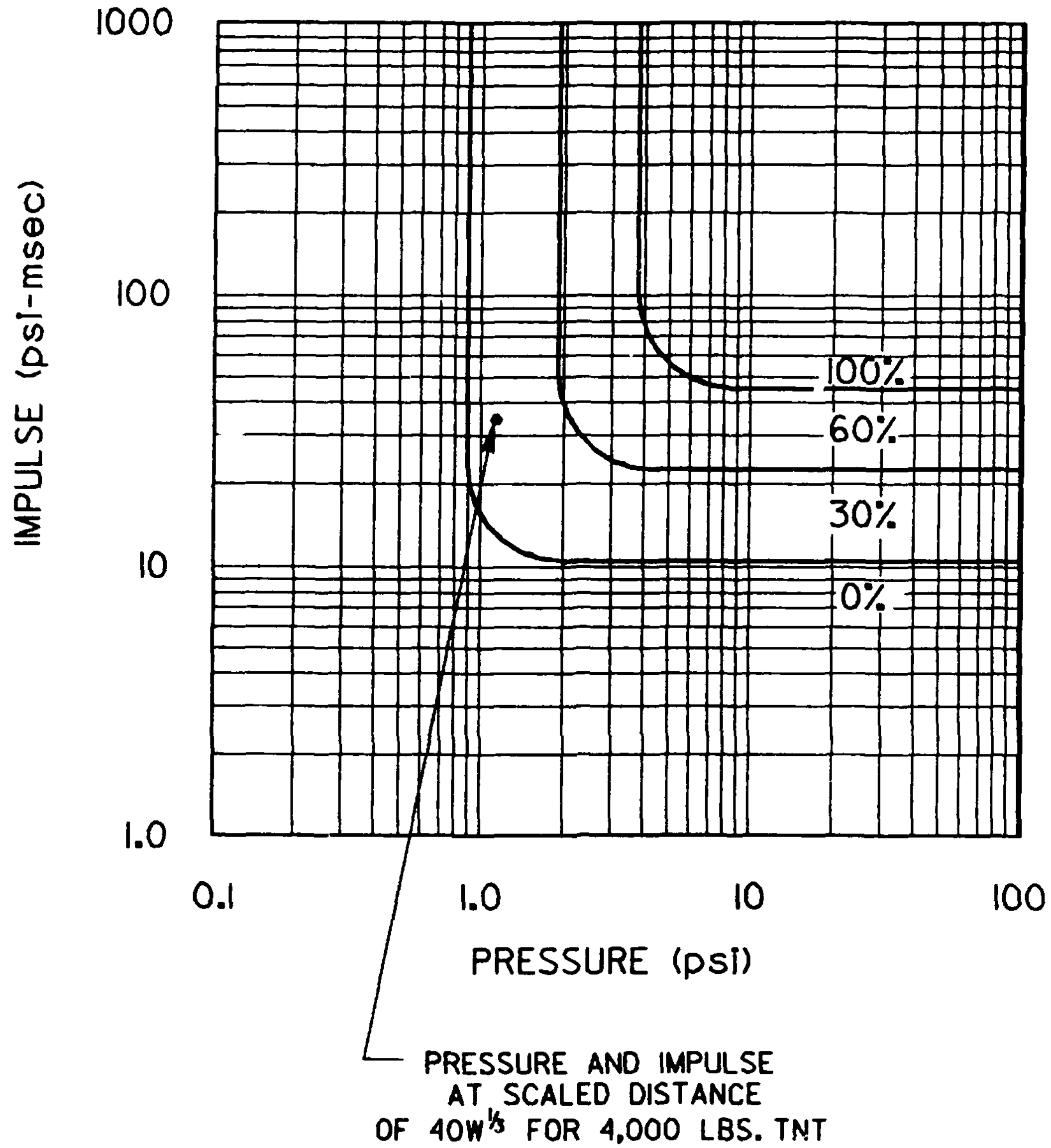

Figure 3.2 - Pressure-Impulse Diagram for modern residential wall construction (Curves separate different percentages of structural damage).

An examination of the limiting values in Figures 3.1 and 3.2 provides a striking comparison of the reduction in resistance of modern residential construction. The asymptote defining resistance to long duration pressure load is approximately 3.2 psi for the older wall construction; for the modern wall system, it is about 0.9 psi. The newer wall framing has only 28 percent of the resistance of the older system. Similarly, the impulse resistance has been reduced from 19 psi-msec to 11 psi-msec, or to about 57 percent of the previous resistance. For large quantities of stored explosives, almost all building structural elements are pressure sensitive rather than impulse sensitive. Thus, the degradation in pressure resistance is more significant. Unfortunately, present IBD distances are based on expected damage to the older, more substantial residential structures.

3.3 Comparison of Residential Repair Costs at IBD

In order to evaluate probable repair costs for older and modern residential construction, a comparison has been made of expected damages and repair costs for a 1945-69 era house and for a modern house damaged at their IBD distance. Data on the older house were obtained from the "House Damage Assessment" report discussed under section 3.1. In the analysis, the average damage and repair cost for Houses I-5 and I-6 were used. These houses were chosen because they were located at their IBD overpressure distance, the damage reported for each house was from a single event (instead of the worst of four events as was reported for Houses I-10 and I-11), and the quantity of explosives detonated was low (10,000 pounds), thereby providing a conservative analysis.

For the modern house, data developed from contacts with insurance companies along with the data developed earlier in this report were used to estimate damage to a house similar to Houses I-5 and I-6 but constructed of typical modern construction materials. The modern house was evaluated for the same blast loading as the older house. Expected damage and repair costs for the older and modern house are compared in Table 3.1.

In reviewing Table 3.1, it can be seen that increased damage to the modern house was expected for "roof framing and roof surface", "exterior and interior wall framing", and "interior plaster". As was discussed under section 3.2, the increased damage to wall framing and plaster is primarily due to the change from the plaster on wood lath and wood sheathing typical of older construction to the gypsum board and insulating board sheathing typical of modern construction. Damage to the remaining structural elements was conservatively assumed to be unchanged. Even with this conservative assumption, the estimated cost to repair structural damage increased from 5.8 percent to 10.0 percent of the house replacement cost. For larger explosive quantities, damage at IBD distances would be even greater due to the increase in the loading duration.

ITEM	OBJECTIVE VALUE (% OF TOTAL)	% DAMAGE (OLDER CONST.)	% CHANGE (OLDER CONST.)	% DAMAGE (MODERN CONST.)	% CHANGE (MODERN CONST.)
Floor and Ceiling Framing	17.0	0	0	0	0
Roof Framing and Roof Surface	7.0	2	0.1	10	0.7
Exterior and Interior Wall Framing	16.0	0	0	10	1.6
Interior Plaster	11.0	6	0.7	16	1.8
Exterior Sheathing and Siding	8.6	0	0	10	0.9
Foundation and Basement	19.0	0	0	0	0
Misc.: Stairs, Paint, Fireplace, Trim	12.0	13.5	1.6	13.5	1.6
Doors	4.6	20	0.9	20	0.9
Windows	4.8	52.5	2.5	52.5	2.5
TOTAL	**100.0**		**5.8**		**10.0**

Table 3.1 - Comparison of estimated costs to repair structural damage to older and modern residential structures damaged at IBD distances. (Note: Costs do not consider damage to furnishings.)

4.0 DAMAGE TO MODERN PRE-ENGINEERED BUILDINGS AT INHABITED BUILDING DISTANCES

During the last twenty years, the application of pre-engineered steel buildings has spread rapidly from its initial use in light industrial building. It is now commonly employed for all types of low rise buildings (less than three stories) including public and commercial office space, retail space and shopping malls, churches, schools, gymnasiums, and libraries.

Pre-engineered buildings can be constructed with glass or masonry curtain walls to provide an attractive appearance. They are designed to an industry standard developed by the Metal Building Manufacturers Association (MBMA) which uses less conservatism in load development than standard design codes. As a result, while they are adequate for code loadings, they have little reserve capacity.

Pre-engineered buildings represent a significant cross section of all new non-residential construction. This type of construction is now estimated to account for more than 50 percent of all new low rise non-residential construction in the United States.

To provide an engineering assessment of IBD performance for this type of non-residential structure, an analysis has been performed on a typical long span, pre-engineered building. The design of this building was prepared under contract and was reviewed by our office. It has recently been constructed at Aberdeen Proving Ground. The structure would be representative of a moderate size commercial building such as a gymnasium or a shopping mall.

The building has plan dimensions of 170'-6" x 302'-6" and varies in height from approximately 19'-2" to 27'-6". The main roof support beams span the 170'-6" dimension and are supported at both ends and at their approximate center. These beams are spaced at 20'-0".

The main roof support beams are I-beams with varying flange and web dimensions. The webs have a high depth to thickness ratio and are, therefore, particularly susceptible to buckling under loading if not properly braced. The roof purlins brace the top flange of the beam in addition to supporting the roof deck. This system is typical of those used in modern pre-engineered buildings.

There are three different structural elements that make up the structural system of such a building:

a. Wall panels and roof decking

b. Wall panel support beams (girts) and roof deck support beams (purlins)

c. Primary framing columns and roof beams

The wall panels and roof decking receive the blast load and transfer it to the girts and purlins which in turn transfer it to the columns and roof beams. These elements can only transfer load to supporting members equal to their capacity.

In our initial analysis, it was assumed that the roof deck and purlins which frame into the roof support beams would fully transfer the blast load on them. The validity of this assumption will be discussed later in this section. The roof beams were assumed to develop their full plastic capacity under loading. This is a very optimistic assumption and will result in an upper bound on load capacity.

Our results were as follows. If the building roof beam system were located at the minimum IBD scaled distance of 40 $W^{1/3}$ from a 30,000 pound detonation, its maximum dynamic deflection would be approximately 9'-11". The roof beams would likely collapse prior to reaching this deflection. Even if collapse did not occur, replacement would obviously be required. The roof beams would have to be located at a scaled distance in excess of 100 $W^{1/3}$ from the detonation before they would escape permanent structural damage.

If the building were located at the minimum IBD scaled distance of 50 $W^{1/3}$ from a 500,000 pound detonation, its calculated maximum dynamic deflection would exceed the building height; collapse of the roof system would occur. For these roof beams to escape permanent structural damage, the building would have to be located at a scaled distance well in excess of 100 $W^{1/3}$ from the detonation.

An analysis was also performed on a typical wall panel, wall purlin, roof deck, and roof purlin. Properties used in analyzing these structural elements were developed from the Armco Building Systems and Products Design Manual. Armco is one of the largest suppliers of metal building systems. These elements are representative of those most commonly used in modern pre-engineered building construction.

The elements were analyzed at a scaled distance of 40 $W^{1/3}$ from a 30,000 pound detonation. Results were as follows. The roof purlins underwent a maximum dynamic inelastic deflection of 14.7" over a 20' span. Obviously, these purlins and the supported deck would have to be replaced. If the roof purlins were not damaged (i.e., were much stronger and provided the needed support to the roof deck), the roof deck would fare much better and would likely suffer no permanent damage. However, this would then assure that all loads were transferred to the main roof beams with the consequences described earlier.

The wall girts would collapse under the loading; the maximum dynamic deflection calculated for these elements exceeded their span length. Assuming the wall girts were not damaged, the wall panels would undergo a maximum dynamic deflection of approximately 4.8" over a 12' span and would require replacement.

In a typical design condition, the wall panels, wall girts, and roof purlins would be substantially damaged and would require replacement. They would not transfer sufficient load to fail the frame members. Since, however, the purlins and girts provide critical bracing for the framing columns and roof beams, there is a high risk of collapse due to instability.

The major conclusions of our analysis are as follows. Modern pre-engineered metal building systems are extremely vulnerable to serious damage at current IBD criteria for quantities of explosive above 30,000 pounds. Major damage would be expected to facing and parallel walls and all roofing and supporting members. Replacement of these elements would likely be required. The repair cost could exceed 50 percent of the original cost of the structure. Damage to contents would increase this percentage even further.

Based on the foregoing analysis, it would be necessary to site a modern pre-engineered commercial building at a scaled distance in excess of 100 $W^{1/3}$ from a standard Army magazine to provide a level of risk consistent with IBD criteria. In a port siting situation where loading of munitions for transport by ship is present, the required scaled distance would be significantly larger due to the greater quantity of explosives involved and the resulting increase in loading duration.

The expanded use of this type building system for applications where large numbers of people are present is inevitable due to its low initial cost and speed of erection. Further, the level of probable damage leads to a risk of injury to occupants which is significantly higher than the current standard assumes at IBD.

5.0 CONCLUSIONS

The explosive safety quantity-distance criteria presented in DoD 6055.9-STD evolved from the original American Table of Distances first published in 1910. During the period from 1945 through 1969, substantial technical data and criteria were developed which clearly indicated that modification of the older ATD criteria was required to reflect the increase in the damage data base for large explosions and observations from full scale tests. The most significant results from this period were the recognition of the negligible value of barricades, the risk of greater damage to specialized structures, and the risk when large amounts of glass were present in a building.

In the years since the current IBD criteria were formalized, modern construction materials and construction methods have resulted in structures which are much lighter and more vulnerable to overpressure. Our literature search, analysis, and design experience have confirmed that damage to many modern residential, public, and commercial buildings will be greater than that described in the current standard.

Our calculations indicate that structural damage to modern residential construction will almost double compared to structures on which the current standard is based. In addition to this increase in replacement cost for the structure, other costs will be incurred which were not considered in the original standard. These costs include replacement of furnishing such as curtains, carpet, and furniture. Insurers will pay these expenses and then seek recovery from the government. Property owners will seek recovery for real or perceived damage not covered by their insurer.

While damage cost increases are a concern for residential construction, a more serious concern exists over commercial-public buildings. Construction materials and design techniques for these structures have advanced rapidly and have resulted in very low cost, lightweight structures. These structures are now widely used for schools, gymnasiums, shopping malls, restaurants, etc.

Many of these structures also have a very large percentage of glass in their curtain wall system. It is now common to see curtain wall systems which are 50 to 70 percent glass. Risk of injury for occupants of both lightweight steel structures and structures with glass curtain walls is much greater than that presumed in the existing standard. The potential for serious injury or structural collapse is high for large quantities of explosives at current IBD. The present standard is not adequate to address these risks. Many other conventional structures described by Dr. Ilsley in 1948 are also still subjected to these same risks.

The research and analysis provided in this report can be summarized as follows. First, a large percentage of modern residential, commercial, and public construction will suffer damage substantially in excess of the 5 percent criteria postulated in the current IBD standard. Second, associated with that increased damage will be a greater risk of personnel injury. These conclusions are particularly applicable to quantities of explosives in excess of 30,000 pounds.

6.0 ACKNOWLEDGMENTS

The information provided in this report was funded by the DDESB with Captain David Wallace, United States Navy, chairman. Technical assistance was provided by Dr. Chester Canada.

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EVALUATION OF OPERATOR PROTECTION FROM REMOTE OPERATIONS IN EXISTING BUILDINGS WITH 12-INCH SUBSTANTIAL DIVIDING WALLS (SDWs)

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ABSTRACT

Procedures to relate Net Explosive Weights (NEWs) to combinations of intervening 12-inch Substantial Dividing Walls (SDWs) to provide protection to personnel from remote operations has been developed. Protection is IAW DoD and Army policy: 2.3 psi maximum overpressure exposure and no hazardous fragments. The procedures are reported in a two-volume guide: Volume I is a "how to" guide for installation use, and Volume II is the rationale behind Volume I. Protection from thermal effects (flash fire, deflagration, etc.) is not addressed. The guide is a "simple-to-use stand-alone" document that can be used by operating contractors and installation personnel.

This paper summarizes key features of the guide and provides an example problem using the guide methodology.

1.0 BACKGROUND

In recent years, the Department of Defense Explosive Safety Board (DDESB), introduced increased protection requirements for personnel exposed to remotely controlled operations. One of the requirements is limiting exposure of personnel to blast pressures not in excess of 2.3 psi. This requirement has; 1) forced some Army installations to relocate operators to bays sufficiently removed from the donor bay to comply with the new regulation, and 2) for the most part, imposed operational constraints since intervening bays can be occupied only when the remote operation is not in progress.

As a result of the above, The US Army Technical Center for Explosive Safety (USATCES) saw a need for relating Net Explosive Weight (NEW) to combinations of intervening 12-inch SDWs. Figure 1 shows a representative ammunition production facility layout. The primary goal was development of a "simple-to-use" guide that would allow installation personnel to assess existing munition facilities for conformance with present safety requirements.

The guide supplements the DDESB approved method in determining the 2.3 psi boundary arc from the front, sides and back of three walled cubicles without a roof. This method, developed by USATCES has been made an integral part of the guide.

2.0 FORMAT AND AVAILABILITY OF THE GUIDE

The guide is organized into two volumes: Volume I, User's Guide and Volume II, Rationale. Volume I is developed as a "stand-alone" document. Volume II forms the basis for the User's Guide and is not required for field use. The guide is available through the Defense Technical Information Center (DTIC) and the National Technical Information Service (NTIS).

1. DoD Activities can order the guide from DTIC.

   a. DTIC address is:

   Defense Technical Information Center
   Cameron Station
   Alexandria, VA 22304-6145

   b. DTIC report numbers:

   Volume I: ADA 250251
   Volume II: ADA 250252

2. Non DOD activities can order the guide from NTIS.

   a. Their address:

   National Technical Information Service (NTIS)
   5285 Port Royal Road
   Springfield, VA 22161

   b. Copies can be ordered by mail of phone; (703) 487-4650

   c. The cost of the guide is $26.00 (paper) or $12.50 (microfiche). When ordering, ask for NTIS accession number PB92-180140.

3.0 GENERAL

The approach taken in development of the guide was the recognition that the guide must be a "stand-alone" and "simple-to-use" document. The intent is not to burden installation personnel with tedious complicated procedures in performing the required analysis, and in particular predicting the blast loading. Installations do not have the necessary computer software to accomplish such a task, neither it is expected that they perform such a complicated engineering function. As a result, all data needed to evaluate facilities constructed with 12-inch SDWs are contained within the guide. The guide assumes 12-inch SDWs are reinforced with #4 reinforcements each way each face and spaced at 12 inches on centers, and considers wall elements that are cantilevered, fixed on two-sides and fixed on three-sides. These are prevalent fixity conditions at existing ammunition production facilities. The guide includes:

a. Dynamic properties and blast capacities of Substantial Dividing Walls. Using TM5-1300 methodology, walls ultimate resistance, stiffness, and natural frequency were developed for various wall sizes and fixity conditions.

b. Overpressure prediction at personnel occupied bays due to an incident in a donor bay where the remote explosive operation is underway. The method developed by USATCES is used, and supplemented by Table 1 which provides a quick evaluation of the number of unoccupied bays required to separate the operator from the donor bay.

c. Assessment of Substantial Dividing Wall' capability to provide the necessary protection to operators (Category I protection) from a remote controlled operation. The procedure entails prediction of the blast loading at the acceptor bay, and comparing the walls resistance to the predicted loads. Pressure-Load Duration (P-T) plots have been generated for various size walls and fixity condition. Figure 2 is a representative plot contained in the guide.

d. Concepts for upgrading SDWs for increased capacity. The guide addresses two methods, namely; structural strengthening of wall elements by providing additional fixity condition to increase the wall's ultimate resistance, and/or increasing the mass of the element to alter the dynamic response of the wall. The latter option is achieved through the addition of sand layer behind the deficient wall. P-T plots showing sand layer effects are also included in the guide. Figure 3 is a representative plot contained in the guide.

e. Application Example.

4.0 ANALYSIS PROCEDURE

4.1 IDENTIFY HAZARDOUS OPERATIONS

Army installations must determine the nature of the hazardous operations at the particular facility. The primary considerations must be how this operation relates to personnel. Personnel must be afforded Category I protection if the operation is remotely controlled.

4.2 SPECIFIC REQUIREMENTS FOR PERSONNEL

This step requires the determination of location of personnel. Personnel in close proximity of a donor bay may be exposed to hazards from overpressure, fragmentation from cased explosives, spalling of the concrete wall, and collapse of structural elements (wall, roof, etc.). All of these conditions must be considered during the evaluation.

4.3 DETERMINATION OF CHARGE PARAMETERS

Charge parameters must include the following:

a. Net Explosive Weight (NEW)

b. Explosive type (for determining the TNT equivalency)

c. Cased or bare explosives

4.4 EQUIVALENT CHARGE WEIGHT (W)

The equivalent charge weight is determined using the following equation:

$$W = NEW \times TNT\ Equivalency \qquad \text{EQ. 4-1}$$

TNT Equivalences are presented in Table 2.

4.5 DESIGN CHARGE WEIGHT

The design charge weight is determined using the following equation:

$$W' = NEW \times TNT\ Equivalency \times 1.20\ Safety\ Factor \qquad \text{EQ. 4-2}$$
$$= W \times 1.20\ Safety\ Factor$$

Note: W' is used in the evaluation of wall elements. The 1.20 safety factor is required by TM5-1300.

4.6 SCALED DISTANCE

The customary scaled distance Z is used in this guide.

$$Z = R/W^{1/3} \quad \text{used for overpressure determination} \qquad \text{EQ. 4-3a}$$

or $$Z = R/W'^{1/3} \quad \text{used for determining wall capacity} \qquad \text{EQ. 4-3b}$$

where:

R = Standoff distance from center of explosive source to point of interest, ft. (wall element, operator location, etc.).

4.7 PREDICTION OF BLAST OVERPRESSURE AT OPERATOR'S LOCATION

The prediction of overpressures from an incident in a donor bay follow the method developed by USATCES. This method is based on on the default distance of $D=24w^{1/3}$. For a quick determination of the number of unoccupied bays required between the explosive source and the operator, Table 1 may be used.

4.8 REFLECTIVE SURFACES

Recent test data indicate that shock wave reflections occur even with frangible elements having a minimum mass. A typical SDW cubicle bay will have 4 reflective surfaces: a floor, a roof, a right wall, a left wall. Each reflection scaled impulse value is set equal to the impulse on the element in question.Therefore the total impulse on the element in question is:

$$\text{Total } i_r/W'^{1/3} = i_r/W'^{1/3} + (n) i_r/W'^{1/3} \qquad \text{EQ. 4-4}$$

where n = number of reflective surfaces

4.9 PREDICTION OF THE BLAST LOADS ON THE ELEMENT IN QUESTION

Prediction of the blast loads on the element in question requires the following:

a. Determining the free-field shock wave pressure and impulse, at the prescribed scaled distance Z, using Figure 4. The design charge weight W' is used in this scaled distance.

b. Estimating the effects of walls reflection on the element in question using EQ 4-4.

c. Applying correction coefficients to both the free-field shock wave pressure and impulse using Figures 5 and 6. These coefficient are applied to accurately duplicate the blast loading if the the computer program "SHOCK" was used.

d. Comparing the predicted pressure and load-duration on the element in question to the wall capacity. This comparison reveals wall adequacy or inadequacy and requirements for upgrade.

5.0 EXAMPLE PROBLEM

PROBLEM- An ammunition processing building is composed of a series of 12-inch Substantial Dividing Walls. A donor bay is remotely controlled by operators located at a specified standoff from the explosive source. The acceptor bay (occupied bay) is a concrete cubicle constructed of 12-inch Substantial Dividing Walls. Safety criteria require that personnel in the acceptor bay be afforded Category I protection.

GIVEN: R = Distance from center of explosive source (standoff [ft.]) to point in question, in this case, to nearest wall of cubicle housing operator

NEW = Net Explosive Weight

Type of explosive

Acceptor Bay Size: 12' wide X 14' long X 12' high

Cubicle Configuration: (Acceptor Bay) — Two side walls, a back wall, a transite roof and a corrugated exterior siding 6 feet from the cubicle.

FIND: a. What is the blast loadings on the wall (pressure and duration)?

b. Will the 12-inch SDW provide Category I protection?

SOLUTION:		REFERENCE
1.	Design charge weight $W' = NEW \times TNT\ equivalency \times 1.20$ safety factor	Table 2 for TNT equivalency factor and EQ. 4-2.
2.	Calculate the scaled distance $Z = R/W'^{1/3}$	EQ. 4-3b
3.	Determine the reflected pressure (P_r) and reflected scaled impulse ($i_r/W'^{1/3}$) corresponding to Z	Figure 4
4.	Set the number of reflective surfaces = 4	
5.	Total $i_r/W'^{1/3} = i_r/W^{1/3} + (4)i_r/W^{1/3}$	EQ. 4-4
6.	Determine the coefficients C_{pr} and C_{ir} corresponding to the standoff distance R.	Figure 5 & Figure 6
7.	Calculate $P = P_r\ (C_{pr})$ and calculate $i_r/W'^{1/3} = \text{Total } i_r/W'^{1/3}\ (C_{ir})$.	
8.	Determine $i_r = (i_r/W'^{1/3})(W'^{1/3})$	
9.	Determine duration $T = 2\ (i_r)/P$	
10.	Blast loads summary: Pressure on wall from step 7: Load duration on wall from step 9:	
11.	Enter Figure 2 with T from step 9 and proceed upward to wall size. Read Allowable dynamic pressure P	
12.	Compare P from step 11 with P from	

step 7. If P from step 11 is greater than P from step 7 the wall will provide Category I protection. If not the wall is inadequate. If the difference between the calculated value and the required value is within 5%, the wall is acceptable.

CALCULATIONS:

GIVEN: R = 40 ft.
NEW = 37.5 lb.
Type of explosive - Composition B

FIND: a. The pressure and load duration on the wall between the operator and the donor bay.

b. Whether 12-inch SDW provides Category I protection

SOLUTION:

1. $W' = (37.5)(1.092)(1.20) = 50$ lb.

2. $Z = 40/50^{1/3} = 10.87$ ft./lb$^{1/3}$

3. Enter Figure 4 for $Z = 10.87$ ft./lb$^{1/3}$ and read:

   $P_r = 14$ psi and $i_r/W'^{1/3} = 10.0$ psi-msec/lb$^{1/3}$

4. Total reflected surfaces = 4

5. $i_r/W'^{1/3} = (10.0) + (4)(10.0) = 50$ psi-msec/lb$^{1/3}$

6. Enter Figures 5 and 6 for R = 40 ft. and read:

   $C_{pr} = 1.27$ and $C_{ir} = 1.1$

7. $P = (14)(1.27) = 17.8$ psi

   $i_r/W^{1/3} = (50)(1.1) = 55$ psi-msec/lb$^{1/3}$

8. $i_r = (55)(50)^{1/3} = 202.4$ psi-msec

9. $T = 2(202.4)/17.8 = 22.74$ msec

10. Blast loads summary:
    Pressure on wall .... 17.8 psi
    Load duration .... 22.74 ms

11. Enter Figure 2 with T = 22.74 msec and
wall size 14'L x 12' H and read:

P = 17.5 psi This is the allowable dynamic pressure.

12. P = 17.5 psi is less than P = 17.8 psi.
Wall is inadequate. However, since the variance is within 5% consider the wall adequate.

NOTES:

1. The example problem presents a situation where wall is shown inadequate. Strengthening method is also presented.

2. This example problem does address personnel exposure to overpressure. Its is not sufficient that wall adequacy be checked. Table 1 or USATCES method may be used in assuring that personnel are not exposed to overpressures greater than 2.3 psi. Overpressure will usually control.

3. Also wall breach must be checked. Refer to the guide for this procedure. Breach does not normally control, but may control at close range.

Table 1 ESTIMATE OF NUMBER OF UNOCCUPIED[1] BAYS REQUIRED TO LIMIT PERSONNEL EXPOSURE TO 2.3 PSI OR LESS

EQUIVALENT CHARGE WEIGHT, LB.	NUMBER OF UNOCCUPIED BAYS (N)				
	BAY WIDTH				
W = NEW x TNT Equivalency	10'	12'	14'	15'	16'
3	2	2	1	1	1
5	2	2	2	2	1
10	4	3	3	3	2
15	5	4	3	3	2
20	5	5	4	4	3
30	6	6	4	4	4
40	7	6	5	5	5
50	7	7	6	5	5
70	8	8	6	6	6
80	9	8	7	6	6
100	10	9	7	7	6
120	11	10	8	7	7
140	11	10	8	8	7
150	12	10	9	8	7
180	12	11	9	9	8

(1) "Unoccupied" means no personnel allowed during the actual remote operation. Bays may be used for inert materials and explosives up to the bay limit.

Assumptions:

1. Donor bay width same as bay width.
2. Charge in center of donor bay at 3' above finish floor.
3. 2.3 psi limit measured to point 6' above finish floor at center of bay.

TABLE 2 TNT EQUIVALENCY

EXPLOSIVE	TNT EQUIVALENCY
Composition A-3	1.09
Composition B	1.10
Composition C-4	1.13
Cyclotol (75/25)	1.12
HBX-1	1.17
HBX-3	1.14
H-6	1.36
HMX	1.15
Minol II	1.20
Octol (70/30)	1.12
PBX	1.14
PETN	1.18
Pentolite (50/50)	1.09
Picratol	0.90
RDX	1.16
Tetryl	1.07
TNETB	1.36
TNT	1.00
Tritonal (80/20)	1.07

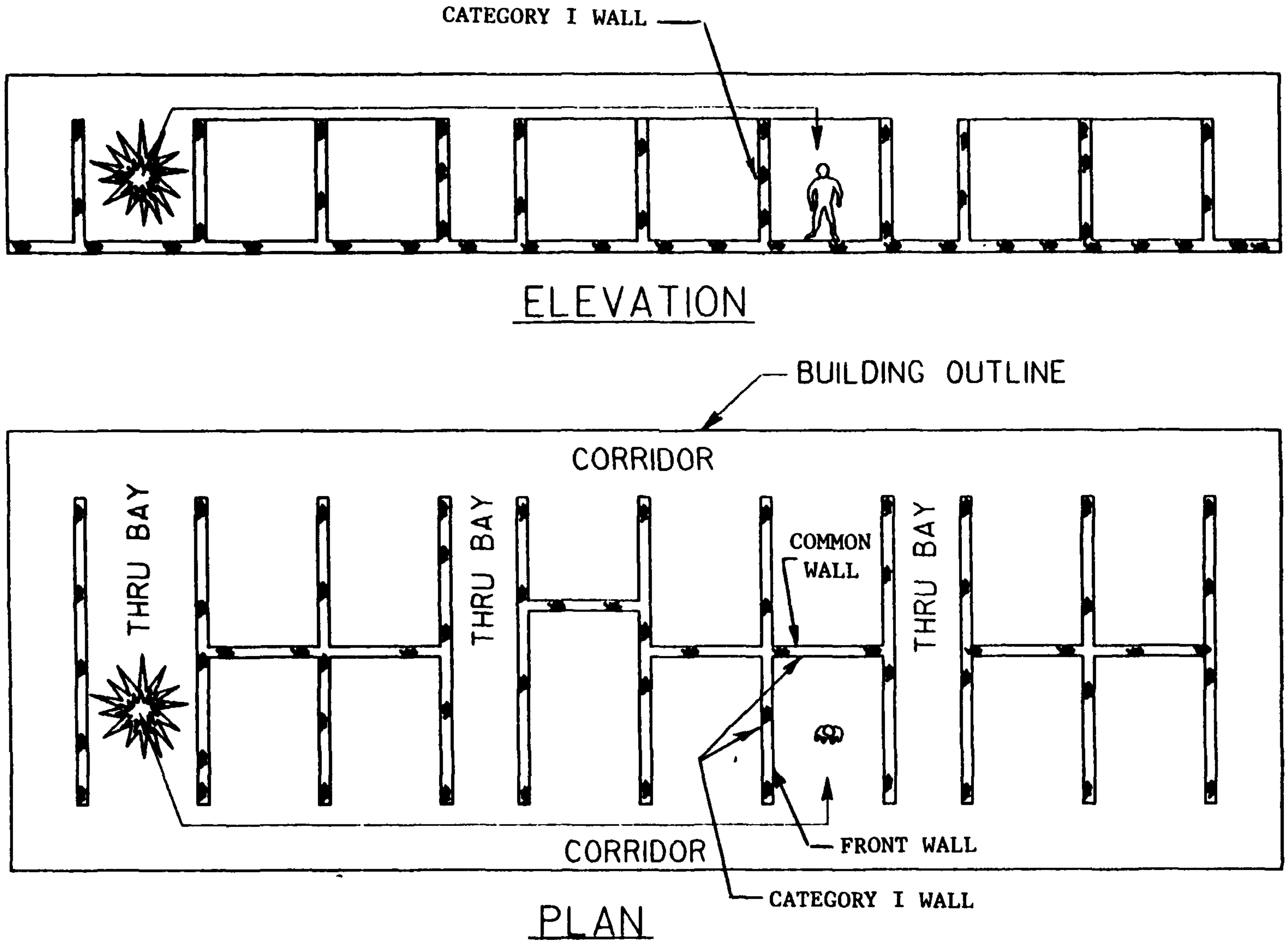

FIGURE 1 OPERATOR LOCATED AT DISTANCE OF INCIDENT OVERPRESSURE $\leq$ 2.3 PSI

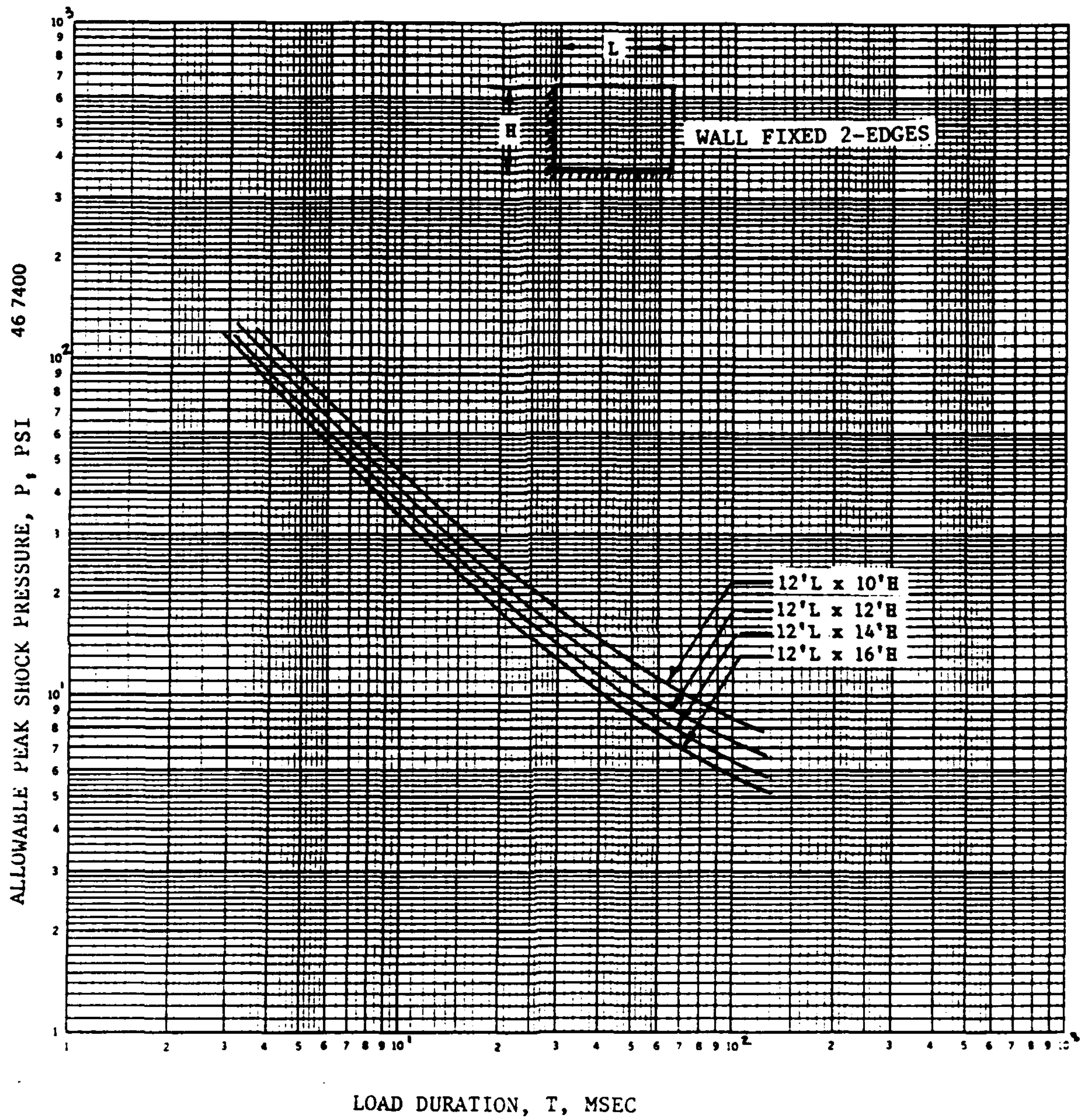

FIGURE 2 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

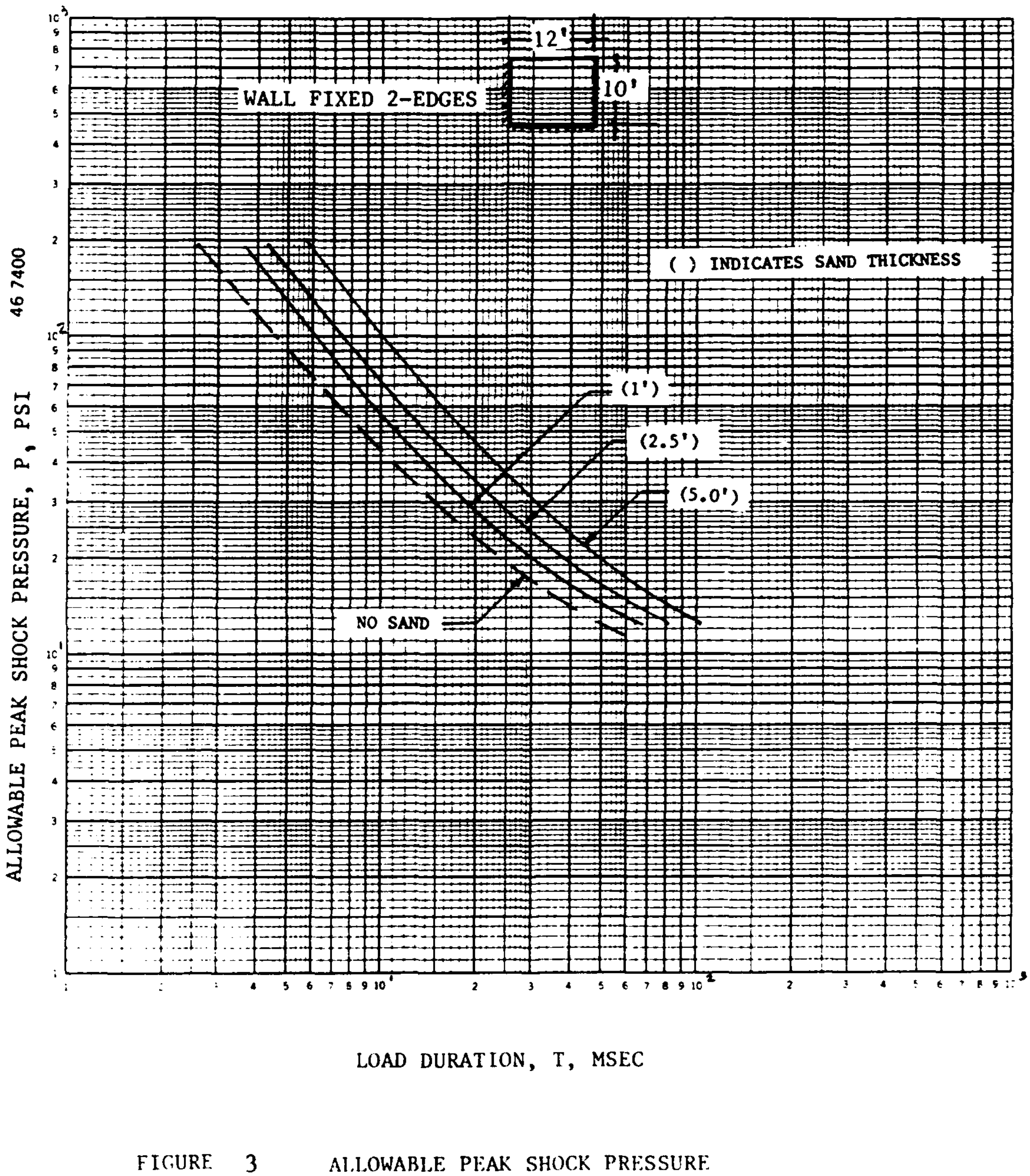

FIGURE 3 ALLOWABLE PEAK SHOCK PRESSURE VS LOAD DURATION

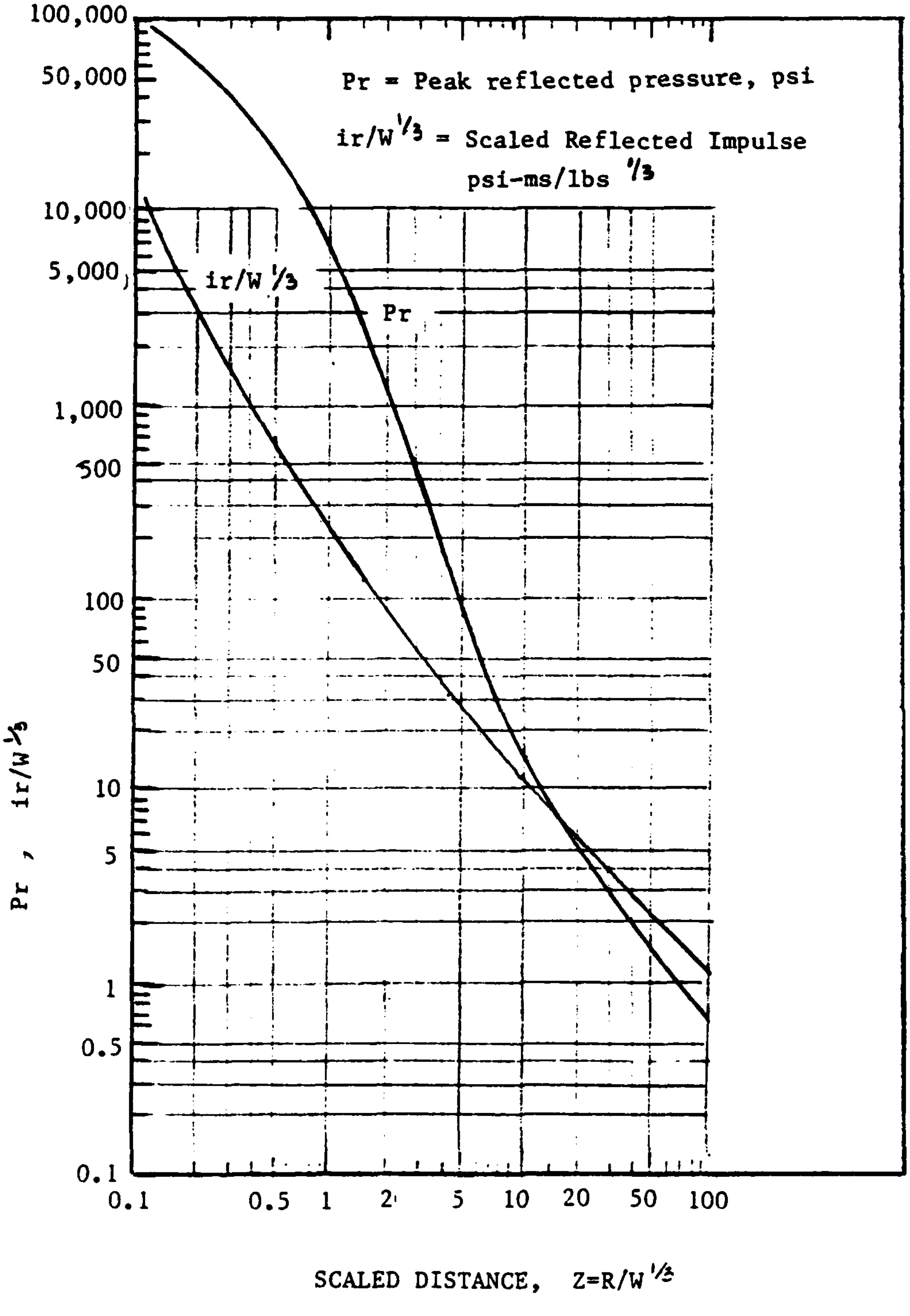

FIGURE 4 SHOCK WAVE PARAMETERS

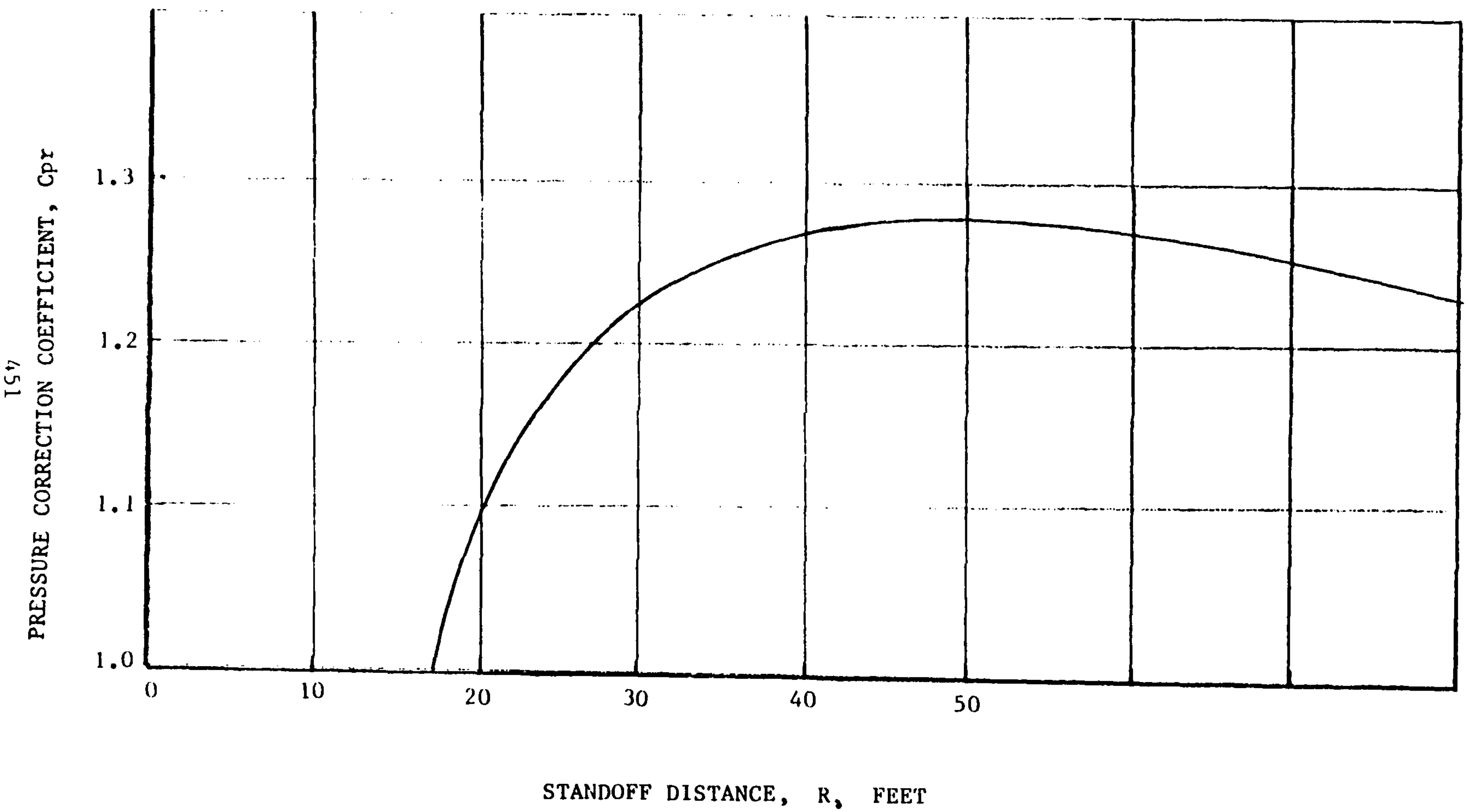

FIGURE 5 PRESSURE CORRECTION COEFFICIENT VERSUS STANDOFF DISTANCE

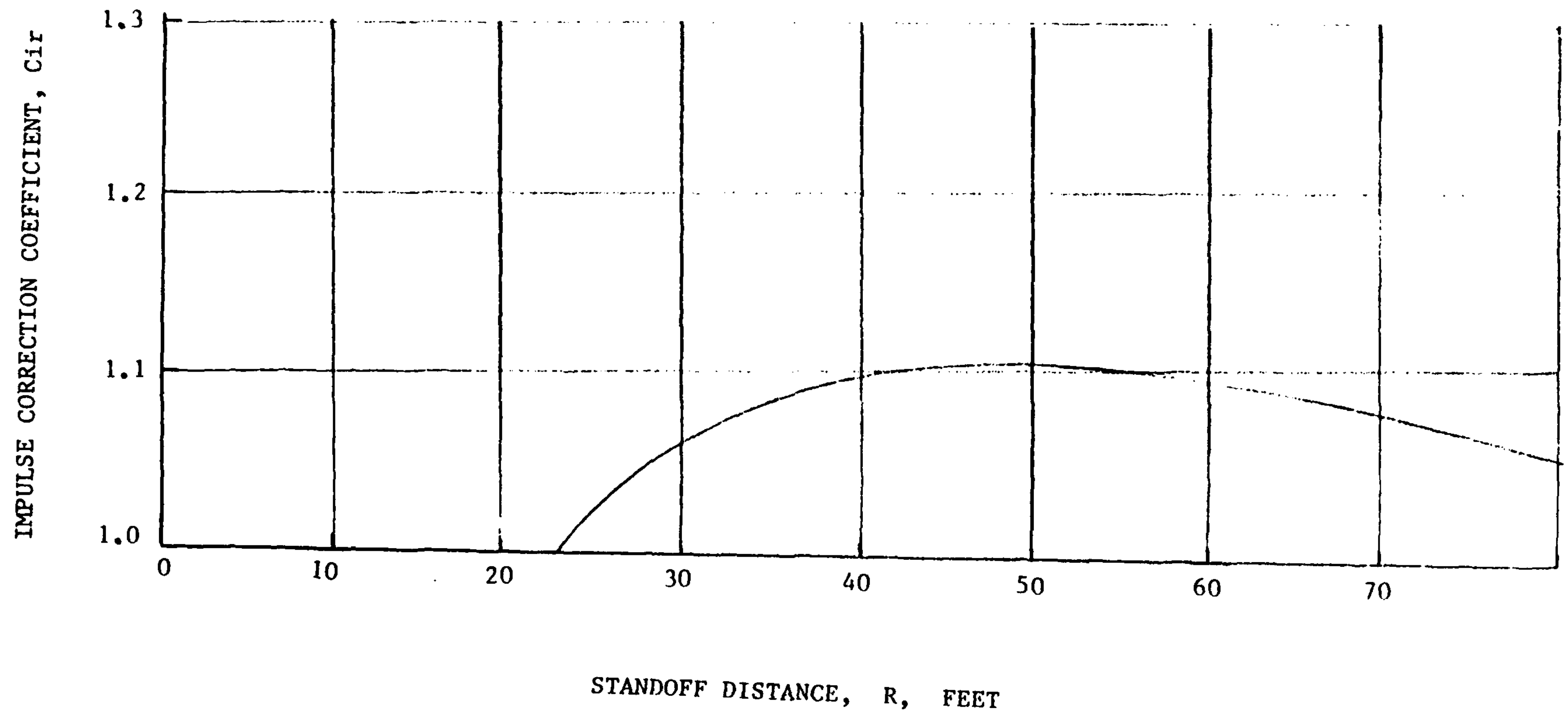

FIGURE 6 IMPULSE CORRECTION COEFFICIENT VERSUS STANDOFF DISTANCE

A NEW PROCESSING FACILITY FOR THE PRINS MAURITS LABORATORY TNO

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Summary

The Prins Maurits Laboratory TNO has built a new facility for formulation and processing work with explosives. The ideas according to which this facility was built are: maximum prevention of an explosion, maximum protection in case of an explosion, minimum propagation in case of an explosion or fire, minimum pollution of the environment in normal operations and good working conditions for carrying out high quality research.
This paper will describe these ideas and the design of the facility in more detail.

Introduction

The Prins Maurits Laboratory is part of TNO, the Netherlands organization for applied scientific research. The Prins Maurits Laboratory is one of the laboratories within the Defence Division and deals, amongst other things, with research on explosive compositions and explosive reactions. The Prins Maurits Laboratory is located in Rijswijk, the Netherlands.
Other TNO Institutes are also located at the Rijswijk premises, and many potentially hazardous activities were combined there; research on explosives, on highly toxic materials and on recombinant DNA.
The expansion of the PML and the building of a new laboratory for toxic materials urged us to reconsider the safety aspects of all these combined activities, especially the research with highly explosive materials. The conclusion was that all the activities with relatively large quantities of explosives (including the storage of explosives) should be transferred to another location. On the nearby airbase 'Ypenburg' a PML-test facility for ballistic research already existed. Therefore this location was chosen for a new facility where all the formulation and processing work with explosive materials should take place.

VIAK AB in Örebro, Sweden was contracted for the design of this new facility . They have experience in the design of buildings for processing explosives for Swedish defence industries.
The design process was started at the end of 1988. By the end of 1989, VIAK had completed the pre-design for the facility and the final design phase was started together with a Dutch construction & engineering company. This resulted in a public call for tenders in July 1990. The building contract was granted to the Dutch construction company 'Nelissen & van Egteren' and work commenced towards the end of 1990. The facility was completed in October 1991.
The entire design and realisation process took slightly less than 3 years. Considering the complexity of the facility and technical installations, this was extremely fast. This presentation will provide some background information about the ideas according to which the facility was built.

Activities on explosive formulations and processing

To understand the design problem for the new facility it is indispensable to have some insight into the activities which have to be performed there. The Dutch Ministry of Defence is the principal client of the Prins Maurits Laboratory. Since the Netherlands hardly has any defence related industries, our main research goal is directed towards technology development. The Prins Maurits Laboratory aims to be a knowledge backup for the Ministry of Defence. To fulfil this goal we research all areas which deal with explosive materials: pyrotechnics, propellants and explosives. More in detail our activities are:

- small scale laboratory work (10-250 g) for investigation of compatibility, characterisation of raw materials, pre-treatment of raw materials etc.
- handling (e.g. sieving, mixing, drying) of explosives, up to 5 kg
- mixing facilities for composite propellants and explosives (1-25 kg)
- melt casting of TNT based compositions, up to 25 kg
- pressing of explosives, up to 2 kg
- handling and mixing of pyrotechnic compositions up to 1 kg
- synthesis and handling of primary explosives, up to 300 g

The building

The ideas according which the building was built are as follows:

1 combination of all activities within one facility
2 maximum precautions to prevent any unwanted explosion or reaction
3 maximum protection against an accidental explosion for the personnel in the facility, the rest of the building and the environment
4 maximum precautions to avoid propagation of an explosion or fire
5 minimum pollution to the environment during normal operations
6 optimum conditions for performing high quality work

All these aspects will be discussed in more detail in the next paragraphs.

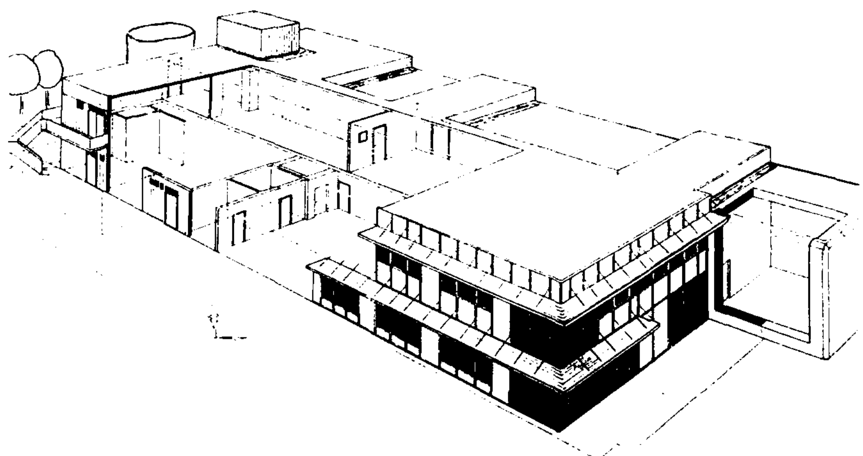

Figure 1. *General view of the building*

Firstly, a general view of the building is presented in Figure 1. The building consists of two floors. The offices and technical installations are located on the second floor and the experimental facilities are on the ground floor. The offices are located directly above the laboratories in which only small amounts of explosives are allowed (gram scale) and have reinforced concrete floors. However, it is assumed that there is no significant explosion hazard in these laboratories.
Only technical installations are located above experimental rooms for larger amounts of explosives with any explosion hazard

Combination of activities

The design opted for combining activities within one building because of the relationship between the various activities. The product is research and not regular production, so even the large scale mixers for PBX-es can not do without the laboratory to solve unexpected problems, pressing and casting need the laboratory for preparation of the raw materials and of course all materials and intermediate products need to be characterised.
Combination in one building would avoid extensive transport of dangerous materials between the various buildings. Shortened communication and transportation routes would increase the safety of the operations, and therefore increase the efficiency. An additional advantage of having just one building is a more friendly working environment for the personnel because each work group is within easy walking distance
By including offices within the same building, the relationship between the practical and theoretical work is emphasized and communications between staff performing the experimental work and more theoretically oriented staff will be increased.

Prevention of accidental reactions

This safety aspect seems contradictory to the previous goal: combining all activities.
Safety often demands a division of activities with various kinds of explosives to prevent contamination of one type with other types of explosives. This problem is solved by defining separated areas for the various activities. Each area is separated from other areas by concrete walls, fire proof and/or explosion proof doors. (See figure 1)
Other important aspects for explosive prevention present in the facility are:

- all fixed electrical installations are at least according to IP 54 and in explosive areas to IP 65 and/or explosion proof
- power units or other electrical equipment are placed outside working rooms as much as possible

- other electrical equipment should also be according IP 65 or explosive proof
- all floors are semi-conductive and grounded, all rooms have ground strips along all the walls and fixed installations
- the air in the rooms for work with sensitive materials can be moistened up to 70% R.H.
- working areas have floor heating to avoid hot surfaces and dust gathering behind heating radiators.
- All openings for electrical cables, control cables etc. are specially tightened to withstand high overpressures.

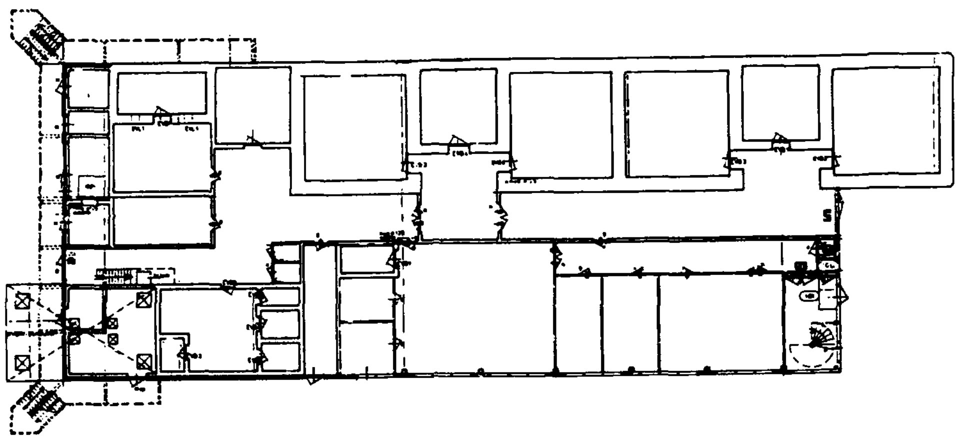

Figure 2. *Ground plan of experimental facilities (ground floor)*

Protection against an accidental explosion

The second step is that the personnel in the facility and the surroundings need maximum protection from explosions, since an accidental explosion can never be excluded.

Therefore the experimental work (with more than a few grams) takes place in highly reinforced concrete bunkers with heavy explosion proof doors without a blow-out wall. These bunkers are designed to withstand a detonation of the maximum amount of explosives. Venting valves will release the overpressure created by the explosion. The maximum allowable amount of explosives in the bunkers varies from 500g up to 25 kg. In this way personnel and the surroundings are optimally protected against an explosion and safety distances around the building could be reduced. Of even more importance is that nearly all operations are remotely controlled, so personnel will never be present in the bunker when an explosion occurs.

Prevention of propagation of an explosion or fire

The third step is prevention of propagation reactions in case an explosion should take place. To prevent this the following precautions are taken:

- All pipes through the bunker walls are fitted with 'rapid closing valves' to prevent propagation through these openings in the walls.
- A sprinkler installation is installed throughout the building and all bunkers are equipped with smoke and/or UV detectors. In this way a fire will be detected in the earliest stage and can probably be extinguished quickly. Thus damage to the building and equipment can be minimised.
- All rooms are fire-proof compartments because they have walls, doors, floors and ceilings that can withstand a fire for one hour. Additionally the ground floor is divided into three fire-proof areas by additional fireproof doors in the corridors. During normal operations, the doors can remain opened by means of electro-magnetic contacts but they will close auto-matically in case of fire. Propagation outside a room is therefore extremely unlikely and will be limited to the fire proof area.
- There is no storage facility in the building so only the explosives necessary for operations are present. In this way the amounts of explosives can easily be kept within the allowable limits. The storage facilities for large amounts are elsewhere on the airbase 'Ypenburg'.

Minimum pollution of the environment

Another element of the design was that the pollution of the environment should be absolutely minimised. This was a requirement set by the TNO management and is even more severe than the Government re-

quirements. TNO did so to be prepared for future government requirements and, as a research institute, to set a good example for industry.
This meant that all the air from the laboratory fumehoods and all the other working rooms should be washed in scrubbers. In this way the explosive dust and water soluble organic solvents would be removed from the air before leaving the building.
The polluted water created in the scrubbers is cleaned, together with all the water from the laboratories and other experimental facilities, in a waste water treatment plant. The cleaning process consists of three main steps:

- precipitation of solid materials by cooling and flocculation followed by filtering
- absorption of dissolved organic (explosive) compounds in columns of active carbon
- a biological treatment to remove the last parts of dissolved organic (explosive) material

In this way very clean water, from which nearly all heavy metal compounds, explosives and organic compounds are removed, is disposed to the municipal sewage system.
The problem of disposal of explosive waste generated during operations (only small amounts) is dealt with in an indoor burning site. This is created to burn small amounts of explosive of explosive contaminated waste. The smoke generated is also cleaned in a scrubber and the water is treated in the water cleaning plant.

Optimum conditions for high quality work

Last but not least: not only is safety important, but also the working conditions in order to perform high quality work.
This means that most operations have their own room to prevent negative interference between activities. The rooms are not too small and provide enough space for optimum performing of operations and the rooms have specially designed and treated floors and walls to facilitate cleaning and tidying. The atmospheric conditions can also be controlled. The room in which the air can be humidified has already been mentioned but most rooms also have the option to be supplied with dry air (down to 15 % RH). This option is important for research with hygroscopic materials such as Ammonium Nitrate. For the standard work with curable binders a controlled humidity is also favourable.

For good control over the work all bunkers are installed with cameras and monitors are placed in the corridors next to the control equipment. On the second floor, in the office area, two monitors are present to be able to follow operations if necessary. One monitor can be fixed to a certain room, the other switching automatically from room to room to give an overview of ongoing operations .
For performing good work minimum disturbance is important too. Therefore all technical installations can be reached from outside for maintenance and repair activities and researchers need not be disturbed during their work. To prevent disturbance the entrance to the ground floor is through keycard doors, so preventing unauthorised access.

Conclusions

It can be concluded that with this building the Prins Maurits Laboratory has obtained a very good facility for performing research on explosive compositions and processing. This facility will enable the Prins Maurits Laboratory to perform the research on explosives safely, efficiently and according to high quality standards which will be necessary to maintain our (leading) position in the field of Defence research in the Netherlands.

LACING AND STIRRUPS IN ONE-WAY SLABS

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BACKGROUND

Section 4.23.1 of the Tri-Service Technical Manual (TM) 5-1300 (1) provides some discussion on construction economy. It states that construction costs are divided between labor and material costs, with labor cost accounting for as much as 70 percent of the cost of blast-resistant concrete. TM 5-1300 states that the initial design, optimized for material quantities, may need to be modified when constructibility is considered. It further states that such a modification may actually increase the total cost of materials for the structure while reducing labor-intensive activities. It is generally known that the fabrication and installation of large quantities of shear reinforcement, particularly that having a complex configuration (such as lacing bars), are labor-intensive activities.

An extensive review of test data on reinforced concrete slabs and a study of the related significant parameters from those data were presented at the 24th Department of Defense Explosives Safety Seminar (Reference 1). It was shown that some relaxation in the then current shear reinforcement requirements for military protective structures was justified (References 2 and 3). However, some data gaps need to be filled before new guidelines can be developed for facilities used for explosives handling and storage.

A thorough study of the role of shear reinforcement (stirrups and lacing) in structures designed to resist blast loadings or undergo large deflections has never been conducted.

A better understanding of the contributions of the shear reinforcement will allow the designer to compare the benefits of using (or not using) shear reinforcement and to determine which type is most desirable for the given structure. This capability will result in more efficient and effective designs as reflected by lower cost structures without the loss of blast-resistant capacity. A reasonable first step toward this goal is to perform a series of laboratory experiments that compare the effects of stirrups and lacing bars on the large-deflection behavior of one-way slabs.

OBJECTIVE

The overall objective of this study was to better understand the effects of shear reinforcement details on slab behavior to improve the state-of-the-art in protective construction design, for both safety and cost effectiveness. This was not particularly a study of shear stresses in slabs, but rather a study of the effects of shear reinforcement on the large-deflection behavior of slabs.

Specifically, the objective was to evaluate and compare the effectiveness of stirrups and lacing bars in enhancing the ductility of one-way slabs. This included a consideration of how shear reinforcement details interact with other physical details to affect the response of a slab. The work reported herein was directed toward the development of new guidelines for designing shear reinforcement in blast-resistant structures.

SCOPE

Sixteen one-way reinforced concrete slabs were statically (slowly) loaded with water pressure in the 4-foot-diameter blast load generator located at the U.S. Army Engineer Waterways Experiment Station (WES). The design, construction, and loading of the specimens are described herein. The responses of the slabs to the uniform loading and the effects of the reinforcement details on the responses are evaluated.

RESPONSE LIMITS

The data presented in Reference 2 provided a basis for the establishment of the allowable response limits of Reference 3 (ETL 1110-9-7) with qualifications that reflect gaps in the existing data base. The response limits are partially described in Table 1.

The design of structures to resist the effects of accidental explosions is governed by TM 5-1300 (Reference 4), which calls for the use of laced reinforcement for large deflections (support rotations greater than 8 degrees) and for close-in blast (scaled ranges less than 1.0 $ft/lb^{1/3}$). It is obvious that the safety requirements of ETL 1110-9-7 are less conservative than those of TM 5-1300 due to the military nature of structures to be designed in accordance with the ETL guidance. The data base on previous experiments does not include a thorough study comparing the behavior of laced and nonlaced slabs. It is rather a collection of experiments which were conducted for various purposes, thus the various design parameters are difficult to correlate between experiments. The experimental study discussed in the remainder of this paper is a first step toward a more thorough comparison of laced and nonlaced slabs.

CONSTRUCTION DETAILS

In addition to shear reinforcement details, the primary parameters that affect the large-deflection behavior of a one-way reinforced concrete slab include, but may not be limited to: support conditions, amount and spacing of principal reinforcement, scaled range (for blast loads), and the span-to-effective-depth (L/d) ratio. The effects of these parameters on the structural response of a slab must be considered in the study of the role of shear reinforcement.

The slabs were designed to reflect the interaction of shear reinforcement details with the other primary parameters. Table 2 qualitatively presents the characteristics of each slab. Table 3 presents the same characteristics in a quantitative manner, reflecting the practical designs based on available construction materials. All slabs were designed to be loaded in a clamped (laterally and rotationally restrained) condition and may be considered to be approximately 1/4-scale models of prototype wall or roof slabs of protective structures. Each slab had a clear span of 24 inches, a width of 24 inches, and an effective depth of 2.4 inches, maintaining the L/d ratio at a value of 10. The experimental program was designed to compare the effects of lacing bars and stirrups on slab behavior for three values of principal reinforcement ratio and three values of shear reinforcement spacing.

Figure 1 is a plan view showing the typical reinforcement pattern for some of the slabs. Figures 2, 3, and 4 are sectional views cut through the lengths of the laced slabs. The dashed lacing bar in each figure indicates the configuration of the lacing bar associated with the next principal steel bar. The positions of the lacing bars were alternated to encompass all temperature steel bars. However, some temperature steel bars were not encompassed by lacing bars in slabs No. 4 and 5 due to the spacing of the lacing bar bends. The spacings of the lacing bar bends were controlled by the shear reinforcement quantities in corresponding slabs with stirrups. Figures 5 through 8 are sectional views cut through the lengths of the slabs with stirrups. In slabs with stirrups, the stirrups were spaced along the principal steel bar at the spacings shown in Table 3, never encompassing the temperature steel.

EXPERIMENTAL PROCEDURE

The 4-foot diameter blast load generator was used to slowly load the slabs with water pressure. Preparations for the experiments began with the reaction structure being placed inside the test chamber and surrounded with compacted sand. A slab was then placed on the reaction structure, and the wire leads from the instrumentation gages and transducers were connected. A 1/8-inch-thick fiber-reinforced neoprene rubber membrane and a 1/8-inch-thick unreinforced neoprene rubber membrane were placed over the slab, and 1/2- by 6- by 24-inch steel plates were bolted into position at each support. Prior to the bolting of the plates, a waterproofing putty was placed between the rubber membrane and the steel plates to seal gaps around the bolts in order to prevent a loss of water pressure during the experiment. The bonnet was bolted into position, and a commercial waterline was diverted to the chamber's bonnet. The waterline valve was again opened slowly, inducing a slowly increasing load to the slab's surface. A pneumatic water pump was connected to the waterline to facilitate water pressure loading in the case that commercial line pressure was not great enough to reach ultimate resistance of the slab in any of the experiments. Monitoring of the pressure gages and deflection gages indicated the behavior of the slab during the experiment and enabled this author to make a decision for termination by closing the waterline valve. Following termination of the experiment, the bonnet was drained and removed. Detailed measurements and photographs of the slab were taken after removal of the neoprene membrane. Finally, the damaged slab was removed and the reaction structure was prepared for another slab.

Figure 9 is a posttest view of the undersurfaces of all sixteen slabs. The slabs were numbered in increasing order from left to right with slabs No. 1 through 5 being shown on the front row. Detailed posttest measurements, photographs, damage survey data, deflection profiles, and the instrumentation data are presented in Reference 5.

Figure 10 shows the general shape of the midspan load-deflection curve for the slabs as measured with the pressure and deflection transducers. Values of load and deflection at points A through D are given in Table 4. The decision to terminate an experiment depended upon the trend of the monitored load-deflection curves; therefore, the deflection at termination varied among the slabs. The complete load-deflection curves at midspan were not recorded for slabs No. 12, 14, and 16 due to degradation of the deflection gage connections to the slabs (large cracks formed directly at the points of connection) during the experiments. However, the complete load-deflection curves at the one-quarter span location were successfully recorded for slabs No. 12, 14, and 16 and aided in the data analysis.

Compressive membrane forces acted to increase the ultimate capacities of the sixteen one-way slabs from approximately 1.2 to 4.0 times the computed Johansen yield-line resistance. It appeared that lacing was slightly more effective than stirrups in enhancing the ultimate capacities of the slabs. Only for the case of the slabs with a medium ρ value (0.0056) did the slab with stirrups attain a greater ultimate capacity than that with lacing.

The average Δ_A/t ratio (the ratio of midspan deflection occurring at ultimate capacity to the slab thickness) for the slabs was approximately 0.29. There was no consistent pattern to indicate that the Δ_A/t ratio was affected by the construction parameters studied. Consistent with previous work by others, the enhancement in ultimate capacity by compressive membrane forces was greatest for slabs with the smallest ρ, and it decreased as ρ increased. The generally-known compressive membrane theory closely predicted the ultimate capacities of the slabs having the ρ values of 0.0025 and 0.0056 when the experimental values of Δ_A/t were used; but, a low Δ_A/t value of approximately 0.1 was required for the theory to predict the ultimate capacities of the slabs having a ρ value of 0.0097.

Significant spreading of cracking along the length of the slabs did not occur; therefore, significant tensile-membrane behavior did not develop. The tensile-membrane response (and thus the peak reserve capacity) appeared to be best enhanced by lacing in the slabs with a ρ value of 0.0025, but by stirrups in the slabs with a ρ value of 0.0097. The two types of shear reinforcement appeared to be equally effective in the slabs with the medium ρ value of 0.0056. Of the parameters that were varied, the principal reinforcement ratio was the most significant parameter affecting the reserve capacity. The tensile-membrane theory closely predicted the peak reserve capacities of the slabs with the large ρ value when one-half of the principal steel was considered to be effective. It closely predicted the peak reserve capacities of the slabs with the small ρ value when all of the principal steel was considered. The peak reserve capacities of the slabs with the medium ρ value were bracketed by the theory when both cases were considered.

This investigation indicated that one-way slabs typical of protective construction (equal top and bottom steel, restrained at ends) are susceptible to shear failure when reinforced with approximately 0.5 percent or more principal reinforcement, but no shear reinforcement. Shear reinforcement may not be needed to insure a flexural failure mode in slabs with approximately 0.25 percent principal reinforcement. Support rotations from approximately 20 to 30 degrees were achieved by the 14 slabs that did not incur shear failure.

Due to the response of the slabs as three-hinge mechanisms, crack width was highly dependent on deflection. Some smoothing (spreading of cracking and formation of a catenary, particularly on the top face) occurred in the slabs with the large ρ value. This smoothing appeared to be greatest for slab No. 5; however, slab No. 5 exhibited the least tendency for tensile membrane behavior. Slab No. 5 did exhibit a significantly more gradual drop in resistance following the ultimate capacity. In general, crack widths were slightly less in the laced slabs than in the slabs with stirrups. Strain gage data indicated that lacing bars yielded at lower pressure levels and smaller slab deflections than did the vertical stirrups, indicating that the lacing was mobilized earlier in making a contribution to a slab's response. However, the responses of the laced and stirrup slabs were very similar, differing a little in resistance values as mentioned above. Other than for slabs No. 5 and 15, the companion pairs of laced and stirrup slabs exhibited load-deflection curves with very similar shapes.

CONCLUSIONS

There were no significant differences in the behavior of the slabs with lacing bars and the slabs with stirrups that were experimentally evaluated in this study. The slight increase in ultimate capacity for laced slabs cannot justify the complications and expense associated with the construction of laced slabs. Single-leg stirrups with a 90-degree bend on one end and a 135-degree bend on the other are sufficient for preventing shear failure and for enhancing the reserve capacity to the same level (or, as in some cases of this study, better) than lacing bars. The experiments showed that, for slabs with principal steel spaced at approximately one-half to two-thirds of d and shear reinforcement spaced less than d, variations in the principal reinforcement ratio have significantly greater effect on slab response than do the type and ratio of the shear reinforcement.

The more ductile response and improved large-deflection behavior that one would expect, based on TM 5-1300, from a laced slab over a slab with stirrups did not occur in this study. The damage levels experienced by the slabs in this study fall into the heavy damage category of ETL 1110-9-7. The data from these experiments support the response limits given in the ETL as being aggressive, yet adequate, design values for slabs of military protective structures that can allow the occurrence of heavy damage, but not collapse. Additionally, this study indicated that design criteria concerning shear reinforcement and slab response limits in TM 5-1300 may be overly restricted. Although the experiments conducted in this study do not necessarily demonstrate the response of the slabs to any possible blast environment that may occur in an explosives manufacturing/storage facility, they are at least representative of slabs loaded by the slower rising quasi-static pressure that accompanies an internal detonation. In addition, by combining the findings of the experiments conducted during this investigation with the parameter study of Reference 2, one may be reasonably confident that the failure modes and response limits exhibited by the slabs will be duplicated in a direct blast pressure loading that results from a detonation at a scaled range greater than 2.0 $ft/lb^{1/3}$ and possibly as low as 1.0 $ft/lb^{1/3}$.

RECOMMENDATIONS

This investigation merged together an understanding of the history of the development of current design criteria with new data that showed the similar effects of lacing bars and stirrups. Experiments using dynamic loading conditions should be conducted to validate the findings of this study and to further study the effects of lacing and stirrups in close-in blast environments. Additionally, this work study should be extended to slabs with other L/d ratios, particularly "deep" ($L/d < 5$) slabs.

ACKNOWLEDGEMENTS

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Table 1 Response Limits of ETL 1110-9-7

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

Table 2 Slab Characteristics (Qualitative)

Slab	$\rho_{tension}$	ρ_{shear}	Lacing	Stirrups	Principal Steel Spacing	Shear Steel Spacing
1	small	none	-	-	0.67d	-
2	medium	none	-	-	0.63d	-
3	large	none	-	-	0.53d	-
4	small	small	x		0.67d	a
5	large	small	x		0.55d	d
6	small	medium	x		0.67d	3d/4
7	medium	medium	x		0.63d	3d/4
8	small	large	x		0.67d	d/2
9	large	large	x		0.55d	d/2
10	small	small		x	0.67d	d
11	small	medium		x	0.67d	3d/4
12	medium	medium		x	0.63d	3d/4
13	medium	medium		x	0.63d	3d/4
	(Temperature steel placed exterior to principal steel)					
14	small	large		x	0.67d	d/2
15	large	small		x	0.55d	d
16	large	large		x	0.55d	d/2

Table 3 Slab Characteristics (Quantitative)

Slab	$\rho_{tension}$	ρ_{shear}	Lacing	Stirrups	Principal Steel Spacing (inches)	Shear Steel Spacing (inches)
1	0.0025	none	-	-	D1 @ 1.60	-
2	0.0056	none	-	-	D2 @ 1.50	-
3	0.0097	none	-	-	D3 @ 1.33	-
4	0.0025	0.0026	x		D1 @ 1.60	2.4
5	0.0097	0.0031	x		D3 @ 1.33	2.4
6	0.0025	0.0034	x		D1 @ 1.60	1.85
7	0.0056	0.0036	x		D2 @ 1.50	1.85
8	0.0025	0.0052	x		D1 @ 1.60	1.2
9	0.0097	0.0063	x		D3 @ 1.33	1.2
10	0.0025	0.0026		x	D1 @ 1.60	2.4
11	0.0025	0.0034		x	D1 @ 1.60	1.85
12	0.0056	0.0036		x	D2 @ 1.50	1.85
13	0.0056	0.0036		x	D2 @ 1.50	1.85
	(Temperature steel placed exterior to principal steel)					
14	0.0025	0.0052		x	D1 @ 1.60	1.2
15	0.0097	0.0031		x	D3 @ 1.33	2.4
16	0.0097	0.0063		x	D3 @ 1.33	1.2

Table 4 Midspan Load-Deflection Summary

Slab	P_A (psi)	Δ_A (in)	P_B (psi)	Δ_B (in)	P_C (psi)	Δ_C (in)	P_D (psi)	Δ_D (in)
1	57*	0.52	8	2.41	8	2.41	23	3.61
2	87	0.80	44	1.10	44	1.10	53	1.65
3	106	0.45	59	0.51	59	0.51	88	2.18
4	71	0.80	10	2.31	10	2.96	31	4.36
5	135	0.89	70	1.69	27	3.88	41	4.96
6	88	0.79	10	2.58	10	2.58	31	4.80
7	83	0.88	38	2.32	11	3.61	43	4.00
8	64	1.00	8	2.50	8	3.10	26	4.50
9	137	0.91	17	2.85	17	2.85	73	4.22
10	63	0.65	3	2.33	8	3.59	25	4.77
11	63	0.91	2	2.65	2	2.65	22	5.00
12	85	1.10	19	3.10	**	**	**	**
13	89	0.74	25	2.00	25	3.19	41	4.63
14	64	0.87	4	2.60	**	**	**	**
15	130	0.81	58	2.30	14	3.11	75	4.00
16	**	**	**	**	**	**	**	**

* Actual experimental value was greater than shown due to data record clip during experiment.

** Large crack formed directly at deflection gage connection on slab, causing loss of connection.

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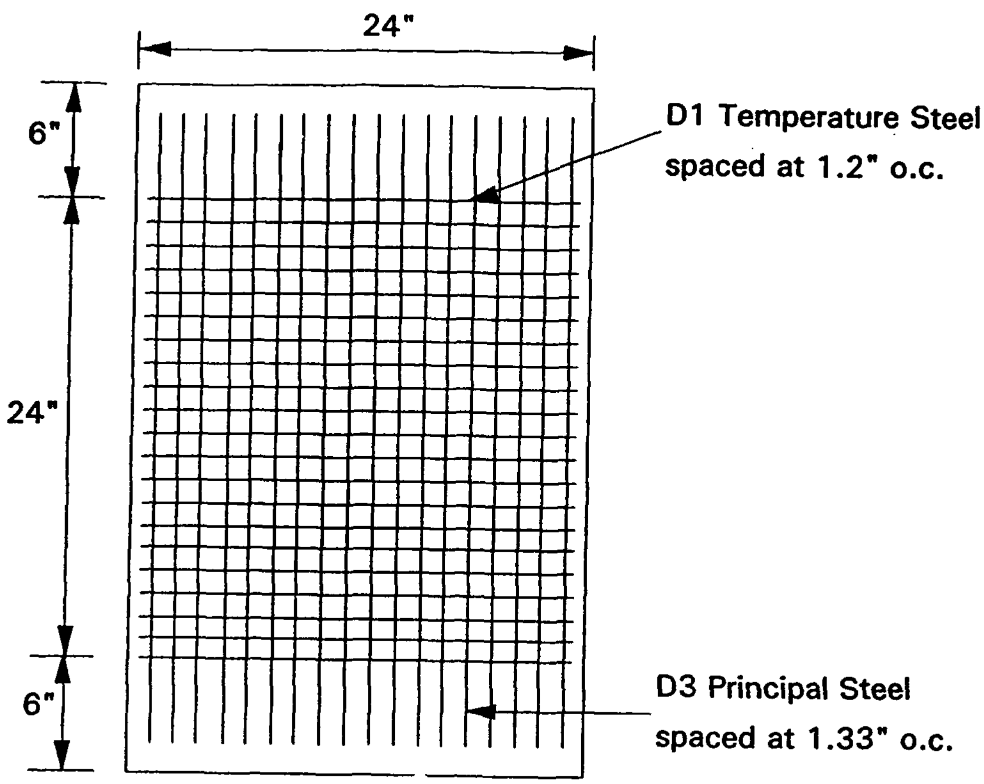

Figure 1. Plan View of Slabs No. 3, 5, 9, 15, and 16

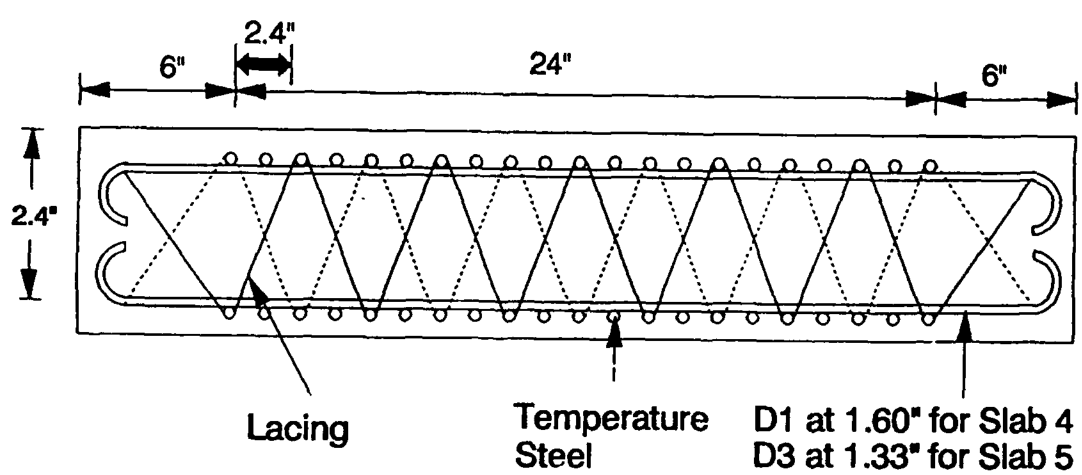

Figure 2. Sectional View Through Length of Slabs No. 4 and 5

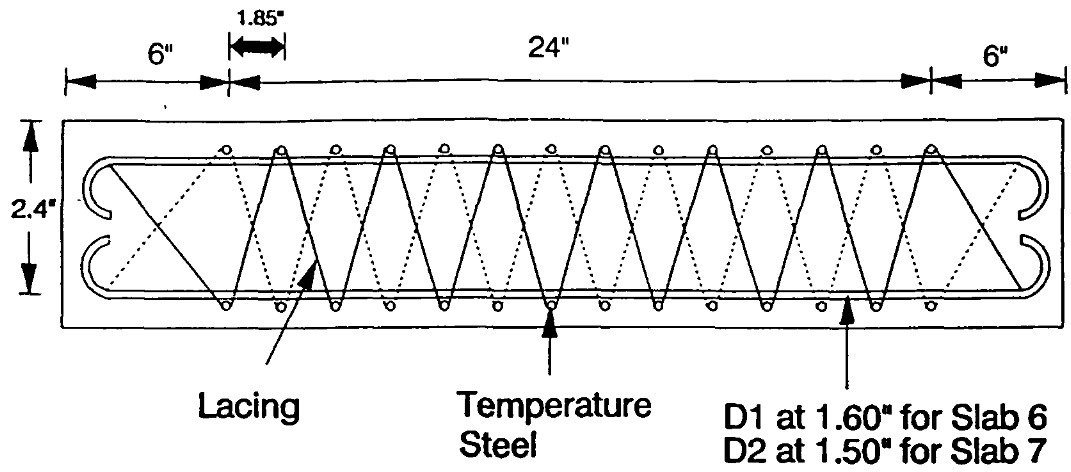

Figure 3. Sectional View Through Length of Slabs No. 6 and 7

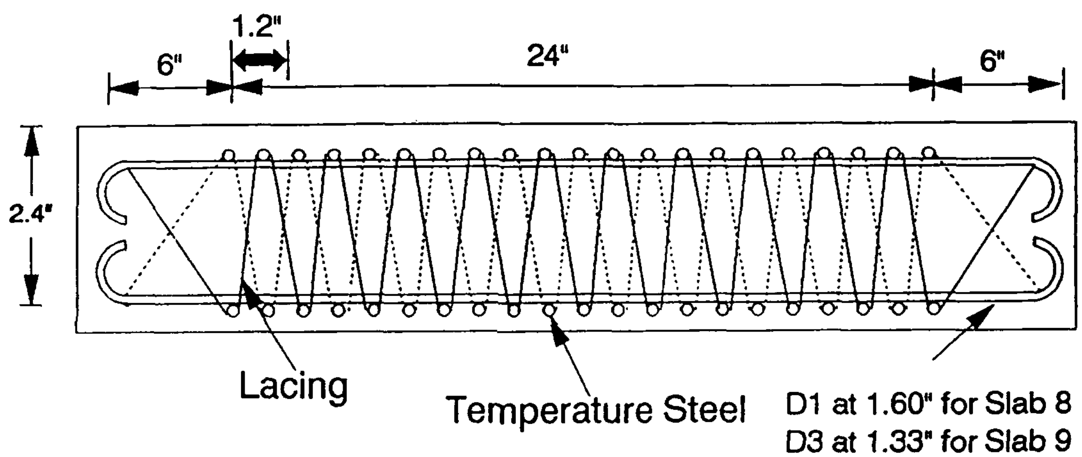

Figure 4. Sectional View Through Length of Slabs No. 8 and 9

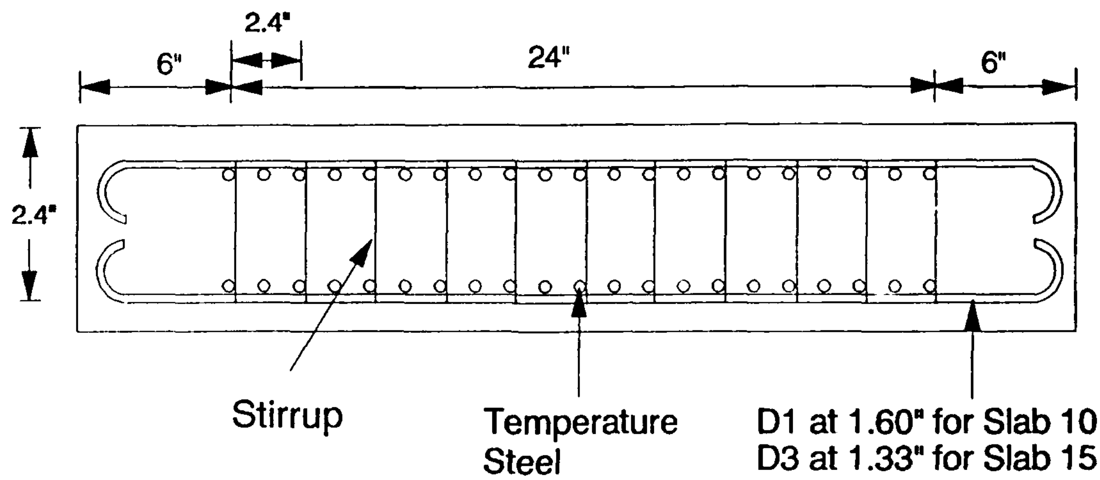

Figure 5. Sectional View Through Length of Slabs No. 10 and 15

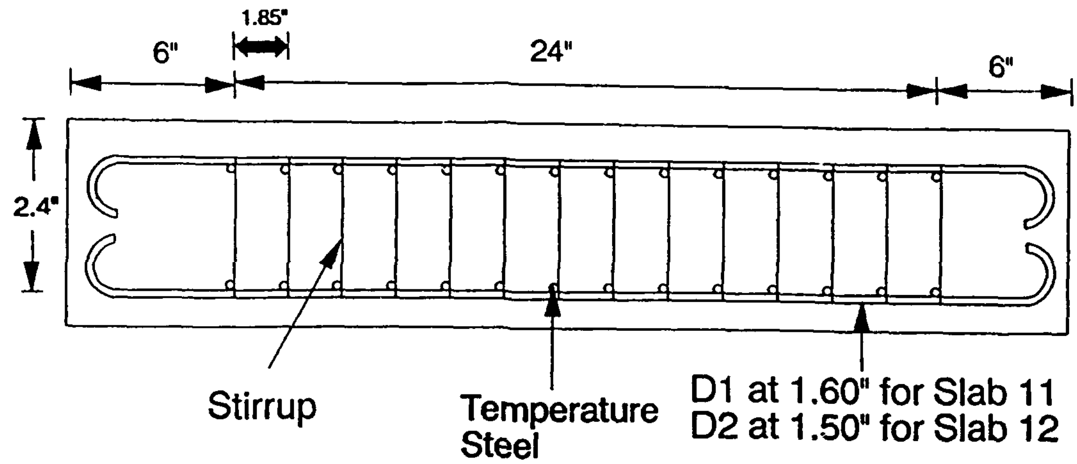

Figure 6. Sectional View Through Length of Slabs No. 11 and 12

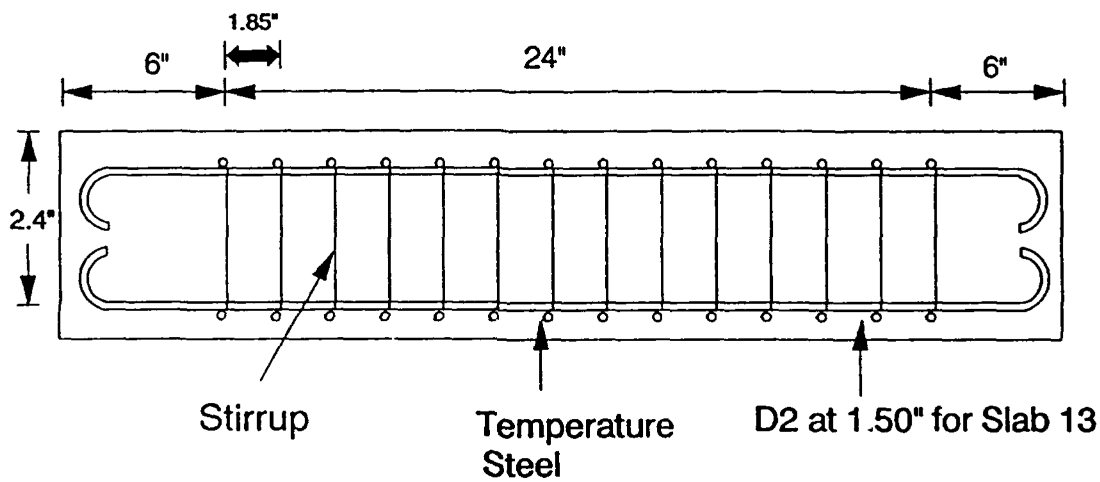

Figure 7. Sectional View Through Length of Slab No. 13

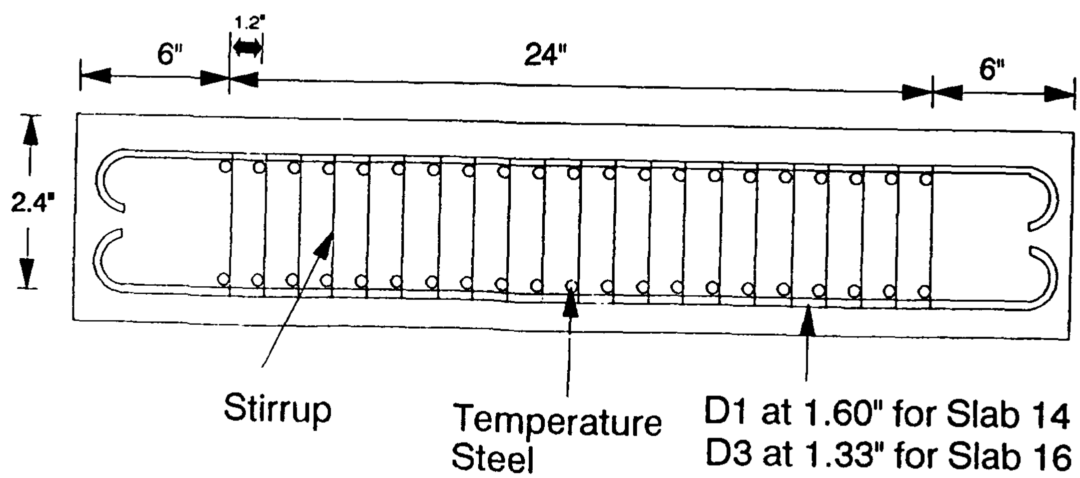

Figure 8. Sectional View Through Length of Slabs No. 14 and 16

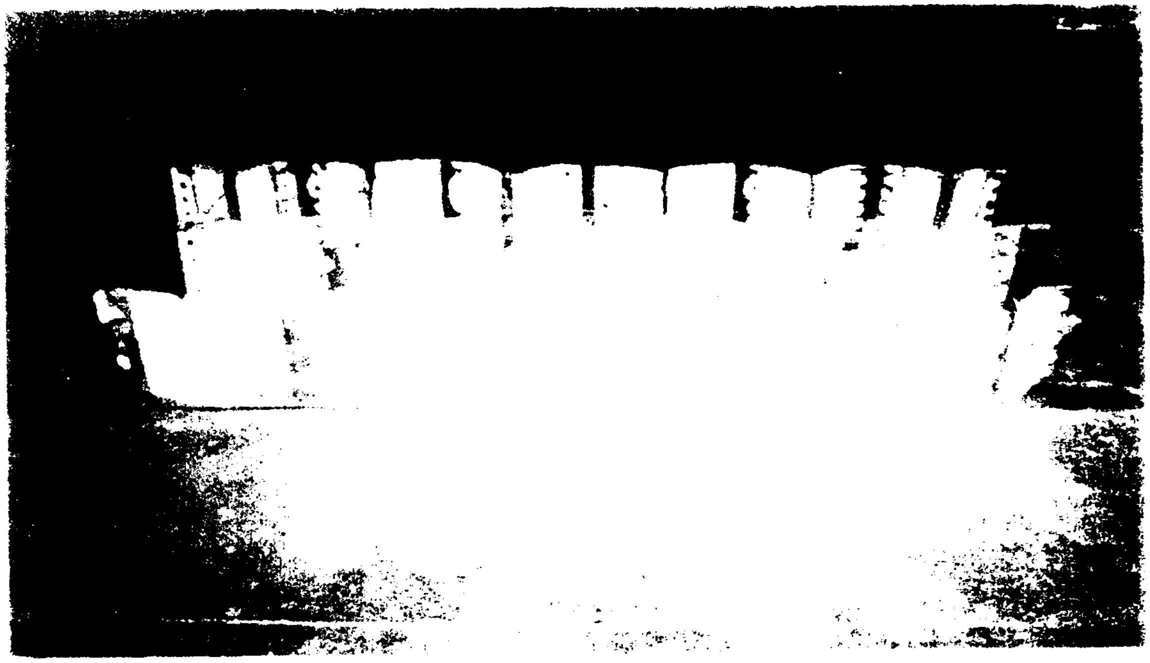

Figure 9. Posttest View of Undersurface of Slabs

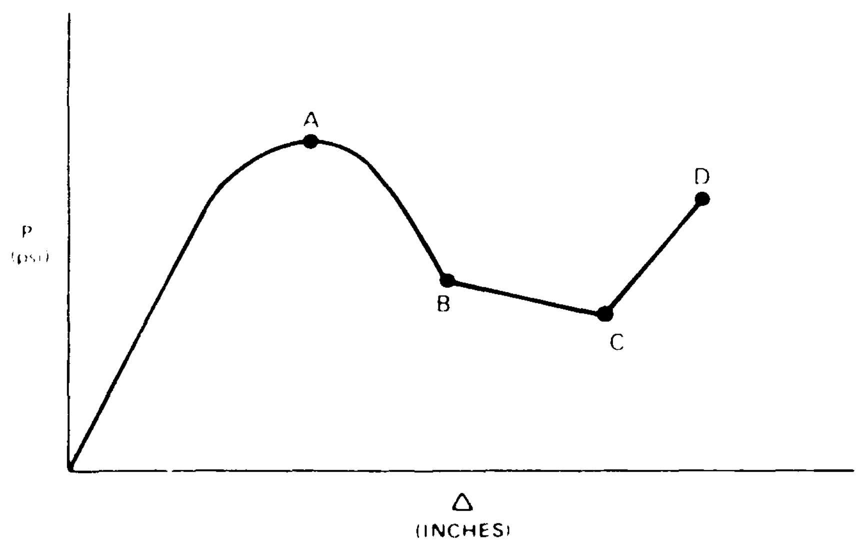

Figure 10. General Midspan Load-Deflection Curve

Practical Use of the Building Debris Hazard Prediction Model, DISPRE

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ABSTRACT

Final validation of the first version of the building debris hazard prediction model DISPRE was completed in 1990. The model was developed for the U.S. Department of Energy (DOE) and was approved as an acceptable siting tool by the U.S. Department of Defense Explosives Safety Board (DDESB) in November 1990. It was verified and refined using data from an extensive component test program. The data from these tests were used to validate the model for analyzing explosives operations buildings constructed of one or more of the following components: reinforced concrete, masonry (clay tiles or concrete masonry units), or lightweight components such as corrugated metal. Since the DDESB approval of DISPRE, its use by both DOE and Department of Defense (DoD) contractors has continued to increase. In this paper, the analysis of an example building will be presented in a step-by-step manner to illustrate how the model can be used to safely site explosives handling or processing facilities. It is important to note that the DISPRE model does not replace, but supplements, the existing broad-ranged DoD 6055.9-STD hazardous debris siting criteria, i.e. the model is recognized as an approved alternative analysis method which can be exercised to reduce the required inhabited building distance for a particular site. The complete model procedure is described in DDESB Technical Paper No. 13, April 1991.

1.0 Introduction

A model has recently been developed to predict safe siting distance for protection from hazardous building debris which can result from an accidental detonation within a structure. Version 1.0 of this model (called "DISPRE" for dispersion prediction) has been validated for providing conservative distance predictions using data from an extensive component test program. In November 1990, the DISPRE model was approved for use as a siting tool by the Department of Energy (DOE) and the Department of Defense Explosives Safety Board (DDESB). Since its verification and approval, DISPRE has been widely used to assess potential debris hazards at a variety of explosives handling and processing facilities. Common usage includes analyzing buildings to determine safety criteria compliance, providing backup analysis for requesting safety exemptions, or determining safe positions for new structures.

The major concentration of this paper is an illustration of a typical building analysis. A single building is analyzed using two different explosive charge locations to demonstrate the importance of accurately defining the worst case charge location for use in the analysis. The analyst must choose a realistic location and not just the closest distance to a component if explosives are not likely to be initiated in that location. The results of each step in the procedure are presented, and the final siting distances are compared to the default inhabited building distances quoted in DoD 6055.9-STD (Reference 1). In addition to the presentation of the example building analysis, several upcoming improvements to the model are discussed, along with recommended future enhancements.

2.0 General Description of DISPRE Model

DISPRE is a procedure which can be used to determine proper siting distance between explosive handling structures and inhabited buildings to prevent both personnel and building exposure to hazardous building debris. The model is a combination of steps which involve the use of computer codes and prescribed intermediate calculations based on analysis of test data. The three computer codes in the model are SHOCK (Reference 2), FRANG (Reference 3), and MUDEMIMP (Reference 4). Version 1.0 of both SHOCK and FRANG, as obtained from the Naval Civil Engineering Laboratory (NCEL), is used in the current model. Version 1.1 (or later) of the MUDEMIMP code should be used. This code has undergone significant modifications based on data from the large component test program associated with the development and refinement of DISPRE. The intermediate calculations establish input for the computer codes.

The procedural steps of the model progress through the following general tasks:

- prediction of internal loads, including shock and gas load contributions,

- component breakup prediction and calculation of debris characteristics (such as mass, velocity, drag, and angle),

- determination of debris trajectories and dispersion, and
- consideration of debris tumble after initial impact (roll and ricochet).

General overviews of each of these tasks are given in this section. Brief descriptions of the actual steps used to make the predictions are provided in Section 3.0. To use the model, one needs to refer to the detailed steps presented in DDESB Technical Paper No. 13 (Reference 5) or the final report for the refinement project sponsored by DOE (Reference 6). Reference 6 provides more detailed information on the creation of the model and the test program used to obtain validation data, and it includes complete documentation of the refinement of the model based on the test data.

2.1 Prediction of Internal Loads

Blast loading inside a confined space can be characterized by an initial shock phase which is usually followed by a gas or quasistatic phase loading. The shock phase consists of very short duration, high pressure pulses which load surfaces as the shock reverberates within the donor bay. The magnitude of the shock phase depends on the charge amount, the distance to the loaded surface, and the location of nearby reflecting surfaces. The magnitude and duration of the quasistatic phase depend on the charge amount, the donor bay volume, and the available vent area and mass of vent covers. If the vent area is sufficiently large and the vent cover mass is small, the gas phase is essentially eliminated.

Two types of shock loading are considered by the model -- close-in and far-range loading. Close-in loading occurs when the charge is so close to the component that the applied pressures locally overwhelm its strength. The component loses all structural integrity, and the maximum wall motion is determined by the maximum applied impulse. Far-range loading occurs when the charge is far enough from the wall so that basic structural integrity is maintained, and the wall responds to an average, more uniform load. The use of model procedures for determining close-in loading is limited to situations where the scaled standoff between the charge and the component is between 0.5 and 1.0 $ft/lb^{1/3}$. All greater standoffs are considered far-range shock loading.

The SHOCK and FRANG computer codes are used to determine the shock and gas impulse on all components in a donor structure. A combination of the impulse predicted using both codes is used to calculate maximum debris velocity (and several other debris characteristics related to velocity) for debris resulting from each loading realm discussed in this section. The model procedures prove to be an accurate treatment of the load based on comparisons to the test data listed in Reference 6. SHOCK is used to predict average shock phase loading on internal surfaces including the shock reflections off nearby surfaces. The program includes a reduced area option which allows determination of average shock impulse over a portion of a wall surface or at a single point on the wall. Thus, loads over the entire component, over a local area, or at a point directly across from the charge can be determined. Any gas impulse caused by a detonation in a confined building is predicted using the computer code FRANG.

2.2 Building Component Breakup and Debris Characteristics

Component breakup is predicted based on the applied load and the component type. A given debris piece can be described by an initial velocity, mass, vertical launch angle, and drag characteristics during flight. The distribution of each of these parameters for a given accident can be defined in terms of a probability density function. High speed film coverage and post-test data collection used in the DISPRE validation test program provided data to use in establishing the particular distribution function to use with each parameter. The breakup is predicted to provide input in a form compatible with the MUDEMIMP computer code used to estimate debris dispersion in the model. The choice of input probability distribution to use for each parameter is based on statistical correlations with test data. The specific recommended distributions for each parameter for each material covered by the model are summarized in Section 3.0, with more detailed descriptions provided in References 5 and 6.

2.3 Determination of Debris Dispersion

A modified version (Version 1.1 or later) of the MUDEMIMP code (Reference 4) for Multiple Debris Missile Impact Simulation is used to determine the hazardous debris distance and debris dispersion for a building. The results of the component breakup and debris characteristics prediction are used to create input for the MUDEMIMP code. Originally written by Louis Huang at the Naval Civil Engineering Laboratory (NCEL), this code uses a probabilistic approach to include variations and uncertainties of launch/flight characteristics of each individual debris missile from an explosion. It uses the Monte-Carlo random sampling technique to select a set of launch/flight parameters for each debris piece. It then calculates the trajectory, impact range, and terminal kinetic energy of each piece based on the selected initial conditions. In addition to an output file containing all input and output parameters for every debris missile simulated, the code also outputs a file containing cumulative hazardous debris density data. Hazardous debris are defined as those debris with impact kinetic energies exceeding a critical energy input by the user, e.g. 58 ft-lbs. Significant modifications to the original code which were made during the refinement of DISPRE are discussed in detail in Reference 6.

Five main launch/flight parameters are required to run the code: debris mass, initial velocity, initial trajectory angle, drag coefficient, and drag area factor. The actual input to the code is in the form of probability distributions which describe the possible range of values for each major parameter. Parameters for each individual debris piece are chosen by the code randomly selecting from the probability distributions. The probability density functions recommended for the five main launch/flight parameters for each of the materials covered by the model are summarized in Section 3.0.

The selected distributions are recommended based on extensive statistical sampling of the data from concrete and masonry tests conducted for this program. Other input includes initial height of debris and characteristic length. All debris are assumed to be launched from a single point. Refer to References 5 and 6 for a more complete description of the input.

2.4 Debris Tumble After Impact

If debris thrown from an explosion impacts the ground at a shallow angle, it will ricochet or roll after impact. Predicting the first impact location as the final resting place is very inaccurate and unconservative. Logic to calculate debris ricochet and roll distances from curve fits to test data is incorporated in Version 1.1 of the MUDEMIMP code. The test data include tests on masonry and concrete walls from both severe close-in loading and severe gas loading. The curve fits are discussed in detail in Reference 6. According to the roll and ricochet logic built into the code, the total debris throw distance is the sum of the distance to the first impact and the roll distance. The roll distance is calculated from the debris angle and velocity at first impact. Debris angle is only considered to the extent that debris with an impact angle less than 55 degrees from the horizontal are assumed to roll, whereas those debris impacting at higher angles are assumed not to roll. The debris impact velocity is used with curve fits from validation test data (Reference 6) and other data (References 7 and 8) to calculate the roll distance. The model will differentiate between concrete roll (roll of debris with three-dimensional breakup) and masonry roll (roll of debris with two-dimensional breakup).

No curve fits of debris roll were developed for lightweight wall debris or beams. There are not enough data available to develop curve fits. Initial attempts to predict measured debris distances for tests of these materials, assuming no roll, significantly underpredicted the measured distances. Predictions were also made assuming roll similar to that of masonry. These predictions compared conservatively to measured debris distances. Therefore, dispersion of all debris which exhibits two-dimensional breakup, i.e. breakup which does not include any fracture through the beam thickness, should be predicted assuming debris roll according to the curve fit developed for masonry. Breakup of light walls and beams is assumed to be two-dimensional breakup.

3.0 Summary of Step-by-Step Procedure

Detailed guidelines for using DISPRE to determine safe siting distance for a building are provided in References 5 and 6. Brief descriptions of the procedure steps are included here as a reference for the example building analysis presented in the following section.

1. *Define the threat.* Describe all structural components and the explosive charge and location. For siting purposes, the charge location should be a plausible location which would result in the worst case debris formation -- the key word is "plausible". As will be seen in the example analysis, charge location significantly affects debris density in any given direction.

2. *Determine vent areas and descriptions.* Define both covered and open vent areas and the panel weight per unit area of the covered areas.

3. *Calculate the impulse load on each component.* Both shock and gas loads are determined since both can contribute to the initial velocity at which debris will leave a building. First, the shock load is calculated using the SHOCK code. The area over which the shock load is applied to a component depends on how well the component is expected to distribute the load. Two types of component response can occur: local or global response. Local response occurs when the component has little strength compared to the applied load. For this type of response, the shock impulse is calculated at a point on the component opposite the explosive charge. Local response is considered for close-in loading of reinforced concrete and for all unreinforced masonry, plaster, and cement asbestos components. Global response results if a component is expected to maintain its integrity and respond to an average impulse over an area (which could be a reduced area of the component opposite the charge or the entire component). This type of response applies to far-range loading of reinforced concrete and to any loading of metal panels or steel beams.

   The gas impulse is calculated using the FRANG code. One or both of two types of venting are considered: venting through the area of the wall or roof with the least mass per unit area, or venting through the breached portion of the wall nearest the charge which is thrown out very quickly by the shock pressures. The type of venting which will govern for a particular component depends on the loading realm for the component and the mass per unit area of the other components (which surface will vent most quickly). The FRANG code calculates an initial gas pressure based on the ratio of the charge weight to the building volume. The code then steps through time, recalculating pressure and impulse at each time step. The pressure decreases as the vent area increases, i.e. as the vent panel moves outward. A critical vent time is marked at which the vent area equals the original vent opening area and the gas pressures in the building are assumed to no longer accelerate the vent panel or debris. The gas impulse at this critical vent time is used if the component being analyzed is a venting component. Non-venting components are exposed to the total gas impulse.

4. *Calculate the maximum debris velocity expected.* The basic form of the velocity calculation is

$$i_T/m$$

   where i_T is the total specific impulse for a particular component, which is the sum of the relevant shock and gas impulse. The parameter m is the mass per unit area of the component. The relevant shock impulse equals the impulse determined by the

SHOCK code, except for cases with close-in loading from a relatively small charge against a relatively thick concrete or masonry wall. In these special cases, the shock impulse is reduced using a curve fit to test data.

Velocities of steel beams and similar components are determined based on velocity predictions for constrained secondary fragments (Reference 6).

Since velocities of all debris, except steel beams, are assumed to be normally distributed, an average (or mean) velocity and a standard deviation of the velocity are calculated to define the distribution for the MUDEMIMP code.

5. *Calculate the average debris weight.* The empirically based equations for average debris weight, m_{avg}, are in the form shown below for concrete and masonry debris. The weight is converted to a mass within the MUDEMIMP code. For steel beams, the debris is considered to be the entire beam with a mass equal to the beam mass. For lightweight metal panels, the mass is assumed to be uniformly distributed between the values of one quarter panel and one full panel mass.

$$m_{avg} = M' \text{ (volume) (density)}$$

where M′ is a factor based on fits to data.

6. *Determine the effective destroyed weight of the component.* The main use of this input by the MUDEMIMP code is to help define the input mass distribution and establish the adjustment factor to get the appropriate number of debris (as adjusted from the 5000 simulations required to obtain accurate parameter distributions). The effective destroyed mass is determined as follows:

   Total effective destroyed mass = T′ (total component weight)

   where the component is the wall or roof being analyzed and T′ is based on curve fits to data.

7. *Calculate the destroyed width, GRIDL, of the component.* Assume a circular destroyed area equal to the total effective destroyed mass divided by the component weight per unit area.

$$GRIDL = \sqrt{((4/\pi)\,(\textit{total effective destroyed mass})/(\textit{weight per unit area}))}$$

8. *Run MUDEMIMP to determine the hazardous debris distance.* The main input parameters are summarized in Table 1. Other key parameters and further descriptions of all the required variables are found in References 5 and 6.

Table 1. MUDEMIMP Input for Key Debris Parameters

Parameter	Density Function	Limits
Mass	Exponential for concrete and masonry Uniform for lightweight metal panels Constant for beams	m_{avg} m_{min}, m_{max} total beam mass
Total Mass	No distribution	total effective destroyed mass
Initial Velocity	Normal Constant for beams	mean = $V_{avg} = 0.6(V_{max})$ sd* = $V_{std} = 0.14(V_{max})$ V_{max}
Initial Trajectory Angle	Normal Constant for beams	mean = the normal to the surface measured relative to the horizontal sd* = 1.3 or 10 degrees angle = the normal to the surface measured relative to the horizontal
Drag Area Factor	Constant	1.0
Drag Coefficient (3-dimensional breakup) Drag Coefficient (2-dimensional breakup) Drag Coefficient (beams)	Uniform Constant Constant	1.0, 2.0 1.5 1.8

* sd = standard deviation

sd = 1.3 degrees
- (a) close-in loading of concrete, masonry, and plaster components
- (b) far-range loading of masonry and plaster components
- (c) far-range loading of concrete components not restrained by the roof

sd = 10 degrees
- (a) all loading of corrugated metal components
- (b) far-range loading of concrete walls restrained at the roof
- (c) all roofs

9. *Obtain pertinent information from the program output files.* The model is run for each component of a building. The number of hazardous debris in a certain direction will be the graphical sum of the number of hazardous debris from the wall components facing that direction and half of the roof hazardous debris. Half of the roof debris are used since potentially half of these debris could contribute to the hazard in a particular direction.

4.0 Example Building Analysis

To illustrate the use of the DISPRE model, an example siting analysis of a building constructed of common materials (for which the model has been verified) is presented in this section. Results are summarized for each step in the procedure for two analyzed cases as described in Step 1.

Step 1: *Define the threat.*

The building, shown in Figure 1, is 20 ft x 20 ft x 12 ft high. It has three 12-in. thick reinforced concrete walls, one unreinforced masonry wall, and a roof composed of metal panels, 5-ply felt, and gravel. The metal panels have a 4 ft width and are 20 ft in length. The panels are supported by open web steel joists spaced at 4 ft on center. The weight per unit area of the metal panels is 2 lb/ft^2. The weight per unit area of the built-up roof (felt and gravel) is 6 lb/ft^2. The weight per unit area of the roof system is then 8 lb/ft^2. A hollow steel door is centered in the unreinforced masonry front wall. The door weight per unit area, considering the cover plates and internal stiffeners, is 5.6 lb/ft^2.

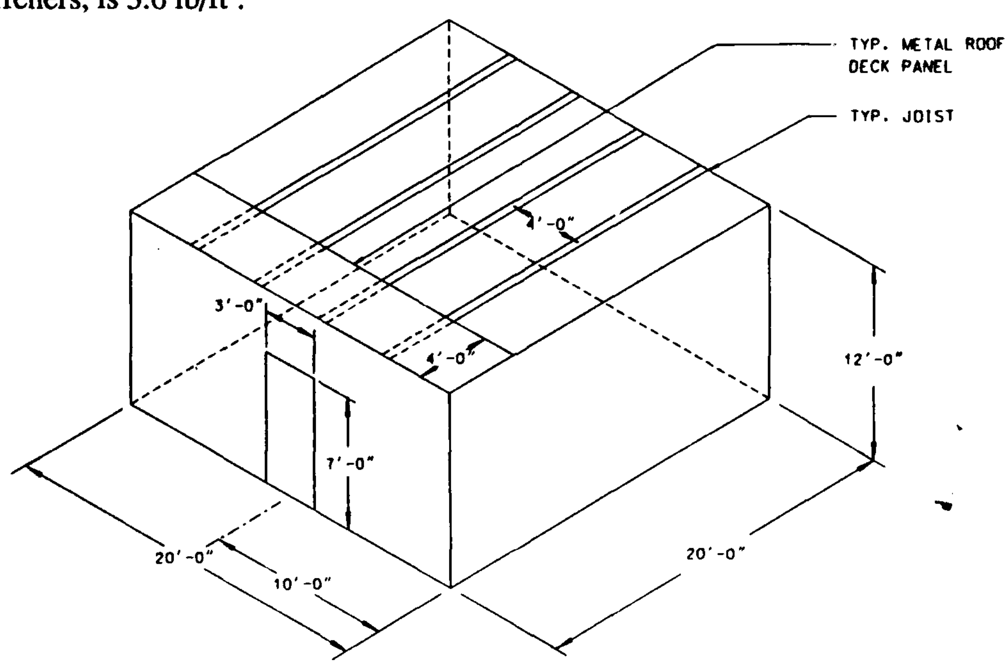

Figure 1. Sketch of Example Building

A bare spherical charge equivalent to 50 lb TNT is assumed. Two cases have been analyzed, with all parameters the same for each case except the charge location. For Case 1, the charge can be located anywhere within a designated high explosives (HE) area which has boundaries 3 ft from each wall as shown in Figure 2. The minimum height off the floor is 2 ft.

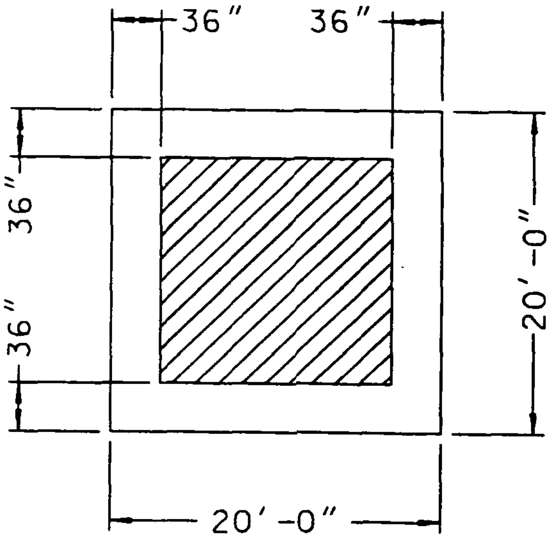

Figure 2. Designated HE Area for Case 1

Case 2 considers a fixed charge location in the center of the building, representing the position of fixed processing or testing equipment. The height off the floor is 4 ft. The loaded surfaces for both cases are defined below:

Surface 1	12 ft x 20 ft clay tile wall
Surface 2	12 ft x 20 ft reinforced concrete wall
Surface 3	12 ft x 20 ft reinforced concrete wall
Surface 4	12 ft x 20 ft reinforced concrete wall
Surface 5	20 ft x 20 ft metal panel roof with 5-ply felt and gravel
Surface 6	steel joist in roof
Surface 7	3 ft x 7 ft steel door in clay tile wall

Step 2: *Determine the vent areas and descriptions.*

Two covered vent areas are considered for the example building for both cases -- the roof and the steel door. There are no open vent areas to be input to the FRANG code. A summary of the vent panel characteristics is shown in Table 2. The door consists of two 16 gauge steel cover plates (with two inch spacing) and internal stiffners.

Table 2. Summary of Vent Characteristics for FRANG Input

Vent	Covered Vent Area (ft^2)	Weight/Area (lb/ft^2)	Vent Perimeter (ft)	Total Panel Weight (lb)
Steel Door	21	5.6	20	117
Metal Roof	400	8.0	80	3200

Step 3: *Calculate the impulse load on each component.*

The shock impulse and gas impulse loads on each surface or component are summarized in Table 3 for Cases 1 and 2. Since the charge location for Case 2 is fixed in the center of the room, the shock impulse is considerably less severe for the walls and door. The shock loads on the roof panels and joists do not vary greatly since the distance from the charge to these parameters only changed from 10 ft to 8 ft between Cases 1 and 2 (the Case 1 charge height is 2 ft off the floor while the Case 2 height is 4 ft). The gas impulse loads for all but the clay tile wall (Surface 1) and the door (Surface 7) do not vary significantly. The gas loads on the clay tile wall and the door are affected by the charge location for several reasons. These components are lighter in weight than the reinforced concrete walls and will vent more quickly with the closer charge location in Case 1. The quicker venting of these components results in less gas impulse for the clay tile wall and the door for Case 1. As with the shock impulse, the gas impulse load on the metal roof does not change much since the distance from the charge to the roof is almost the same for the two cases. The model does not apply a gas load to the steel roof joists since the panels supported by the joists will break away much sooner than the joists (if the joists break away at all), and most of the gas pressure will be vented through the openings created by the failed metal panels.

Step 4: *Calculate the maximum debris velocity for each component.*

As decribed in Section 3.0 and in References 5 and 6, this step involves four calculations: relevant shock impulse, total relevant impulse, maximum debris velocity, and the mean and standard deviation of the normal velocity distribution. The results of these calculations are summarized in Tables 4 and 5.

Table 3. Summary of Impulse Loads

Surface	Description	Shock Impulse (psi-sec)		Gas Impulse (psi-sec)	
		Case 1	Case 2	Case 1	Case 2
1	12 ft x 20 ft clay tile wall	1.9	0.60	0.60	0.99
2-4	12 ft x 20 ft reinforced concrete walls	1.9	0.47	1.0	0.99
5	20 ft x 20 ft metal roof	0.41	0.40	0.86	0.85
6	steel joist in roof	0.42	0.39	0.0	0.0
7	steel door	1.2	0.55	0.10	0.19

Table 4. Intermediate Load Calculations

Surface	Description	Relevant Shock Impulse (psi-sec)		Total Impulse (psi-sec)	
		Case 1	Case 2	Case 1	Case 2
1	12 ft x 20 ft clay tile wall	1.9	0.60	2.5	1.6
2-4	12 ft x 20 ft reinforced concrete walls	1.2	0.47	2.2	1.5
5	20 ft x 20 ft metal roof	0.41	0.40	1.3	1.2
6	steel joist in roof	0.42	0.39	0.42	0.39
7	steel door	1.2	0.55	1.3	0.74

Table 5. Debris Velocity Parameters

Surface	Description	Maximum Velocity (ft/sec)		Average Velocity (ft/sec)		Velocity Standard Deviation (ft/sec)	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	12 ft x 20 ft clay tile wall	521	331	313	199	73	46
2-4	12 ft x 20 ft reinforced concrete walls	68	45	41	27	9.5	6.3
5	20 ft x 20 ft metal roof	730	719	438	431	102	101
6	steel joist in roof	no failure	no failure	--	--	--	--
7	steel door	1046	611	--	--	--	--

Since the loads on the walls and door are significantly decreased for the fixed charge location for Case 2, the maximum debris velocity calculated for these components is substantially less as well. For both Case 1 and 2, the steel joists in the roof are shown by calculations not to fail, so no further debris parameter calculations are necessary for the joists. It is also not necessary to calculate an average velocity and velocity standard deviation for the steel door since no distribution will be defined for the door. The door is treated as a single debris piece. The MUDEMIMP code is still used to determine its trajectory, but constant distributions (single values) are input for its key parameters.

Steps 5-7: *Calculate the average debris weight, the effective destroyed weight, and the destroyed width (for use in determining debris density) for each component.*

Table 6 summarizes the results of these calculations for Cases 1 and 2. Note the average debris weights for all components are not affected by the charge location for this building. The empirically based equations used to determine this parameter are average fits through the range of test data used to validate the model. Since both cases analyzed in this paper fall within the data range, the average weight is not affected by the charge location. The effective destroyed weight varies for the reinforced concrete walls because the velocities for the two cases lie within different regimes of the empirical equations (Reference 6). The destroyed width is determined directly from the effective destroyed weight, so the destroyed width for each component is the same for both cases, except the width for the reinforced concrete walls.

Table 6. Summary of Component Weights and Destroyed Widths

Surface	Description	Average Debris Weight (lb)		Effective Destroyed Weight (lb)		Destroyed Width (ft)	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	12 ft x 20 ft clay tile wall	0.29	0.29	7920	7920	17.5	17.5
2-4	12 ft x 20 ft reinforced concrete walls	2.6	2.6	1800	3600	3.9	5.5
5	20 ft x 20 ft metal roof	m_{max}=160 m_{min}=40*	m_{max}=160 m_{min}=40*	800	800	20***	20***
7	steel door	117**	117**	117	117	20***	20***

* For metal panels, a maximum and minimum mass are needed to define the uniform distribution for mass.

** The door is treated as a single piece of debris.

*** The equation for calculating the destroyed width yields a number greater than the width of the building, so the building width is used.

Step 8: *Set up the input files and run the MUDEMIMP code for each component.*

Most of the key input for the MUDEMIMP code for each component has been summarized in Tables 2 through 6. The probability density functions to be used for mass, velocity, angle, drag coefficient, and drag area factor, along with other varying input are listed in Table 7. Reference 5 or 6 must be referenced for the input file format. The code results for maximum range and maximum cumulative hazardous distance are summarized in Table 8.

Table 7. Additional Input for the MUDEMIMP Code

Surface	Description	Mass (both cases)	Velocity (both cases)	Angle (both cases)	Drag Coefficient (both cases)	Drag Area Factor (both cases)	Initial Height, Y (ft)		Density (lb/ft^3)	Breakup Parameter (both cases)	Charact. Length (ft) (both cases)
							Case 1	Case 2			
1	12 ft x 20 ft clay tile wall	Exponent	Normal	Normal	Constant	Constant	2	4	120	2	0.0625
2-4	12 ft x 20 ft reinforced concrete walls	Exponent	Normal	Normal	Uniform	Constant	2	4	150	3	1
5	20 ft x 20 ft metal roof	Uniform	Normal	Normal	Constant	Constant	12	12	490	2	0.004
7	steel door	Constant	Constant	Constant	Constant	Constant	2	4	33	2	0.17

Table 8. Predicted Hazardous Debris Distance

Surface	Description	Maximum Range (ft)		Cumulative Hazardous Distance (ft)		Cumulative Hazardous Distance x 1.3 (ft)	
		Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	12 ft x 20 ft clay tile wall	770	479	761	479	989	623
2-4	12 ft x 20 ft reinforced concrete walls	132	76	131	74	170	96
5	20 ft x 20 ft metal roof	221	220	50	50	--	--
7	steel door	1011	696	--	--	--	--

A couple of items should be noted concerning the results displayed in Table 8 before discussing the implications of the results. Three distances are recorded for each component for both Case 1 and 2. The maximum distance is the maximum distance any single debris piece is expected to travel following an accidental detonation in the example building. The cumulative hazardous distance is the maximum distance at which to expect more than one hazardous debris per 600 square feet, where a hazardous debris is defined as one having kinetic energy upon impact equal to or greater than an input critical kinetic energy. Since DoD 6055.9-STD defines this critical kinetic energy as 58 ft-lbs, this is the value used as input in the MUDEMIMP code. The density in any particular direction is determined by counting the number of debris landing or passing through an area defined by a trapezoid with one base and height equal to the destroyed width of the component facing that direction. The third column shows the cumulative hazardous distance multiplied by a 1.3 safety factor. This factor is only applied to reinforced concrete or unreinforced masonry debris, such as the clay tile wall debris. The factor is applied to assure a 95% confidence level in the conservatism of the final predicted debris distance. It was derived using statistical analysis on the validation test data during model refinement. The factor accounts for scatter between the test data and curve fits, and the expected variation between accidents.

Step 9: *Make a siting recommendation based on the results for each direction from the structure.*

The default inhabited building distance separation for protection from hazardous debris for a 50 lb charge is 670 ft, as defined by DoD 6055.9-STD. For an actual building, one would conduct an analysis using the DISPRE model in order to possibly reduce this default distance to prove that an existing separation distance is safe or to save distance in siting a new facility. The analyst must examine the debris in each direction. The number of hazardous debris in any given direction will be the graphical sum of the number of hazardous debris from the wall components (and associated doors, windows, etc.) facing that direction and half the roof hazardous debris. The roof debris are generally distributed equally in four directions if the roof is flat, but the model can only distribute the debris in two dimensions. Thus, half the roof debris are used since potentially half these debris could contribute to the hazard in a particular direction.

One exception to the use of the cumulative hazardous debris distance in obtaining a graphical sum is the analysis of a building containing components constructed with steel beams or joists, or one including doors. The maximum debris distance predicted when making single debris runs with the MUDEMIMP code for these components should be compared to the hazardous debris distance predicted for other debris in a given direction. The greater distance of cumulative hazardous debris distance or maximum beam or door distance should set the siting distance in each direction.

The siting distance in the three directions out from the three reinforced concrete walls will be equal, so only two siting distances must be determined for this example -- one distance out from the clay tile wall and one distance out from any of the reinforced concrete walls. The example building/charge configurations analyzed for this paper were chosen mainly to illustrate the difference in debris dispersion for different charge locations within the same building, but the analysis also demonstrates some of the limits of the model and the conservatism built into the predicted results.

First, one should note the significant decrease in both the maximum range and cumulative hazardous debris distance for Case 2, with the charge fixed on a piece of equipment centered in the building. An analyst should always select the charge location producing the worst possible load, but considerable thought should be taken to make certain the location is a plausible one. If the charge will never equal the full maximum limit in one location, then the building should not be analyzed for that situation. Also, if the charge is only processed in a fixed location (such as assumed for Case 2 of this example), and the probability of accidental detonation in transit to that location is extremely small, no other location should be considered in the analysis.

For Case 1, with the charge located anywhere in the defined HE area, the maximum cumulative hazardous distance for the clay tile debris is 761 ft. The maximum range traveled by any of the roof debris is 221 ft, so the roof debris do not increase the hazardous debris distance of the wall debris in the direction of the clay tile wall. Applying the 1.3 safety factor for concrete and masonry debris, the siting distance based on wall debris would be 989 ft. However, the door travels 1011 ft, so the calculated siting distance would be 1011 ft unless a maze or some type of barricade is constructed to stop the door. Presuming some measure would be taken to eliminate the door hazard, the predicted distance for clay tile wall debris still exceeds the default criteria of 670 ft. The default distance of 670 ft from DoD 6055.9-STD can be used if the distance predicted by the model exceeds 670 ft. No distance reduction is achieved for this direction, but distance is saved in the other three directions.

The cumulative hazardous debris distance from the reinforced concrete debris is 131 ft, which converts to 170 ft when the 1.3 safety factor is applied. Although the cumulative hazardous debris distance for the roof debris is 50 ft, the maximum distance traveled by the roof debris is 221 ft. The maximum debris range of concrete wall debris is (132 ft)(1.3) = 172 ft. The roof debris landing in or passing through the area up to 172 ft will contribute to the hazardous debris density. However, the roof debris traveling past 172 ft do not result in cumulative densities greater than one per 600 square feet. Thus, the debris safe siting distance in the directions out from the concrete walls is 172 ft, which is a significant reduction from the default distance of 670 ft for these directions.

For Case 2, with the charge fixed in the center of the building, the maximum cumulative hazardous debris distance for the clay tile wall debris is 479 ft. Applying the 1.3 safety factor, this distance is converted to 623 ft. The maximum range traveled by any roof debris is 220 ft, so the roof debris do not increase the hazardous debris distance of the wall debris. However, the door travels 696 ft in this direction, so a maze or barricade should be designed to stop the door from setting the siting distance. If the door can be stopped in this fashion, the safe debris siting distance in the direction of the clay tile front wall is 623 ft. Although this distance is not much less than the default distance of 670 ft, the separation distances in the other three directions can be even more significantly reduced than for Case 1.

The cumulative hazardous debris distance for reinforced concrete debris is (74 ft)(1.3) = 96 ft. The maximum distance traveled by concrete debris is (76 ft)(1.3) = 99 ft. The maximum cumulative hazardous distance of roof debris is 50 ft, but the maximum range of roof debris is 220 ft. The combination of roof and concrete wall debris would result in a cumulative hazardous distance of 99 ft, since some of the roof debris traveling past 50 ft could contribute to the hazardous debris density between 50 and 99 ft. Beyond 99 ft, there are only roof debris, and these debris do not result in hazardous densities. Thus, the safe debris siting distance out from any of the three reinforced concrete walls is 99 ft, a large reduction from the default distance of 670 ft.

In summary, the DISPRE model could be used to significantly reduce the separation distance between the example explosives processing building and adjacent inhabited buildings in three directions for either proposed charge location, especially for the centered charge location in Case 2. No reduction is gained for the fourth direction out from the clay tile wall. However, if this were an actual building, the clay tile wall may have been included as a "blow-out" wall intended to vent the building following an accident, along with the light metal roof. Clay tile may not usually be considered frangible, but when used with three reinforced concrete walls, it has much less weight per unit area and, thus, can help vent the explosion products. If the wall is intended to vent, the building would be placed in a location such that the debris from this wall would not be thrown toward any other buildings or personnel in the complex.

5.0 Future Improvements in the Model

The DISPRE model has been used to analyze numerous buildings since the DDESB approval of the model in November 1990. In many instances, significant savings have been achieved by allowing reductions in building separation distances, without compromising safety of personnel or processing capability of a plant. The model has indeed been proven to be a useful siting tool. However, as with many empirically based models, DISPRE can and should be further refined. The model has been proven to provide conservative results for the reinforced concrete and masonry components on which the validation tests concentrated. It now needs to be exercised for more situations, including varied charge locations, components made of other common materials, and buried structures. Also, current limits of the model for charge weight and debris velocity are 250 lb of TNT equivalent explosives material and 1000 ft/sec, respectively. One exception to the velocity limit is in the analysis of metal panel components. The breakup of these components for explosive quantities less than 250 lb can result in velocities greater than 1000 ft/sec, so only the explosive quantity limit of 250 lb applies to metal panel components. More tests could be conducted in an effort to raise both the explosive quantity limit and the constraint on debris velocity. The analysis of structures used for explosives material storage typically requires consideration of explosive amounts in excess of 250 lb.

Additional tests and analysis need to be conducted for corrugated metal panel surfaces and other lightweight components since the model bases its current analysis of these components on two validation tests and data collected from limited accident data bases. No recommendations have been included, for instance, on analyzing wood walls, yet several situations have arisen in which an analyst needed to predict debris throw from this type of wall. The effects of close-in and far-range loading on lightweight components need to be studied in much more detail, as the loading has been shown to greatly affect the manner in which these components fail and the size of the resultant debris.

Another key area of additional analysis should be a more detailed study of the 1.3 safety factor. This factor was developed based on a statistical analysis of the ratio of predicted maximum debris distance to measured maximum debris distance for 22 reinforced concrete and unreinforced masonry tests. Of these 22 tests, 8 maximum distances were underpredicted (resulted in a ratio less than 1.0). A safety factor of 1.3 applied to each of the 8 data points was statistically examined. The distance ratios were fit to a Weibull distribution to determine the certainty with which the model will produce conservative results. However, the 14 tests for which distances were conservatively predicted were not included in the distribution. The results of the analysis were that one could be

95% confident that only 11.6% of the predicted maximum distance values would be less than the corresponding actual distance values. A safety factor less than 1.3 may produce an acceptable confidence level if a more detailed statistical analysis is conducted.

The prediction of debris roll in the model should be expanded to include roll for higher velocities since the limit of the data used to derive the roll was about 120 ft/sec. In addition, the roll of debris of material types other than reinforced concrete and masonry needs to be examined with tests and analysis. In the DISPRE validation test program (Reference 6), roll was observed for metal panel debris, for instance, but the metal panel tests did not provide enough data to formulate a separate roll equation for these debris. Use of the masonry debris roll equations for metal panel and other lightweight components does produce conservative final distance predictions, but the predictions may be overly conservative in many instances. The roll equations for masonry have been used to predict final distance for data from accidents and other tests as well. These predictions also appear to be quite conservative. Further data specifically on roll of debris made of other common materials need to be obtained through controlled testing.

Although the DISPRE model has specific usage limits based on the verification data for parameters such as explosive quantity, initial debris velocity, and debris material type, it is, in many cases, the only methodology available and is extrapolated to cover situations outside the limits. Any extrapolation of DISPRE or modification to the step-by-step method must currently be done using good engineering judgment and with appropriate caution. For example, if accurate input distributions for fragment launch/flight parameters can be defined for primary fragments or equipment pieces, the MUDEMIMP code can be used to determine the trajectories and cumulative densities for these fragments as well as building debris. Some effort has also been devoted recently to establishing loads and trajectories to modify the procedure for use in analyzing buried structures. Since few methods exist for establishing fragment and debris densities with confidence to enable safe siting of buildings, DISPRE is frequently modified to cover situations outside its validation range. For this reason, refinement of the model in any or all of the areas described herein is highly recommended.

References

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4. Huang, L.C.P., "Theory and Computer Program for the Multiple Debris Missile Impact Simulation (MUDEMIMP)," Naval Facilities Engineering Command, Naval Civil Engineering Laboratory, Program No. Y0995-01-003-331, June 1984.

5. "Prediction of Building Debris for Quantity-Distance Siting," Department of Defense Explosives Safety Board Technical Paper No. 13, April 1991.

6. Bowles, P.M., Oswald, C.J., Vargas, L.M., and Baker W.E., "Building Debris Hazard Prediction Model," Final Report for SwRI Project 06-2945, prepared for Bernard Johnson Incorporated under Mason & Hanger -- Silas Mason Co., Inc. Contract H0760103, U.S. Government Contract DE-AC04-76DP-00487, February 1991.

ASSESSMENT OF SECONDARY FRAGMENT THREATS FROM CONVENTIONAL DOD BUILDING CONSTRUCTION

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ABSTRACT

Army installations have to begin to make more efficient use of property. The default DoD 6055.9 minimum inhabited building separation distances required for secondary fragments are often excessive and they are difficult and costly to meet. In order to reduce the separation distance it is required to determine, using approved methods, the separation distance providing a fragment density of less than 1 hazardous fragment per 600 square feet. Until recently a standard approved method was not available. A procedure was developed by Southwest Research Institute for the Department of Energy (DOE) and the Department of Defense Explosive Safety Board (DDESB). This procedure was approved for use by DDESB and is described in Technical Paper No. 13 (TP 13), "Prediction of Building Debris for Quantity-Distance Siting". However, this method is complex and requires experience in fragment analysis and the use of three explosive analysis computer programs. This paper summarizes a study by Huntsville Division, U.S. Army Corps of Engineers for DDESB on a simplification of procedures in TP 13 for typical Army construction types. The procedure is intended for personnel with limited fragment analyses experience.

BACKGROUND

The Army explosive safety and processing community requires easy to use, quick, accurate tools to assess safety hazards resulting from explosions. In the past, Army installations had ample property and could ensure personnel and public safety by providing large separation distances between inhabited buildings and explosive processing and storage facilities. Formerly remote Army installations are now often surrounded by inhabited private property. Efficient use of available property is required and desired while maintaining personnel safety. The recent events in Henderson, Nevada have illustrated that neglecting safety is costly in both lives and money. It is therefore necessary that a more accurate and relative determination of threats to personnel safety from accidental explosions be used.

There has been accepted methodology established for determination of the hazards posed by overpressure and primary fragments. There was not a consistently accepted methodology for analyzing the secondary fragment threats resulting from the breakup of the structural elements of facilities in an explosion.

Department of Defense (DoD) 'Ammunition and Explosives Safety Standards', DoD 6055.9-STD, (Reference 1) establishes uniform safety standards applicable to ammunition and explosives. Reference 1 states that "For populous locations ... where military, civilian employees, dependent and/or public personnel are located, the minimum distance (from the explosion source) shall be that distance at which fragments, including debris from structural elements of the facility or process equipment, shall not exceed a hazardous fragment density of one hazardous fragment per 600 square feet." Reference 1 defines a hazardous fragment as one having an impact energy of 58 ft-lb or greater. If this distance is not known, Reference 1 states "For 100 lbs NEW (net equivalent weight) or less of demolition explosives, thin-cased or low fragmentation ammunition items, bulk high explosives, pyrotechnics, and in-process explosives of Class/Division 1.1, the minimum distance ... shall be 670 ft." . Reference 1 further states that "For all types of Class/Division 1.1 in quantities of 101 to 30,000 lbs NEW, the minimum distance shall be 1250 ft ...".

The default minimum inhabited building separation distance for secondary fragments (IBD-F) required by Reference 1 are often overly conservative for structural debris. To avoid using the default IBD-F the hazardous fragment distance corresponding to 1 hazardous fragment per 600 square feet (HFD) must be determined. Historically, explosive safety personnel were given little guidance in determining the HFD. Thus, methods varied substantially. In order to provide consistency in analysis, the Department of Defense Explosive Safety Board (DDESB) issued Technical Paper No.13, 'Prediction of Building Debris for Quantity-Distance Siting', (Reference 2). Reference 2 provides an analytical model for determining the hazardous fragment density resulting from building debris. The model was developed by Southwest Research Institute (SwRI) for the Department of Energy (DOE) Safety Office under funding by DOE and DDESB for some common construction types. The model was refined and verified based upon data from testing by SwRI for DOE.

TECHNICAL PAPER NO.13 ANALYTICAL MODEL

Reference 1 provides a methodology with which to determine the hazardous fragment density resulting from building debris. The method involves the use of the three computer programs in addition to hand calculations. The computer programs SHOCK and FRANG, developed by the Navy Civil Engineering Laboratory (NCEL), are used, respectively, to determine the explosive shock and gas pressures on the structural elements. The computer code MUDEMIMP, developed by NCEL and refined by SwRI to reflect test data, is then used to estimate the hazardous fragment density. MUDEMIMP requires as input the average mass based upon construction type, average velocity calculated using the loadings from SHOCK and FRANG, and initial trajectory of the building debris along with appropriate statistical distribution parameters. Through use of a monte-carlo randomization computer routine and statistics, MUDEMIMP determines trajectory distances for up to 5000 individual fragment weights, velocities, and initial trajectories and predicts a conservative estimate of the debris density.

The fragments are always assumed to eject normal to the surface of the structural element being considered with a standard deviation of between 1.3 and 10 degrees. The horizontal fragment dispersion used by MUDEMIMP is as shown in Figure 1 (from Reference 2). GRIDL is the effective destroyed wall width. MUDEMIMP bases its determination of hazardous fragment densities on an effective destroyed weight of structural element. The number and weight of fragments considered are also based on this effective destroyed weight. Only debris with an impact energy of greater than 58 ft-lbs are considered. MUDEMIMP predicts roll based upon the fragment impact velocity for the fragments with impact angles under 50 degrees. Fragments that have impact angles over 50 degrees are not assumed to roll.

MUDEMIMP produces two output files. 'MIMP.OUT' provides all pertinent information on each of up to 5000 fragment trajectory simulations. 'MIMP.HIS' gives the maximum hazardous fragment distance (MFD) and the critical distance for cumulative risk (HFD). Mimp.his also provides hazardous fragment density (number of fragments per 600 sf) at successive distances from the surface.

This model, while extremely valuable to explosive safety specialists, requires experience in fragment analysis and in the use of the three computer programs. Safety personnel who do not regularly use this analytical model will find it time consuming, frustrating and costly to use. It is therefore desirable to have a simplified procedure for use on common Army building types.

Army Building Debris Study

The purpose of the study by the Corps of Engineers, Huntsville Division, is to provide a simple tool based upon Reference 2 to estimate the hazardous fragment density resulting from structural debris for typical U.S. Army building

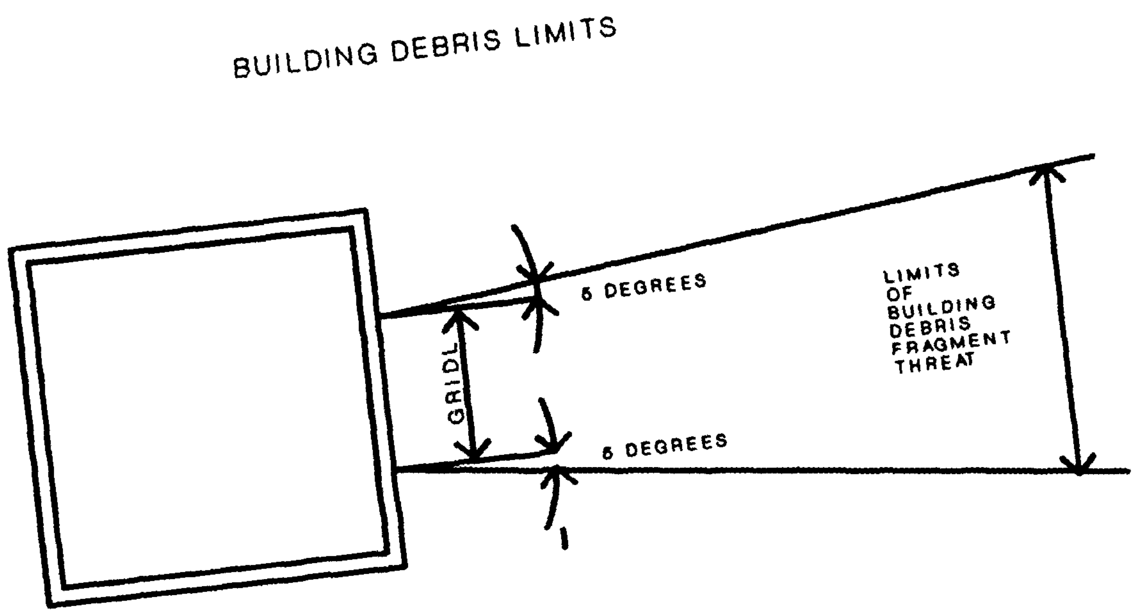
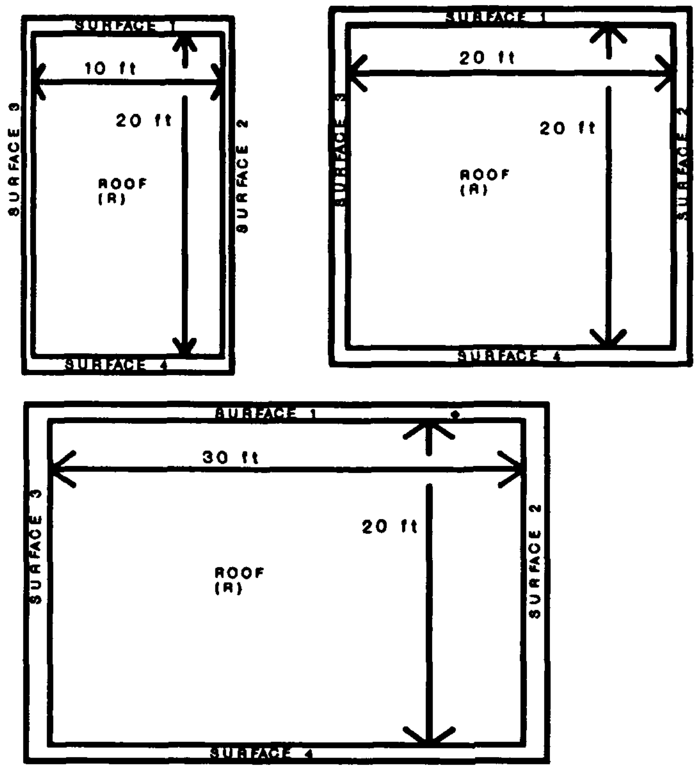


FIGURE 1 - MUDEMIMP BUILDING DEBRIS LIMITS



CONSTRUCTION TYPE

ABRV.	DESCRIPTION	FOR USE ON SURFACES
CSF	CORRUGATEED STEEL PANELS SUPPORTED ON STEEL CHANNELS WITH 1" INSULATION AND 5 PLY FELT AND GRAVEL.	ROOF
CSF	CORRUGATED STEEL PANELS SUPPORTED ON STEEL CHANNELS	1 AND 2
RC	12" THICK REINFORCED CONCRETE WITH #4 BARS @ 12" SPACING IN EACH DIRECTION ON EACH FACE	1,2,3, AND 4
CMU	8" STANDARD CONCRETE MASONRY UNIT	1,2,3, AND 4
SB	8"x12" STRUCTURAL BRICK	1,2,3, AND 4

FIGURE 2 - STUDY PARAMETERS

construction types. The main objective is to provide a method which would require little or no knowledge of the procedures described in reference 2. Therefore, a graphical procedure is being developed based upon the use of a set of graphs depicting hazardous fragment density versus distance for typical construction materials, bay sizes, and venting conditions. The use of the procedure will be described later in this paper.

The study parameters including bay sizes, construction materials, and venting surfaces are shown in Figure 2. Three bay sizes with surfaces 1 and 2 as possible vent surfaces and the roof always as a covered venting surface are considered. The four construction materials considered are as follows:

1 20 gage corrugated metal deck frangible surface (with 1" rigid insulation and 5 ply felt and gravel on roof)
supported on structural steel channels (CSF)

2 12" thick concrete reinforced with #4 bars at 12" spacing each way on each face (RC)

3 unreinforced 8" standard concrete masonry unit (CMU)

4 8"x12" unreinforced structural brick (SB)

The three bay dimensions are as follows:

1 20' long by 10' wide by 20' high

2 20' long by 20' wide by 20' high

3 20' long by 30' wide by 20' high

Fragment analyses based upon Reference 2 will be performed for each bay size, venting condition, and material type for net equivalent explosive weights of 25, 50, and 100 pounds.

The product provided from this study will be a set of 62 graphs of the expected hazardous debris density versus distance from the structural element, the maximum hazardous fragment range (MFD), the maximum critical distance for cumulative risk (HFD), and the zero hazardous fragment density distance (ZFD). A sample graph as will be presented in the final study report is shown in Figure 3.

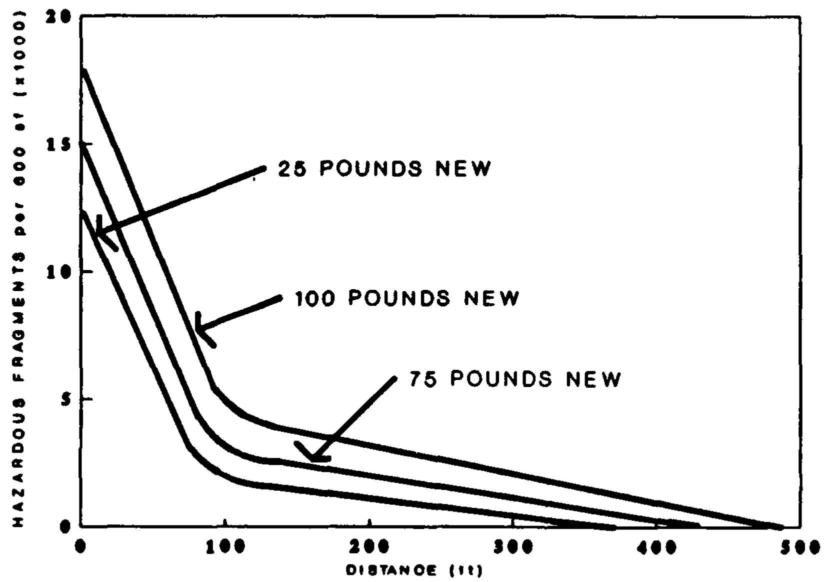
EXAMPLE

As an example to illustrate how the information provided within the study can be used, a situation as shown in Figure 4 is

ARMY BUILDING DEBRIS STUDY

GRAPH 34

FOR EXAMPLE ONLY



25 POUNDS NEW

MAXIMUM PREDICTED DISTANCE - 360 ft

MAXIMUM PREDICTED CRITICAL DITANCE FOR CUMULATIVE RISK (HFD) - 345 ft

ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE - 370 ft

50 POUNDS NEW

MAXIMUM PREDICTED DISTANCE - 430 ft

MAXIMUM PREDICTED CRITICAL DITANCE FOR CUMULATIVE RISK (HFD) - 415 ft

ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE - 440 ft

100 POUNDS NEW

MAXIMUM PREDICTED DISTANCE - 480 ft

MAXIMUM PREDICTED CRITICAL DITANCE FOR CUMULATIVE RISK (HFD) - 465 ft

ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE - 490 ft

FIGURE 3 - SAMPLE STUDY GRAPH (NOT FOR USE - EXAMPLE)

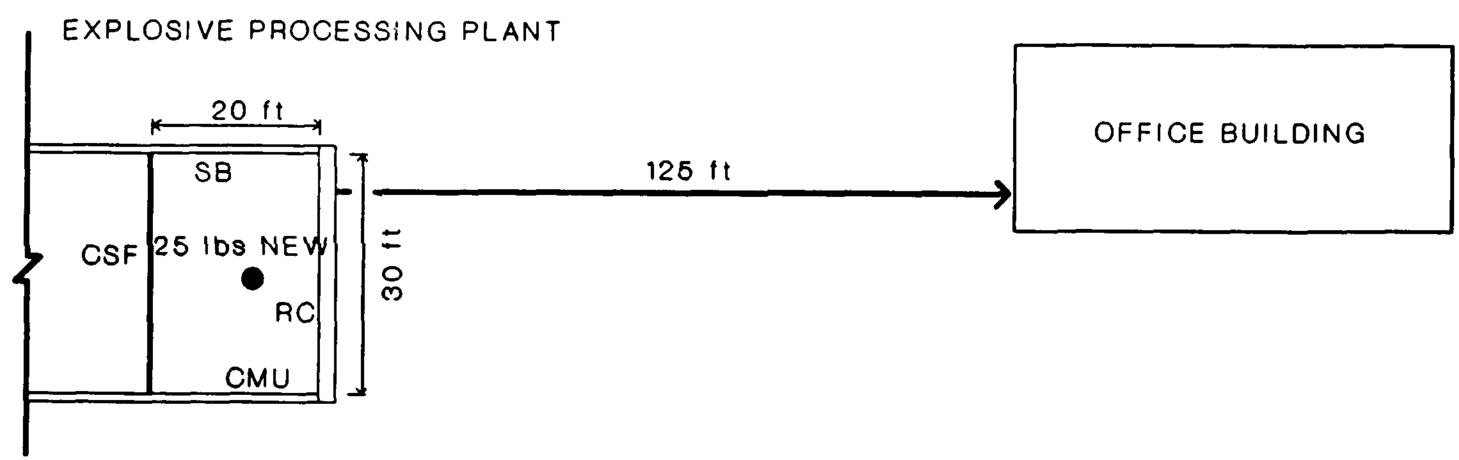


FIGURE 4 - EXAMPLE CONFIGURATION

considered. There is a explosive processing plant with an end bay having a 12" concrete thick back wall, masonry side walls and frangible metal deck front wall and roof. The end bay has interior dimensions of 30 feet wide by 20 feet long by 20 feet high. There is 25 pounds net equivalent weight of explosive in the end bay. An office building is located 125 feet from plant. The default IBD-F required by Reference 1 is 670 feet. The hazard to personnel in the office building resulting from an accidental explosion in the plant's end bay must be determined.

The first step is to determine which surfaces contribute to the secondary fragmentation hazard at the office building. Figure 5 shows the limits of fragment scatter for each surface. It can be seen that only building debris from the concrete back wall and the metal roof deck need be considered for determining the hazardous fragment density at the office building. From figure 2, it is noted that the back concrete wall of the end bay corresponds to surface 4.

The next step is to select the graphs which will be used in determining the aggregate fragment hazard. The graph selection chart (Figure 6) is used to determine which graphs are to be used for the situation in question. Therefore, graph 27 (Figure 7) for the back wall (surface 4) and graph 29 (Figure 8) for the roof (surface R) are selected for venting through surfaces 1 and roof and a bay size of 20 ft by 30 ft by 20 ft.

With the appropriate graphs selected, the values of MFD, HFD, and ZFD should be looked at for both surfaces. If the siting distance is less than either of the two surface's HFD values, the siting does not meet the requirements of Reference 1 since the hazardous fragment density will exceed 1 fragment per 600 square feet. Figure 8 states that the MFD for the roof fragments is 144.2 feet, the HFD is 57.96 feet, and the ZFD is 161 feet. From Figure 7 for the back wall, the MFD is 124.94 feet, the HFD is 119.30 feet, and the ZFD is 128 feet. For this example, the siting distance of 125 feet exceeds the HFD values for both back wall and the roof. The hazardous fragment density for each surface must be determined. The hazardous fragment density can be determined in two ways. First, a direct interpolation between the HFD and ZFD (Equation 1) for a distance of 125 feet can be used.

$$1 - ((1/(ZFD - HFD)) \times (125 - HFD)) \qquad \text{EQUATION 1}$$

Equation 1 can produce an overly conservative number if the difference between the HFD and ZFD is large (more than a 30% difference). Second, the values can be read off of the graph if the level of accuracy can be assured. In most cases the concrete or masonry wall element hazardous fragment density is determined by the interpolation method and the hazardous fragment density

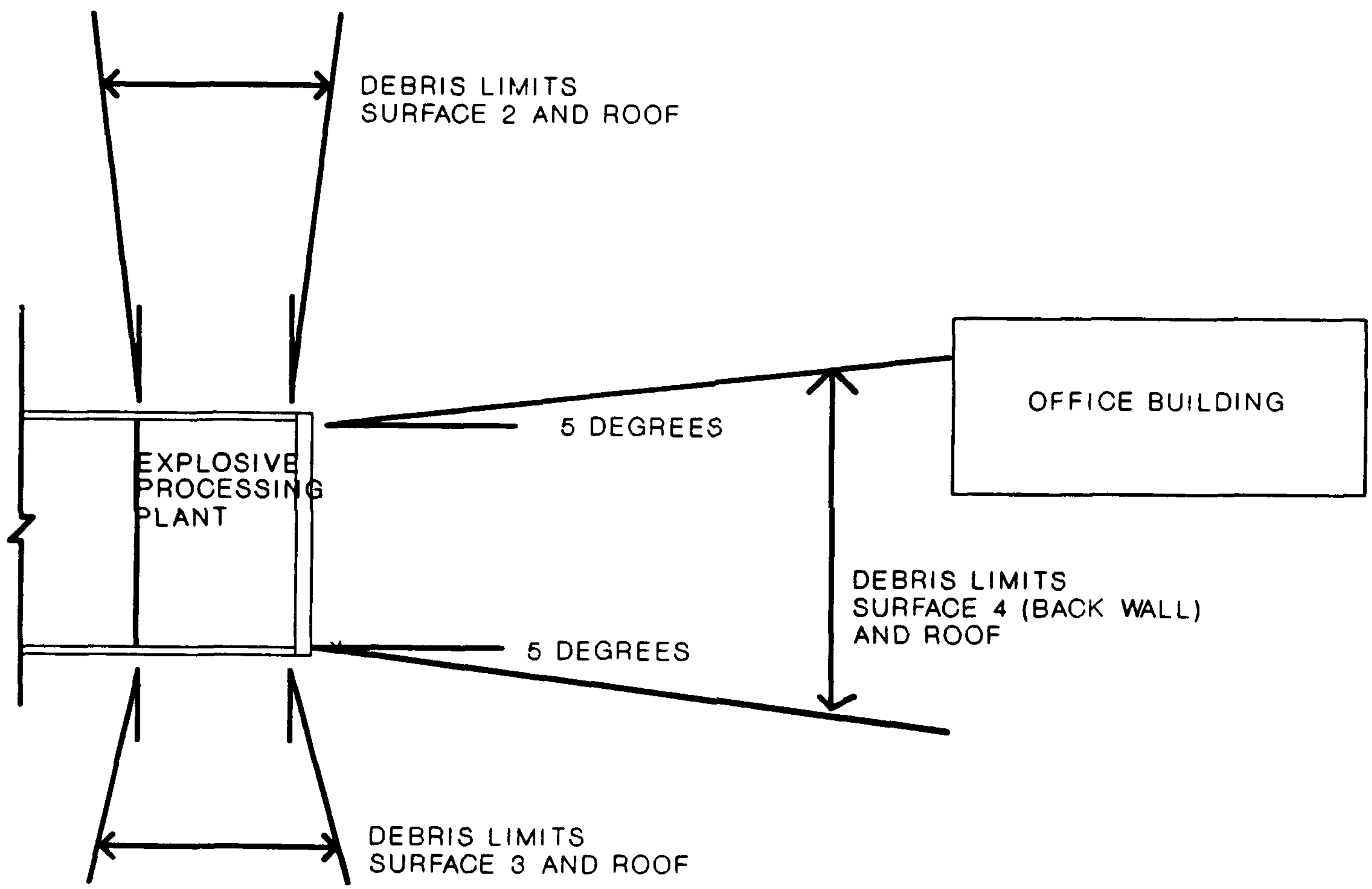


FIGURE 5 - EXAMPLE DEBRIS LIMITS

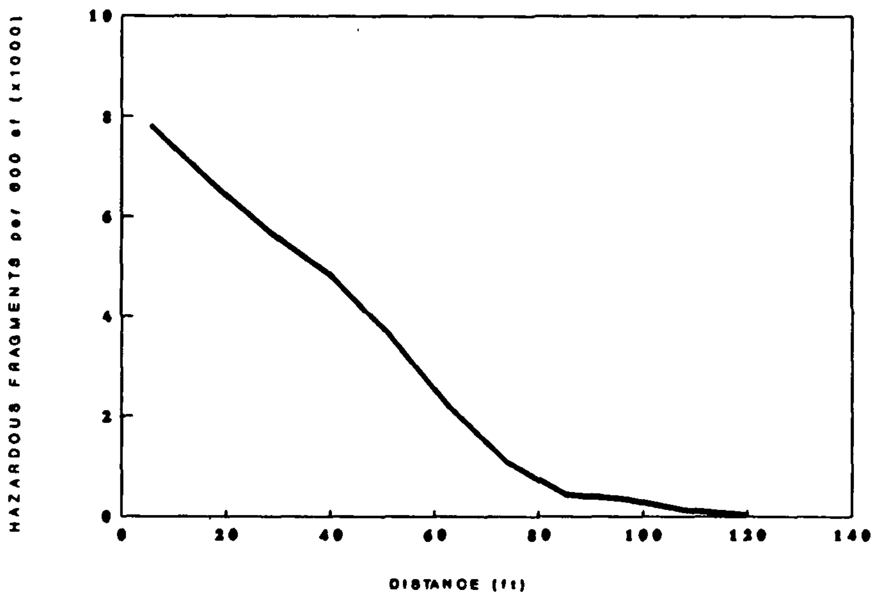
ARMY BUILDING DEBRIS GRAPHS SELECTION CHART

VENT SURFACE(S)	BAY SIZE L x W x H	SURFACE 1 CONSTRUCTION CSF	SURFACE 1 CONSTRUCTION RC	SURFACE 1 CONSTRUCTION CMU	SURFACE 1 CONSTRUCTION SB	SURFACE 2 CONSTRUCTION CSF	SURFACE 2 CONSTRUCTION RC	SURFACE 2 CONSTRUCTION CMU	SURFACE 2 CONSTRUCTION SB	SURFACE 3 CONSTRUCTION CSF	SURFACE 3 CONSTRUCTION RC	SURFACE 3 CONSTRUCTION CMU	SURFACE 3 CONSTRUCTION SB	SURFACE 4 CONSTRUCTION CSF	SURFACE 4 CONSTRUCTION RC	SURFACE 4 CONSTRUCTION CMU	SURFACE 4 CONSTRUCTION SB	SURFACE R CSF
R	20'x10'x20'		1	9	14		2	10	15		2	10	15		1	9	14	3
	20'x20'x20'		4	11	16		4	11	16		4	11	16		4	11	16	5
	20'x30'x20'		6	12	17		7	13	18		7	13	18		6	12	17	8
R,1	20'x10'x20'	19					21	31	36		21	31	36		20	30	35	22
	20'x20'x20'	23					24	32	37		24	32	37		24	32	37	25
	20'x30'x20'	26					28	34	39		28	34	39		27	33	38	29
R,1,2	20'x10'x20'	40				42					43	54	59		41	53	58	44
	20'x20'x20'	45				45					46	55	60		46	55	60	47
	20'x30'x20'	48				48					51	57	62		49	56	61	52

FIGURE 6 - GRAPH SELECTION CHART

ARMY BUILDING DEBRIS STUDY

GRAPH 27 - 25 lbs NEW



MAXIMUM PREDICTED DISTANCE (MFD) = 124.94 ft

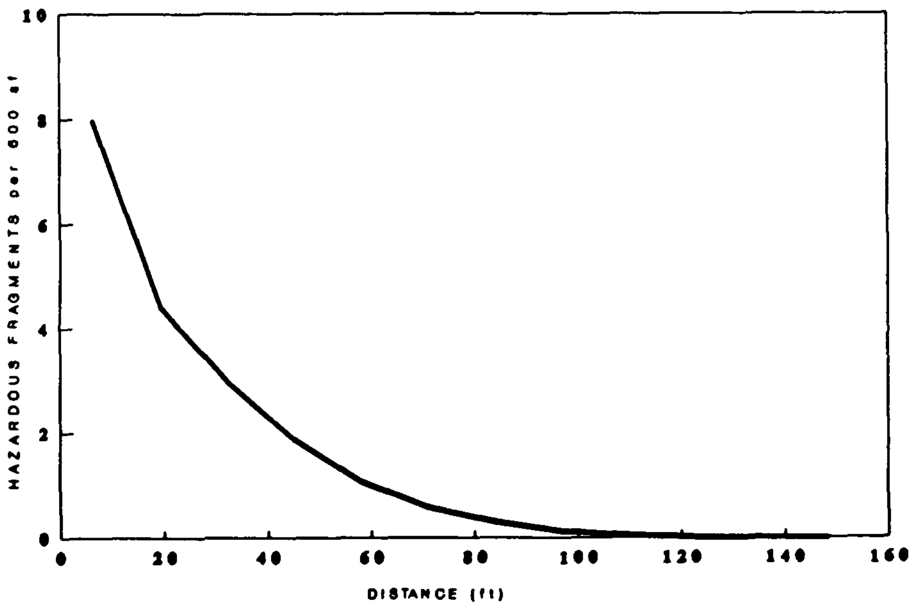
MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) = 119.30 ft

ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE (ZFD) = 128 ft

FIGURE 7 - FRAGMENT DENSITY GRAPH FOR BACK WALL

ARMY BUILDING DEBRIS STUDY

GRAPH 29 - 25 lbs NEW



MAXIMUM PREDICTED DISTANCE (MFD) = 144.2 ft
MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) = 57.96 ft
ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE (ZFD) = 161 ft

FIGURE 8 - FRAGMENT DENSITY GRAPH FOR ROOF

for the frangible metal decking surfaces are read directly off of the graph. Using Equation 1 for the wall a value is .35 hazardous fragments per 600 square feet is determined. Since the ZFD is much larger than the HFD, a direct interpolation between the two values would be unacceptable for the roof. Reading the graph on Figure 8 for a distance of 125 feet the hazardous fragment density for the roof is approximately .015 hazardous fragments per 600 square feet.

The aggregate (added) hazardous fragment density for the wall and the roof fragments is approximately .365 hazardous fragments per 600 square feet. The required IBD-F based upon 1 hazardous fragment per 600 square feet would be approximately 120 feet.

Reference 1 requires an inhabited building separation distance for overpressure (IBD-P) of K40 ($40W^{1/3}$). For 25 pounds NEW this is equal to 117 feet. As previously stated, the default IBD-F between the explosive processing plant and the office building is 670 feet. However, since the hazardous fragment density at 125 feet from the process facility is under 1 hazardous fragment per 600 square feet, and IBD-P is less than 125 feet, the siting meets the requirements of Reference 1. Other factors that must be considered before final safety approval include hazards resulting from any primary fragments.

CONCLUSION

The study of Army building debris for DDESB is at approximately 60% stage of completion with a completion date of 30 September 1992. This study will provide a guide for determining the hazardous fragment density resulting from building debris of typical Army construction. The study will be usable by personnel with limited fragmentation analysis experience. As shown in the example, the required inhabited building separation distance (IBD-F) was reduced from 670 feet to approximately 120 feet. The use of the procedure developed in the study will enable efficient use of property by reducing the required separation distance for secondary fragments from the default Reference 1 values while maintaining personnel safety.

REFERENCES

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

2. Structures To Resist the Effects of Accidental Explosions, TM 5-1300, NAVFAC P-397, AFR 88-22, Revision 1 November 1990

25th DoD Explosive Safety Seminar
Anaheim, California
18-20 August 1992

COMPARISON OF DEBRIS TRAJECTORY MODELS FOR EXPLOSIVE SAFETY HAZARD ANALYSIS

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INTRODUCTION

Robust prediction of the motion of debris from explosions is critical to the estimation of separation distances, fragment density, and debris lethality in explosive safety hazard analysis. Debris dispersion models have been developed and applied to many specific types of hazardous debris (ranging from masonry, concrete, structural steel elements, soil and rock ejecta, to bomb fragments). These models generally use 2-D (degree-of-freedom) or 3-DOF trajectory calculations and consider only the drag component of the aerodynamic force vector (*e.g.*, DOE/TIC-11268 [1980], Huang [1984], McCleskey [1988], Bowles and Oswald [1990]). For many debris geometries (such as plates, slender fragments, and structural elements with high slenderness ratios), drag component trajectory models underpredict maximum debris range and dispersion. In addition, if the potential for spin-stabilized motion exists, the safety distance for plate or disk shape fragments can significantly exceed that which would be predicted for random tumbling or other non-spin-stabilized motion [Twisdale, 1984].

This paper presents several topics related to explosive safety hazardous debris trajectory analysis. The scope of the paper is limited to free-flight trajectory analysis and does not include debris ricochet or ground roll models. Following a review of alternative trajectory models, key features of the random orientation (RO) 6-D model are summarized. The RO 6-D model uses drag, lift, and side force components and randomly updates the rigid body orientation of the missile. It has been implemented in the TORMIS and TURMIS computer codes [Twisdale, *et al.*, 1978, 1979, 1981, 1984] for facility risk assessment from wind-borne debris hazards and for fragments and secondary missiles from exploding equipment. An aerodynamic library from existing databases has been developed for fourteen generic missile/debris shapes (including structural components, plates, chunky fragments, and secondary missiles from internal equipment). An analytically derived random tumbling mode drag coefficient (as a function of the axial and cross-flow coefficients) for cylindrical shapes is summarized for use with 2-D transport predictions of chunky fragments. An equation is also presented that allows an evaluation of whether or not spin-stabilized motion will occur for in-plane rotation of discs and plates. This paper concludes with RO 6-D *vs.* 2-D drag comparisons of free-flight debris range prediction for several secondary debris shapes.

REVIEW OF TRAJECTORY MODELS

Debris transport methodology predicts the free-flight motion of the primary fragments and secondary missiles that are generated by the explosion. A set of initial conditions are required for the trajectory analysis, including: the missile debris mass, geometry, initial translational and angular velocities, ejection angles, and missile inertial orientations.

Given these initial conditions, the transport methodology consists of aerodynamic models of the missile shapes, the governing dynamic and kinematic relations, and the solution scheme for the developed equations of motion. Integration of these equations yields the motion time-history of the missile, which provides the means to predict the free-flight motion, impact conditions and density, lethality, and safety distance.

Table 1 summarizes several basic transport models that are available for explosive safety debris hazard analysis. Trajectory models are most commonly distinguished by the type of motion they describe. Generally, one degree of freedom (1-D) refers to motion of a point along a line; two degree of freedom (2-D), to a point in a plane; three degree of freedom (3-D), to motion of a point in space; and six degree of freedom (6-D), to translational and rotational motion of a rigid body in space. Another distinguishing feature is the number of aerodynamic force components, including moments, that are considered.

The simplest model in Table 1 is the 2-D (2 degree of freedom) model for a particle mass subjected only to the force of gravity. Two ordinary differential equations, which can be integrated in closed form, describe the parabolic motion of the particle within a vertical plane. This model generally is valid only for short distance trajectories within the donor facility to get impact conditions for sympathetic detonations and/or secondary debris generation. The next hierarchy of model sophistication involves the introduction of an aerodynamic drag force in the ballistic 2-D model. The advantage of this model over the no drag model is that it provides much more accurate predictions of motion, impact speed, and position. This model is valid for non-spinning spherical and chunky debris, for which lift and side forces and moments are negligible. The resulting coupled ordinary differential equations are integrated

TABLE 1. SUMMARY OF ALTERNATIVE TRANSPORT MODELS.

	Models				
Features	2-D, No Drag	2-D, Drag	3-D	RO 6-D	6-D
Parameters	g	g	g	g, v	f
Acrodynamic Forces	None	C_D	C_D	C_D, C_L, C_S	$C_D, C_L, C_S, C_l, C_m, C_p$
Equations of Motion[a]	2 ODE	2 Coupled ODE	3 Coupled ODE	3 Coupled ODE 3 Force Eq.	6 Coupled ODE
Simulation Efficiency	Analytic	High	High	Moderate	Low
Impact Speed Prediction[b]	+	~	~	Yes	Yes
Impact Position Prediction[b]	+	-	-	~	Yes
Impact Dispersion	-	-	-	~	Yes
Impact Orientation Prediction[b]	No	No	No	~	Yes
Impact Obliquity Prediction[b]	~	~	~	Yes	Yes
Impact Angular Velocity Prediction[b]	No	No	No	No	Yes

[a] ODE = Ordinary Differential Equations.

[b] ~ = Approximately Correct
- = Tendency to Underestimate
+ = Tendency to Overestimate

numerically to predict debris motion time history. The 3-D model in Table 1 predicts the general motion of a point in space. Its basic parameter is also the drag coefficient, whose value is often specified to account for random tumbling of the object. The 6-D models in Table 1 simulate the aerodynamics of rigid bodies that cannot be adequately treated by the simpler 2-D and 3-D models. The random orientation model (RO 6-D) considers drag, lift, and side forces and simulates missile tumbling by periodic reorientation [Twisdale, 1979]. Its prediction capabilities are enhanced over the particle models with only a modest decrease in simulation efficiency. Conventional 6-D models [Etkin, 1977; Redmann, *et al.*, 1978] track missile translation and rotation using a system of six coupled, ordinary, nonlinear differential equations. Such models require estimation of aerodynamic force and moment coefficients over all body orientations, which are generally not known for arbitrary bluff-body fragments.

RANDOM ORIENTATION MODEL

This section presents the key features of the RO 6-D model for debris dispersion analysis, summarized from Twisdale, *et al.* [1978, 1979, 1981, 1984]. In this model, the actual rigid body orientation of the missile is considered and the aerodynamic specification includes drag, lift, and side force components. Figure 1a shows the inertial reference frame along with other reference frames that will be used in the development of the model.

The missile centerline orientation is specified by two randomly determined angles (ψ, ϕ) measured from a (u, v, w) coordinate system as defined in Figure 1b. The relative velocity vector defines the v direction, while $\hat{u} = (\hat{v} \times \hat{k})/|\hat{v} \times \hat{k}|$ and $\hat{w} = (\hat{u} \times \hat{v})$. Once the missile orientation is established for a time step, wind axis unit vectors are determined by forming the vector cross product of the missile centerline position unit vector ($M\hat{C}L$)

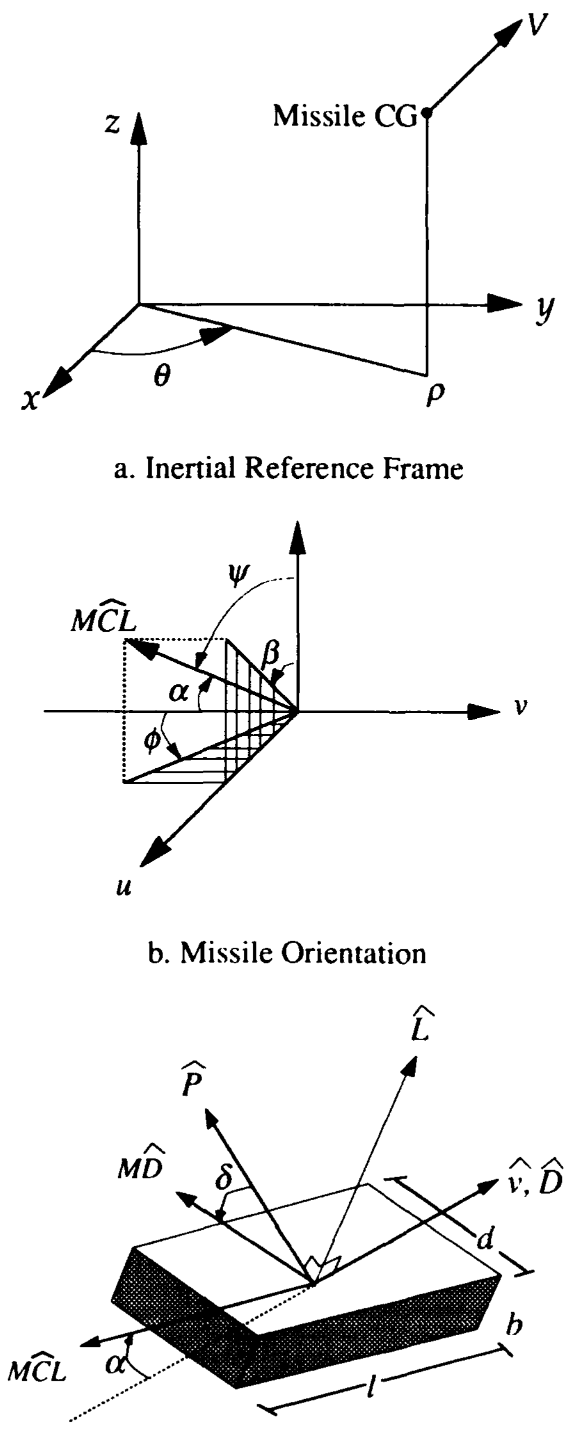


Figure 1. Coordinate Systems and Missile Specification.

with the relative velocity vector ($\hat{\upsilon}$) to establish the pitch axis ($\hat{P}$). The missile diameter unit vector ($M\hat{D}$) is rotated through a randomly selected angle (δ) from the pitch axis. The relative velocity unit vector ($\hat{\upsilon}$) is then combined with the pitch axis ($\hat{P}$) in a vector cross product to establish the lift unit vector ($\hat{L}$). This approach defines the wind axis system ($\hat{\upsilon}$, $\hat{P}$, and $\hat{L}$) for each time step and provides the respective directions for the three aerodynamic force components (drag, lift, and side) properly oriented for the missile attitude.

The magnitudes of the three translational forces are taken as proportional to the square of the relative velocity and to the three aerodynamic coefficients (C_D, C_S, and C_L), which may each be functions of total wind angle of attack (α) and roll angle (δ). These angles (α, δ) are both shown in Figure 1c. The missile angles, and hence vectors $M\hat{C}L$ and $M\hat{D}$, are updated at selected intervals according to

$$\begin{aligned} &\psi = \cos^{-1}(1 - 2\xi_1) && 0 < \psi \leq \pi \\ &\phi = \pi(2\xi_2 - 1) && -\pi \leq \phi < \pi \\ &\alpha = \cos^{-1}(\sin\psi \cos\phi) && 0 < \alpha \leq \pi \\ &\delta = 2\pi\xi_3 && 0 < \delta \leq 2\pi \end{aligned} \quad (1)$$

where ξ_1, ξ_2, and ξ_3 are random numbers selected from a uniform distribution on the unit interval. The time between missile orientation updates is termed the update period, and its reciprocal, update frequency. The angles α and δ are used as input to the aerodynamic coefficient determination. Once the three coefficients are determined, they are combined with the dynamic pressure, reference area (A), and the three appropriate wind axis unit vectors to form the total aerodynamic force for a single time step.

The mass center of the missile is tracked relative to the reference frame, according to the standard dynamic equations of motion. These equations form a set of six coupled, nonlinear, ordinary differential equations that define an initial value problem for a set of prescribed initial conditions. Shampine's method [Shampine and Gordon, 1975] is used to integrate these equations.

MISSILE AERODYNAMICS FOR RO 6-D MODEL

Since complete aerodynamic characteristics generally do not exist for the potentially wide variety of debris shapes, a modified cross-flow theory has been applied to develop the aerodynamic coefficients for the random orientation model. This approach has been successfully used to develop the wind axis aerodynamic forces as a function of angle of attack for slender cylinders knowing only the drag force coefficients for the body in normal flow to the major body axes [Hoerner, 1965].

The basic theory assumes the superposition of two flows perpendicular to the missile axis (axial and cross flow) in which the magnitude of the mutually orthogonal flows is determined vectorally knowing freestream velocity and angle of attack. The aerodynamic forces acting on the missile are parallel to each flow component direction and are proportional to the directional dynamic pressure. For other shapes, flow field similarity in the cross flow regime as the angle of attack changes is the major requirement for the cross flow theory to be applicable. Thus, it is reasonable to consider extension of the theory to sharp-edged debris missiles that force boundary layer separation at a fixed point and, therefore, produce similar potential cross flow fields for all angles of attack. In principle, this concept allows the generation of lift, drag, and side forces for certain sharp-edged planar symmetric sections if the drag coefficients are known for flow normal to the three major faces of each shape. Normal flow coefficients can be found in the literature for a variety of shapes. The final form of the equations includes an aspect ratio (tip loss) correction for finite missile dimensions, and missile face porosity. Table 2 illustrates the form of the equations for a rectangular parallelepiped shape. Figure 2 compares the cross-flow predicted lift coefficients for various roll angles to wind tunnel data for a parallelepiped missile. Summary equations for fourteen basic shapes are given in Twisdale, *et al.* [1981].

RANDOM TUMBLING MODE DRAG COEFFICIENTS

Most debris shapes are not aerodynamically stable and may exhibit autorotation, flat rotation, random tumbling, coning, or other motions during flight. These motions are governed by the initial conditions, the equations of motion, and the resulting aerodynamic and non-aerodynamic forces acting on the missile. Randomizing types of forces may arise from turbulence and non-ideal gas flows, explosive products, and missile interactions, such as debris-debris, debris-structure, and debris-ground impacts. Hence, random tumbling motion drag trajectory coefficients are often used in 2-D and 3-D drag models to predict motion of irregular, bluff body shapes and fragments. Because of the differences in the random tumbling mode (RTM) coefficients presented in the literature (*e.g.*, Bates and Swanson [1967] and Redmann, *et al.* [1976]), a validated equation is summarized herein. Use of RTM coefficients in 2-D or 3-D drag models should be used only to get the approximate center of the impact dispersion pattern and not to estimate the debris dispersion or safety distance.

The expression for the expected value of the drag coefficient, $\bar{C}_d$, of a tumbling missile is

$$\bar{C}_d = \int_0^{2\pi} \int_0^{2\pi} \int_0^{2\pi} C_d(\alpha, \beta, \delta) \, f(\alpha, \beta, \delta) \, d\delta d\beta d\alpha \qquad (2)$$

where α, β, and δ are orientation angles as specified in Figure 1, and $f(\alpha, \beta, \delta)$ is the joint probability density function describing orientation likelihood. For a cylinder of diameter d and length L, cross-flow theory indicates that

$$C_d(\alpha, \beta, \delta) = C_D(\alpha) = C_{Dc} \sin^3 \alpha + \frac{\pi d}{4L} C_{Da} |\cos^3 \alpha| \qquad (3)$$

Assuming uniformly random spatial orientation, $f(\alpha, \beta, \delta) = 1/8\, \pi^2 \sin \alpha$ and the expression for the RTM coefficient is derived as

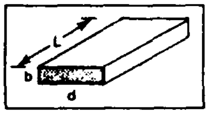
$$\bar{C}_d = \frac{1}{4}\left(\frac{3\pi}{4} C_{Dc} + \frac{\pi d}{4L} C_{Da}\right) \qquad (4)$$

where the subscripts a and c refer to axial and cross-flow directions, respectively. This expression yields a significantly higher expected value than the previously published results of Bates and Swanson [1976] and Redmann, *et al.* [1976]. It is noted that this general formulation agrees with that given by Sentman and Niece [1967]. Trajectories computed using the random orientation model (drag force only) with high update frequencies are shown by Twisdale, *et al.* [1979] to converge exactly to the impact point predicted by 2-D trajectory calculations with $\bar{C}_d$ given by Equation 4.

SPIN-STABILIZED TRAJECTORIES

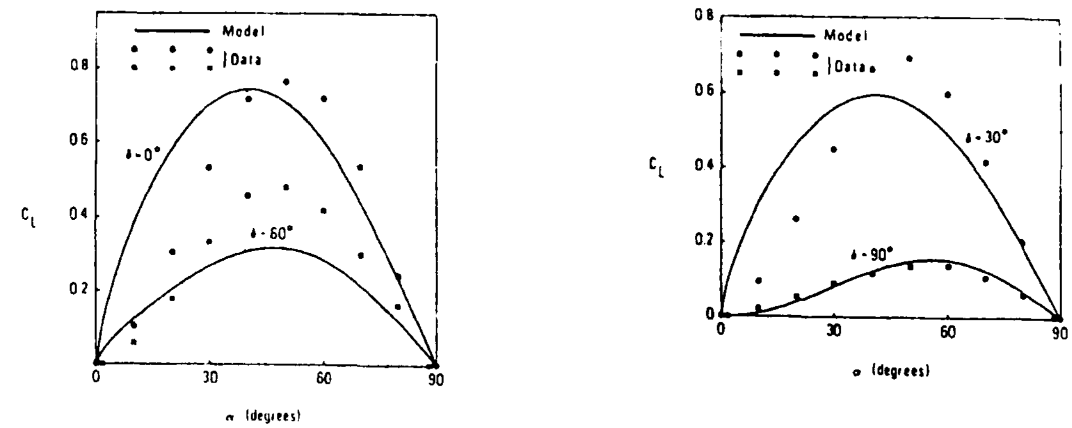
The possibility of spinning flat-plate or disc-shaped fragments has been recognized in the explosive safety literature (*e.g.*, Moseley and Whitney [1980]) in terms of probable maximum debris range. High in-plane spin rates (flat rotation), imparted as a result of the explosion effects or secondary missiles from failed rotating equipment, can lead to lifting forces and significant out-of-plane trajectory motion. When these conditions exist in explosive safety problems, they should be

TABLE 2. CROSS FLOW AERODYNAMICS FOR PARALLELEPIPEDS.

Missile type	Box, beam, plate, frame				
Generic shape	Rectangular parallelepiped				
Subcategories	b/d = 1	b/d = 3	b/d = 4	b/d = 10	b/d = 50
Set nos.	5,6,18,19,20		7,8,9	10,11,21,22,23	12,13
C_{Da}	2.05 Solid 0.82 Frame/ truss	2.05 Solid	2.05 Solid	2.05 Solid 0.82 Frame/ truss	2.05 Solid
C_{Db}	2.05 Solid 0.82 Frame/ truss	2.0 Solid	2.0 Solid	2.0 Solid 0.80 Frame/ truss	2.0 Solid
C_{Dd}	2.05 Solid 0.82 Frame/ truss	1.4 Solid	1.0 Solid	1.075 Solid 0.43 Frame/ truss	1.575 Solid
Skin friction correction, f	$1, L/b < 3$ $0.41 + 0.59e^{-2(L/b-3)}, 3 < L/b < 4$ $0.46 + 0.0061 (L/b), L/b > 4$				
Aspect-ratio correction					
k_a	$0.59 + 0.41e^{-20b/d}$				
k_b	$0.59 + 0.41e^{-20d/L}$				
k_c	$0.59 + 0.41e^{-20b/L}$				
C_D	$(b/L) C_{Da} k_a \|\cos^3\alpha\| + C_{Db} k_b \|\cos\delta \sin\alpha\|^P \|\cos\delta\| \sin\alpha +$ $(b/d) C_{Dd} k_c \|\sin^3\delta\| \sin^3\alpha$				
C_L	$-(b/L) C_{Da} k_a \|\cos\alpha\| \cos\alpha \sin\alpha +$ $C_{Db} k_b \|\cos\delta \sin\alpha\|^P \|\cos\delta\| \cos\alpha +$ $(b/d) C_{Db} k_d \| \sin^3\delta\| \sin^2\alpha \cos\alpha$				
C_S	$C_{Db} k_b \cos\delta\|\cos\delta\|^{P-1} \sin\delta \sin^P\alpha -$ $(b/d) C_{Dd} k_d \sin\delta \|\sin\delta\| \cos\delta \sin^2\alpha$				
P	$0.5 + 0.15 (b/d) + 1.35 (b/d)^2$				
Ref. area, A	dL				

considered since they will influence the safety distance. A procedure to determine if the initial in-plane rotation rate is sufficient to stabilize a plate or disk-shaped fragment is summarized herein from the work of Twisdale, *et al.* [1984].

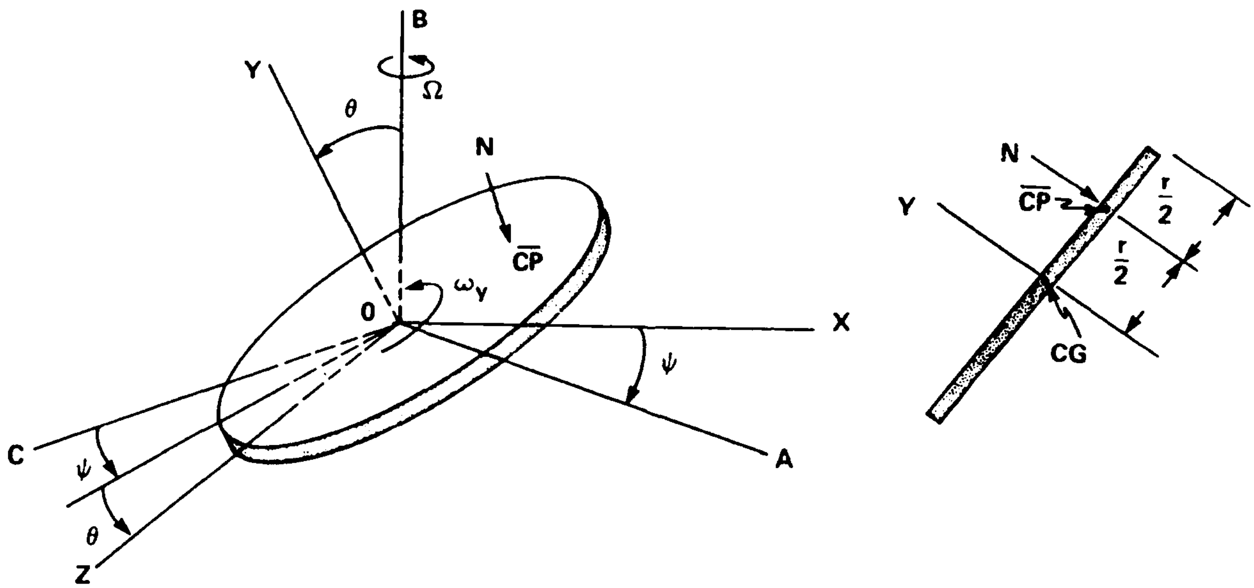
For purposes of developing the governing equations, a circular disc geometry is assumed. Coupling between the resultant aerodynamic force vector and the gyroscopic angular momentum vector will cause the spinning disc to slowly precess about an axis perpendicular to the spin axis. The minimal rotational speed required to maintain this spin stabilized motion and the resulting precessional rate is developed for a symmetric disk rotating about its center of gravity. The disc sector rotates about an axis parallel to the Y-axis and passing through the center of gravity. Referring to Figure 3, let the Y-axis of the rotating reference system lie along the axis of the disk. Let this axis make an angle θ with a fixed vertical axis OB, and let it precess at a rate Ω about OB. The X-axis is in the horizontal plane AOC and is



a. Lift Coefficients for $\delta = 0°, 60°$

b. Lift Coefficients for $\delta = 30°, 90°$

Figure 2. Comparison of Cross Flow Lift Coefficients to Wind Tunnel Data for Parallelepiped.



a. Reference Frame and Notation

b. Aerodynamic Center of Pressure

Figure 3. Conical Precession of a Disc About a Vertical Axis.

perpendicular to both OY and OB. The Z-axis, perpendicular to OY and OX, lies in the vertical plane through OB and OY. Projection of Ω on the three rotating axes thus gives

$$\Omega_x = 0; \quad \Omega_y = \Omega \cos \theta; \quad \Omega_z = \Omega \cos \theta \quad (5)$$

and, since OY coincides with the axis of the disk,

$$\omega_x = \Omega_x = 0; \quad \omega_z = \Omega_z = -\Omega \sin \theta \quad (6)$$

The angular velocity ω_y of the disk about OY is an input value determined by the initial conditions.

Euler's dynamical equations of motion reduce to

$$M_x = \Omega \sin \theta \,(I_y\, \omega_y - I_z\, \Omega \cos \theta); \quad M_y = 0; \quad M_z = 0 \quad (7)$$

where I_y and I_z are the moments of inertia. From Equation 7, the maintenance of the assumed motion requires only a moment about the X-axis. This moment is provided by the aerodynamic force normal to the circular face of the disk acting at the center of pressure, $\overline{CP}$ (Figure 3b). Assuming for the circular disk that the center of pressure is located approximately halfway between the "leading edge" of the disc and its geometric center, the moment due to the aerodynamic forces is estimated by

$$M_x = {}^1/_2\, Nr \quad (8)$$

where N is the aerodynamic force acting normal to the plane of the disc. From Equations 7 and 8, the steady precessional motion maintained by this moment is

$$\Omega = \frac{I_y\, \omega_y \pm \left[I_y^2\, \omega_y^2 - 2Nr\, I_z \cos \theta\right]^{1/2}}{2I_z \cos_\theta} \quad (9)$$

Neglecting the high rate of precession corresponding to the plus sign [Rauscher, 1953], Equation 9 is evaluated from l'Hopital's rule, which leads to

$$\Omega = \frac{Nr}{2I_y\, \omega_y}, \ \theta = \frac{\pi}{2} \quad (10)$$

Since the angle θ will always be less than or equal to $\pi/2$, so that $\cos \theta$ is non-negative, a steady precession (and thus a constant θ) is possible only if the rotational speed of the disk is such that the radical in Equation 9 is non-negative, *i.e.*,

$$\omega_y^* \geq \frac{1}{I_y}\left[2Nr\, I_z \cos \theta\right]^{1/2} \quad (11)$$

Equation 11 suggests that $\omega_y{}^*$ may be as low as zero when θ = 90 *degrees*. However, examination of Equation 10 shows that the rate of precession corresponding to this minimum rate of spin is infinite. Thus, while mathematically there is no minimum ω_y required to spin stabilize the disc at $\theta = \pi/2$, in practice if the product $\Omega I_y \omega_y$ is not sufficient to absorb the moment $^1/_2\, Nr$, the disc will tumble until θ becomes of sufficient magnitude that $\omega_y > \omega_y{}^*$, at which point the disc will become spin stabilized and will then precess at the angular velocity given by Equation 9.

Table 3 summarizes initial angular velocities, ω_y, required to stabilize several circular disk missiles for different angles of attack (α), initial velocities (v_o), and inertial orientations (θ). Three steel disks were selected with weights of 10, 100, and 1000 *lbs*, and radius/thickness ratios of about 10. Solutions are shown for α = 10 and 30 *degrees*, v_o = 100 and 500 *ft/sec*, and θ = 30, 65, and 90 *degrees*. For the smaller disk (A), higher $\omega_y{}^*$ are required to maintain the fixed

TABLE 3. SPIN RATES REQUIRED FOR SPIN-STABILIZED TRAJECTORIES OF CIRCULAR STEEL DISKS.

Initial Conditions			ω_y^* (*rpm*) for Disks A, B, and C		
α (*deg*)	v_O (*ft/sec*)	θ (*deg*)	A wt = 10 *lbs*, r = 4.7 *in* thk = 0.5 *in*	B wt = 100 *lbs*, r = 10.6 *in* thk = 1.0 *in*	C wt = 1000 *lbs*, r = 23.7 *in* thk = 2.0 *in*
10	100	30	54	26	12
		65	38	18	8
		89	8	4	2
	500	30	270	128	60
		65	189	89	42
		89	38	18	9
30	100	30	94	44	21
		65	65	31	15
		89	13	6	3
	500	30	468	221	105
		65	327	155	73
		89	66	31	15

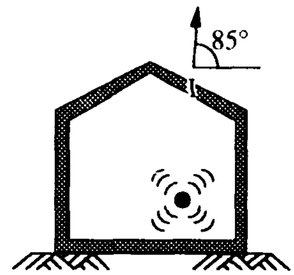
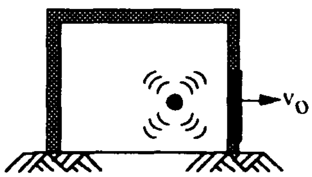
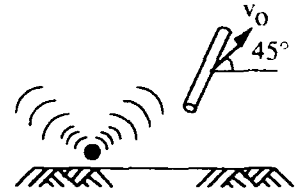
orientation than are required for the heavier disks. For all three disks, minimum spin rates are needed as $\theta \rightarrow 90°$ (horizontally spinning disks). The required spin rates increase significantly as v_O is increased. These example calculations indicate that for low angles of attack, and horizontally oriented disks, less than one revolution per second (60 *rpm*) may stabilize > 10 *lb* disks traveling at less than 500 *ft/sec*. If spin stabilization is possible, trajectory calculations can be made using the RO 6-D model with zero update frequency for fixed inertial orientation flight.

MODEL COMPARISONS AND RESULTS

The random orientation trajectory model has been developed such that it can operate in any of three modes: 3-D constant drag, random orientation with drag force only (random drag), or random orientation, with drag, lift, and side forces (full random). Calculations with the RO 6-D model as presented for the three secondary debris missiles summarized in Table 4. The ejection angles in Table 4 are measured from the horizontal axis.

Steel Joist. In ESB Technical Paper Number 13 [DoD, 1991], the steel joist in Example Problem 1 is estimated to travel a maximum distance of 62 *ft*, based on a MUDEMIMP constant drag calculation. Using the RO 6-D model with drag, lift, and side force components and an update frequency of 2 *hz*, 100 trajectory simulations produce the impact scattergram shown in Figure 4. The initial position of the missile is X = 0, Y = 0, and the horizontal component of v_O points in the positive X direction The range statistics are summarized in Table 5.

TABLE 4. SECONDARY MISSILE DESCRIPTIONS FOR TRAJECTORY COMPARISONS.

Parameters	Missile Description		
	1. Steel Joist 	2. Steel Door 	3. Secondary Fragment 
Weight (*lbs*)	320	117	0.2
d (*in*)	8	36	0.53
L/*d*	20	2.33	6
V_O (*ft*/*sec*)	111	677	985
Ejection Angle (*deg*)	85°	0°	45°
Reference	ESB No. 13 [DoD, 1991] Ex. Problem No. 1	ESB No. 13 [DoD, 1991] Ex. Problem No. 2	Kineke, 1976

The centroid of this scattergram is indicated by the circle. About half the trajectories travel further than the mean, and about 20% exceed the 62 *ft* maximum in ESB No. 13. Random tumbling flight with drag forces only has also been simulated with the RO 6-D model by using an update frequency of 100 *hz*. The predicted impact point is very near the centroid of the data.

Steel Door. The results for the steel door [DoD, 1991] indicate a maximum range of 808 *ft*. The RO 6-D scattergram for 5 *hz* update frequency is shown in Figure 5, and the range-to-first-impact is summarized in Table 5. The RTM-predicted range is 226 *ft* to first impact. These results are sensitive to update frequency with slower updates yielding larger variances in both x and y directions. Higher update frequencies converge to RTM results with minimal variance. Note the cluster of points at about $x = 100$ *ft*. These indicate the position of first impact for initial orientations that result in a net downward aerodynamic force, which would cause a skid or ricochet, followed by an upward rebound of the door.

Secondary Fragment. The steel cylindrical fragment comparisons are given in Figure 6, and the statistics are summarized in Table 5 for an update frequency of 10 *hz*. Similar to the other missiles, the $\mu + 1\sigma$ and $\mu + 2\sigma$ distances significantly exceed the predicted RTM drag range. However, the dispersion pattern is significantly smaller, reflecting the reduced *L*/*d* over the beam missile and the higher update frequency used for this smaller fragment.

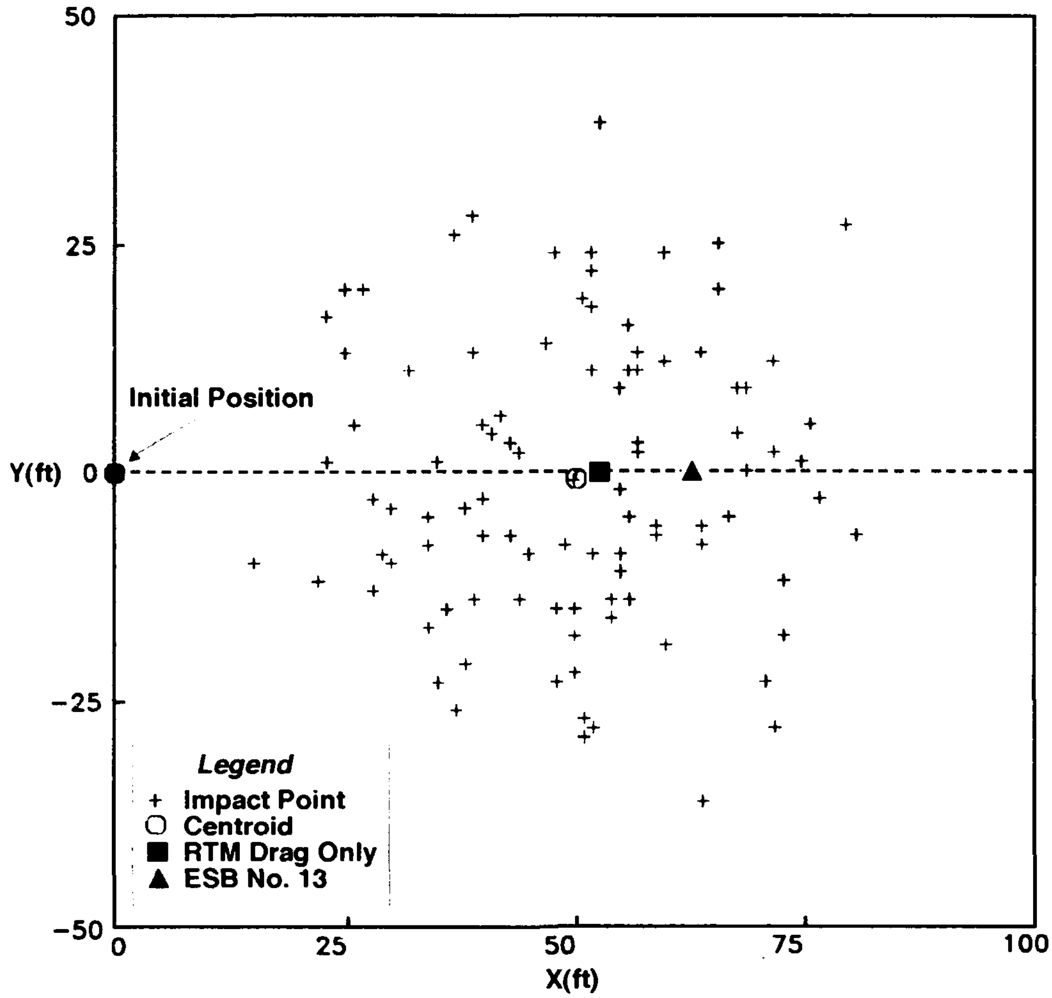


Figure 4. Impact Scattergram for Steel Joist Missile.

TABLE 5. RO 6-D TRANSPORT RANGE STATISTICS.

Missile Type	Update Frequency (hz)	2-D Drag RTM Range (ft)	RO 6-D Range Distance[1]				
			Mean (μ)	St. Dev. (σ)	$\mu + 1\sigma$	$\mu + 2\sigma$	Max
Steel Joist	2	52	52	15	67	82	84
Steel Door	5	226	495	280	775	1055	1083
Steel Fragment	10	1715	1797	121	1918	2039	2252

[1] Based on 100 simulated trajectories.

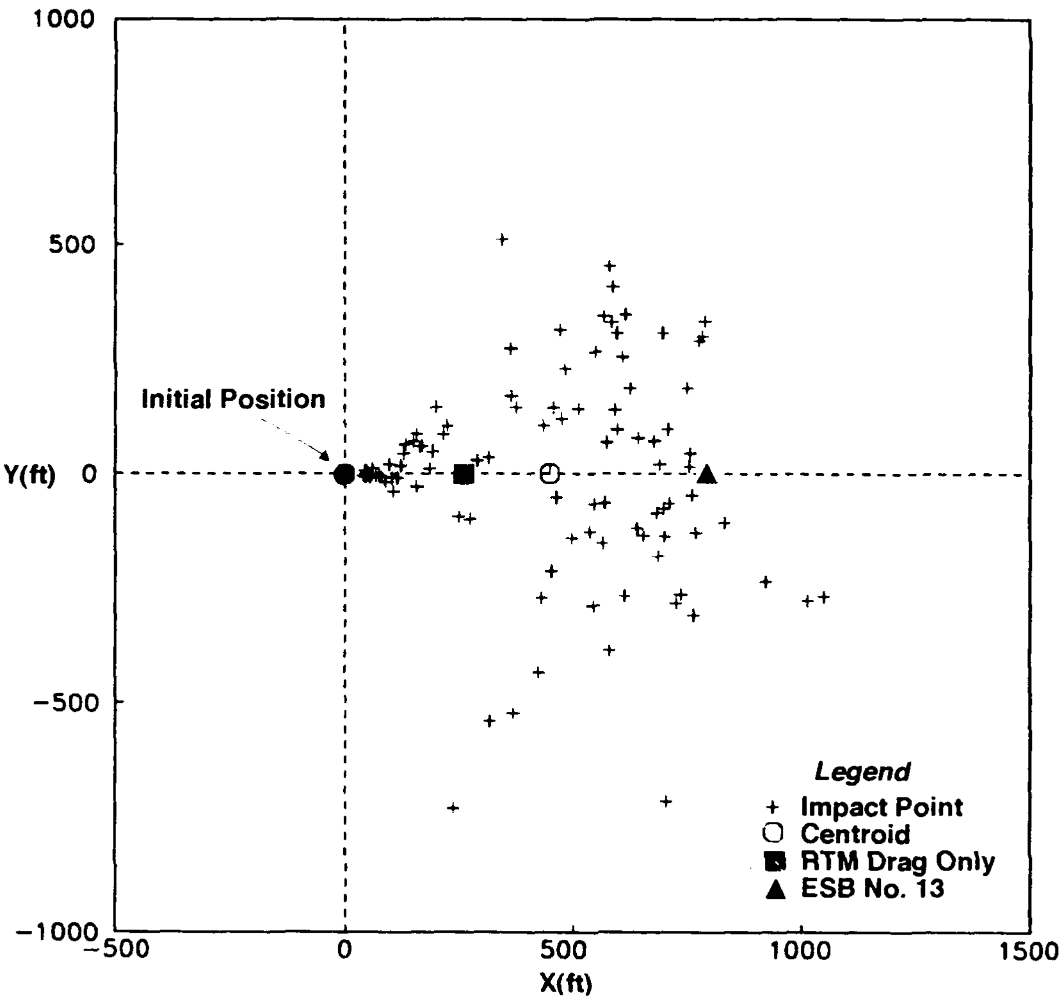


Figure 5. Impact Scattergram for Steel Door Missile.

SUMMARY

For primary fragments and secondary missiles with non-chunky shapes (plates, doors, slender fragments, and structural elements with high slenderness ratios), trajectory models that treat only the drag component of the aerodynamic force underpredict maximum debris range and dispersion. The RO 6-D model, which considers drag, lift, and side force components, provides an efficient alternative model that has been used previously in nuclear power plant missile risk assessment and to recommend debris impact velocities for the DOE NPR program. An aerodynamic library for typical secondary missile shapes has been developed for use with the RO 6-D model. A formula for evaluating spin-stabilized flight potential for disk-shaped fragments is presented and evaluated for several disk sizes and weights.

The trajectory calculations illustrate some basic features of the RO 6-D model and the fact that maximum ranges for hazardous debris density may be underestimated by current prediction methods. The model would easily be validated for explosive safety siting analysis through a series of calculations with a full 6-D model for selected shapes, coupled

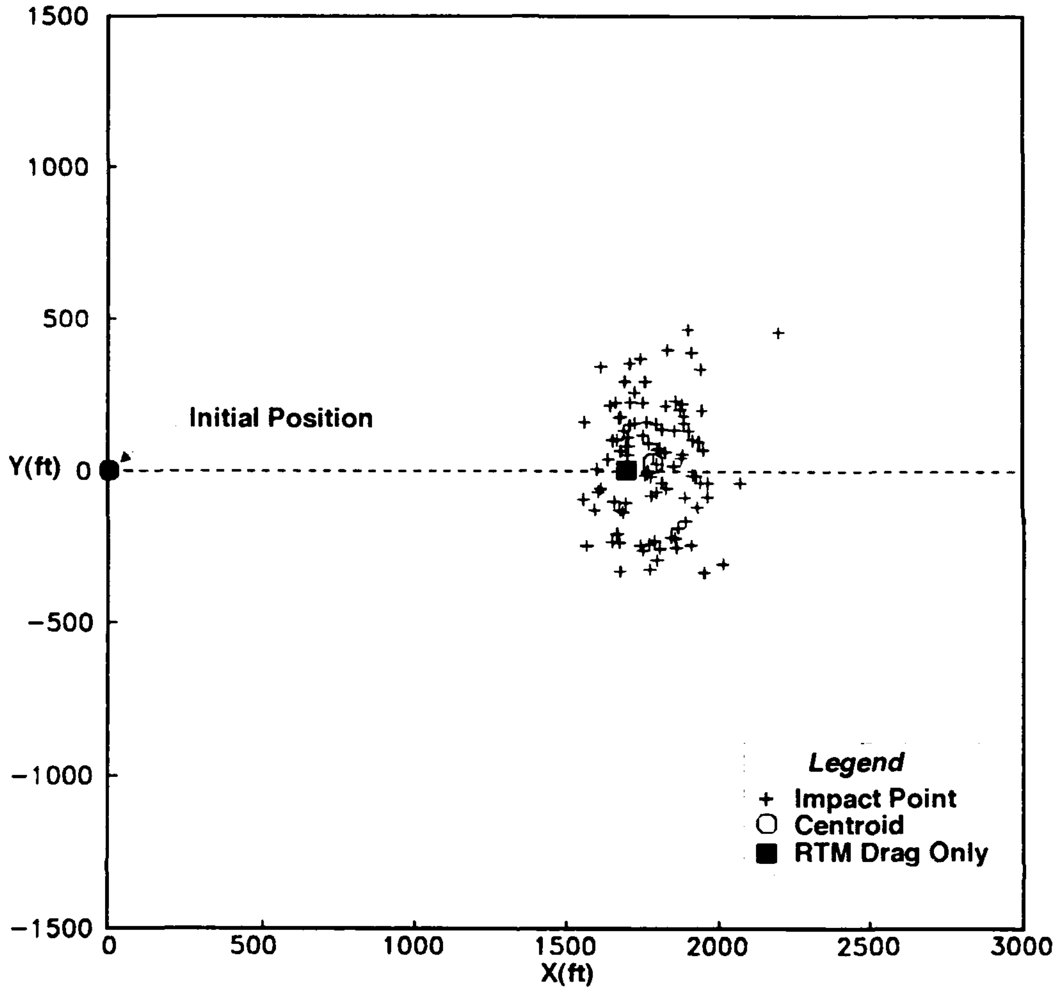


Figure 6. Impact Scattergram for Steel Cylindrical Missile.

with direct statistical analysis and comparisons to Q/D test data. The prediction methodology can efficiently simulate both chunky and non-chunky debris, and it offers several important theoretical advantages over the drag models for non-chunky shapes.

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PRESSURE VESSEL BURST TEST PROGRAM: PROGRESS PAPER NO. 3*

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Abstract

An updated progress report is provided on a program developed to study through test and analysis, the characteristics of blast waves and fragmentation generated by ruptured gas filled pressure vessels. Prior papers on this USAF/NASA/General Physics program were presented to the AIAA in July 1990[1] and June 1991[2].

Ten pressure vessels have been burst using pneumatic pressure. Tests were designed to explore burst characteristics and used an instrumented arena. Data trends for current experiments are presented.

This paper is the third progress report on the program and addresses: 1) a brief review of current methods for assessing vessel safety and burst parameters, 2) a review of pneumatic burst testing operations and testing results, including a comparison to current methods for burst assessment and 3) a review of the basis for the current test program including planned testing.

I. Introduction

Pressure vessels are used extensively in both ground and spacecraft applications. Explosive failures of vessels are rare due to precautions normally taken including adherence to consensus design, fabrication and test codes and standards. Inservice integrity is maintained through monitoring of vessel service conditions and cyclic history. Yet pressure vessels do occasionally fail, releasing significant energy and possible hazardous commodities into the surroundings. Often it is prudent to assess the damage that could result from explosive failure when locating pressure vessels, designing nearby structures and equipment, performing pressure tests, or considering other safety precautions.

A considerable body of data exists on damage and injury due to blast wave and fragmentation, much of it from research using TNT or similar high explosives. However substantially less is known about blast and fragmentation of bursting pressure vessels than of chemical explosions such as TNT[3]. Further, current methods documented in standards, handbooks and other references used to quantify expected energy release, blast waves, and fragmentation are inconsistent and vary in results[4]. Accordingly, a pressure vessel burst test program is being conducted for the USAF -45th Space Wing (formerly the Eastern Space and Missile Center) and NASA Headquarters. The program studies the blast wave and fragmentation of bursting gas filled pressure vessels.

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II. Energy Release

An explosive rupture of a pressure vessel, where the stored energy is released instantaneously, would create a blast wave (i.e., shockwave) in the surrounding air and propel fragments. The shockwave and fragment characteristics depend on such things as vessel contents, pressure, vessel geometry and mode of vessel failure.

Energy & TNT Equivalency

The explosive energy from the rapid expansion of compressed gas can be determined by application of basic thermodynamic relationships that are a function of pressure, volume, and temperature. The expansion is most often assumed to be isentropic (isothermal, considered applicable by some references, would require that heat be added to the expanding gas). The following equation gives the isentropic energy released by the failure of a vessel containing a volume of ideal gas, V_1, at a pressure of P_1. P_2 is the surrounding atmospheric pressure. γ is the specific heat ratio:

$$W=\frac{P_1V_1}{\gamma-1}\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad \text{(eq. 1)}$$

This equation assumes ideal gas behavior. Ideal gas behavior is considered adequate for most low pressure situations (1500 psi). The ideal gas assumption for high pressure ruptures gives expansion energies that can be unrealistically high due to compressibility effects, about 20% at 7500 psi. Accurate estimates of available blast energy from high pressure bursts require calculations based on real gas equations of state. (Such estimates are not provided in this report because the accuracy of measured data is not sufficient for comparison purposes.)

Using an isentropic ideal gas relationship, the calculated stored energy in a cubic foot of GN2 at a pressure of 7,500 psi would be 1,642,305 ft-lb. A common practice in determining explosive potential of a rupturing pressure vessel is to assume the explosive characteristics are what would be generated by a TNT detonation of equivalent energy. (Other high explosives, such as composition B and composition C-4 are used in the test program and their characteristics relative to TNT have been established[5]. The TNT energy equivalence of the 7,500 psi, 53 cubic ft, vessel filled with GN2 is 77.0 lbs using 1.545×10^6 ft-lb/lb after Kinney[6].

Blast Wave

Explosive disintegration will generate a blast wave resulting in a high overpressure (pressure above atmospheric) at the vessel surface. As the blast wave advances, the energy is spread over the wave's frontal volume, which increases with the cube of the distance from the point of rupture. Overpressure, blast wave velocity and therefore blast effect, decrease rapidly with distance. After passage of the shockwave, the pressure decreases until a suction phase follows in which pressure drops below normal atmospheric pressure. The negative pressure is a result of the outrush of gases from the center of the rupture causing an overexpansion. The pressure above atmospheric at the shockwave front is the peak overpressure and is used with impulse to establish the relative hazard (i.e., shockwave intensity and energy in the shockwave, the impulse being the area under the positive position of the pressure versus time curve) associated with ruptures and explosions at a given distance. The blast wave emanating from a bursting pressure vessel (discussed in Section IV) is somewhat similar to that caused by a high explosive detonation. The pressure close in (0 to 10 ft) due to vessel burst is generally lower than high explosive detonation and is a function of burst pressure. This is because the pressure at the vessel surface (see eq. 2 and Fig. 12) is less than that of a high explosive blast at the same distance from the explosion center. Other variations are caused by vessel and failure geometry and distance from a firm reflecting surface. Figure 1 shows the overpressure vs. time characteristics from the detonation of 30 lb of composition B high explosive that was exploded in a well instrumented arena as part of this study (See Sections III and IV).

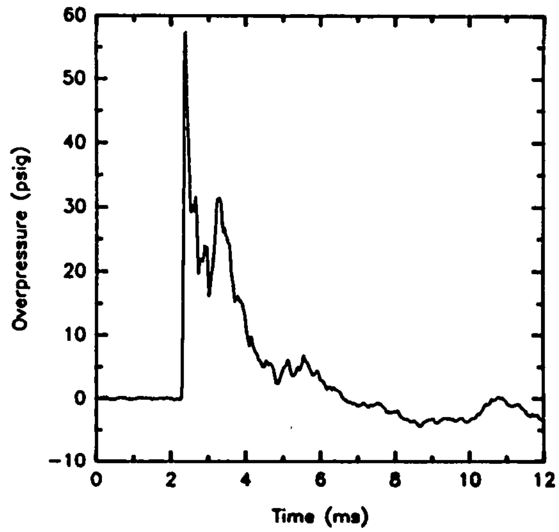


Figure 1, Overpressure versus Time for Composition B (measured at 90° and 15 feet).

Fragmentation

The explosive failure of a pressure vessel not only generates a blast wave but produces fragments, with very high velocities possible. Fragments constitute a significant hazard to personnel, systems, components and structures in the vicinity. Primary fragments are portions of the vessel or its attachments that are accelerated due to the internal pressure of the vessel. Secondary fragments may also be produced due to the action of the blast wave or primary fragments on nearby objects.

Studies[7,8,9] of the characteristics of vessel fragments have addressed the velocities of fragments produced, their trajectories and, as a result, their ranges and their impact velocities. Determination of the initial velocities of fragments has been undertaken by several researchers. Most such studies are based upon work by Taylor and Price[10] which predicted the velocities of two spherical vessel fragments accelerated by an expanding adiabatic ideal gas. Wiederman[11] has shown that real gas effects can be expected to reduce the fragment velocity from the ideal gas prediction.

Once the initial velocity of a fragment has been determined, its range may be found through ballistic calculations, generally done through the use of a computer code, a number of which are available. Code considerations are drag coefficient, lift coefficient (if any), initial trajectory angle and reference area - either fixed or varying (tumbling or gradually changing).

The reader is also referred to work by Pittman[12] for velocities of fragments burst from flight weight vessels at 600 and 8000 psig. Baum[8,14] compiles data from his own work and other researchers on fragments from vessels burst at 70 to 4400 psig, mostly at 750 psig or less.

III. Test Program

Test Program Matrix

A test program matrix was developed that included a series of test plans each with multiple pneumatic vessel bursts. The objective of the program matrix was to force vessel bursts in such a way as to generate worst case blast waves and fragmentation, such that a model could be developed that would envelop generally expected vessel failures. The latter test plans of the matrix would include such representative vessel failures. Worst case however is a function of several variables, including location and orientation of failure, pressure, vessel shape, fragment type and number, and height above ground. The plans and tests comprising the program matrix have been developed to minimize the number of vessel bursts yet meet the stated objective with valid data.

In the development of a test matrix, it was also recognized that a pressure vessel burst may not produce a spherical shockwave as does a TNT explosion. The blast wave from a pressure vessel burst may be much stronger in one direction than another based on how the vessel shell comes apart. To provide a direct experimental comparison with pressure vessel bursts, spherical high explosive detonations have been conducted as part of the test program.

Accordingly, a test program matrix was developed which incorporated varied failure locations and mechanisms. Seven test plans were envisioned with each test plan consisting of several vessel bursts. The failure geometry shown in Figure 2 for five of the seven test plans would be accomplished through the use of optimally selected shaped charges and pre-machining of grooves. Test plan four would use shaped charges alone. Test plan seven is intended to produce only one fragment with a side split. The anticipated split will be oriented toward the arena transducer field at burst.

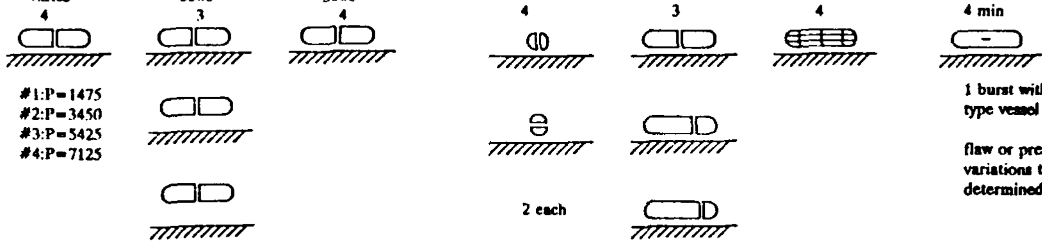
Description	Test Plan #1	Test Plan #2	Test Plan #3	Test Plan #4	Test Plan #5	Test Plan #6	Test Plan#7
Vessel:							
Material:	Steel	Steel	Steel	Composite	Steel	Steel	Steel
Vols., ft^3:	53	53	53,22		53	53,22	53,22
Diameters,in:	24	24	24,16,34	14	24	24,16,34	24,16
L/Ds:	11	11	11,17,2,4	1	11	11,17,2,4	11
Burst Pressure:	varies	3500	3500	4000	3500	3500	TBD
No. of bursts:	4	3	4	4	3	4	4 min
Configurations: 	#1:P=1475 #2:P=3450 #3:P=5425 #4:P=7125			2 each			1 burst with each type vessel; flaw or pressure variations to be determined
Para Varied:	burst pressure	burst height	L/D-2 frags	vessel shape & orientation	split location	L/D multi-fragment	machined flaw

Figure 2, Test Program Matrix

Other burst parameters are also varied in the program matrix. These include the split location, burst pressure and vessel length to diameter ratio (L/D) for two fragments and multi-fragment vessels as shown in Figure 2.

Actual burst pressures for test plan (TP) #1 are shown in Figure 2. These bursts occurred at a centerline height of 3.5 feet. TP #2 burst pressures and heights of burst are 3450 psig at 3.5 feet, 3450 psig at 8.7 feet and 3475 psig at 14 feet.

The following are addressed for all test plans: overpressure and impulse versus expectations, burst asymmetry, reflection factor and fragment initial velocity. For instance: in TP 3, by varying the length to diameter ratio, the vessel approaches a sphere which is expected to yield the highest overpressure for a given internal energy. Very light weight spheres are then used in TP#4 which will result in very high fragment velocities. For each vessel in TP #3, TP #6 will provide identical vessels with multiple gas escape paths and a projected increase in blast overpressure.

Test Planning & Testing

Vessel and Hardware Preparation

The typical vessel groove geometry is shown in Figure 3 with the linear shaped charge (LSC) and the shaped charge cut area shown with dotted lines. Machining such a groove with a constant remaining wall thickness in a vessel of non-uniform roundness and wall thickness presents an interesting challenge. For single circumferential grooves, this challenge was initially met using a special procedure to approximate a constant groove wall on an ordinary lathe. For later single cut and for multi-fragment vessels, having grooves in two directions, Computer Numerical Control milling is being used.

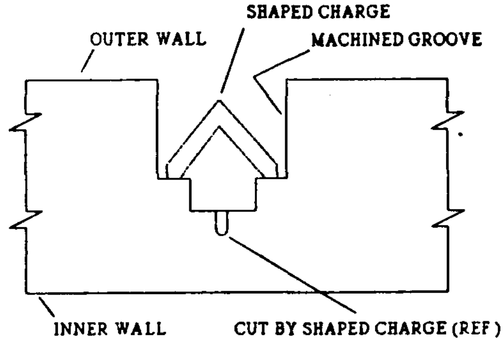


Figure 3, Typical Vessel Cross Section Showing Groove and Shaped Charge

A vessel test stand was designed and fabricated for an initial vessel centerline height of 3.5 feet. Other heights require replacement of a four inch pipe acting as center post of each stand and guy wire bracing at heights above six feet. Good accelerometer data was not obtained during preliminary testing and a 5-wire makewire stand was subsequently provided for obtaining average velocities close to the vessel. Very high noise levels were obtained at frequencies which could not be explained by sound conduction/bouncing off end caps or by vibration on release of pressurization expansion.

Test Site

Three pneumatic burst tests, comprising 10 vessels, have been conducted at the Naval Surface Warfare Center's (NSWC) Dahlgren, VA explosives test area. The Center has personnel experienced in explosive detonation and blast data recording from small up to very large charges of high explosive. High speed motion picture coverage is available with multiple cameras and hardened camera shelters. Heavy duty handling equipment is available such as cranes, fork lifts, payloaders, etc. A variety of transducers, tape recorders and timing controls are available for testing. A hardened blockhouse and instrumentation room plus the capability of tape recorder control from a remote site is available. This site provides an already wired arena in close proximity to a blockhouse which can prevent penetration of high kinetic energy fragments. An isometric drawing of a pressure vessel installed in a blast field arena at NSWC is shown in Figure 4. (When the vessel center edge is not at the arena center, pressure versus distance data is corrected accordingly.)

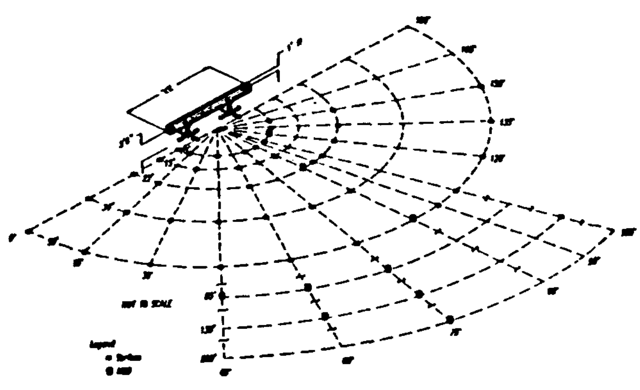


Figure 4, Pressure Vessel Installed in NSWC Arena

Vessels

Of the ten vessels burst using pneumatic pressure (using gaseous nitrogen) nine were cylindrical steel vessels with an outer diameter of 24 inches and a volume of 53 cubic feet. The other vessel was a spherical stainless steel/Kevlar overwrap vessel with a volume of 2.7 cubic feet. The latter vessel provides a vessel geometry variation from the cylinder and very light weight fragments. This vessel will be called "spherical" or "COPV" for composite overwrapped pressure vessel. See Table 1 for other vessel details.

Burst Initiation

Longitudinal stress at the groove (for developing axial fragments) runs 40% to 80% of tensile strength at completion of pressurization. The lower level represents a perceived lower limit on groove wall thickness for safe machining and handling (vessels for lower burst pressures). The stress is increased to failure when the shaped charge is detonated by the shaped charge cutting part way through the machined wall. Preliminary tests showed that the longitudinal stress in a narrow circumferential groove can be used to predict failure in a non-cyclic application.

There were initial concerns that even a small linear shaped charge (LSC) could bias the blast overpressure measurement, however the preliminary test, with steel vessels, showed that any shock effect was minimal and that the LSC blast pressure has practically returned to ambient prior to the vessel blast shock arrival as shown in Figure 5, thus minimizing measurement problems. The initial pressure rise at 13 ms in Figure 5 was produced by the LSC.

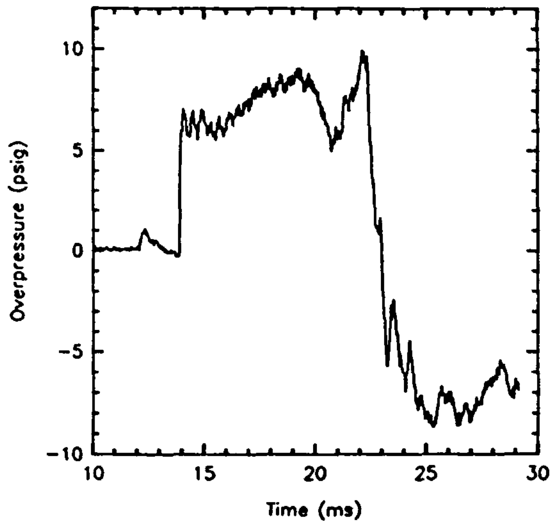


Figure 5. Overpressure versus Time for 3250 psig Cylindrical Vessel (measured at 90^0 and 15 feet)

Table 1

Vessel #	Vess Pres psig	Vess Vol ft^3	Vess Wt lbs	Frag Vel fps	ER* %	TNT Equiv lbs
1-1	1475	53	5525	145	8.7	13.5
P-1	3250	53	5800	246	11.1	31.7
1-2	3450	53	5900	248	10.8	33.8
2-1	3450	53	5025	250	9.3	33.8
2-2	3450	53	5300	255	10.3	33.8
2-3	3475	53	5400	265	11.2	34.1
COPV	3975	2.7	43.6	851	15.8	2.0
P-2	4700	53	5775	307	11.6	47.0
1-3	5425	53	5825	315	10.6	54.8
1-4	7125	53	5250	360	9.3	73.4

* Energy ratio = Kinetic Energy/isentropic expansion energy

Data Recording

High speed motion picture and video are used for event recording. Approximately 46 channels of fast response piezoelectric pressure transducers are used to record blast overpressure. Data is later digitized by NSWC. For the first test, blast transducer ranging was based on the expectation from high explosives of the vessel TNT equivalence[5]. Subsequent ranging is based on test experience.

IV Test Results

Ten vessels have been burst under pneumatic pressure as shown in Table 1. Three vessels, two steel and one composite, were burst during preliminary testing. Four vessels were burst as part of Test Plan #1, a vessel pressure variation test. Three vessels were burst as part of Test Plan #2, a height of burst (HOB) variation test. The TNT equivalence in the table is based on the ideal gas stored energy using isentropic expansion and a conversion factor of 1.545×10^6 as discussed earlier. Other table information will be discussed later.

Eight high explosive charges have also been detonated as part of the test program. These vary in strength from 0.66 lbs pentolite (.9 lbs. TNT equivalence) to 50 lbs composition C-4 (68 lbs TNT equivalence).

The cylindrical vessels were burst along a circumferential line in the vessel center with the vessel parallel to the ground and to the 0° - 180° line of the arena as shown in Figure 4. The vessel edge was at the arena center, placing the vessel center one foot away from the arena center. The spherical vessel and the 8.7' and 14' HOB explosive charges were detonated at the same location. All data herein is corrected for the foot offset. The spherical vessel was a composite overwrapped vessel and was cut with a shaped charge (no groove) around its center and parallel to the ground.

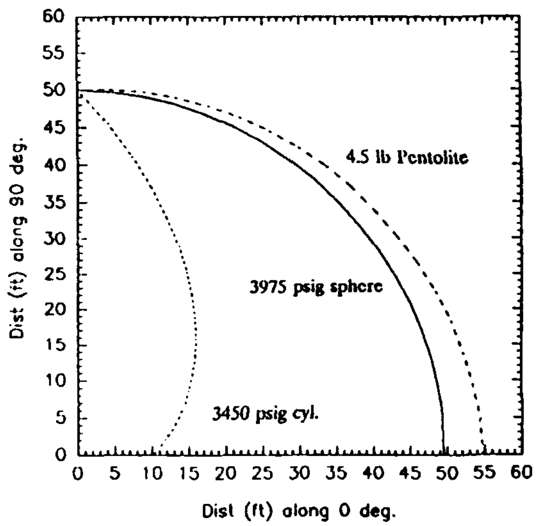


Figure 6. Some Lines of Equal Impulse for a High Explosive and Two Vessel Bursts

Asymmetry

Overpressure (and similarly impulse) data versus distance and arena angle (due to asymmetry) were reduced to the model:

$$\log_e P = B_1 + B_2 \log_e D + B_3 A + B_4 (\log_e D)^2 \qquad \text{(eq. 2)}$$

where
- P = pressure psig
- D = distance from vessel center (and burst point)
- A = angle, 0° vessel axis at either end, 90° = normal line
- Bs = are coefficients, B_4 is zero unless 2nd order provides an accuracy improvement

As expected, high explosive charges were quite symmetric, as also was the spherical composite vessel. The cylindrical steel vessels were quite asymmetric due to their burst geometry. The impulse (the area under the positive portion of the overpressure vs. time curve) is more directional than the peak overpressure. Figure 6 shows lines of equal impulse for 4.5# pentolite (I = 4.52 psi-ms), a cylindrical steel vessel burst at 3450 psi (I = 21.1 psi-ms) and the spherical vessel (I = 2.98 psi-ms). These were plotted by computing the distance where the impulse at 50 ft. and 90° occurs at different angles. The symmetry of the spherical vessel is a result of both its shape and the circumferential burst plane oriented parallel to the ground.

Pressure versus Time Waveform

Pressure vs. time waveform has been shown in Figure 1 for high explosive and Figure 5 for the steel cylindrical vessel (with the vessel a foot offset from the arena). The flat top wave form is typical for the cylindrical vessels at 3.5 foot HOB, at distances of 22 feet and closer, and angles within 30° of normal. At greater distances or lesser angles the flat top tends to peak, approaching the high explosive waveform. The waveform for the spherical vessel is shown in Figure 7. All waveforms shown were recorded at similar locations (within 5 ft. and 30°). The spherical vessel overpressure closely resembles that of the high explosive. It has a peak, semi-exponential decay and a second shock. the difference in appearance between this vessel and the cylindrical vessel is attributed to the overall gas release rate between the two vessels, i.e., the vessel and burst geometry and fragment acceleration (due to their mass).

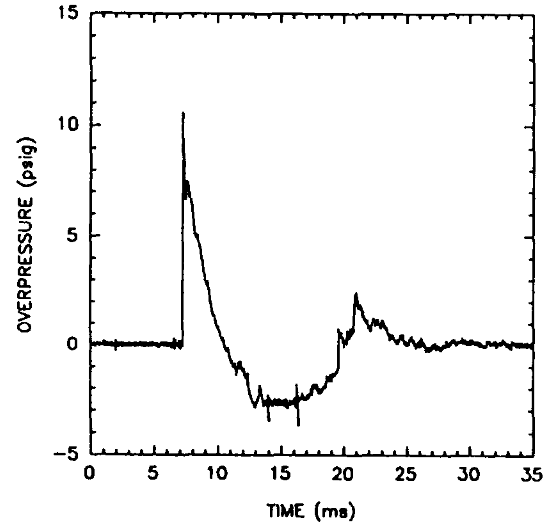


Figure 7, Overpressure versus Time for 3975 psig Spherical Vessel (measured at 120° and 10 feet)

Height of Burst effects

The presence of a reflecting surface, such as the ground, intensifies the peak overpressure from the blast. This effect is well documented in the literature for explosives[5,6]. Height of burst detonations were made using 4.5# pentolite at 3.5, 8.7 and 14.0 ft HOB and 3450 psi (nominal) pressure cylindrical steel vessels at the same height. The high explosive was chosen to yield approximately the same overpressure as the vessels at 10 foot distance so that all measurements are within recorder range without rescaling.

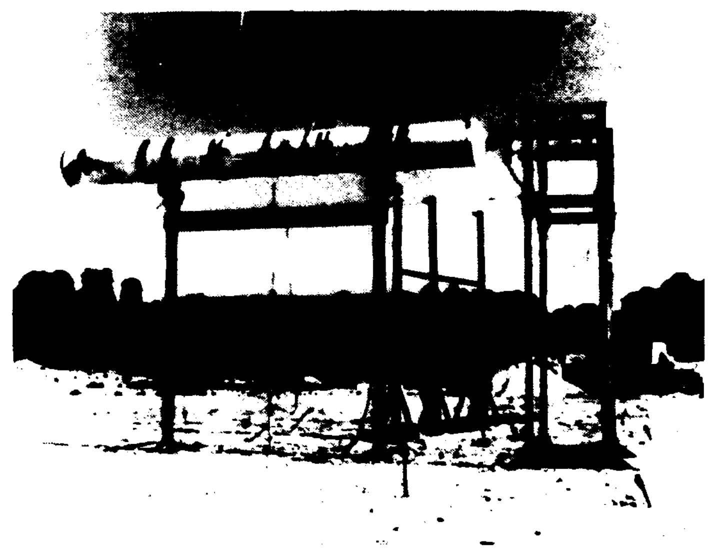


Figure 8, 14' HOB Pressure Vessel

The difference between the incident (or non-reflected pressure) and the reflected pressure wave cannot always be clearly discerned at a reflected (i.e. ground) transducer location. Accordingly, pressure measurements were made above ground under the vessel when burst at 8.7 ft and 14 ft HOB and at vessel height at 10, 15 and 22 foot distances along the ground. Figure 8 shows the setup for the 14 ft HOB vessel test. These measurements are used for the incident pressure for comparison to ground measured pressures. Incident pressures for the pentolite blast were measured only on the auxiliary HOB transducer stand shown in Figure 8.

Compared to reflected data the incident pressure equations are therefore based on less data and closer in measurements and at straight line distances (as opposed to a slant height) with only the ground distance being considered.

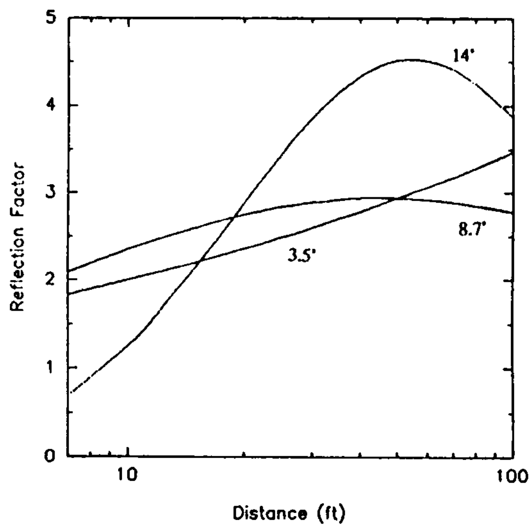


Figure 9, Reflection Factors Measured for 4.5 lbs. Pentolite

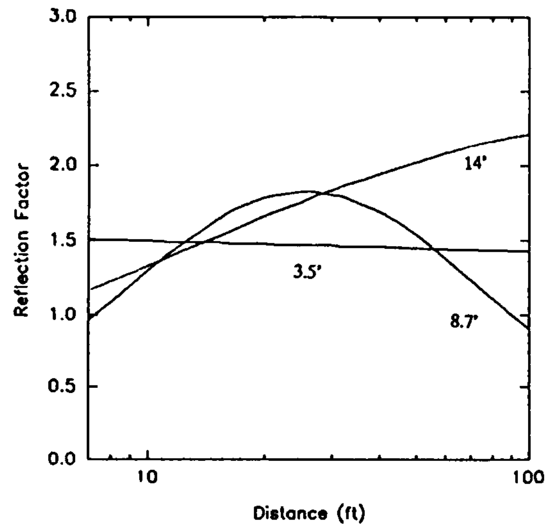


Figure 10, Reflection Factors Measured for 53 cubic feet Cylindrical Pressure Vessels at (nominal) 3450 psig

Figure 9 shows reflection factors for the three high explosives tested and Figure 10 shows the reflection factors for three pressure vessels tested. Second order (log-log) curve fits were used for 8.7 and 14.0 ft HOB where they yielded better fits. Reflection factors are all based on the 90°, maximum pressure, array for pressure vessels. Comparing the two figures shows that reflection factors were obtained for pressure vessel blast waves, similar to high explosive, but of a lesser magnitude.

Vessel Pressure Variation Results versus Theory

Curve fit results for two pressure vessels, 1475 and 5425 psi are shown in Figure 11 (the solid straight lines). These were obtained using ground mounted transducers and are thus reflected pressures. They are also the 90° array lines on the arena. The dotted lines serve to guide the reader to pressures measured on the ground, 2.5 ft below the vessel surface (and plotted at 2.5 feet from arena center). The curved lines represent pressures calculated using the methods of Baker[7] (assuming spherical vessels since correction factors for cylinders are for high explosives). The calculations used a recommended vessel volume of twice the actual 53 cubic feet to allow for a reflection factor with a factor of 1.5 applied to the resulting overpressure. Baker's curves assume sudden vessel wall disappearance, hence the theory is higher than actual. The actual burst required a finite time for the gas to flow to the rupture and then exhaust.

It should be noted from Figure 11 that ground pressures measured under the vessel increase at a faster rate, compared to vessel pressure, than theory would predict. Also, (not shown) maximum pressure at this location was not the initial pressure but rather increased over several milliseconds. This would seem to indicate that, at higher vessel pressures, gas exhausts from the vessel faster than it escapes the immediate area and hence a pressure buildup occurs.

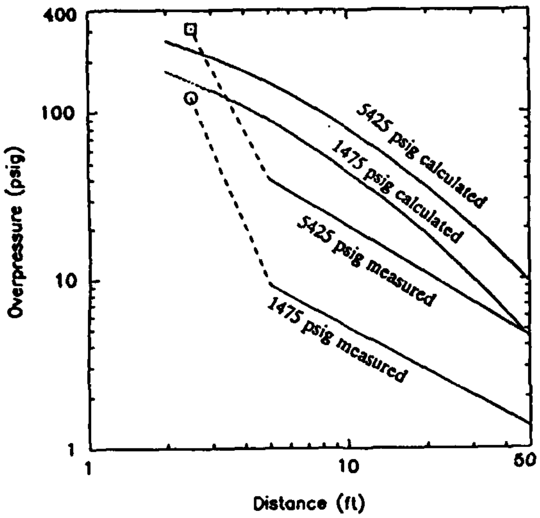


Figure 11, Measured and Calculated Overpressures for Burst of Two Cylindrical Vessels

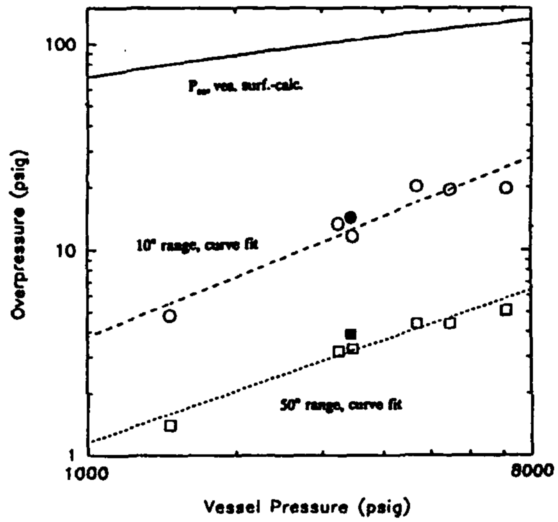


Figure 12, Measured Reflected Overpressure at 10' and 50' and Calculated Incident Overpressure at Vessel Surface

Overpressure vs. Vessel Pressure

Figure 12 shows a plot of overpressure vs. vessel pressure for seven vessel bursts of identical geometry but varying vessel pressure. The vessels were all at a centerline height of 3.5 feet above ground. The pressures shown are the pressures at ten foot and fifty foot range, 90° array end points and are from curve fit data. (Two points are filled for convenience in pairing data in Figure 12.)

Also plotted in the figure is the initial shock overpressure, P_{SO}, the incident pressure at the vessel surface. P_{SO} is a calculated pressure, from aerodynamic considerations, and represents the shock overpressure at the vessel surface when no reflecting surface exists.

This pressure is calculated using the one dimensional shock tube equation[15]:

$$P_{so}=p_1\left[1-\frac{(\gamma_{ves}-1)(\frac{a_o}{a_1})(\frac{P_{so}-1}{p_o})}{\sqrt{2\gamma_o}\sqrt{2\gamma_o+(\gamma_o+1)(\frac{P_{so}}{p_o}-1)}}\right]^{\frac{2\gamma_{ves}}{\gamma_{ves}-1}} \qquad \text{(eq.3)}$$

where p_1 = initial vessel pressure, psia
P_{so} = initial shock pressure, psia
a_o = ambient sound velocity
a_1 = sound velocity in vessel gas
p_o = ambient pressure
γ = specific heat ratio, either ambient (γ_o) or vessel gas (γ_{ves})

The initial shock overpressure is nearly a straight line on log-log coordinates. Therefore, the straight line drawn through the ten and fifty foot range points is not unreasonable. The 7125 psig vessel appears to have produced low overpressures throughout the arena. This might be partly due to real gas effects, and/or it might be attributed to some erosion in the center of the arena caused by the escaping gas. Effects cannot be separated at this time.

Fragment Velocity vs. Vessel Pressure

Table 1 shows fragment velocities and energy ratio (ER) for all the pneumatic burst vessels. The energy ratio is defined herein as the ratio of the kinetic energy of the two fragments to the total stored energy of the gas using isentropic expansion of an ideal gas to atmospheric pressure. This ratio ran around 9% for the heavy steel cylindrical vessel fragments to about 16% for the light spherical composite vessel (COPV) fragments which attained a high velocity. Fragment velocities for the two preliminary vessels, P-1 and P-2 are believed to be determined to a lesser accuracy than later measurements made with improved techniques. Also, the spherical vessel fragment may have been slowed somewhat in breaking the steel wires in the experimental makewire frame.

Figure 13 is a plot of fragment velocity vs. pressure for steel vessels of Table 1, all of which were of the same design. Unlike Table 1, which shows the average fragment velocity (where both velocities could be obtained), Figure 13 shows separate velocities for the east and west fragments.

Figure 13 also shows lines of velocity vs. vessel pressure from computer calculations based upon a work of Taylor and Price[9]. Shown are lines calculated using the original model (ACTA, Inc. code version 1.0) and discharge coefficients, k, of 0.7 and 1.0. A discharge coefficient of 0.6 to 1.0 is expected from orifice flow theory. It was found[2] that discharge coefficients of .41 to .55 were required to match measured fragment velocities for tested configurations. The program was revised (code version 1.1) to limit the flow area to the actual exhaust area. A line of velocities is also shown in Figure 13 using the revised program and a discharge coefficient of 1.0. This changed the slope of the line and indicates that more work is required on the program. The program also computes supersonic velocities for the lightweight spherical composite vessel fragments and indicates another area to be addressed.

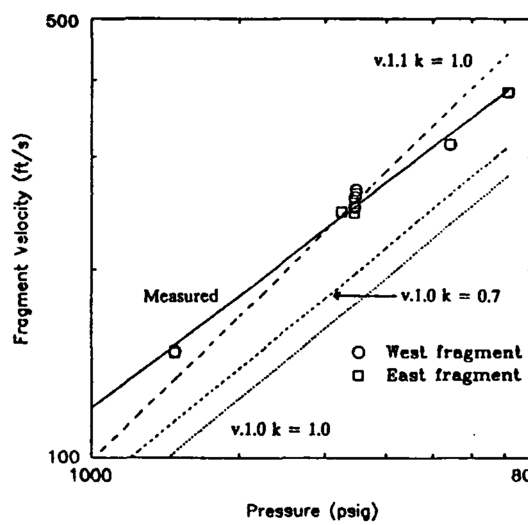


Figure 13, Calculated and Measured Fragment Velocities for Cylindrical Vessels

Blast effect - spherical (COPV) vs. cylindrical (steel) vessels

The differences in the pressure vs. time waveform were shown in Figures 5 and 7 for a cylindrical steel vessel at 3250 psi and a spherical COPV vessel at 4000 psi, respectively. Both had similar maximum overpressure in spite of having a ratio of TNT equivalence of 31.7:2, Table 1. Figure 14 shows that the spherical vessel more closely resembled a high explosive detonation than the cylindrical vessel. This is attributed to the differences in vessel geometry. The spherical composite vessel permitted a much faster release of stored energy (pressurized gas) than a circumferential failure in the center of a long cylinder.

Figure 14 shows incident pressure vs. distance for lines of constant TNT equivalence from 2.5 lbs to 40 lbs TNT. If we allow a reflection factor of 1.5 (from Figure 10), then we should have expected pressures for the spherical vessel to be equivalent to 4 lbs TNT e.g. 18.0 psig at 10 feet and 1.1 psig at 50 feet. Actual values were 12.3 and 1.4 at 10 feet and 50 feet respectively and were thus less than TNT at the lesser distance and greater than TNT farther out.

The cylindrical vessel has a slope which is less than the spherical vessel and much less than the TNT equivalence. The overpressures within the well instrumented arena were less than TNT equivalence, however beyond 50 feet where the shock becomes weaker the overpressure would exceed that for TNT. Spot measurements (not suitable for determining an angle coefficient) confirm this trend. It should be noted that the pressure vessel lines in Figure 14 are computed for the 45° array. Using a linear coefficient for angle, 45° should be the average array, 90° being the strongest and 0° the weakest for the asymmetrical cylindrical vessel. Scatter in overpressure data was too great to obtain a non-linear angle coefficient. If the worst case failure is considered, then the 90° array should be used for the cylinders which places the vessel blast above the TNT equivalent at 50 feet.

Figure 15 compares impulse curve fits, again for the 45° arena array, to that for high explosives. The impulse for the spherical vessel exceeds TNT equivalence, and the cylindrical vessel approaches its TNT equivalence. The impulse is more asymmetric than the overpressure and 45° may be a poor average array. The TNT equivalence is from a Bode type equation in Kinney & Graham[6] and does not include considerations of reflection factor. Reflection factors for impulses have not been obtained as part of the present testing effort.

Table 1 shows the kinetic energy in the fragments for the spherical COPV vessel is 15.8% of the ideal gas stored energy. The blast overpressure at 10 foot range, considering reflection factor, is about 60% of the TNT equivalent. However, at 50 foot range the overpressure is greater than the TNT equivalent. It seems inconclusive whether the kinetic energy in the fragments actually reduces the energy in the blastwave.

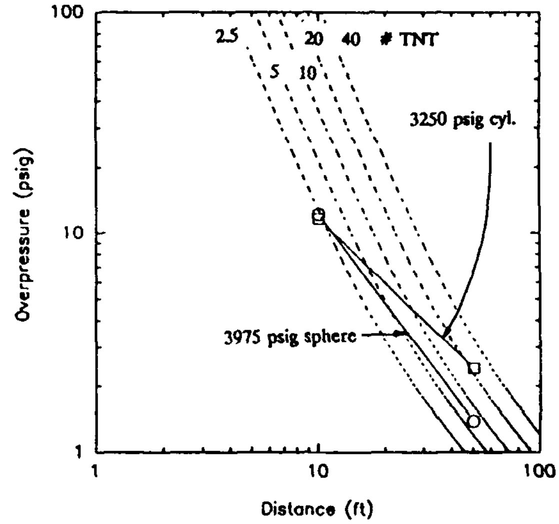


Figure 14. Reflected Overpressures from 45° Array Curve Fits for Two Vessels and Incident Overpressures for TNT

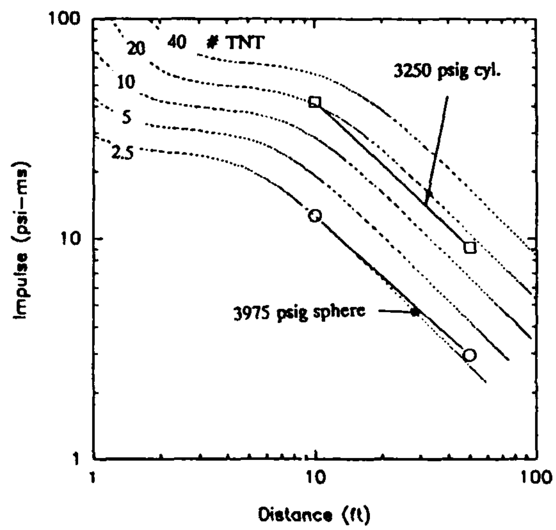


Figure 15. Impulse from 45° Array Curve Fits for Two Vessels and for TNT

V. Future Efforts

Future efforts will explore new areas where data has not been previously published. These include: the effect of L/D (i.e. exhaust rate) on overpressure, the effect of L/D in a multi-fragment vessel (i.e. increased exhaust rate and differences between sphere and cylindrical geometries in real vessels) and the asymmetries in a vessel with a side-split.

The possibility of a non-linear angle versus impulse relationship will be examined for the curve fit model.

The effect of gas escape rate has already been seen for a spherical vessel and for a long cylinder, both of which were split into two halves. This effect will be further examined in Test Plan 4 which will utilize four spherical vessels and in Test Plan 3 and 6 utilizing cylinders.

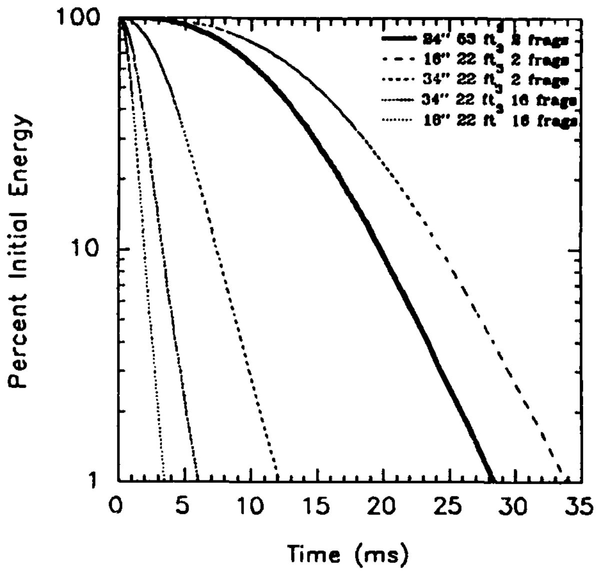


Figure 16. Remaining Vessel Energy versus Time Following Vessel Burst

Test Plans #3 (dual fragment) and #6 (multifragment) will each vary the vessel length to diameter ratio (L/D). Figure 16 shows the calculated vessel energy remaining as a function of time, shown as a percent of the energy at 3500 psi burst for five vessels and failure geometries. Four of the curves are for a 22 cubic foot vessel which shows a large variation with L/D from 16 inch diameter vessels to 34 inch diameter vessels. The other curve applies to the 53 cubic foot, 24 inch diameter burst at 3500 psi (Test Plan #2). The escape rate of the vessel energy should effect overpressure measurements and fragment velocity. The two test plans should permit an approach to the case of sudden disintegration of the pressure vessel walls, an assumption made in some comparisons of vessel burst overpressure to high explosive blast.

VI. Summary

Substantial documentation exists for estimating injury and damage from blast wave overpressure and impulse and from fragment impact velocity and mass. However much of the data compares a pressure vessel burst to a high energy explosive blast. Additional vessel burst testing is needed to augment existing data in quantifying pressure vessel burst characteristics. The current test program will provide a mix of vessel failure modes, pressures, and other variables. This data, together with data from other researchers will permit assessing the results of different assumed options for vessel failures such that the installation designer or user can weigh the likelihood of such failures and the hazards should they occur.

This paper is the third progress report on the pressure vessel burst test program. Some pneumatic burst testing has been accomplished and limited conclusions are drawn. Since test plans are interrelated, further testing will clarify existing results and provide conclusions to be presented in the future.

Tentative conclusions are as follows:

1. Overpressure versus distance for pressure vessels depends on the failure mode but was generally less than TNT equivalent at 10 feet and greater than TNT equivalent at 50 feet for the strongest array.

2. Exhaust flow rate from a pressure vessel has a large effect on overpressure.

3. Average impulse appears to be the same as the TNT equivalent, particularly for a fast exhaust vessel and failure geometry.

4. It seems inconclusive whether the energy in the blastwave is reduced due to the kinetic energy of the fragments.

5. Very close pressures at a reflecting surface may be greater than theory.

6. Pressure vessel overpressure reflection factors appear to be less than that of a high explosive blast having a similar overpressure at a 10 foot range.

7. Good fragment velocity data has been achieved for most shots but measurement of fragment acceleration has been elusive.

8. Additional effort is required for computer calculation of accurate fragment velocities.

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MR.	BRODERICK	CHARLES	LAWRENCE LIVERMORE NATIONAL LABORATORY
MR.	BROOKS	JESSIE	KAO
MR.	BROWER	JAMES	US ARMY TECH ESCORT-UNIT

MR	BROWN	WARREN	OLIN CORPORATION
MR.	BROWN	NICHOLAS	PUEBLO DEPOT ACTIVITY
MR.	BROWN	MICHAEL	NAVAL SURFACE WARFARE CENTER
MR.	BROWN	LARRY	DENVER RESEARCH INSTITUTE
MR.	BRUNO	FRED	MCDONNELL DOUGLAS MISSILE SYSTEM CO.
MR.	BRUNTY	JOE	FEDERAL/OSHA
SMSGT	BRYANT	JAMES	102ND FW/SE
MR	BUEHLER	KURT	6510 TW/DORH
MR.	BUMMER	GLENN	CALIFORNIA INSTITUTE OF TECHNOLOGY
MR.	BURCH	V.	NAVAL SURFACE WARFARE CENTER
M/SGT	BURCHETT	STEPHEN	2701 EXPLOSIVES ORD SQUADRON
MR.	BUTLER	FENOY	GEO-CENTERS, INC.
MR.	BUTLER		US ARMY YUMA PROVING GROUND
SSGT	CACIOPPU	BEN	EOD 7E5B 1ESSG
MR.	CAIN	MAURICE	GENERAL PHYSICS SERVICE CORP.
MR.	CALHOUN	JAMES	ATLANTIC RESEARCH CORPORATION
MR.	CALTAGIRONE	JOSEPH	U.S. ARMY ARMAMENT R&D CENTER
MR	CAMPBELL	JAMES	BMO/SE
MR.	CAMPBELL	DEAN	BRISTOL AEROSPACE LIMITED
DR.	CANADA	CHESTER	
MR	CANNON	PAUL	THIOKOL CORPORATION
COLONEL	CARLSSON	BERNDT-IVAN	DEFENCE MATERIEL ADMINISTRATION
CAPTAIN	CARROLL	JAMES	HEADQUARTERS, USAFE
CAPTAIN	CARTER	JOHN	11 AF/SEW
MR.	CATES	CHARLES	
MR.	CENTENNIAL	CARL	SOUTHWEST RESEARCH INSTITUTE
MR.	CHANDLER	ERNEST	RED RIVER ARMY DEPOT
MSGT	CHARON	ROBERT	388 FIGHTER WING
MR.	CHASE	RONALD	542D CPTS/FMFP
MR.	CHIA	CAKE HAN	LANDS & ESTATES ORGANIZATION, LEOMINDEF
MR.	CHING	REGINALD	OLAC PHILLIPS LABORATORY
MR.	CHIZALLET	MAURICE	GIAT INDUSTRIES - B.M.P.
MR.	CHRISTENSON	ALAN	MCDONNELL DOUGLAS SPACE AND
MS.	CINNAMON	CYNTHIA	DEFENSE CONTRACT MGMT DISTRICT WEST
MR.	CLAFFY	JOHN	LOCKHEED ENGINEERING & SCIENCES COMPANY
MR.	CLAPP	ROBERT	MARTIN MARIETTA MISSILE SYSTEMS

MR.	CLARK	RONALD	CRANE ARMY AMMUNITION ACTIVITY
MR.	CLARK	EUGENE	DDESB
MR.	CLIFFORD	LIM KONG	EXPLOMO TECHNICAL SERVICES PTE LTD
MR.	CLINTON	STEPHEN	HAYES, SEAY, MATTERN & MATTERN, INC.
MR	CLOONAN	JAMES	SM-ALC/SEW
MR.	COBB	WILLIAM	436 AW/SEW
MR.	COLBERG	MELVIN	U.S. ARMY DEFENSE AMMUNITION CENTER
MR.	COLLIER	RICHARD	Electro Magnetic Applications
MR.	COLLIS	DAVID	NEW MEXICO INSTITUTE OF MINING
MR.	COLTON	JAMES	SRI INTERNATIONAL-POULTER LABORATORY
MR.	CONNOR	J	Naval Surface Weapons Center
MR.	CONNOR	JOHN	CHIEF OF SAFETY
MR.	CONSTANTINO	LARRY	PACIFIC SCIENTIFIC
MR.	COONFARE	GREGORY	445 AW/SEG
MR.	COULSON	JOHN	COULSON CONSULTING CORPORATION
MR.	CRAVEN	JEFFERY	REDSTONE TECHNICAL TEST CENTER
MR.	CRAWFORD	KENNETH	US ARMY CORPS OF ENGINEERS
MR.	CREVECOEUR	RONALD	HQ, ARMY MATERIEL COMMAND
LTCOL	CROWE	STEWART	DIRECTORATE OF LAND SERVICE AMMUNITION
MR.	CRUFF	DELBERT	Lawrence Livermore National Laboratory
MR.	CUMMINGS	BRUCE	SRS TECHNOLOGIES
MR.	DAHN	CARL	SAFETY CONSULTING ENGINEERS, INC.
LT COL	DANIELSON	WILLIAM	DIRECTOR OF NUCLEAR SURETY
MR	DAVIS	KIM	WATERWAYS EXPERIMENT STATION
MAJOR	DAVIS	ALAN	DIRECTORATE OF LAND SERVICES AMMUNITION
MR.	DAY	ROBERT	DEFENSE CONTRACT MGMT DISTRICT WEST
MR.	DAY	KEVIN	NAVAL SURFACE WARFARE CENTER CRANE
MR.	DAYE	JAMES	NAVSEACENLANT
MR.	DAYWALT	RAYMOND	NAVAL SURFACE WARFARE CENTER
MAJOR	DEHOFF	BRYAN	AEDC DOPR
MR.	DEMERSON	ELISHA	DEPARTMENT OF ENERGY

MR.	DEMIN	B.	DEFENCE MATERIEL ADMINISTRATION
MR.	DENISON	THOMAS	ALLIANT TECHSYSTEMS, INC.
MR.	DESCHAMBAULT	ERIC	NAVAL SURFACE WARFARE CENTER
MR.	DESSAIX	LOUIS	GROUPE EPC
MSGT	DEUTSCH	KENT	EOD MALS-16 MAG-16 3RD MAW
MR.	DIBELLA	FRED	CONVENTIONAL MUNITIONS SYSTEMS, INC.
MR.	DICKINSON	PAUL	DCMAO DENVER
MR.	DILLARD	DONALD	OLIN CORPORATION
MR.	DILLEHAY	DAVID	THIOKOL CORPORATION - LONGHORN DIVISION
MR.	DILTS	CHARLES	MCDONNELL DOUGLAS MISSILE SYSTEMS CO.
MR.	DITTMAN	HARRY	DCMD MID-ATLANTIC
MR.	DIVINE	KIRBY	CRANE DIV NAVAL SURFACE WARFARE CENTER
MR.	DODGEN	JAMES	DODGEN ENGINEERING COMPANY
MR.	DONALD	DILLARD	OLIN CORPORATION
MR.	DOOLITTLE	CRAIG	NAVAL SURFACE WARFARE CENTER
MR.	DOTTS	JAMES	SANDIA NATIONAL LABORATORIES
MR.	DOUTHAT	C.	U.S. ARMY CORPS OF ENGINEERS
MR.	DOW	ROBERT	ATTENUATION TECHNOLOGY INC.
MR	DOWLING	THOMAS	INSTITUTE OF MAKERS OF EXPLOSIVES
MR	DRAKE	JAMES	APPLIED RESEARCH ASSOC. INC.
MR.	DRAKE	RICHARD	FLUOR DANIEL
MR.	DRURY	CHUCK	SHAMROCK SERVICES
MR.	DUA	BALBIR	DAY & ZIMMERMANN, INC.
MR.	DUCHOCK	JEFF	
MR.	DUDLEY	MICHAEL	DEFENSE LOGISTICS AGENCY
MAJOR	DUNAND	MAURICE	ENAA/4 B
MR	DUNCAN	KENDAL	US ARMY ARMAMENT, MUNITIONS,
MR.	DUNHAM	C	US ARMY JEFFERSON PROVING GROUND
CWO-2	DUNN	JOSEPH	MALS-13 EOD TEAM
MR.	DUNSETH	CLIFFORD	U.S. ARMY SAFETY CENTER
MR.	EDDY	JOHN	Defense Nuclear Agency
MR.	EIFF	ARTHUR	HEIERLI CONSULTING ENGINEERS
MR.	EINERTH	BENGT	NATIONAL INSPECTORATE OF EXPLOSIVES

MR.	EISLER	ROBERT	MISSION RESEARCH CORPORATION
MR	ELLEDGE	JAMES	UNITED TECHNOLOGIES/CHEMICAL
MR	ELLIOTT	JAMES	US ARMY RESEARC DEVELOPMENT AND
MR.	ELLIOTT	MARTIN	US ARMY TOXIC & HAZARDOUS MATERIALS
CWO2	ELLIS	JUDITH	MARINE CORPS SYSTEMS COMMAND
MR.	ELMSHAEUSER	KARL	AEROJET ORDNANCE
MSGT	EMERTON	SHERWOOD	9AF, ATTN: SEW
MR.	ERDLEY		US ARMY COMBAT SYSTEMS TEST ACTIVITY
CAPTAIN	ERIKSEN	STEINAR	ROYAL NORWEGIAN NAVY MATERIAL COMMAND
MR.	ERNESTO	VIGIL	LOS ALAMOS NATIONAL LABORATORY
MR.	ESCRICHE	GABRIEL	UNION ESPANOLA DEEXPLOSIVOS
MR	ESPARZA	EDWARD	SOUTHWEST RESEARCH INSTITUTE
MR.	EWING	THOMAS	HERCULES, INC.
MR.	EYTAN	REUBEN	EYTAN BUILDING DESIGN, LTD
COLONEL	FABRE	JACQUES	FRENCH LIAISON OFFICER
COL	FAHL	ROBERT	
MR.	FALLON	JOHN	ACCUDYNE CORPORATION
MR.	FANNIN	GERALD	DEFENSE LOGISTICS AGENCY
MR.	FARRAR	STEPHEN	NATIONAL TECHNICAL SYSTEMS
MR.	FARSOUN	A.	U.S. ARMY ENGINEERING DIVISION
DR.	FELLER	SHAUL	RAFAEL-ISRAEL ARMAMENT DEVELOPMENT
MR.	FELTEN	PHILIP	HERCULES INCORPORATED
MR.	FENNESSY	RICHARD	MILSEARCH PROPRIETARY LIMITED
LT	FENTON	WILLIAM	EODMU TWO DET NEWPORT
MR.	FERNANDEZ	HERBERT	NEW MEXICO INSTITUTE OF MINING
CAPTAIN	FICK	RUDI	FEDERAL MINISTRY OF DEFENCE
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MR	FLORY	ROBERT	APPLIED RESEARCH ASSOC. INC.
MR.	FOGLIETTA	JAMES	WYLE LABORATORIES
MR.	FORDHAM	THOMAS	TRW SS/M
MR.	FORSYTHE	FRANKLIN	UNIROYAL CHEMICAL COMPANY, INC.

1LT	FORSYTHE	MICHELLE	51 WING/SEW
MR.	FOULK	DAVID	U.S. ARMY DEFENSE AMMUNITION CENTER
MR.	FOWLER	NORM	HQ AFESC/DEMM
MR.	FRAY	ROBERT	BALLISTIC RESEARCH LABORATORY
MR.	FREIMANIS	ALVIS	KNIGHT ARCHITECTS ENGINEERS
CAPTAIN	FREITAS	ANTONIO	COMANDO OPERATIONAL DA FORCA AEREA
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MR.	GILL	RANDOLPH	US ARMY COMBAT SYSTEMS TEST
MR.	GLAD	THOMAS	GENCORP AEROJET
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MR.	GOOLD	JOHN	INSTITUTE OF EXPLOSIVES ENGINEERS
MR.	GORDON	D.	IRECO, INC.
MR.	GORDON	WALT	STRATEGIC WEAPONS FACILITY, ATLANTIC
MR.	GORDON	REX	SUPPRESSION SYSTEMS ENGINEERING, INC.
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MR.	GUENNEL	RANDOLPH	380TH AIR REFUELING WING
MR.	GUERKE	GERHARD	ERNST INSTITUT
MR	HAGER	KEVIN	NAVAL CIVIL ENGINEERING LAB
MR.	HAGGARD	PAUL	MASON & HANGER ENGINEERING INC.
MR.	HAINES	ROBERT	IOWA ARMY AMMUNITION PLANT
MR.	HAINS	DAN	NAVEODTECHCEN
MR.	HALL	JACK	SUNFLOWER ARMY AMMUNITION PLANT
MR.	HALL	THOMAS	BATTELLE PANTEX
MR.	HALSEY	CARL	NAVAL AIR WARFARE CENTER
MR.	HAMILTON	JERRY	VITRO CORPORATION
MR.	HAMMEL-MUELLER	JUERGEN	HQ USAFE, PLANS & PROGRAMMING DIVISION
MR.	HAMPTON	ROBERT	NORTHROP CORPORATION-AIRCRAFT DIVISION
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MR.	HAMRICK	MICHAEL	BATTELLE-PANTEX
LT	HANEWICH	STEVEN	U.S. COAST GUARD
MR.	HANLEY	PETER	CANADA, EXPLOSIVES DIVISION
MR.	HARDIN	ROBERT	MISSISSIPPI ARMY AMMUNITION PLANT
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MR.	HARVEY	HARRY	HERCULES AEROSPACE COMPANY
MR.	HASAN	NAJMUL	THE RALPH M. PARSONS COMPANY
MR.	HASH	HARMON	USA COMBAT SYSTEMS ACTIVITY
MR.	HAWKINS	JERRY	CENTRAL AMMO MGMT OFFICE-PACIFIC
MR.	HAY	EDMOND	BUREAU OF MINES
SQNLDR	HAYDEN	ANDREW	RAAF TECHNICAL LISISON OFFICE NAVAIR
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MSGT	HAYES	ROBERT	EOD, RMD, SOMS
MR	HEATH	C.	DIRECTOR, SAFETY & ENVIRONMENTAL AFFAIR
MSGT	HEISE	DEAN	HQ AFSPAECOM

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MR	HENDERSON	JON	MINISTRY OF DEFENCE
MR.	HENDERSON	JIMI	DEFENSE CONTRACT MGMT DISTRICT WEST
MR.	HENDERSON	WILLIAM	NAVAL SURFACE WARFARE CENTER
MR.	HERRBACH	ALLAN	US DEPARTMENT OF ENERGY
MR.	HERRON	ROGER	U.S. ARMY BALLISTIC RESEARCH LABORATORY
DR.	HEWKIN	DAVID	MOD (UK) ESTC
MR.	HOFER	HERBERT	MINISTRY OF DEFENSE
MR	HOFFMAN	NORMAN	TECHNICAL ORDNANCE INC.
MR.	HOFFMAN	ROBIN	NAVAL AIR WARFARE CENTER
MR.	HOFFMAN	WILLIAM	NAVAL SURFACE WEAPONS CENTER
MR.	HOFFMAN	HARRY	JHU-CPIA
MR.	HOLLAND	LAURENCE	LOS ALAMOS NATIONAL LABORATORY
MR.	HOLLOWAY	BOBBY	VOLUNTEER ARMY AMMUNITION PLANT
MR.	HOWE	PHILIP	LOS ALAMOS NATIONAL LABORATORY
MR.	HUDSON	MELVIN	NAVAL SURFACE WARFARE CENTER
LT.COL	HUEHN	WILFRIED	GERMAN ARMY OFFICE
LTCOL	HUMPHREY	JAMES	US ARMY ARMAMENT, MUNITIONS,
MR.	HUNT	EDDIE	USASDC
MR.	HUNTER	DENNIS	NEW MEXICO INSTITUTE OF MINING
MR.	HUSCHKA	HOWARD	DEFENSE CONTRACT MANAGEMENT DISTRICT
COLONEL	HUTCHINSON	ALAN	PRESIDENT, AUSTRALIAN ORDNANCE COUNCIL
MR.	HUTCHISON	KEN	WESTERN AUSTRALIA POLICE
MR.	HUTCHISON	VERL	US ARMY WHITE SANDS MISSILE RANGE
MR.	ISBELL	JOHNNY	ICI EXPLOSIVES, ENVIRONMENTAL
MR.	IWANCIOW	BERNARD	STONE ENGINEERING
MR.	JACOBS	EDWARD	INTEGRATED SYSTEMS ANALYSTS, INC.
MR.	JACOBSSON	LARS-OLOF	ROYAL SWEDISH FORTIFICATIONS
MR.	JAMIN	PIERRE	FRENCH MOD/DGA
MR	JENSSEN	ARNFINN	CHIEF, OF OFFICE TEST & DEVELOPMENT
MR	JENUS	J.	EXPLOSIVES HAZARD REDUCTION DIRECTORATE
MR.	JOACHIM	CHARLES	U.S. ARMY ENGINEER WATERWAYS

DR.	JOHN	CONNOR	MINISTRY OF DEFENCE
LTCOL	JONASSEN	KIELL	NORWEGIAN DEFENSE CONSTRUCTION SERVICE
MR.	JONES	STEVE	U.S. ARMY MATERIEL COMMAND
MS.	JONES	KATHRYN	LOS ALAMOS NATIONAL LABORATORY
MS.	JONES	PATRICIA	SENECA ARMY DEPOT
MR.	JONES	DONOVAN	TALLEY DEFENSE SYSTEMS, INC.
MR.	JORGENSEN		US ARMY DUGWAY PROVING GROUND
MR.	JOSEPHSON	LARRY	NAVAL AIR WARFARE CENTER
MR.	JOYNER	TAYLOR	TERA GROUP
MR.	KATSANIS	DAVID	SHIELDING TECHNOLOGIES, INC.
MR.	KEENAN	WILLIAM	NAVAL CIVIL ENGINEERING LABORATORY
MR.	KELLEY	PHILIP	BATTELLE PANTEX
GYSGT	KELLY	JOHN	EXPLOSIVE ORDNANCE DISPOSAL
DR.	KENNEDY	LYNN	S-CUBED, A DIVISION OF MAXWELL LABS
MR.	KERNEN	PATRICK	ORGANIZATION DUE TRAITE DE L'ATLANTIQUE
MR.	KERR	SCOTT	TALLEY DEFENSE SYSTEMS, INC.
MAJOR	KIEHN	ERNEST	2701 EXPLOSIVE ORDNANCE DISPOSAL SQDN
MR.	KIGER	SAM	WEST VIRGINIA UNIVERSITY
MR.	KING	JAMES	LOS ALAMOS LABORATORY, M-6
MR.	KINNISON	ROBERT	DCMAO DENVER
MR.	KLAPMEIER	KENNETH	DETECTOR ELECTRONICS CORP
	KLINE	LESLIE	U.S. ARMY CHEMICAL MATERIEL DESTRUCTION
MR	KNAPE	RALPH	U.S. ARMY ARMAMENT, MUNITIONS &
COLONEL	KNIGHT	JOHN	HQ AFSA/SEW
MR.	KOBAN	G	EODMU TWO DETACHMENT DAHLGREN
MR.	KODDE	HERMAN	VITRO CORPORATION
LTC	KONGEHL	H. F.	Bundesministerium der Verteidigung
MR	KRACH	FRED	EG&G MOUND APPLIED TECHNOGIES
MR.	KRAKE	JAMES	NAVAL SURFACE WARFARE CENTER
MR.	KRATOVIL	EDWARD	NAVAL SEA SYSTEMS COMMAND
MR	KRAUSE	WILLIAM	UNITED TECHNOLOGIES-ASD
MR.	KRAUTHAMMER	THEODOR	PENN STATE UNIVERSITY

MR.	KRIETZ	TERRY	DEPARTMENT OF ENERGY
MR.	KRISTOFF	F	Hercules Inc.
MR.	KUMMER	PETER	BIENZ, KUMMER & PARTNER LTD
SMSGT	KUNKLE	RONALD	HQ AFOTEC/SE
MAJOR	LAMBRECHT	MICHAEL	FIELD COMMAND DEFENSE NUCLEAR AGENCY
MR.	LAMY	PATRICK	FRENCH MOD/DGA
MR.	LANGBERG	HELGE	ESTABLISHMENT
MR.	LAVERENTZ	HAROLD	BLACK AND VEATCH
MR.	LAVERTU	ROGER	DEFENCE RESEARCH ESTABLISHMENT
MR	LAWRENCE	WILLIAM	BALLISTICS RES. LABORATORY
MR.	LEACH	GLENN	HQ AMCCOM, SAFETY OFFICE
MR.	LEANDER	RICHARD	THIKOL CORPORATION
MR.	LEATHAM	SCOTT	DEFENSE CONTRACT MANAGEMENT COMMAND
MR.	LEDERER	JOHN	DIRECTORATE OF NUCLEAR SYSTEMS
MR.	LEE	J.	AGENCY FOR DEFENSE DEVELOPMENT/KOREA
MR.	LEE	BENJAMIN	NAVAL AIR WARFARE CENTER
CAPTAIN	LEE	DIANA	VANDENBERG AFB
CAPTAIN	LEE	TIONG HUA	HQ SUPPLY & TRANSPORT
MR.	LEGALUPPI	MARCO	WHITNEY, BAILEY, COX & MAGNANI
MS.	LEGALUPPI	CRYSTAL	PM CHEMICAL DEMILITARIZATION
MR.	LEK	HUAT LEE	CHARTERED INDUSTRIES OF SINGAPORE
MR.	LEROUZES	GILLES	ICI EXPLOSIVES CANADA
MR.	LEWIS	BUD	KANSAS ARMY AMMUNITION PLANT
MR.	LIBERMAN	PAUL	NATIONAL TECHNICAL SYSTEMS
MR.	LIM	CLIFFORD	EXPLOMO TECHNICAL SERVICES, LTD
MR.	LIM	KONG HING	NO.80, GENTING LANE
MR.	LIN	JACK	NATIONAL TECHNICAL SYSTEMS, INC.
MR.	LIND	LARRY	WESTNAVFACENGCOM
MR.	LINDELL	CARL	KDI PRECISION PRODUCTS, INC.
MR	LIPP	CURTIS	AEROJET PROPULSION DIVISION
MR.	LITTLE	THOMAS	COUNTY OF LOS ANGELES FIRE DEPT.
MR.	LOCKARD	MICHAEL	RED RIVER ARMY DEPOT
MR.	LONG	EVERETT	NAVAL AIR WARFARE CENTER
MR.	LOWE	ALONZO	NAVAL SEA SUPPORT CENTER, ATLANTIC

MR.	LOYD	ROBERT	US ARMY ARMAMENT, MUNITIONS &
MS	MACINTYRE	ANNETTE	LAWRENCE LIVERMORE NATIONAL LABORATORY
MR.	MACKENZIE	GERALD	STONE ENGINEERING COMPANY
MR.	MAGNANI	RICHARD	WHITNEY, BAILEY, COX & MAGNANI
MR.	MAHANEY	KENNETH	MOTSU (META-SU-SAS)
MR.	MAIRANTZ	BENNY	B. MAIRANTZ CONSULTING ENGINEERS
MS.	MALONE	DOROTHY	MCALESTER ARMY AMMUNITION PLANT
MR.	MANNSHRECK	WILLIAM	NAVAL SAFETY CENTER
MR	MANTHEY	J.	US ARMY CORPS OF ENGINEERS
MR.	MAPLE	GARY	900 E. CAMINITO MADRIGAL
SMSGT	MARSH	JOHN	3246 EQUIPMENT MAINTENANCE SQUADRON
MS.	MARTIN	SUSAN	ATLANTIC RESEARCH CORPORATION
CAPTAIN	MARTIN	MARK	HQ, AIR COMBAT COMMAND
MR.	MARTIN	ELLIOTT	US ARMY TOXIC & HAZARDOUS MATERIALS
MS.	MASSIE	JOYCE	EG&G MOUND APPLIED TECHNOLOGIES, INC.
CAPTAIN	MATTERN	STEVEN	ASC/NA
DR.	MAURITS	WILLIAM	
MS.	MCBRIDE	CLAIR	US ARMY DUGWAY PROVING GROUND
MR.	MCCLELLAN	JAY	NAWC WEAPONS DIVISION
MR.	MCCLESKEY	FRANCIS	BOOZE, ALLEN & HAMILTON
MR.	MCCLURE	GERALD	AEROJET ELECTRONIC SYSTEMS DIVISION
MR.	MCCORMICK	BILL	LOS ALAMOS NATIONAL LABORATORY
MR.	MCDANIELS	E.	E.O.D. WORLD SERVICES, INC.
MR.	MCDONALD	JACK	DCMAO SAN ANTONIO
MR.	MCENTEE	ROGER	NAVAL WEAPONS CENTER
MR.	MCFALL	LARRY	U.S. ARMY LABORATORY COMMAND
MR.	MCGRAW	R.	ENSIGN BICKFORD AEROSPACE COMPANY
MR.	MCINTOSH	ALVIN	00-ALC/SEW
MR.	MCKENZIE	ALLAN	UNITED TECHNOLOGIES/CHEMICAL
MR.	MCLAIN	JOHN	NEW MEXICO INSTITUTE OF MINING
MR.	MCNEIL	DOYLE	AEROJET PROPULSION DIVISION
MS.	MCNULTY	SUZANNE	MENDES & MOUNT

MR.	MCPHERSON	DARREL	U.S. DEPARTMENT OF ENERGY
MR.	MCQUEEN	JERRY	MOTOROLA INC.
MR.	MELSER	CHARLES	DEFENSE CONTRACT MGMT DISTRICT WEST
DR	MERRIFIELD	R.	TECHNOLGY DIVISION
MR	MERRILL	CLAUDE	OL-AC PL/RKCP
LTCOL	MEYER	WALLACE	825 BRENTWOOD PLACE
MR	MEYERS	GERALD	US DEPARTMENT OF ENERGY
MR.	MIKASA	GLENN	NAVAL WEAPONS STATION
MR.	MIKOLEIT	KURT	NAVAL SURFACE WARFARE CENTER
MR.	MIKULA	JAMES	U.S. ARMY ARDEC
MR.	MILLER	STEVE	UINIVERSAL PROPULSION CO.& INC
MR.	MILLER	STEPHEN	UNIVERSAL PROPULSION COMPANY, INC.
MR.	MILLER	PAUL	ALLIANT TECHSYSTEMS
CAPTAIN	MITTELMAN	GREG	AFMC, NUCLEAR SUPPORT OFFICE
MR.	MIXTER	HENRY	E.O.D. WORLD SERVICES, INC.
CAPTAIN	MONTANA	SCOTT	351 MW/SEP
MR.	MONTANARO	PAUL	NAVAL SURFACE WARFARE CENTER
MR.	MONTELEONE	PAUL	USARDEC
MS.	MONTROSS	JAN	SAFETY ENGINEERING
COMMANDER	MOODY	DEWITT	
MR.	MOOI	KOK HEONG	LANDS AND ESTATES ORGANIZATION
MR.	MOONEY	R.	TALLEY DEFENSE SYSTEMS, INC.
MR.	MOORE	HAROLD	TECHNICAL ANALYSIS, INC
MR.	MORAN	EDWARD	DDESB
MR.	MORCOS	MICHAEL	NAWC-WEAPONS
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LTC	MORLEY	ALAN	UK ORDNANCE BOARD
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1LT	MUHL	GERALD	ESCORT & DISPOSAL DET
MSGT	MULDROW	JEFFERY	96TH WING WEAPONS SAFETY OFFICE
MR.	MURPHY	DAVID	LOCKHEED MISSILES & SPACE COMPANY, INC.
MR.	MURPHY	THOMAS	DEFENSE CONTRACT MGMT DISTRICT WEST
MR	MURTHA	ROBERT	NAVAL CIVIL ENGINEERING LABORATORY
MR.	MYERS	PAUL-REGIS	JOHN HOPKINS UNIVERSITY

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