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Techniques To Improve The Environmental Safety Of OB and OD Operations

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INTRODUCTION

During the Cold War, the United States of America, its allies and the former Soviet Union accumulated over 9,000,000 tons of conventional propellants, explosives (includes munitions) and pyrotechnic (PEP) materials. With the ending of the Cold War, the United States, as well as these other countries, are now faced with disposing of large inventories of unneeded or unserviceable PEP (energetic) materials in an environmentally sound manner. For example, the U.S. Department of Defense (DoD) has 450,000 tons in its "demil inventory" and this inventory has been increasing by 40,000 to 50,000 tons per year[1].

The three methods commonly used to dispose of unneeded PEP materials are: (1) incineration; (2) disassembly, recovery and recycling (DRC); and (3) burning or detonating in the open (OB, OD). Although, incineration and DRC are the environmentally-preferred methods disposal, they cannot presently be used on many of the items in the inventory for one or more of the following reasons. First, the composition is either unknown, unstable, obsolete or has degraded. Second, they cannot be safely disassembled. Third, the financial and environmental expense of developing a recovery and reuse technology for them cannot be justified based on the quantity in the demil inventory or the commercial value of the material that would be recovered. For these materials, OB and OD are the only disposal techniques currently available and, thus, they continue to be an integral part of all nations PEP demil programs.

The disposal of PEP materials by OB and OD is regulated under Subpart X of the Resource Conservation and Recovery Act (Subpart X of 40CFR264)[2]. A Subpart X permit is required for OB and OD because of concerns about: (1) the degree to which they convert PEP materials to innocuous chemicals; (2) the toxicities and dispersion in the environment of the ash, soil and chemical pollutants released; and (3) the impact of the blast waves and sound waves released. Because of these concerns the Subpart X permits that have been issued are very restrictive in terms of the meteorological conditions under which OB and OD can be carried out and the quantities that can be destroyed at one time, and over selected periods[2]. For example, at many DoD facilities, the Subpart X permit requires the facility to bury the munitions under one to three meters of soil before they are detonated. This mitigates the blast noise and blast effect. However, burial likely increases the quantities of potentially dangerous chemicals released because it reduces the O2 available for combustion of the molecular fragments released by the detonation. Burial also increases the dirt and dust lofted into the air. Such restrictions have contributed to the increase in the demil inventory[1].

To obtain a Subpart X permit, a facility must, at a minimum, provide the following information to the regulatory agency. First, the identity and quantities of pollutants and debris that will be released per event and over time. Second, the intensity of the blast waves and sound waves that will be generated. Third, a description of how these pollutants, debris, blast waves and sound waves will be distributed in the environment. Fourth, the degree to which the health of humans and the environment may be endangered in the short term (event basis) and over the lifetime of the OB and OD program.

Because OB and OD have been used to dispose of unneeded or unserviceable PEP materials for over 150 years, one might expect that it would be easy to compile this information. However, this is not the case, because OB and OD technologies have been developed almost exclusively through a "cut and try" approach, where the primary objective was to ensure that the PEP material is completely destroyed and noise is controlled. There was little concern about the pollutants released. Consequently, the dynamics of the OB and OD processes are not well-characterized and the technology is not optimized to ensure that all the energetic material is converted to innocuous compounds.

The project described in this paper is developing computational and experimental methods to identify and quantify the emission products released by OB and OD activities as a function of such variables as: type and quantity of energetic material; stacking configuration; site geology and meteorology; and pollutant and noise reduction procedures. Its objectives are: (1) to obtain an understanding of the chemical and physical processes which occur when PEP materials are destroyed by OB and OD; (2) to combine this information with that from previous studies to develop methods that minimize and control the noise, heat, shrapnel, blast wave and toxic inorganic and organic compounds released by OB and OD activities; (3) to modernize the OB and OD technologies; and (4) to expand the range of meteorological conditions and locales where OB and OD can be carried out.

If these objectives are accomplished, OB and OD technologies could be environmentally safe methods to destroy large quantities (tons) of PEP materials over short periods of time and on a routine basis, while also protecting the health of humans and ecosystems. This will allow DoD to reduce substantially the demil inventory to a manageable level through a balanced demil program and at a much lower cost per ton than that for the current technologies.

This OB and OD characterization emissions project is being directed by Dugway Proving Ground (DPG) with financial support from DoD's Strategic Environmental Research and Development Program (SERDP) and technical support from the United States Naval Research Lab (NRL), Lawrence Livermore National Lab (LLNL) and the Office of Research and Development of EPA (EPA/ORD).

HISTORICAL BASIS FOR OB AND OD CHARACTERIZATION

Earlier Studies

In 1989-1990, the U.S. Army detonated 225 g quantities of TNT, RDX, Explosive D and Comp B and burned 2 kg quantities of M-6 propellant, M-1 propellant, and a triple-based propellant in a 950 m3 chamber and determined the identities and concentrations of the compounds emitted[3,4]. The chamber was located at Sandia Laboratories in Albuerquerque NM. The following classes of compounds were measured: inorganic gases (CO2, CO, NO, NO2, O3, HCN); particles; volatile organic compounds (VOC); and semivolatile compounds (SVOC).

The emission factors (the ratio of quantities of compounds released to the quantities of the PEP material detonated or burned) obtained in the tests at Sandia were then compared to the emission factors obtained when 900 kg of the same explosives were detonated and 3,200 kg of the same propellants were burned in the open at DPG, UT in 1989-1990[5]. Most of the detonations at DPG were done with the explosive on the ground, but some of the TNT detonations were also done with the TNT suspended approximately 10 m above the ground; all burn tests were done with the propellant in steel, open-top pans.

The test results showed that the identities and quantities (emission factors) of the compounds released during the chamber detonations and burns were very similar to those released in the field detonations and burns[2]. It was concluded that BangBox tests provided emission factors which are statistically equivalent to those from field tests. These studies also demonstrated that small scale chamber tests could be done at a fraction of the cost required to conduct field tests and that the BangBox results could be interpreted as upper bounds on the emission factors.

Acceptance Of the Methodology By USEPA

In 1991, the U.S. Army submitted their results to the USEPA with the recommendation that they accept the emission factors obtained from chamber tests as being equivalent to those that would be obtained from detonating and burning much larger quantities of the same materials in the open. In 1992, the EPA concurred with this recommendation This concurrence was a major boost to DoD's efforts to determine the emission products from OB and OD activities on PEP materials. Using chamber studies to simulate field test results provided the DoD the opportunity to: (1) characterize ten or more PEP materials at a cost comparable to conducting field tests on one PEP material; (2) collect sufficient sample to meet the minimum quantitation limits of the pollution measurement systems for the target compounds (analytes); (3) study the decay rates of the primary and secondary products released from detonations and burns; (4) minimize testing delays due to adverse weather conditions; and (5) obtain the minimum number of detonations and burns required to calculate statistically valid emission factors on each type of PEP material under repeatable and controlled conditions.

This last advantage is very important because it allows one to calculate the statistical uncertainty associated with each emission factor and, thus, to statistically compare the emission factors from different PEP materials or for the same material detonated or burned under different conditions. Thus, one can evaluate the affect that procedural changes have on the emission products released from OB and OD operations. For example, an underground detonation could be simulated in the chamber by detonating the PEP material in an O2-deprived environment. Similarly, the effect of adding an oxygen-rich substance with the PEP material to be detonated could be simulated in the chamber by using an O2-enriched atmosphere.

Computational Fluid Dynamic (CFD) Assessments of Detonations and Burns

The flexibility, speed, scalability and multiphase, reactive flow capabilities of CFD modeling make it an ideal tool to study the processes that occur in detonations and burns. Time-dependent CFD has been applied to: nuclear blasts and detonations; flow-structure and shock-structure interactions such as flows involving ships, planes, submarines, buildings and ground topography; the interaction of blasts with objects; multiphase and reactive effects in underwater blasts; safety and hazard evaluations; fire initiation, propagation, and quenching; design of propulsion devices such as ramjets and scramjets; and inertial confinement fusion[6].

In 1995, DPG funded scoping studies[7,8] to assess the value of applying CFD to the open-air detonation and open-air burning of PEP materials. It was concluded that CFD could be used effectively with BangBox tests and the air pollution dispersion models being developed in another SERDP project to: (1) gain an understanding of OB and OD process dynamics; (2) modernize these technologies; and (3) determine accurately such parameters as initial buoyancy of the plume, the propagation and intensity of the blast wave, the type and amounts of pollutants released and the plume dimensions as a function of time, model confinement and mitigation strategies.

Two CFD programs, FAST3D[7] (a DoD-developed program) and ALE3D[8] (a DOE-developed program), were selected for use in this study. These CFD programs have had extensive use in solving three-dimensional, time-dependent, compressible, multiphase, reactive-flow problems in geometrically complex configurations similar to those which occur when a PEP material is detonated. They have been optimized to run on computers ranging from work stations to massively parallel supercomputers. One of them, FAST3D, was selected as one of the CFD projects in the DOD Common HPPC Support Software Initiative (CHSSI) and will be made generally available in the DOD software library to all DOD personnel.

EXPERIMENTAL

Description Of DPG BangBox Facility

In 1993, the U.S. army constructed a 950 m3 chamber at DPG (Figure 1) similar to the one at Sandia Laboratories and installed the pollutant sampling instrumentation which had been developed and validated during the earlier study. This facility (BangBox) sits on a concrete pad and has two sections: an inflatable, 16 m diameter hemisphere (test chamber) made from plastic-coated nylon fabric and a 5.5 x 2.1 x 2.5 m building (airlock) made from plywood. The test chamber is kept inflated by a blower with its volume maintained at approximately 950 m3 by adjusting a damper at the outlet to the blower. Air is circulated in the test chamber by six fans spaced 60 degrees apart. Presently, the test chamber contains the following pollutant sampling equipment: three high volume samplers for collecting total particulate, metals and selected semivolatile organic compounds (SVOC); a TEOM PM-10 automated particle sampler and three high volume based PM-10 samplers for measuring particles in the inhalable range; and three EPA semi-VOST samplers for collecting selected SVOC and volatile organic compounds (VOC). It also contains a "suppressive shield" (to permit detonating fragment/shrapnel-generating PEP materials in the chamber) constructed from 5.1-cm angle iron and a pollutant gas sampling probe which exits into the airlock. The maximum net explosive weight, NEW, of PEP material which can be detonated in the test chamber is 225 g and the maximum quantity of PEP which can be burned is 2.2 kg.

The airlock contains the following pollutant sampling equipment: CO2, CO; O3; NO; NO2; HCl; HCN; and canisters (for VOCs, CO2 and CO). Passage into the test chamber from the airlock is through a power-operated door; this door is closed when testing is being conducted.

PEP Materials Tested In The BangBox In 1993-1995

Seventeen propellants, 12 explosives and 3 pyrotechnics commonly found in the demil inventory were tested in 1993-1995. The 17 propellants and 3 pyrotechnics were burned and the 12 explosives were detonated in a normal atmosphere, i.e., 21% O2.

The following special studies were also done: (1) burns of TNT, propellant manufacturing waste, diesel-soaked dunnage and impulse cartridges (ARN 446); (2) detonations of amatol (50% TNT : 50% NH4NO3 and tritonal (80% TNT : 20% Al) in contact with plastic bags containing 200 g of water; (3) detonation of tritonal in the presence of a small amount of calcium stearate (an inhibitor); (4) detonations of two synthetic explosive mixtures which approximated poorly prepared/degraded HBX; (5) release of HCl from a container while a propellant (M31A1E1) which did not contain chlorine was burned; and (6) a study to determine the applicability of an extractive FTIR systems (with a folded-optical path cell equivalent to a 100 m open path) for measuring inorganic gases and light hydrocarbon gases in the BangBox.

The TNT and impulse cartridge trial burns were done to compare the compounds emitted when explosives are burned to those emitted when they are detonated. Manufacturing waste was burned because this is the traditional means used to dispose of it and dunnage was burned because it is commonly used as an initiator when PEP materials are open burned.

The detonations of amatol and tritonal in the presence of water were done to provide preliminary emission factor data on a blast and noise suppression technique developed in the U.S.[9], and refined in Europe[10,11] and South Africa [12]. This technique, which involves detonating the munition with plastic bags containing water touching it, reduces the blast noise by more than 90% when compared to an equivalent unrestricted detonation[10]. However, the water also quenches the fireball which could reduce the overall destruction efficiency of the detonation process. Amatol and tritonal were selected for this experiment because they represent two extremes in the oxygen content of commonly used explosives. When detonated, amatol, an oxygen-balanced explosive, contains sufficient oxygen to convert its carbon to CO2, whereas tritonal contains only 20% of the oxygen required to convert all its carbon to CO2.

The HCl release was done to determine if HCl released when chlorine-containing propellants were burned was lost to the walls and floor of the BangBox. The FTIR study was done to determine if this multi-pollutant analyzer could yield improved data collection and quality with respect to the single-pollutant, inorganic pollutant measurement and the VOC measurement systems being used in the BangBox.

BANGBOX TEST RESULTS AND DISCUSSION

The TNT and impulse cartridge burns yielded emission factors for HCN, CO, particles and many SVOCs which were higher than those obtained when these materials were detonated. This was expected, because the quantities burned were small and combustion started slowly. Had larger quantities been burned, the emission factors would likely still be higher than for a detonation, but the differences would likely have been smaller.

The detonations of amatol and tritonal in the presence of water also yielded emission products for HCN, CO, VOCs and SVOCs which were markedly higher and CO2 emission factors which were lower than those resulting from the corresponding unrestricted detonations. Substantially more soot was also evident from the detonations in the presence of water compared to the corresponding unrestricted detonation. Relative to the corresponding unrestricted detonation, the emission factors for the oxygen-deficient tritonal changed considerably more than those for the oxygen-balanced amatol.

The results from the HCl release showed that HCl emissions could be measured in the BangBox. The results from the FTIR study indicate that the FTIR system had lower sensitivities than most of the single-pollutant analyzers already in use in the BangBox.

The results from these special studies and from the 32 PEP materials are now being compiled and statistically examined to determine if PEP materials can be classified into "emission product families" based on the chemical composition of the PEP material. The statistical analysis will also determine: (1) if the number of background samples and/or field samples collected for each PEP material can be reduced or should be increased; (2) if the target analyte list, sampling methods or the sample-collecting times should be changed; and (3) if there are artifact pollutants which should be removed from the test data. A database management system which will provide access to the BangBox data via DoD's Munitions Items Disposition Action System (MIDAS), is also being developed.

FUTURE EXPERIMENTS

The BangBox will continue to be used to characterize the emissions from PEP materials. However, as noted earlier, the maximum quantities of PEP materials which can be detonated and burned in the BangBox are 0.22 kg and 2.2 kg, respectively. While these limits are adequate for determining the chemical emission products from many of the small items in the demil inventory, they are inadequate for most of the large items (e.g., cluster bombs (CBUs), artillery shells and rocket motors). These latter items represent more than 70% of the items in the demil inventory. These weight limits and the construction materials of the BangBox also prevent us from determining the effectiveness of many of the procedures used or proposed for use in controlling the noise, blast effect, shrapnel and pollutants (e.g., soil particles, soot, chemical compounds, etc.) released by OB and OD operations.

Preliminary Design Of Large Detonation Chamber

We plan to characterize the OD emissions from some of these large items and emission control procedures using a large detonation chamber (ODOBi), which will be built at DPG in the summer of 1996. CFD modeling, the results from the BangBox studies and from other studies[9,10,11,13] are being used to design this facility which will take advantage of the incineration benefits from partially confining the plume with the fireball. As viewed from above, the ODOBi will likely be conical or octagonal in shape; stand approximately 9 m high and have a 1 to 3 m diameter opening at the top. A side view of an octagonal-shaped structure is given in Figure 2. The floor of the chamber will be a steel pan; the materials of construction for the sides have not yet been determined. The PEP material to be detonated will be lowered into the ODOBi by a crane and suspended approximately 2 m above the floor. The pan comprising the floor will contain approximately 0.25 m of water. The ODOBi will be sealable immediately after the detonation and it will have sampling ports for collecting plume samples. To protect the ground water, the ODOBi will be sited to ensure that any water that escapes from the ODOBi is collected. More details concerning the dimensions, materials of construction, operating procedures, will be available in April 1996.

Technologies To Be Studied In The ODOBi

We plan to evaluate the performance of the following technologies in the ODOBi.

Hydro Abrasive Cutting/Low Temperature Thermite Initiated Burning. The Defence Test and Evaluation Organization (DTEO) of the Defence Evaluation and Research Agency United Kingdom has developed a demil procedure which allows them to burn large quantities of munitions (e.g., 16 tons of bar mines at one time)[11,13,14]. They use this procedure when OD is not feasible because of noise concerns, the nature of the munition, etc. Their procedure involves the following steps: (1) the munition is cut into pieces (to expose the explosive) using a low pressure (3,500 psi) remotely-operated, hydro-cutting system Colt Industrial Services Ltd., Hull, U.K.); (2) the exposed explosive is then covered with plastic caps and moved to the burn site; and (3) the munitions pieces are then stacked together and one ot the pieces is ignited using low temperature thermite. (The thermite, which is manufactured by Disarmco, Barling Magnia, Essex, U.K., burns for 5 min. at 250ºC- a temperature below the detonating temperature of many military explosives.) DTEO has never had a spontaneous detonation occur with this procedure.

This technique has great potential for destroying large quantities of explosives located at bases and depots in close proximity to densely inhabited areas (such as the 231,800, 3.5-inch, HE, shaped-charge bazooka rounds at Seneca, NY), but first the emission products (e. g., unburned propellant, soot, HCN, SVOC, VOC and metals) must be determined to be within acceptable limits.

Use Of Water In Bags To reduce Noise From OD Activities. Salter and Parkes[10], Keenan and Wager[9], Barrett[12] and the DTEO[11] have shown conclusively that water can be used to substantially reduce the noise, peak pressure (blast wave), shrapnel travel and soil particles released when explosives are detonated. Salter and Parkes in cooperation with the U.K. Ministry of Defence have done extensive field tests on using water to mitigate the noise generated when large quantities of explosives are detonated in the open. They have developed a technology which involves covering the explosive to be detonated with either water-containing, polyethylene bags or with a thick water mist. (This technology is available from Dell Explosives, Edinburgh Scotland.) Preliminary BangBox tests, conducted with amatol and tritonal in DPG's BangBox, indicate that when the water-containing bags are in contact with the explosive, the combustion process is inhibited. However, others have shown[9,10,11] that some reduction in the noise, blast wave and shrapnel travel distance can still be obtained when an air gap exists between the water and the munition. Therefore, it should be possible to use water to achieve some reduction in the total emissions from OD operations. We plan to use CFD modelling with experimental confirmation in the ODOBi facility to develop an engineering model DoD and DOE facilities can use to customize this technology for use at their facilities.

Use of Ceramic Filters To Reduce Pollutants Released From OB And OD Operations. The DTEO (U.K.) has also developed a technology in which the PEP material is burned in an aerated steel cage with ceramic filter elements attached to the sides of the cage[11]. The ceramic filters are flexible and are contained in a modular system that is easily attached to the cage. The temperature achieved in the cage is high enough to destroy a large percentage of the VOCs and SVOCs, and the ceramic filters remove the majority of the particulate matter to approximately 10 microns. DTEO has successfully completed small scale prototype tests on this system and are now actively working on conducting full scale equipment and tests. To date only small quantities of a few PEP materials have been studied. We are arranging with the U.K. Ministry of Defence to bring this technology to DPG for further evaluation in the ODOBi or another DoD facility.

Assisted OB and OD Operations. The most commonly used procedure for "assisted OB and OD operations" is bundling. In bundling, an easy-to-detonate energetic material (donor charge), such as C-4, PETN or high density TNT block, is used to ensure the destruction of an energetic material which, by itself, is difficult to destroy by OD. Some of these latter PEP materials are: CBUs; improved conventional munitions (ICM); encapsulated PEP materials in which the propellant, the explosive or both are either unknown or have degraded; rounds in which the fuse cannot be removed; and colored smokes containing potentially carcinogenic dyes. The "assisting" energetic material, which is placed in contact with the "problem" material, produces temperatures and pressures sufficient to cause the "destruction" of the "problem" material. Another "assisted detonation/burn procedure" places an O2-enriched material (e.g., NaO2, O2-enriched air) in contact with the "problem" material to ensure the more complete destruction of the latter.

These and other "assisted" OB/OD procedures have been developed through "cut and try" approaches rather than from fundamental detonation and combustion theory. Assisted-destruction procedures hold great promise as a means to destroy the large quantities of degraded, damaged, PEP of unknown composition that are in the demil inventory and could provide a cost effective use for the explosives and propellants recovered from other items in the demil inventory. We plan to use CFD modeling in conjunction with chamber experiments to maximize the destruction efficiency of these procedures while protecting human health and the environment.

Engineering And Operation Models For Second Generation ODOBi

We anticipate that the DPG ODOBi detonation facility will also serve as the prototype for an OD and OB chamber which can be installed at any demil facility. This latter chamber will likely use a combination of the technologies evaluated in the ODOBi and CFD modelling to substantially reduce the noise, blast effects, entrained soil, shrapnel and potentially-toxic pollutants released when PEP materials are destroyed by OB and OD processes. Since this detonation chamber will be designed to hold the fireball in contact with the plume for a longer time than that which occurs when a PEP material is detonated in the open or underground, the destruction efficiency of the fireball will increase. We also anticipate that the use of this chamber will simplify modeling the emissions from OB and OD activities because plume rise and travel distance will be reduced and this should increase the frequency at which detonations can be conducted.

When used in conjunction with the air pollutant dispersion models and upper air meteorological measurement systems being developed in a companion SERDP project (# 96-251)[15], the engineering design and operation models developed in this project should allow the siting and permitting of above ground, full-scale OD activities even for facilities which are close to inhabited areas. Each DoD and DOE unit will be able to use these specifications and procedures to construct and operate detonation chambers customized for its own situation.

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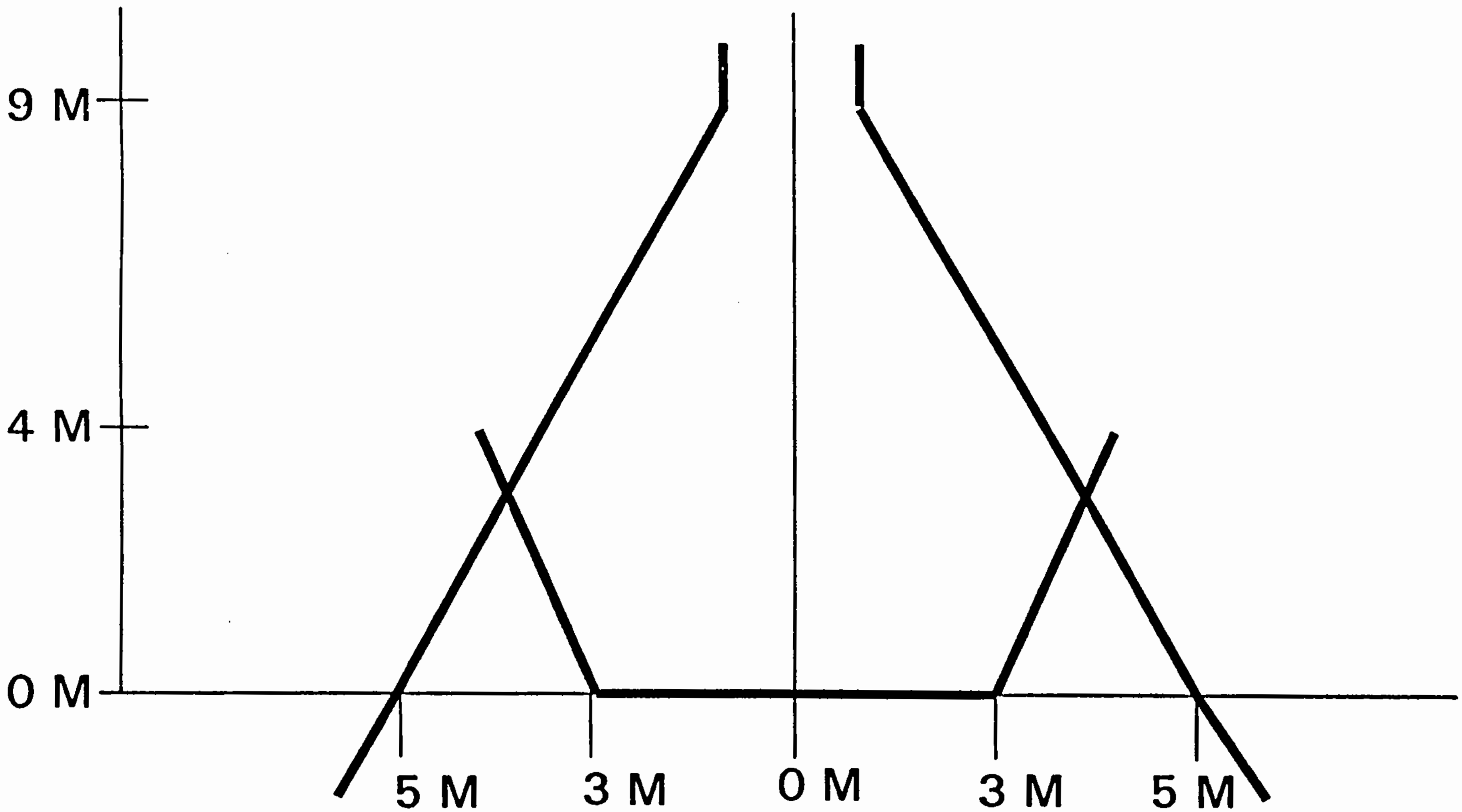
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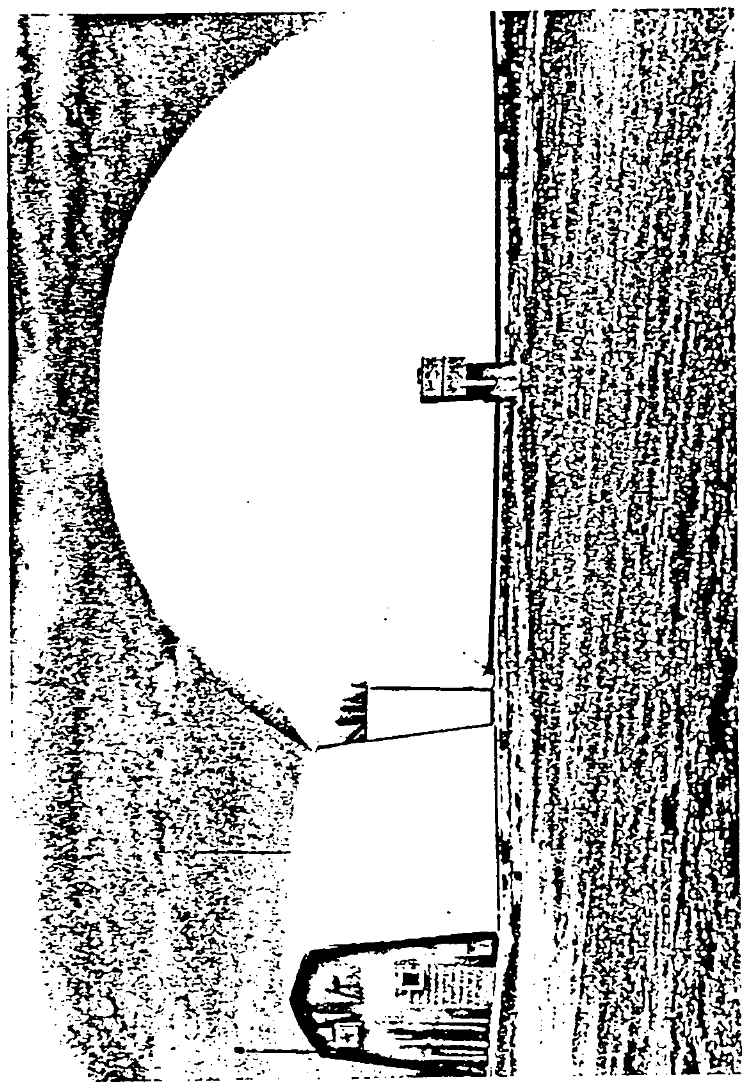

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16. ABSTRACT

This paper describes a RDT&E effort by the United States Army and Navy and the Environmental Protection Agency which is focused on reducing the noise, pollutants, entrained soil, blast wave and shrapnel released when conventional propellants, explosives and pyrotechnics (PEP) are destroyed by open-air burning (OB) and detonation (OD). This cooperative effort is using computational and experimental methods to identify and quantify the emission products released by OB and OD activities as a function of such variables as: type and quantity of energetic material; stacking configuration; site geology and meteorology; and pollutant and noise reduction procedures. Its objectives are: (1) to obtain an understanding of the chemical and physical processes which occur when PEP materials are destroyed by OB and OD; (2) to combine this information with that from previous studies to develop methods that minimize and control the noise, heat, shrapnel, blast wave and toxic inorganic and organic compounds released by OB and OD activities; and (3) to modernize the OB and OD technologies.

17. KEY WORDS AND DOCUMENT ANALYSIS

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