

**SERDP Munition Disposal Source Characterization
Pilot Study**

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September 1995

 Lawrence
Livermore
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Table of Contents

1.0	Background	2
2.0	Objective and Scope	3
3.0	Technological Approach	5
3.1	Attenuation of High-Explosive Detonations using Contained Water	5
3.2	Attenuation of High-Explosive Detonations using Aqueous Foam.....	6
3.3	Attenuation of High-Explosive Detonations using Wet Sand.....	9
3.4	Rapid Through-Put System.....	12
3.5	The Unconfined, Unmitigated Burn and Detonation	13
4.0	Numerical Model Development and Analysis	14
4.1	LLNL's Existing Sophisticated Physics Models.....	14
4.1.1	Modeling the Source Variation with Stacking Configuration and Timed Detonation or Burning	15
4.1.2	Modeling the Detonation and Burn Products	17
4.1.3	Modeling the Blast Wave and Cloud at Early Times with Mitigation Devices...	19
4.1.4	Dusty Boundary Layers from Explosions over Ground Surfaces	21
4.1.5	Dust/Gaseous Clouds from Explosions over Ground Surfaces.....	23
4.2	The Pseudo-Empirical Models.....	24
4.2.1	Pseudo-Empirical Model for Explosions with Noise and Shrapnel Mitigation Devices	24
4.2.2	Turbulent Dust/Gaseous Cloud Model.....	25
4.3	Summary of Numerical Modeling Schedule, Effort and Cost.....	25
5.0	Experiments for Model Validation and Field Testing of Each Technological Approach.....	27
5.1	HEAF Experiments.....	27
5.1.1	HEAF Facility	28
5.1.2	Scope of Work	29
5.2	Site 300 Facility	29
5.3	Big Explosives Experimental Facility (NTS)	30
5.3.1	Proposed Experiments at BEEF	32
6.0	Conclusions and Recommendations	33
6.1	Recommendations for Short-Term Effort	33
6.2	Recommendations for Long-Term Efforts	35
6.3	Conclusions.....	35

Appendix A: Work Plan for Pilot Study

Appendix B: Details on 3.5 inch Rocket

Appendix C: Detail information on the 10 kg spherical tank

1.0 Background

The Strategic Environmental Research and Development Program (SERDP) is supporting studies to develop and implement technologies for the safe, efficient, and environmentally sound disposal of obsolete munitions and propellants which are stored at various locations across the country. One proposed disposal technique is the open-air burning or detonation (OB/OD) of this material. Although OB/OD is viewed as an efficient and cost-effective method for reducing the inventory of unwanted munitions and propellants, questions regarding its safety and environmental impacts must be addressed.

The United States Army has 3.8 million tons of conventional weapons in its inventory. Approximately 400,000 tons of this inventory are excess, unserviceable and/or obsolete munitions and propellants including waste from the manufacture of munitions and propellants. The amount of excess munitions and propellants is also increasing by 40,000 tons annually.

Attempts to sell the excess inventory overseas has been unsuccessful. Many items in the inventory cannot be transported to facilities for destruction, and the facilities at which they are stored are facing closure. The traditional and currently predominant method for destroying munitions and propellants is OB/OD. To perform open-air burns or detonation at a U.S. facility, a permit issued by the U.S. Environmental Protection Agency (EPA) is required. These permits can be very restrictive. For example, in 1992, only 4 of 17 U.S. Army facilities could detonate more than 500 lbs and only 1 facility could detonate more than 3,000 lbs at one time. In several situations, populated areas have grown closer to the facilities so that toxic emissions, generation of shrapnel, and blast wave effects (i.e., noise and destructive effects) are of critical concern. Methods for reducing OB/OD emissions and shrapnel and mitigating the explosive blast must be developed to dispose of munitions at their storage site and for large-scale OB/OD (25-50 tons at a time).

EPA regulators currently have almost no means of assessing the effects of OB/OD. The issuing of EPA permits are largely based on extrapolation from small-scale detonations conducted in "bang-box" facilities or a few larger-scale open-air detonations. While these demonstrations largely validate certain aspects of the OB/OD technique, many questions regarding large-scale OB/OD cannot be answered in this way.

Experimentally validated and accurately predictive numerical models that produce data acceptable to Federal and State regulators would be a fast, convenient, and inexpensive means of evaluating a OB/OD method and determining site specific explosive limits to satisfy EPA requirements. Numerical models can also be design tools used, for instance, to choose stacking configurations, determine detonation requirements, and design blast mitigation and shrapnel reduction devices for the various types or classes of munitions.

Specific unanswered questions about large-scale OB/OD activities include the efficiency with which various munitions and propellants, some of which involve casings or packing materials, can be consumed. Other questions include the heat generated, its radiative loss, and the remaining energy available for plume rise. The entrainment of dust and the noise and destruction levels of a blast wave for varying amounts or types of munitions are also

of concern. Before operational permits can be issued, these important safety and environmental concerns must be resolved. An OB/OD Source Characterization Model is needed to address these safety and environmental issues and to provide bulk source terms (detonation products, the quantity of entrained dust, effective heat released, and initial cloud dimensions) for atmospheric dispersion models.

Since very large amounts of munitions and propellants must be consumed inexpensively in relatively short time periods and with the very restrictive Federal and State regulations on environmental issues, it is clear that traditional OB/OD procedures will *not* be acceptable and that it is necessary to develop modified or advanced OB/OD technology. The effectiveness and environmental impact of the OB/OD technology must be verified by experimental data and with validated numerical models for acceptance by Federal and State regulators. Specifically, technology must be developed and tested that minimizes

toxic burn and detonation products
the noise (peak pressure) and destructive effect (impulse) of the explosive blast
generation and travel distance of shrapnel, and
entrainment of dust.

To reduce the need for extensive testing for each OB/OD disposal scenario and to provide a design tool for the technology development, a numerical modeling capability is needed.

2.0 Objective and Scope

In the work plan for this pilot study, which is included in Appendix A, the pilot study objective and tasks are stated as follows:

The SERDP munition disposal source characterization pilot study is needed to evaluate available models that could, with modification, become an OB/OD Source Characterization Model. The pilot study includes several tasks as detailed below:

- a. *Task 1. Survey Available Models. Review available literature on relevant models and evaluate the capability of these models to address OB/OD issues.*
- b. *Task 2. Modeling Requirements Definition. Define model deficiencies and provide recommendations on whether or how to proceed with the development of an OB/OD Source Characterization Model, along with time and cost estimates for accomplishing this task. This should be accomplished in coordination with the contract monitor, who will provide information on the specific bulk source terms needed for input to the OB/OD dispersion model.*

The deliverable for the pilot study is a report that addresses these two tasks.

As we became more involved with the pilot study, it was clear that the traditional OB/OD approach of detonating munitions on bare ground without mitigation devices may be inadequate for large-scale OB/OD at most of the current storage facilities. To quickly, conve-

niently, and inexpensively reduce the excess inventory, an environmentally safe method for large-scale and/or rapid consumption of excess munitions and propellants by OB/OD must be developed. The effectiveness and environmental impact of the OB/OD technology must be verified by experimental data and with validated numerical models. The numerical models must be sophisticated enough to simulate the effects of various munitions as a function of quantity, stacking configuration, detonation or burn timing, blast mitigation techniques, and shrapnel reduction devices. These models must also be validated by experiment and the OB/OD method of choice should be field tested. Therefore, with the permission of our SERDP sponsors, we have expanded the pilot study to include not only the identification of numerical models and their deficiencies for the traditional OB/OD approach, but we also propose various advanced OB/OD approaches with optimized configuration and detonation methods, blast mitigation, and shrapnel and emission reduction techniques. In addition, we have included a description of the needed experimental data for validation of numerical models and method field testing.

We were directed by our SERDP sponsors to breakdown the required effort and cost for code development into deliverables for 6 months and 1 year project durations for costs of \$250K, \$500K, and \$750K, and to also project long-term efforts. Since the expanded scope of the pilot study includes the proposal of several advanced OB/OD technologies, we have also included effort and cost estimates for technology development, experiments for model validation, and experiments for field testing the advanced OB/OD technology.

The best method of OB/OD most likely will vary for each type and class of munition and will also be dependent on the OB/OD site. To make the most significant impact, we propose in our first year effort to develop the technology and numerical modeling capability for OB/OD of the most abundant types or classes of munitions that *must* be open burned or detonated. The developed technology and numerical models may also be applicable to other types and classes, but the applicability will require further study beyond the one year effort.

Our SERDP sponsor, Dr. Bill Mitchell, has identified the 3.5 inch rocket as the munition that should be considered in our first year effort. Figure 1 is a cut-away view of the rocket showing that it is composed of a copper liner, high explosive, and solid propellant in a metal casing. Details on the rocket design are included in Appendix B. The rocket can not be dismantled, but if necessary, it would be possible to divide them in half lengthwise for burning or detonation.

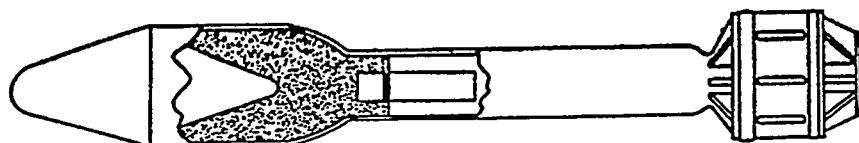


FIGURE 1. Sketch of 3.5 inch rocket.

It should be emphasized that this report documents our pilot study results and is *not* a formal proposal for work. We have included effort and cost estimates for proposed activities,

but a formal proposal reviewed and accepted by the Department of Energy (DOE) would be required before we could proceed with any of the proposed tasks. Depending on the decisions of our sponsors, Dugway Proving Grounds and Dr. Bill Mitchell of the EPA, we can submit formal proposals for any part or all of the herein described activities.

3.0 Technological Approach

The following sections include descriptions of four advanced technological approaches for OB/OD. Also included as a fifth option is the traditional OB/OD approach that is an unconfined, unmitigated burn and detonation. However, we include some suggested modifications to the traditional approach to minimize environmental impact and blast effects.

The objective for each approach is to cost effectively and conveniently mitigate the air blast wave, minimize the environmental impact, and confine shrapnel while fully consuming the maximum amount of munition. Required technological developments which are common to each of the approaches include the

- development of timed burning or detonation techniques,
- determination of optimum stacking configuration/geometry, and
- determination of the effectiveness of each method with quantity or type of munitions (i.e., scaling issues).

The choice of approach will depend on the class or mixture of munitions and the OB/OD site and its proximity to populated areas.

3.1 Attenuation of High-Explosive Detonations using Contained Water

It is possible to attenuate the noise and pressure resulting from high-explosive detonations using water-filled plastic or canvas containers surrounding the charge(s) (S.H. Salter and J.H. Parkes, "The Use of Water-Filled Bags to Reduce the Effects of Explosives," Department of State Conference, Miami, August 1994). Figure 2 shows a typical stack of water bags. The explosive energy is partially absorbed by work performed against the inertia of the water mass, and partially by heating the water to the vaporization point. A significant amount of mixing of the heated water/steam and the surrounding air occurs as a result of the detonation, which absorbs energy due to entropy creation. This air/water mixture can better attenuate shock and sound propagation speeds due to the low shock/sound propagation speeds in the mixture. These speeds can be reduced by several orders of magnitude from the sound speeds in water or heated air alone. The minimum shock and sound propagation speeds occurs at approximately a 50% mixture of water and air, but depends on the confinement and proximity to the charge and, therefore, on the time from detonation. One possibility for increasing the amount of air mixed into the attenuating water system is to use high pressure water jets from continuously-supplied hoses or propellant-driven mortars to shower the charge(s) with finely-divided water droplets (Figure 3). Optimal mixing of water and air using aqueous foam probably provides the best blast and sound attenuation (see Section 3.2), but a combination of water containment, water jets, and foaming might be suitable for some applications.

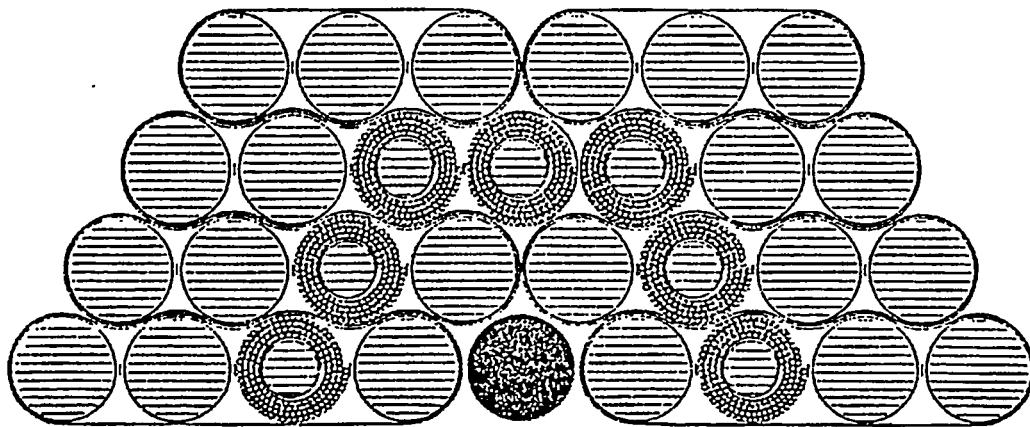


FIGURE 2. A typical stack of water bags including air spaces to increase surface area and delay the shock fronts. The very small gas volumes have a profound effect on the speed of sound.

The water containers can be purchased commercially or fabricated from plastic sheeting for minimal cost (i.e., \$10/m²). The containers can be assembled quickly and require only a continuous water supply to setup the attenuator system. Loading and stacking of the water containers requires some care due to the weight of water per bag and the tendency of the bags to roll. Water jetting can be accomplished using standard "fire hose" technology. Staging explosive detonations so that they occur at slightly delayed times (i.e., a few milliseconds delay) could allow very large amounts of munitions to be destroyed with little additional environmental impact while increasing the temperatures for volatile compound disintegration and increasing the sound attenuation by providing more thorough mixing of water and heated product gases.

3.2 Attenuation of High-Explosive Detonations using Aqueous Foam

For nearly two decades, aqueous foams have been employed to attenuate noise and reduce blast and shrapnel from high explosive detonations (D.A. Dadley, E.A. Robinson, and V.C. Pickett, "The Use of Foam to Muffle Blast from Explosions," IBP-ABCA-5 Conference, June 1976, and R. Raspet and S.K. Griffiths, "The Reduction of Blast Noise with Aqueous Foam," J. Acoust. Soc. Am 74 (6) (1983) 1757-1763). The primary mechanism of energy attenuation is strong-pressure-wave decay due to irreversible energy and momentum transfer between the air and water in the foam, i.e., the breakup of the foam absorbs blast energy in the form of heat. This is also partly due to the low sound speed relative to that of the pure air or water components. This mechanism depends only on the foam density and not on the details of the foam structure.

Experimental tests of this technology have been carried out on high-explosive charges weighing from 0.06 kg up to 100 kg (220 lbs). The general method involves containing the charge in the center of a plastic or canvas tent supported by an outer metal or plastic frame (Figure 4). The cylindrical or cone-shaped tent dimensions are typically 20 m in diameter at the base and 8 m high (approximately 90,000 ft³ volume). The tent is filled with water-

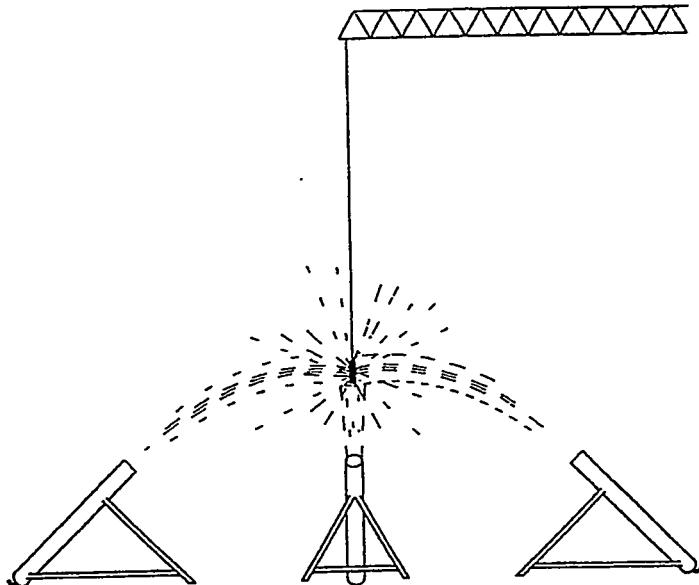


FIGURE 3. Water can be thrown at a suspended charge by injecting propellant fuels into the breech of a mortar tube. The necessary pressure is far below anything needed for a gun.

based foam using commercially-available foam generators in concentrations typically between 30:1 to 250:1 air:water volume ratio, which corresponds to air:water mass ratios of 0.04 and 0.32, respectively.

Results for a 100 kg high-explosive charge tested in the above described configuration resulted in a peak pressure of approximately 1 psi outside the foam tent. The standard safe overpressure/noise exposure for explosive blasts with no ear protection is 0.5 psi. Based on this criterion, the 100 kg blast can be considered to have been completely contained, and the noise impact to the surrounding environment was minimal. The tent material was intact after the blast and could have been used again. Furthermore, this technique has been shown to be effective at entraining aluminum and steel shrapnel from detonating munitions. It is unknown how these results would scale to charges of much larger weight.

In order to reduce the shock strength (i.e., peak pressure and impulse) from open-air detonations of excess munitions and propellants, one must influence the effective energy E coupled into the blast wave. Simplistically, one can say that the blast wave pressure can be estimated from:

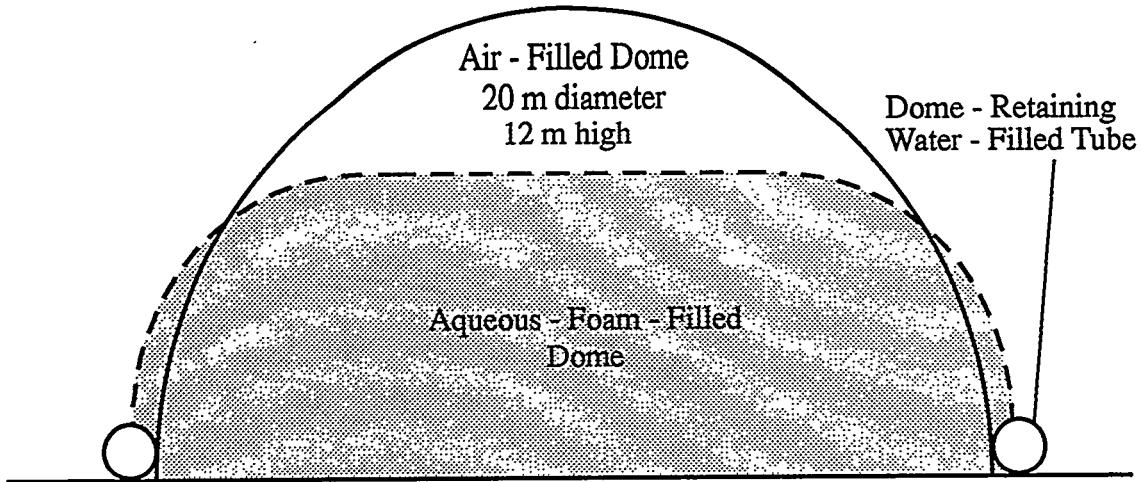


FIGURE 4. Conceptual design of aqueous foam tent showing configuration before and after fill.

$$p(t) \propto E/V(t)$$

where V denotes the volume within the shock front envelope: $V(t) \approx (4\pi/3)R^3(t)$ and R represents the shock front radius. Normally, E is equal to the sum of the chemical energy in the munition and the initiating charge. However, if the explosion occurs in an aqueous foam environment, then some of the blast energy is consumed in accelerating and vaporizing the foam droplets, and is therefore not available to drive the blast wave. Thus, the blast wave decays more rapidly, and the shock strength of the blast wave is reduced. However, based on the above relation, a large amount of foam will be required: if the foam mass is equal to the charge mass, then one can expect approximately a 25% reduction in the distance to a given shock strength level, while if the foam mass is ten times the charge mass, one can expect a factor of 2 reduction to a given shock strength level.

Extensive studies are available for predicting the shock strength from unconfined explosions (e.g., "Estimating Air Blast Characteristics for Single Point Explosions in Air, with a Guide to Evaluation of Atmospheric Propagation and Effects," ANSI S2.20-1983). However, the "N-wave" signature (i.e., the blast wave in the acoustic regime) from foam-suppressed explosions will be considerably different, and field tests are needed to accurately predict the shock strength from such non-ideal explosions.

The primary benefit of an aqueous foam attenuation system is the speed with which the containment tent and foam can be setup. The total setup time for the above experiment is estimated to be between 3 and 5 hours. The foam generators and tent materials are available commercially so that little development effort is required to field such an attenuation system. The foam generators and, possibly, the tent materials can be used many times. Some work is required to scale the approach up to charges of very large weight.

Sandia National Laboratory has developed a simple numerical model consisting of programs implemented on the TI-85 calculator that are designed to assist during containment planning associated with a nuclear emergency response incident (M.E. Larsen, "NEST

Containment Calculator," SAND 94-2030, November 1994). The programs estimate a) blast wave parameters of overpressure and specific impulse in aqueous foam and air systems, b) aerosol capture fraction associated with the implementation of an aqueous foam containment system, and c) water and foam concentrate requirements associated with a containment design. Use of the programs, their underlying models and algorithms, and their implementation on the TI-85 calculator are discussed in the above referenced report. The programs may be amenable to transfer onto a laptop or workstation computing environment. In any case, the information is available to design aqueous attenuator systems for very large charge/munition array.

3.3 Attenuation of High-Explosive Detonations using Wet Sand

When high explosives are detonated, the amount of sound which is audible surrounding the blast is determined by the wind and temperature distributions in the area up to about a 10,000 ft altitude. For example, at Lawrence Livermore National Laboratory's (LLNL) Site 300 Explosives Testing Facility, consideration of the noise and destructive impact on the neighboring community of Tracy, California, located approximately 10 miles to the east, limits the weight of high explosives that may be detonated in a given experiment. The maximum allowable weight of explosive detonation is administratively limited to at least a factor of ten below the weight at which pressures can become damaging to any structures and a factor of two below the weight at which the sound might become a nuisance as determined by continuous monitoring of microbarographic instruments stationed in the Tracy area. All experiments carried out at Site 300 must conform to this weather-determined high-explosive weight limit.

In some instances, it is desirable to carry out experiments without regard to weather conditions either because weather-related delay would compromise the experiment or because high explosive weights in excess of the weight limit are required. In these cases, LLNL has developed an attenuation system which allows detonation of high-explosive charge weights larger than weather conditions would normally allow (R. K. Mullins and L. M. Erickson, "Sound Forecasting and Attenuation Procedures for Site 300," January, 1965). The attenuation system was constrained to meet the following conditions:

- It must tie into the existing weather rules;
- The expense must be reasonable;
- The attenuator must be portable, or able to withstand multiple shots;
- The design should allow for rapid deployment and set up;
- It must be compatible with existing bunkers and diagnostics;
- High explosive charge weights up to 1000 lbs should be sufficiently attenuated.

A silo structure, with a central chamber for the high explosives surrounded by a suitable muffling material, was found through experimentation to best satisfy these constraints. Several muffling materials were tested. The most effective was wet sand, which is also inexpensive and easy to handle. Since wet sand has greater mass than aqueous foam, it

should be more effective in containing shrapnel. However, its actual effectiveness at reducing shrapnel will need to be demonstrated.

Experiments were carried out to validate the attenuation of this system using charge weights of 10, 50, 400, and 1000 lbs. Sizes of the central cylindrical chamber are shown in Table 1.

TABLE 1. Wet sand experimental chambers and tested explosive weights.

HE Weight (lbs)	Diameter (ft)	Height (ft)
10	2	2
50	3	3
400	6	6
1000	8	8

All charges were spherical with central detonation. Pressure sensors were placed approximately 100 ft from the shot center, and the pressure versus time history of the resulting shock wave was recorded. From these records, attenuations of both peak pressure and impulse were calculated, and the attenuation curves shown in Figure 5 were developed.

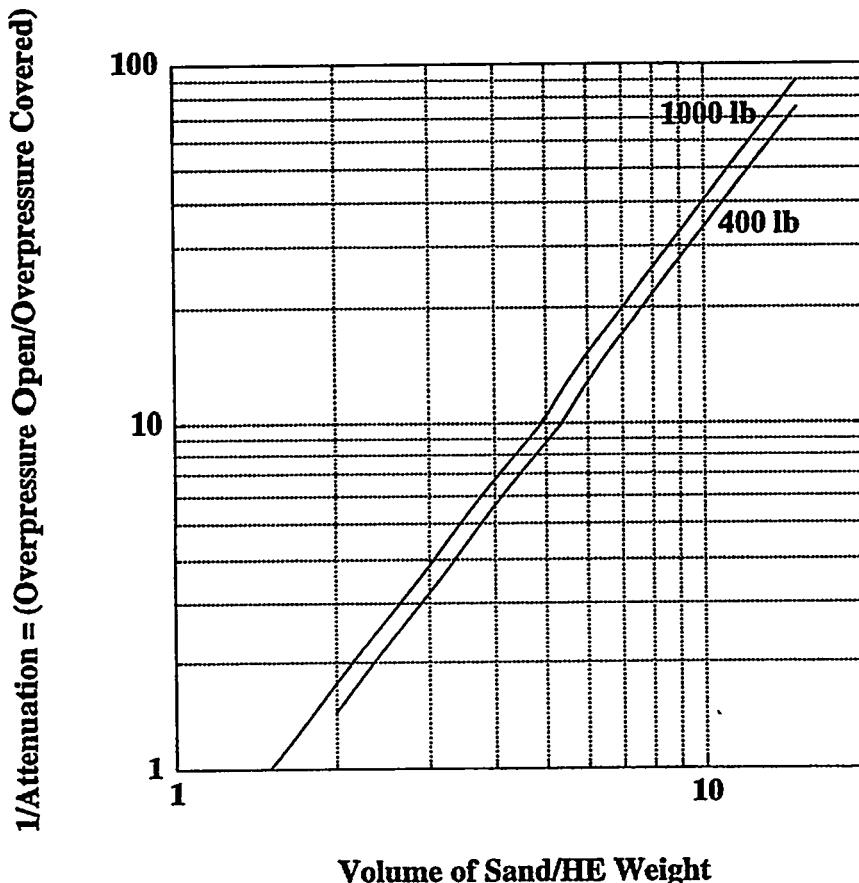


FIGURE 5. Attenuation curves for wet sand experiments.

The existing weather rules as developed by the LLNL Weather Department are embodied by the following formula:

$$\text{minimum inverse attenuation} = (10 \times W_1/W_2)^{1/2.5}$$

where W_1 is the experimental high-explosive charge mass, W_2 is the weather-dictated high-explosive weight limit, and 10 is a safety factor. The exponent is empirical and varies between 2.5 and 3.5 so that the above formula is very conservative. The formula and the attenuation curves can be used to predict the maximum high explosive charge weight that can be safely fired using wet-sand noise mitigation. To demonstrate the use of the above formula, we choose a criterion of $W_2 = 6$ lbs so that the explosive can be fired independent of weather, i.e., at Site 300, weather places no restrictions on shots up to 6 lbs. We will find the attenuation required to produce the equivalent noise as that of a 6 lb open detonation. The criteria can be modified according to the specific circumstances near the actual detonation site. Under this extremely conservative criterion, the minimum inverse attenuation required to detonate a 1000 lb high-explosive charge with no adverse noise impact is given by

$$\text{minimum inverse attenuation} = (10 \times 1000/6)^{1/2.5} = 19.4$$

which, according to the empirical curves, means that a 7000 ft^3 volume of wet sand is required. Using inner dimensions given in the above table for 1000 lbs, this corresponds to a structure with a total diameter of approximately 34 ft, which includes a 13 ft thick wet-sand-filled cylindrical container surrounding the inner 1000 lb charge. Such experiments have been carried out at Site 300 with considerable success. Without the factor-of-ten safety margin, the required volume of wet sand becomes approximately 4500 ft^3 , corresponding to a total container diameter of approximately 28 ft, i.e., 10 ft thick walls.

We can extrapolate to a 20,000 lb (ten-ton) detonation of high explosive contained within a 20 ft diameter by 20 ft high central cylindrical chamber based on the above data with the caveat that no experiments using this technology have yet been carried out that contained more than 1000 lbs of high explosive. The minimum inverse attenuation required would be

$$\text{minimum inverse attenuation} = (10 \times 20000/6)^{1/2.5} = 64.4,$$

which would require approximately $12,000 \text{ ft}^3$ of wet sand corresponding to a total silo diameter of approximately 34 ft with 7 ft thick walls. We expect these sample calculations to be upper limits; the optimum dimensions and size of the silos depends on the configuration, type, and amount of explosive to be detonated and on the specific conditions surrounding the detonation site.

Shown in Figure 6 is a conceptual design for a wet sand silo. The inner containers can be fabricated from standard corrugated metal drain pipe. The outer silo material can be made out of tunnel liner plate, which can be rapidly erected to almost any size required. Sand is readily available and can be loaded into the silo using a belt conveyor. A silo structure for

a 1000 lb detonation can be erected in about 2.5 days, which can be considerably shortened if sophisticated diagnostics and monitoring systems are not included inside the silo.

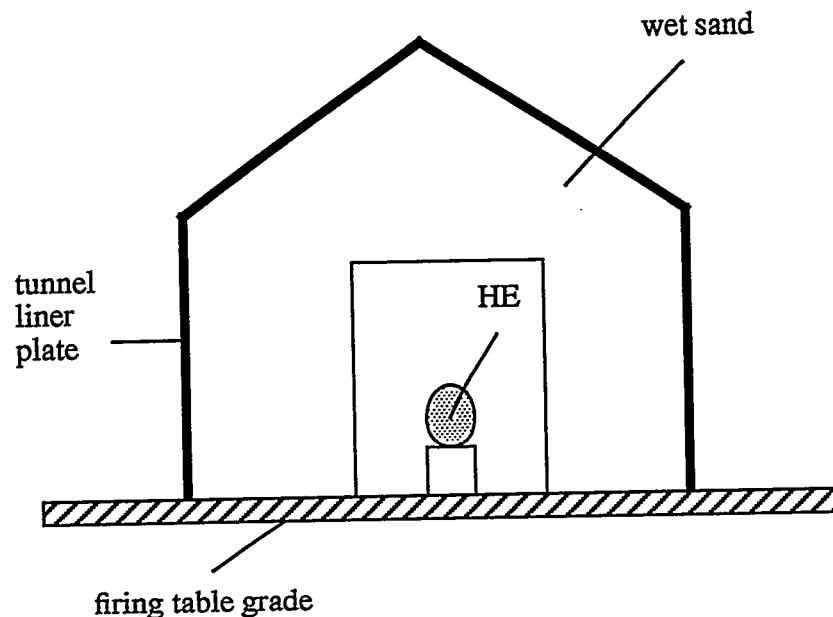


FIGURE 6. Conceptual design of wet sand configuration.

If wet sand proves to be too heavy or difficult to configure or transport for this use, we may want to consider a substitute material like vermiculite. Vermiculite is much lighter than sand, but should be just as effective at mitigating the blast wave and reducing shrapnel. British explosive experts have used vermiculite for blast mitigation with much success.

3.4 Rapid Through-Put System

In the previous sections, we presented systems that allow for large-scale OB/OD. In this section, we present ideas for a system with a rapid through-put of munitions with relatively small-scale detonations. The design criteria is still to mitigate the blast and shrapnel and minimize the environmental impact, but we also wish for the system to be reusable or even transportable for use at various locations. We envision that the system could be partially to fully confined for blast mitigation and shrapnel confinement.

A partially-confined explosion is one that occurs behind or within an obstruction like a barrier, cubicle, or a partial enclosure that interferes with the explosive shock wave and flying shrapnel. When an explosion occurs within a structure, the peak pressure from the initial shock wave and its subsequent reflections are imposed on the structure along with additional pressure due to the accumulation of explosive gases. Guidelines for designing 'fully-vented' and 'partially-vented' explosions can be found in publications such as "Structures to Resist the Effects of Accidental Explosions," Depts. of the Army (TM 5-1300), Navy (NAVFAC P-397), and Air Force (AFM 88-22), June 1969.

A fully-vented structure has one or more surfaces that would break away during the explosion and permit the blast wave to leave the structure and would also vent the explosive gases. Such break-away walls are called 'frangible' surfaces. Unfortunately, experiments have shown that structures with frangible walls generate blasts not too different from unconfined explosions. They also tend to have a shot-gun effect by enhancing the blast in the direction of the frangible wall.

A partially-vented explosion is one where the venting is small relative to the volume of the chamber and quantity of explosive. Partial venting does not effect the maximum pressure imposed on the structure so that the total impulse (initial shock plus its reflections plus gas accumulation) must be considered in designing the structure.

Thus, it appears that with fully-vented explosions, blast mitigation devices would be needed, and partially-vented explosions would require very stout structures or would be explosive-weight limited. These factors will need to be considered in designing a partially-confined rapid through-put system.

One possible confined system design for small-scale detonations could incorporate a containment vessel which could conceivably be mounted on a rail car for transport to each of the designated disposal sites. The vessel could potentially be an 8 to 10 ft diameter cylinder. The design would incorporate a system that allows for rapid loading of munitions. A muffler/baffle design may be a key element in the suppression of noise and shrapnel while allowing release of spent gasses and pressure. If desired, pollution abatement systems could also be incorporated.

Another design idea, utilizing a fully-vented approach, would involve a reusable concrete pit, filled with water to absorb shrapnel and the explosive blast. This approach would also reduce the entrainment of dust in the explosive cloud.

The design of a partial-confinement technology would first require an in-depth feasibility study. The study would include evaluation of the vessel design, armor requirements for the various munitions, noise suppression systems, solid waste removal, safety features, and handling systems. Previous work by others would be used to support this study. Example publications include: M. Whitney, W. Baker, J. Riegel, and L. Garza, "Design of a Detonation Chamber for Demilitarizing Munitions," Southwest Research Inst., San Antonio, TX, 1982; "Blast and Fragment Loading on Containment Structures—A Manual Overview," Southwest Research Inst., San Antonio, TX, 1984; J. Pastranak, C. Baker, and L. Simmons, "Quarter Scale Close-In Blast Loading Experiments in Support of the Planned Contained Firing Facility," LLNL, Livermore, CA, 1994; and "Structures to Resist the Effects of Accidental Explosions," Department of Defense Explosives Safety Board, Alexandria, VA, 1990.

3.5 The Unconfined, Unmitigated Burn and Detonation

One can reduce the dust cloud from open detonations by a judicious emplacement of the charge. For small charges, it is practical to elevate the charge to some height H above the ground surface. For heights $H > 10\text{cm}/\text{kg}^{1/3}$, the cratering and ejecta accompanying sur-

face burst explosions are eliminated. For larger charges (approximately 50 tons), only a surface burst configuration may be practical. In this case, a reusable blast pad can be used to eliminate the cratering and ejecta. Under these circumstances, the only source of dust in the cloud will be the dust swept up from the ground surface by the blast wave (Section 4.1.4) and entrained into the rising fireball.

We do not believe that the traditional approach of an unconfined, unmitigated burn or detonation will allow for large-scale burn or detonation. The large-scale unmitigated explosion will result in too much noise and destructive pressure impulse that will be a nuisance to the surrounding communities, the produced shrapnel will pose safety issues, and the release of gases and entrained dust in the explosive cloud will be detrimental to the environment.

4.0 Numerical Model Development and Analysis

To address the safety and environmental issues related to OB/OD, to determine blast effects, and to provide bulk source terms (detonation products, the quantity of entrained dust, effective heat released, and initial cloud dimensions) for the dispersion model without extensive experimental testing, we must be able to numerically model each of the above described technological approaches. The numerical model must be relatively easy to use by personnel at the OB/OD site and fast running on a workstation, so that multiple scenarios can be investigated in relatively short turnaround time.

LLNL has developed a suite of sophisticated numerical tools that can accurately simulate the various aspects of each of the technological approaches with only a moderate code development effort. However, their use usually requires relatively long computer run times and experienced users. We propose that the sophisticated models be used during the technology development and analysis phase and that simple pseudo-empirical models be developed for production use.

The sophisticated LLNL models and their deficiencies for the OB/OD application and the corresponding pseudo-empirical models proposed for development are described in the following sections with relation to the common and various modeling requirements for each of the technological approaches. It is essential that each model be validated with experimental results for OB/OD application. Experimental requirements are outlined in Section 5.

4.1 LLNL's Existing Sophisticated Physics Models

Each of the technological approaches requires the modeling of the

source energy with timed detonations or burning,

detonation and burn products,

explosion blast wave and cloud at early times, and

explosion blast and cloud evolution.

Each of these characteristics will need to be modeled with or without blast and shrapnel mitigation devices and for various geometry and ground conditions. In the following sections, we discuss the modeling of each of these OB/OD characteristics and outline any model deficiencies that will require further code development. Also included are descriptions of the experimental data needed for model validation.

The estimated costs for the proposed code development and validation is expressed in LLNL's full-time equivalent (FTE). The cost for a one-year full-time effort by an LLNL scientist or engineer is approximately \$250,000.

4.1.1 Modeling the Source Variation with Stacking Configuration and Timed Detonation or Burning

The CHEETAH (L. Fried and P. C. Souers, "CHEETAH: A Next Generation Thermochemical Code," LLNL, UCRL-ID-117240, 1994) and CHEQ (A. Nichols, F. Ree, "CHEQ 2.0: Users Manual," LLNL, UCRL-MA-106754, 1991) thermochemical codes can predict temperatures and pressures at the explosive detonation point. They do this by finding the chemical equilibrium of the reacting explosive products. The codes can also track the thermodynamic state of the explosive gases as they expand. Thermochemical codes can accurately predict detonation velocities and energies. The principal use of these codes at LLNL is to construct simplified equations of state for the high explosive product gases, which are then employed in a hydrodynamic code such as LLNL's ALE3D (S. Anderson, E. Dube, S. Futral, I. Otero, R. Sharp, "Users Manual for ALE3D: An Arbitrary Lagrange/Eulerian 3D Code System," to be published).

The principal difficulty in applying these codes to OB/OD is that the explosive is surrounded by a large quantity of secondary material -- wood, metal, and various organic materials. In contrast to the explosive, much of the secondary material is difficult to ignite. Current codes do not have the capability to distinguish which materials will ignite, and which will not. For instance, if all the iron in a steel casing were fed into a thermochemical code, it would react almost completely to iron oxide. In reality, however, the oxidation of iron is self-quenching, since the iron oxide provides a protective coating around the iron.

Therefore, we must have a means of determining which secondary materials are likely to ignite and provide additional impetus to the reaction. We propose to make initial educated guesses by looking at existing reports on previous open burns. For instance, most of the iron mass in the shell should probably be excluded from the reaction. Our initial guesses can be improved by measurements of the gaseous products formed in the open detonation, and by taking an assay of material left behind after the detonation. For specific materials of importance, a thermal transport-chemical code such as LLNL's Chemical TOPAZ can provide more quantitative estimates of the degree of reaction under varying conditions (A. Nichols, "Chemical TOPAZ Modification to the Heat Transfer Code TOPAZ: The addition of Chemical Reaction, Kinetics, and Chemical Mixtures, LLNL UCID 20824 Add1, 1990). In the case of incomplete gaseous combustion, a gas kinetics code such as CHEMKIN can be applied (R.J. Kee, J.A. Miller, and T.H. Jefferson, "CHEMKIN: A

General-Purpose, Problem-Independent, Transportable, FORTRAN Chemical Kinetics Code Package," Sandia National Laboratories, Livermore, CA, SAND80-8003, 1980).

We have incorporated models that describe the shock initiation of explosives and propellants in our two- and three-dimensional computer simulation programs DYNA (R. Whirley, B. Engelmann, and J. Hallquist, "DYNA2D A Nonlinear, Explicit, Two-Dimensional, Finite Element Code for Solid Mechanics User Manual," 1992, LLNL, UCRL-MA-110630; R. Whirley and J. Hallquist, "DYNA3D A Nonlinear, Explicit, Three-Dimensional Finite Element Code for Solid and Structural Mechanics User Manual," 1991, LLNL, UCRL-MA-107254), CALE (R. Tipton, "Reference Manual," LLNL), and ALE3D. These models describe both the initiation and the subsequent growth to full detonation or, alternatively, the decay to extinction (E. L. Lee and C. M. Tarver, "Phenomenological model of shock initiation in heterogeneous explosives," *Phys. Fluids*, vol. 23, No. 12, p 2362, 1980). One such model has recently been fitted to data on initiation of Composition B (M. J. Murphy, E. L. Lee, A. M. Weston and A. E. Williams, "Modeling Shock Initiation in Composition B," in *Proceedings, 10th International Symposium on Detonation*, in press), which is the explosive fill used in the 3.5 inch rocket M28A2. These models have been used to describe a variety of explosive sensitivity tests, wherein a donor explosive is detonated at some distance from the acceptor explosive. This latter charge does or does not detonate, depending on the geometry, separation, and intervening materials. This is just the situation when a stack of these rockets is started with one or more booster charges.

These models have not been applied to the M7 propellant used in the 3.5 inch rockets. Since the propellant weight is less than 20 percent of the total energetic material, we may be able to bound the results computationally by alternatively assuming a prompt detonation of the propellant or a deflagration without detonation. We have applied these simulation programs and burn models to interior ballistics, where propellant is burned with a rate that depends on pressure and the geometric shape of the propellant grains, while the moving projectile increases the volume available and reduces the pressure (J. E. Reaugh B. J. Cunningham, and A. C. Holt, "Bushmaster Enhancement Project," in *Joint DOD/DOE Munitions Technology Development Program FY-94 Progress Report*, LLNL document UCRL-ID-103482-94, 1994). The material properties required for these calculations are the laminar burn rate as a function of pressure, the flame temperature, and the combustion products. For the latter two items, we will use the results of the thermochemical analyses described later (Section 4.1.2). The burn rate must be measured or otherwise separately estimated by correlations with similar formulations.

In our computer simulations with the above-mentioned models, the burning process continues without ceasing. In practical problems if the pressure drops enough, the burn rates are so slow that they effectively stop burning. The models, however, do not consider heat transfer. As a consequence, there are no submodels that describe igniting propellant in rocket B by impingement of the hot gas products of rocket A. As already mentioned, we would apply our computer program Chemical TOPAZ, if needed. The gas-producing reactions can be initiated by heat transfer from other parts of the system.

The loading method used in placing these munitions in the burn- or detonation-pit will be significant. If the wooden crates are neatly stacked, the mass density of energetic material is less than 0.2 g/cm^3 . If the crates are haphazardly placed, the mass density could be as little as half that. In addition, the energetic material is only 13 percent of the total weight. If the rockets are extracted from the wooden crates and from the fiber or metal containers before emplacement, the energetic material is still only about 25 percent of the total weight. We believe it plausible that burning could be sustained with the wooden crates in the pit. We are less certain that a detonation could be sustained without filling the interstices with additional energetic material. It may be desirable to use such energetic material for chemical balance anyway (Section 4.1.2). This would be an attractive method, so long as the weight limit for detonation were the products released to the atmosphere, and not ground shock or blast.

We propose to use our computer simulation programs with their deflagration/detonation models to examine the progress of detonation through a variety of stacking geometries and ignition schemes. We will assess the rate of progress through the stack and/or its failure to propagate. We will also examine deflagrations in candidate stack geometries. Experiments with a small number of munitions will be crucial in assessing the accuracy of our simulations (Section 5.1).

For modeling the source variation with timed detonation or burning, we estimate that no computer program development will be required, although developments to the programs we use by other program elements will be of benefit for us as well. The task in this effort will be one of exercising existing models in application, and comparison with experimental results. We will rely on the modeling of detonation and burn products (Section 4.1.2) to estimate the properties of the product gases. Our results for the source variations will be input directly to the blast wave models (Section 4.1.3).

We would focus the early efforts on the propagation of detonations in a simplified but representative stacking geometry. The geometry would be selected for its application to open detonation, and to experiments with small numbers of munitions. The first of these results would be directed to experiment design, and be available approximately 3 months from the start. We envision a level of effort corresponding to one-quarter time for an analyst.

The cost estimated for this work is 0.25 FTE to be completed in 6 months time at a cost of approximately \$65K. In addition, approximately \$20K in computer resources are needed for the analysis.

4.1.2 Modeling the Detonation and Burn Products

The chemical equilibrium codes CHEETAH and CHEQ used to predict the temperatures, pressures, and energies of reacting explosives also yield predictions on detonation products. These predictions are usually in good accord with experimental measurements of detonation products done through detonation calorimetry. CHEQ has also been shown to yield reasonable results for the gaseous products.

The product sets used in the codes, however, are not geared toward pollution prediction. For instance, there is no dioxin in CHEETAH or CHEQ because this product is not formed in concentrations sufficient to change explosive performance. New materials must be added to the codes' product database before full pollution prediction can be undertaken. This would entail researching the thermodynamic properties of these materials and putting them into the prerequisite form. We will need to use a quantum chemical code to calculate standard thermodynamic data for those compounds where it is not available, it may also be necessary to renormalize some of the molecular potential parameters in the database for those compounds that require more accurate concentrations.

It may also be necessary to use kinetic models to describe the product sets at lower temperatures and pressures. This can be done by coupling the thermodynamic engine in either CHEQ or CHEETAH to a reactive chemistry model. A generalized reaction model is currently being built into ALE3D and is already in Chemical TOPAZ. Reaction rates for the production and destruction of the important species would need to be determined. The final composition can then either be calculated within the framework of the larger ALE3D code, or the ALE3D or compressible AMR code (J. Bell, M. Berger, J. Saltzman, M. Welcome, "Three-Dimensional Adaptive Mesh Refinement for Hyperbolic Conservation Laws," SIAM J. Sci. Comput., Vol. 15, No. 1, pp 127-138, 1994) could be used to provide the time/temperature/pressure history that is then used in the reaction model. The latter approach would be faster but slightly less accurate than the former approach.

The issue of kinetics is also important when considering the reactions of entrained materials within the gas cloud. These entrained materials would include the water or aqueous foam shock and shrapnel mitigators. For these systems we could use the compressible AMR code to provide a baseline composition. The chemical kinetics code with the appropriate kinetic parameters can then be used to predict the final non-equilibrium composition.

We need to create a stand alone chemical kinetics code capable of reading the state information from ALE3D and the compressible AMR code and producing a final non-equilibrium result. This code can be used to provide the final chemical component to the environmental load.

These proposals envision a solution scheme as follows:

1. Predict the equation of state for the explosives in the system. This provides the thermal and pressure load that the explosives will directly place on the environment. Depending on how exotic the explosives are, some work may be required to characterize the detonation products.
2. Calculate the spatial distribution of this load using ALE3D and AMR codes.
3. Use entrainment data from AMR codes to modify the composition of the gas cloud.
4. Using the kinetics code, calculate the time dependent composition. We believe that the kinetics will have only a small effect on the thermal and pressure environments, but will have a significant effect on the types of materials which will be dispersed into the atmosphere.

An estimate of the effort and total cost to complete the described tasks is given in Table 2.

TABLE 2. Estimated effort for modeling detonation and burn products.

Action Item	Effort
Analysis of burn products from previous OB/OD experiments	1 man-month
New material entered into database	3 man-months
30 standard materials	
8 unusual materials	
Stand-alone chemical kinetics code	6 man-months
Determining chemical reaction parameters	2 man-months
Total Effort: for completion over 1 year	12 man-months (1.0 FTE)
Total Cost: \$250K	
Computer Resources: \$20K	

4.1.3 Modeling the Blast Wave and Cloud at Early Times with Mitigation Devices

ALE3D is a versatile, multipurpose code which can contribute to analysis of the OB/OD problem in a variety of ways.

ALE3D is a finite element code which treats fluid and elastic-plastic response on an unstructured mesh. The grid may consist of arbitrarily connected hexahedra, beam, and shell elements. The mesh can be constructed from disjoint blocks of elements which interact at the boundaries via slide surfaces. The basic computational cycle consists of a Lagrangian step followed by an advection step. In the advection step, nodes in selected regions can be relaxed either to relieve distortion or to improve accuracy and efficiency. Thus, ALE3D has the option of treating structural members in a Lagrangian mode and treating materials which undergo large distortions in an ALE (arbitrary Lagrangian-Eulerian) mode, all within the same mesh/problem configuration. The code also has the ability to treat thermomechanical coupling with reactive chemistry.

The dynamic solver currently operates with explicit time integration appropriate for relatively short-duration events. A method for implicit time integration is under development. When completed, ALE3D will be capable of transitioning back and forth between the two methods as the problem dynamics dictate.

ALE3D is currently being applied to a number of problems involving fluid/structural dynamics, including steady state and transient fluid dynamics and shock hydrodynamics. For example, ALE3D has been used to predict the explosion in a four-room structure, shown in Figure 7. For this problem the code calculated the explosion shock wave and the shock/structure interaction, along with the impulse pressure on the structure and the flow

of the gas cloud. The code even predicts the venting of gases out a peripheral door in the four-room structure.

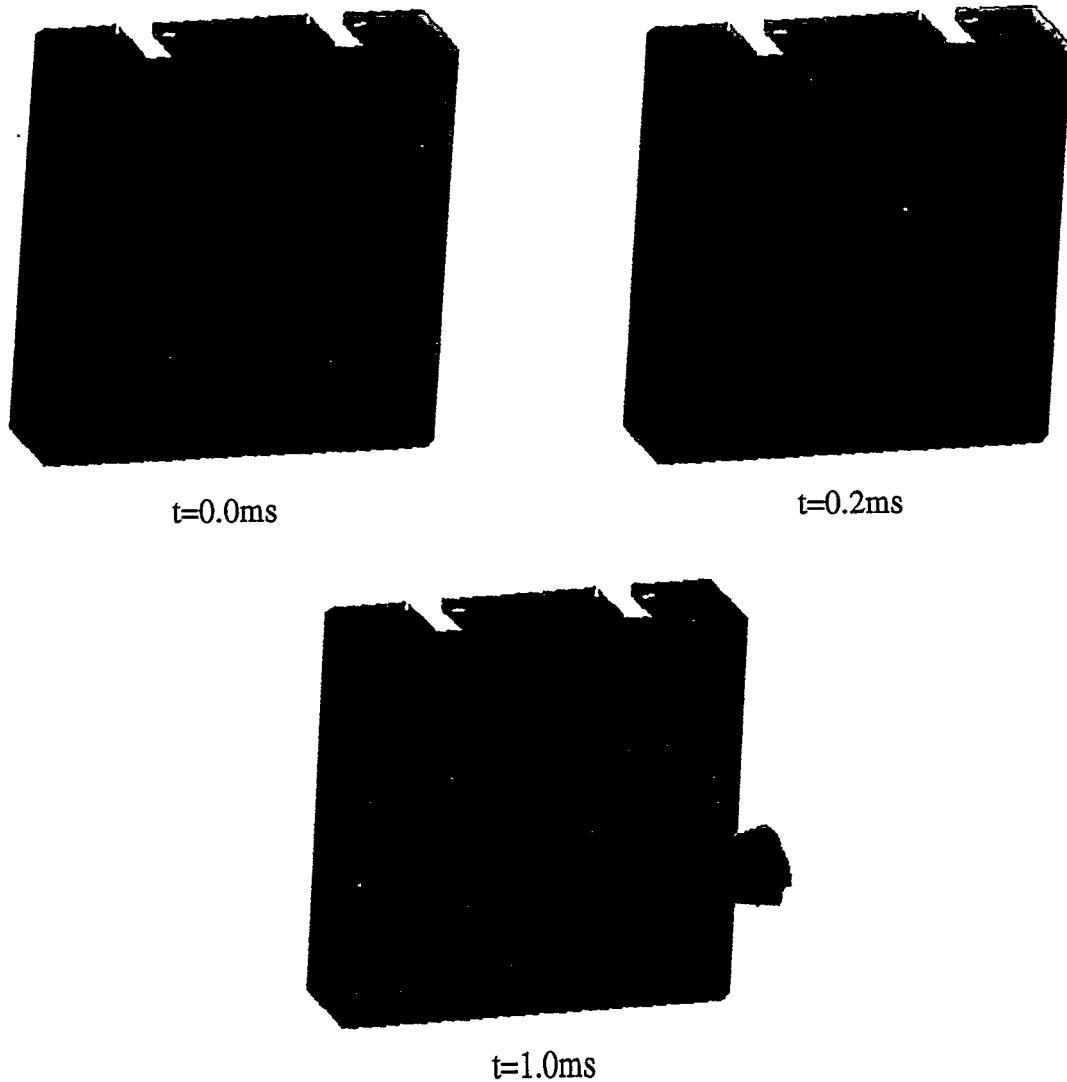


FIGURE 7. Explosion in four-room structure predicted by ALE3D.

The code is available to members of the defense community under a collaborative licensing agreement. There is a two-dimensional (2D) ALE code, CALE, which has many of the same characteristics as ALE3D, and could be applied to those situations in which 2D simulations are appropriate.

ALE3D is being applied to a number of simulations of blast loading on structures because of its ability to provide a detailed representation of both complex structures and complex fluid flow on those structures. Instances where that capability is likely to be of value are in modeling details of the initiation process at as fine a resolution scale as necessary, and the evaluation of various blast and debris mitigation techniques.

ALE3D is also capable of providing a continuum representation of the dynamics of a large-scale explosive event. It is anticipated that the code would provide an accurate prediction of the amount of ground material that is displaced when an explosion occurs. The

entrainment of the removed material and its ultimate dispersal require a multiphase flow description that is not currently available in ALE3D. A link to a code that does have that capability would be required.

ALE3D can be used in determining the design requirements for any of the technological approaches described in Section 3. It can also be used for data generation in the development of the pseudo-empirical model discussed in Section 4.2. Areas in which development would be required in ALE3D would be associated with special purpose material models and links to other codes. It is not anticipated that either of these instances would involve large amounts of time or resources. A reasonable estimate of the effort required to support the OB/OD project would be approximately 0.25-.5 FTE or \$65-125K for analysis and design assistance for the shock and shrapnel mitigating technology. Since this is essentially a support function for the analysis activities, these resources would be utilized as they are needed. The cost for required computer resources would vary depending on the decision of which of the OB/OD technological approaches discussed in Section 3 would be used, but the computer resource cost could run as high as \$100K.

4.1.4 Dusty Boundary Layers from Explosions over Ground Surfaces

If the decision is made *not* to use noise and shrapnel mitigation devices, it will be important to consider the dusty boundary layers so as to accurately predict dust entrainment in the explosive cloud.

Shocktube experiments show that when a blast wave propagates along a ground surface, a fluidized bed (consisting of fine dust particles and air) is created within a centimeter behind the shock front. This generates a shear layer at the surface, which rapidly rolls up into a turbulent boundary-layer flow. The vortex structures in the boundary layer induce a velocity field which entrains dust from the fluidized bed—thus creating a turbulent dusty boundary layer which evolves during the positive and negative phases of the explosion.

Figure 8 shows the evolution of the turbulent dusty boundary layer flow from a point explosion on a soil surface as predicted using the compressible AMR code.

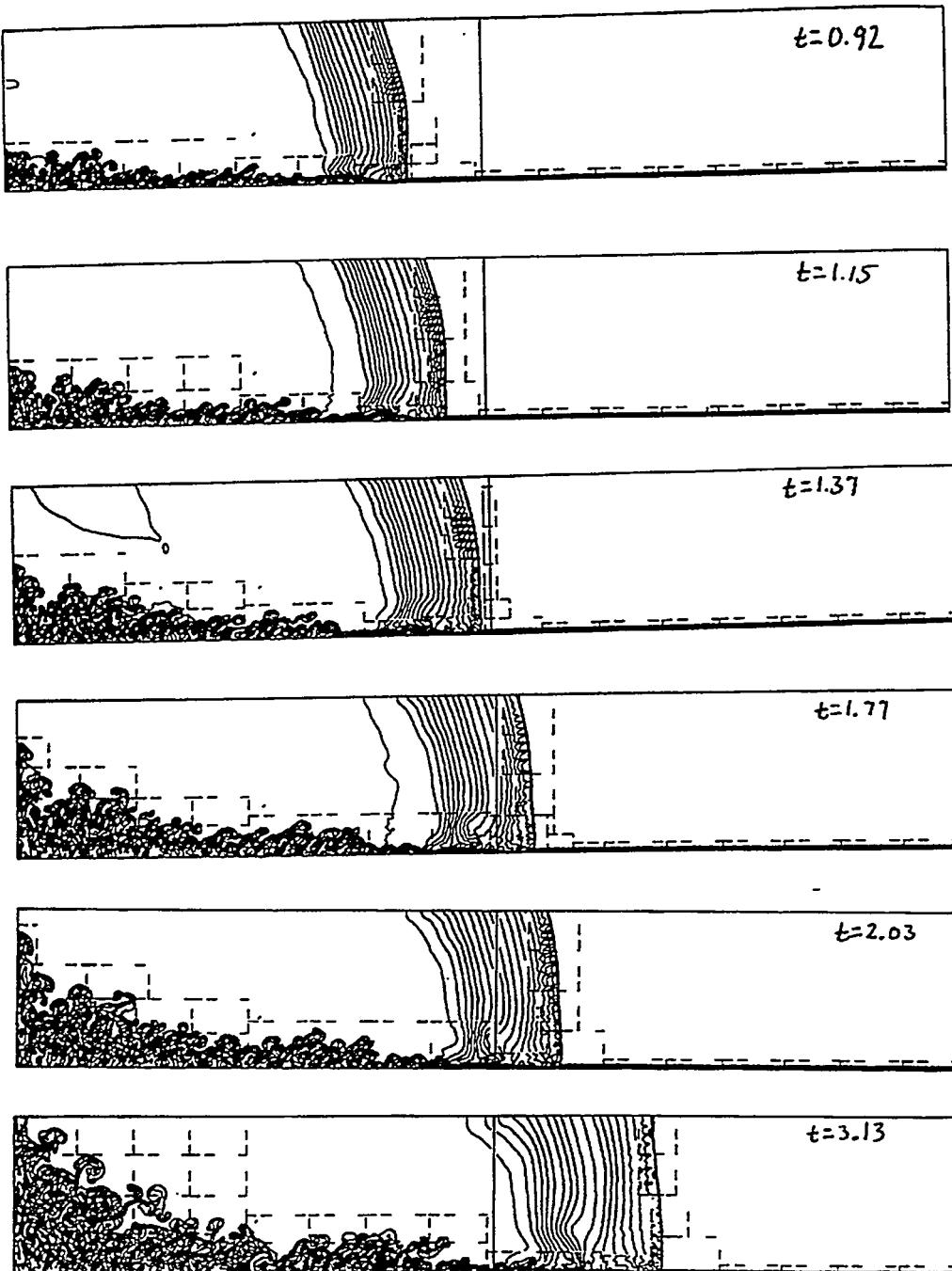


FIGURE 8. The evolution of the turbulent dusty boundary layer flow from a 1 kiloton (KT) explosion on a soil surface. The plot labels indicate the time in $\text{ms}/\text{KT}^{1/3}$.

Subsequently, buoyancy forces cause the fireball to rise, and the dusty boundary layer fluid is entrained into the rising fireball—forming the dust cloud. The turbulent dust cloud

entrains air as it rises, eventually leading to cloud stabilization at a height that depends on the explosion scale. Although extensive field tests of dust clouds from high explosive sources have been carried out at White Sands Missile Range, it was concluded that the most reliable way of characterizing such dust clouds is through direct numerical simulations.

Thus, a computer code AMR was developed to provide detailed numerical simulations of the turbulent dusty flow created by nuclear explosions over ground surfaces. By changing the nuclear source to a high-explosives source, the AMR code can be used to predict dusty flows created by open-air detonations of excess munitions to support EPA studies. The code is based on a model of turbulent two-phase flow at large Reynolds numbers which properly accounts for turbulent transport and dust entrainment from the surface. The code uses a high-order Godunov scheme to integrate the three-dimensional (3D) conservation laws governing the explosion field. Adaptive Mesh Refinement (AMR) is used to follow the convective mixing processes on the computational grid. With AMR, we can afford enough grid resolution to capture the turbulence spectrum—including the inertial range—without resorting to turbulence modeling. The model also takes into account the afterburning effects caused by turbulent mixing of the fuel-rich detonation products gases with air, thereby depositing an additional 2500 Cal/g over and above that deposited by the detonation of the explosives charge, which effects the buoyant cloud rise. Typically, detailed 3D numerical simulations are run time intensive and take approximately 100's of CPU hours on a super computer like the CRAY Y-MP.

This model of turbulent, shock-induced dusty flow has been extensively checked by comparison with shocktube experiments, windtunnel experiments and field tests, thus no further experimental data is needed for 'code validation.' An additional phase (water droplets) could be added to simulate open-air detonations in foams.

The cost estimated for this work is 1.5 FTE to be completed in 1 years time at a cost of approximately \$375K. In addition, approximately \$50K in computer resources are needed for the analysis.

4.1.5 Dust/Gaseous Clouds from Explosions over Ground Surfaces

Evolution of the turbulent dust/gaseous cloud can be calculated with an Incompressible Adaptive Mesh Refinement code, IAMR (A. Almgren, J. Bell, P. Colella, L. Howell, "An Adaptive Projection Method for the Incompressible Euler Equations," *Proceedings of the 11th AIAA Computational Fluid Dynamics Conference*, Orlando, Fla., July 6-9, 1993). This code uses the Projection Method to solve the 3D Navier-Stokes equations in the limit of zero Mach number. Convective derivatives are treated with the same Godunov methodology used in AMR. Large density variations inherent in such problems (e.g., variations of one thousand) are treated properly with an elastic model—thus avoiding the typical Boussinesq approximation. Time steps are determined by the convective velocity, thereby avoiding the sound speed limitations imposed in the compressible version of the code. IAMR has been checked against a variety of incompressible turbulent flow problems, thus no further experimental data is needed for 'code validation.' Additional routines will have to be added for multi-phase flows.

The cost estimated for this work is 1.5 FTE to be completed in 1 years time at a cost of approximately \$375K. This effort includes problem formulation and setup, dust/gaseous cloud calculations, and the analysis and synthesis of the results. In addition, approximately \$50K in computer resources are needed for the analysis.

4.2 The Pseudo-Empirical Models

The above described LLNL models are capable of accurately modeling the details of each of the technological approaches. However, as already mentioned, their use usually requires long computer run times and experienced users. It is not economically feasible to use them to run the possible thousands of OB/OD scenarios to satisfy the EPA permit regulations. The numerical model must be relatively easy to use by personnel at the OB/OD site and fast running on a workstation so that multiple scenarios can be investigated in relatively short turnaround time.

We propose that the sophisticated models be used during the technology development and analysis phase and that a simple pseudo-empirical model be developed for production use. The pseudo-empirical model will provide estimates for the levels of toxic emissions, the peak pressure and impulse from the blast wave, and the size and characteristics of the explosive plume depending on the quantity of explosive. The scaling relations implemented in the pseudo-empirical model will be defined by performing limited analyses using the sophisticated models for various munition quantities.

It is likely that the scaling parameters in the pseudo-empirical models will need adjustment for each of the different types or classes of munitions and that the scaling will be dependent on detonation or burning times and blast mitigation and shrapnel reducing devices. However, these variations in scaling parameters can be determined economically by limited analyses with the sophisticated models, rather than performing the many case studies using the sophisticated models directly.

Our LLNL code developers and analysts will initially develop the pseudo-empirical model based on the 3.5 inch rocket and selected blast mitigation and shrapnel reduction devices. If desired, LLNL's analysts can provide future analysis assistance to determine parameter adjustments for different munitions and mitigation devices. Otherwise, Army personnel or contractors with analysis and code development skills can be trained to perform the detailed analysis themselves.

4.2.1 Pseudo-Empirical Model for Explosions with Noise and Shrapnel Mitigation Devices

An analytic model will be developed for the acoustic noise, pressure impulse, and gaseous products released from either contained water, aqueous-foam, or wet sand suppressed explosions or with partial confinement—based on the source burn/detonation simulations and either the AMR or ALE3D simulations validated by field test data. This model will then be available for EPA noise, pressure impulse, and gaseous product predictions from open-air detonations of excess munitions. The predicted gaseous cloud can be used for input to the available atmospheric models to predict the cloud evolution and dispersion.

The cost estimated for this work is 1.0 FTE to be completed in 1 years time at a cost of approximately \$250K. This effort includes problem formulation, simulations, the analysis and synthesis of the results, and development of the pseudo-empirical model. In addition, approximately \$50K in computer resources are needed for the analysis.

4.2.2 Turbulent Dust/Gaseous Cloud Model

If the decision is made *not* to use noise and shrapnel mitigation devices, it will be important to consider the entrained dust in the explosive cloud due to the unconfined, unmitigated open detonation. It is impractical (and unnecessary) to perform parametric calculations of 3D turbulent dust clouds—since the scaling laws for these flows are known. Instead, we will perform one detailed simulation of the explosion phase with AMR, and continue that simulation to cloud stabilization with the IAMR code—for each class of open-air detonation.

If the blast is mitigated, thus minimizing the dust entrainment from the dusty boundary layer, the results from the ALE3D code with the mitigated blast can be used as input to the IAMR code. These results will then be synthesized to provide an analytical model of the dust/gaseous cloud, which can then be used as initial conditions for parametric studies of the toxic cloud transport in meteorological wind fields corresponding to EPA scenarios of interest.

The cost estimated for this work is 0.5 FTE to be completed in 1 years time at a cost of approximately \$125K. In addition, approximately \$20K in computer resources are needed for the analysis.

4.3 Summary of Numerical Modeling Schedule, Effort and Cost

Table 3 is a cost and effort summary for code development required for the sophisticated models because of the code deficiencies for the OB/OD application, as described above in detail. This code development work includes the time and effort to validate the sophisti-

cated models with experimental data. Table 3 also includes the effort required to develop and test the pseudo-empirical model, described in Section 4.2.

TABLE 3. Summary of code development and validation costs.

Item	Time Duration	Cost	Subtotals
1. Source			
a) configuration and timing	6 months	\$65K	
computer resources		<u>\$20K</u>	<u>\$85K</u>
b) detonation and burn	12 months	\$250K	
computer resources		<u>\$20K</u>	<u>\$270K</u>
2. Blast Wave and Cloud			
a) mitigated explosion	6-12 months	\$65K-125K	
computer resources		<u>\$100K</u>	<u>\$165-225K</u>
b) dusty boundary layer	12 months	\$375K	
computer resources		<u>\$50K</u>	<u>\$425K</u>
c) dust/gaseous cloud	12 months	\$375K	
computer resources		<u>\$50K</u>	<u>\$425K</u>
3. Pseudo-Empirical Model			
a) mitigated explosion	12 months	\$250K	
computer resources		<u>\$50K</u>	<u>\$300K</u>
b) turbulent dust/gaseous cloud	12 months	\$125K	
computer resources		<u>\$20K</u>	<u>\$145K</u>

We believe that the tasks for source modeling described in Sections 4.1.1 and 4.1.2 with costs listed under Item 1 in Table 3 are necessary and critical for the successful modeling of the OB/OD technology. Task 1a, which includes modeling of the source variation with stacking configuration and timed detonation or burning, can be completed in 6 months for \$85K, and Task 1b, which includes modeling the detonation and burn products, can be completed in 1 year for \$270K. Tasks 1a and 1b can be performed simultaneously during the first year effort at a total cost of \$355K.

Task 2a in Table 3, which is described in Section 4.1.3, is required for modeling the blast wave at early times with mitigation devices. This task will produce preliminary results in less than 6 months and be complete in 1 year for a cost somewhere in the range of \$165-225K. This effort can be done in parallel with Tasks 1a and 1b.

We do not believe that the traditional OB/OD approach of an unmitigated, unconfined approach will allow for large-scale detonations, but if modeling of this approach is desired, Task 2b, which is modeling of dusty boundary layers described in section 4.1.4, would be needed (in addition to Task 1c) at a cost of \$425K.

To fully satisfy the EPA requirement for dust/gaseous cloud predictions that are needed as input into the atmospheric dispersion models, Task 2c in Table 3, which is modeling of the dust/gaseous clouds and described in section 4.1.5, is required at a cost of \$425K. If mitigation devices are used, Task 2c can be completed, without having to consider dusty boundary layers, Task 2b.

We strongly recommend that after the first year of effort, a pseudo-empirical model be developed. As described in Section 4.2, the pseudo-empirical models will be developed by performing limited analyses using the sophisticated models that were developed and validated during the first-year effort. The resulting model will be relatively easy to use by the personnel at the OB/OD site and fast running, on say a workstation, so that multiple scenarios can be investigated in relatively short turnaround time.

5.0 Experiments for Model Validation and Field Testing of Each Technological Approach

Some of the experimental data needed for model validation most likely exists, but locating it will need to be part of the project effort. Remaining data can be acquired through small- and medium-scale experiments. However, we recommend that if possible, field testing of the technological approach be done at various scales including full-scale experiments so that scaling laws are verified and the method is fully field tested. Use of the numerical models to estimate the optimum experimental conditions should minimize the number of experiments.

LLNL has three experimental facilities for OB/OD technology testing, however, the tests could be performed at Dugway Proving Grounds or other OB/OD sites, if desired. LLNL's facilities include the High Explosive Applications Facility (HEAF) for tests under 22 lbs, the Site 300 facility for tests under 1000 lbs, and the Nevada Test Site (NTS) Big Explosive Experimental Facility (BEEF) for tests under 50,000 lbs and other NTS sites for tests over 50,000 lbs.

The following sections describe the experiments needed to obtain the required model validation as specified in Section 4 and experiments needed for the actual field testing of each technology. Also included are effort and cost estimates for each class of experiments.

5.1 HEAF Experiments

We are already working with Dugway Proving Ground and Dr. Bill Mitchell of the EPA in writing a proposal to test the 3.5 inch rockets in the LLNL HEAF Facility. The major objective is to investigate the effects of water on the detonation/burn products. These experiments are summarized in the following sections.

5.1.1 HEAF Facility

Confined detonation experiments will be performed in the 10 kg spherical confined firing chamber in the HEAF Facility at LLNL (Figure 9). This tank has 62 m^3 internal volume and will contain detonations up to 10 kg trinitrotoluene (TNT) equivalent. The firing tank has portholes that can be modified for the removal of gas samples. It is fitted with a floor grating and drain pan for the collection of liquid samples and may operate up to 82 psi. Shaped charges are generally not permitted in this tank, and thus, established methods for mitigating directed blast and shrapnel damage to the tank will be implemented. More details on the 10 kg tank can be found in Appendix C.

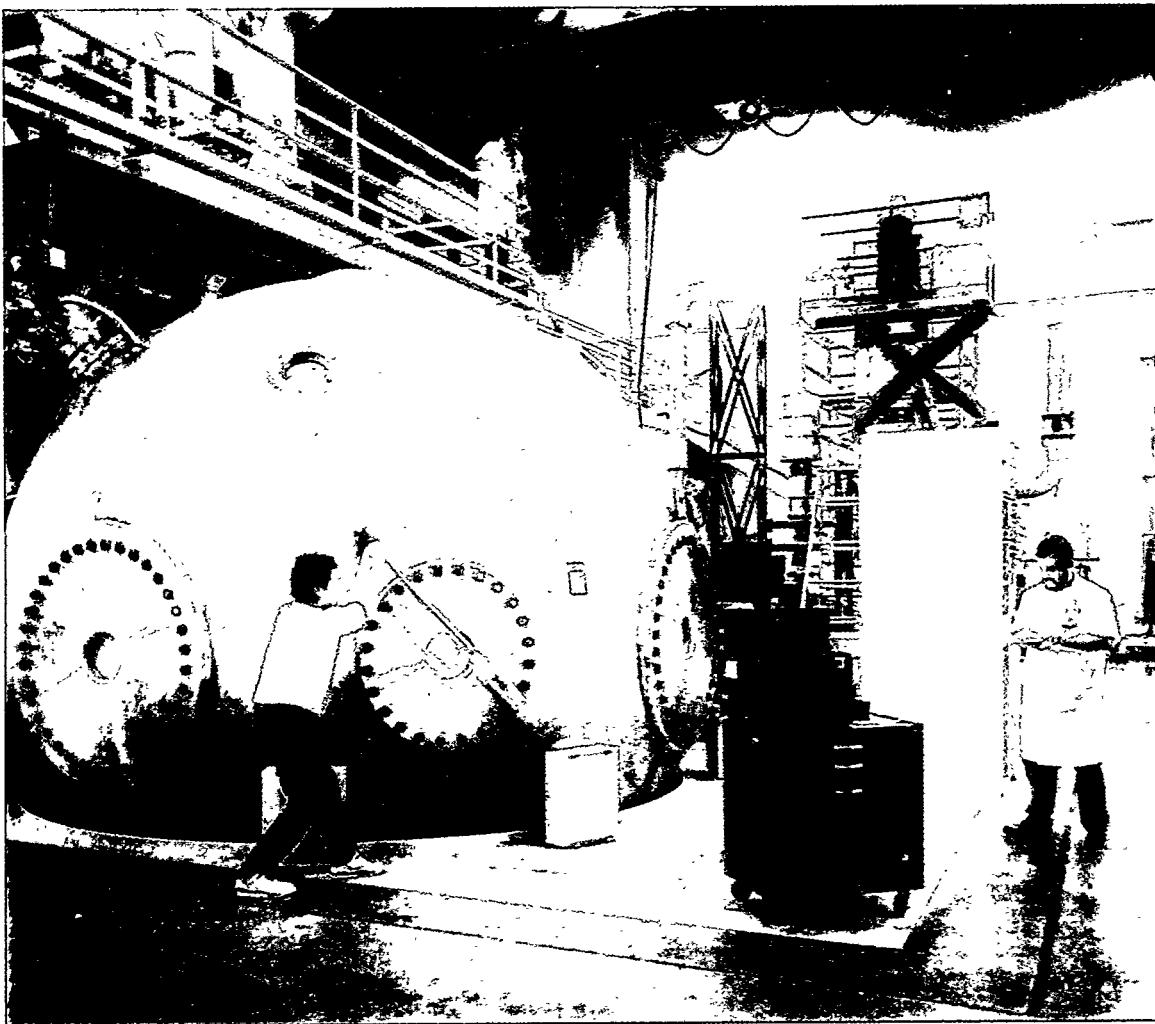


FIGURE 9. Photo of 10 kg spherical tank.

5.1.2 Scope of Work

Pre-experimental

We will obtain the required peer reviews of detonation experiments in the 10 kg contained firing tank. Calculations will be performed to determine the 10 kg chamber air volume/energetic materials ratios and pressures and their effects on OB/OD experimental design. In addition, the presence of additional water from water bags and water mist may contribute to the final tank pressure and may reduce the practical explosive limit. NEPA and other environmental/health/safety permits will be obtained.

The chamber will be modified to allow the introduction of water mist and the recovery of water samples after detonations. Portholes and valving will be modified to allow gas sampling. Certification of these tank modifications will need to be obtained.

- Open detonation tests

The suite of tests include: uncovered TNT, uncovered rockets, uncovered TNT and rockets, TNT covered by water bags, rockets covered by water bags, TNT in heavy fog (mist), rockets in heavy fog (mist), TNT covered by sand bags, rockets covered by sand bags. Each test will be performed in triplicate at a rate of 3 firings in two days for a total of 27 experiments. It may be possible to perform 3 tests/day after the initial tests have been performed. Gas, solid, and water samples will be obtained. Samples will be taken prior to testing and after each firing by sponsor/LLNL-specified contractor. The chamber will be washed down between firings, and noise level, latent heat released, detonation pressure, and final pressure will be determined.

- Open burn tests

The suite of tests include: uncovered rockets, rockets under water fog (mist), rockets under alkaline (sodium hydroxide/water) mist (fog). Tests will be conducted just as done for the open detonation tests for a total of nine experiments.

Estimated costs for both the open detonation and open burn experiments at HEAF are given in Table 4.

TABLE 4. Cost estimates for HEAF experiments on the 3.5 inch rocket.

Task	Cost
Pre-experimental/PI	\$40K
10 kg chamber (36 firings, 3 firings/2days)	\$50K (or \$10K/wk)
Report writing	\$5K
Total Cost	\$95K

5.2 Site 300 Facility

Site 300 is LLNL's open-air hydrodynamics testing facility near Tracy, California. Experiments up to 450 kg can be performed at Site 300 in state-of-the-art facilities such as the Contained Firing Facility (CFF) or as mitigated unconfined explosions.

Because of the close proximity of neighboring communities to Site 300, open air testing of high explosives continues to be impacted by changing environmental regulations as well as increasing sensitivity to effects on surrounding facilities and adjacent property. Potentially detrimental emissions to the environment can include noxious gases, hazardous particulates, blast overpressures, shrapnel, and noise. Because of these considerations, new construction of high explosive test facilities is planned for chambers and facilities that will contain these effects.

Major areas of testing to help achieve containment have recently been performed at Site 300. They include shrapnel effects, close-in impulse structural loading, and replica 1/4-scale model structural response testing. This testing provides valuable data for designers to use in all reinforced concrete high explosive containment structures planned for the future, but particularly for the 60 kg CCF to be completed in 1999. The project will add approximately 28,500 ft² to an existing bunker in the form of a 60 kg high-explosive contained firing chamber, a firing chamber support facility, and a clean diagnostics area. At present, the needed OB/OD small-scale tests can be performed at the existing HEAF facility described in the above Section 5.1, but for future experimental needs, the CCF facility may be of interest.

5.3 Big Explosives Experimental Facility (NTS)

The Big Explosives Experimental Facility (BEEF) shown in Figure 10 is located in north-central Area 4 of Yucca Flat at NTS. The site contains two buried structures, bunkers 4-300 and 4-480, which have been modified to accommodate modern hydrodiagnostic equipment to serve as a hydrodynamics test facility for detonations of very large conventional high-explosive charges and devices. The intent of the modifications was to provide all of the sophisticated diagnostics capability of LLNL's Site 300 Hydrotesting Facility, but for experiments containing more than the currently available 1000 lbs high-explosive weight limit.

The structural soundness of the modified bunkers for expanded operations and the potential environmental impacts of blast, noise, and dust uplift due to hydrodynamic testing were investigated in the five experiments of the POPOVER test series conducted between March and August of 1995. The tests consisted of detonations of successively larger amounts of spherical charges of conventional TNT explosive beginning at 512 lbs and ending with 7800 lbs. The noise, acceleration, strain, overpressure, dust uplift, and area contamination was monitored in order to validate predictive models of shock, blast, noise, and gas product dispersion, and to certify the safety of manned operation of bunker 4-300 during hydrodynamic testing. The results of this testing can serve as a baseline from which to compare the effects of proposed sound and blast mitigation technologies.

The high-explosive weight limit for safe, manned operations at BEEF is based on the following facility design criteria: 1000 lbs of conventional high explosive detonated 15 ft from the bunker 4-480 outer wall, or 5000 lbs of conventional high explosive detonated 27 ft from the bunker 4-480 outer wall. Based on the results of the POPOVER test series, the relationship between conventional high-explosive charge mass and safe detonation distance was determined to conform to these two criteria. For experiments involving larger or

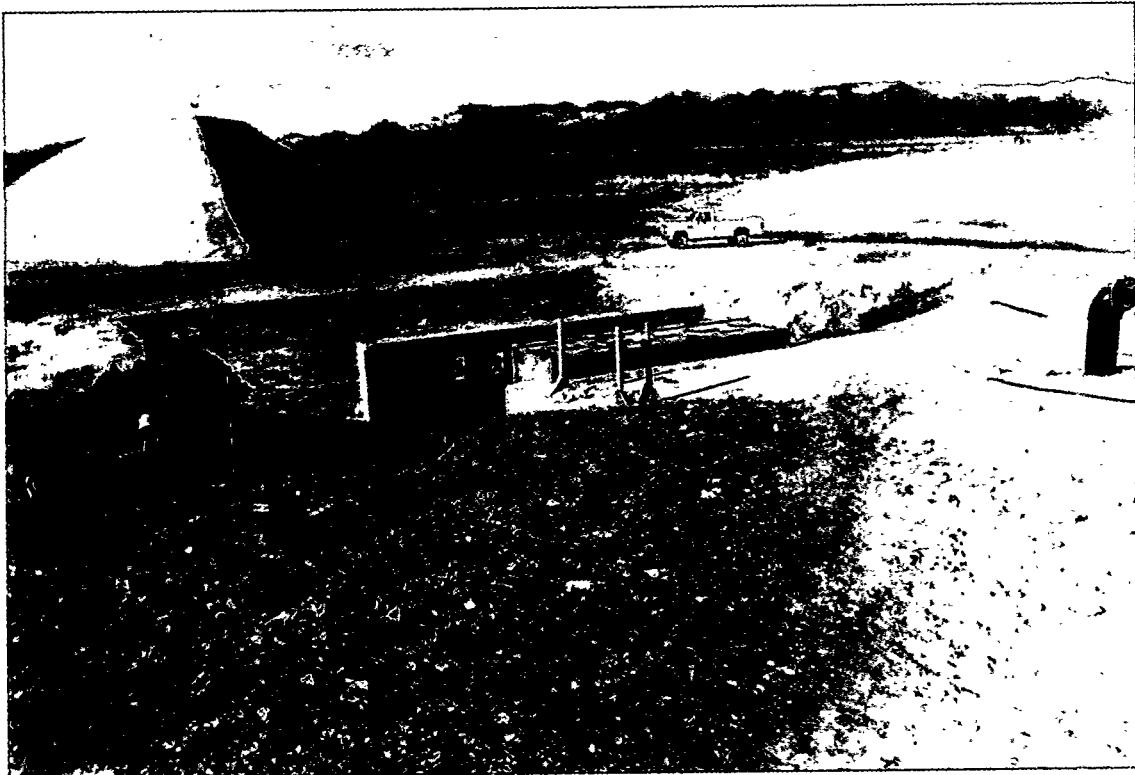


FIGURE 10. Photo of BEEF at NTS.

smaller charge masses than previously tested, or involving charge configurations different than those previously tested, the safe operating distance(s) of the charge(s) will be determined using these criteria and standard engineering practice. In this way, arbitrarily large conventional high-explosive charge masses in practically any configuration can be safely detonated as long as the equivalent impact of the detonation on the facility in terms of overpressure, blast, shock, and noise is less than or equal to the facility design criteria.

This equivalent impact can be estimated using the well-established cube-root rule for high-explosive detonations: the impact of an explosive detonation decreases as the cube-root of the high-explosive charge mass. All high-explosive detonations at BEEF would be carried out on the 20 m x 20 m wide x 2.0 m deep gravel firing table in order to minimize dust uplift, dispersal of soil contaminants, and coupling of ground shocks to surrounding structures. This places an effective upper limit on the size of explosive charges that can be detonated at BEEF. The maximum distance from the bunker 4-480 outer wall to the end of the gravel firing table is 20 m (65 ft), so that the largest charge that can be detonated at BEEF with the current firing table configuration is

$$W_{\max} = (65/27)^3 \times 5000 \text{ lbs} = 70,000 \text{ lbs} = 35 \text{ tons.}$$

Of course, the firing table could be extended with minimum effort to accommodate still larger charge weights if necessary.

5.3.1 Proposed Experiments at BEEF

Although several technologies have been developed and tested for blast and noise mitigation and attenuation of high explosive detonations, none have been well-characterized in tests using very large amounts (i.e., 1-25 tons) of high explosive. We propose to carry out well-characterized tests of any of the chosen four mitigation technologies (contained water, aqueous foam, wet sand, or a rapid through-put system) described in Section 3 initially using point-like detonations of 1000 and 10,000 lb charges of TNT or composition C4 (plasticized RDX) explosive. We propose to measure the overpressure and noise as a function of distance from the detonation point, and the high-explosive product dispersal and shrapnel patterns for both open (for reference) and mitigated detonations. The mitigation will be characterized for each of the four technologies or combinations of technologies. The technology best able to minimize the environmental impacts would be identified on the basis of the results. Also, the results would be used as input for code validation and optimization, and as a basis for further experiments using actual munitions in large quantities. These subsequent experiments would test the optimum mitigation technology under the actual conditions of use, perhaps with some variations to test possible improvements. Proposed schedule of tests for the first year are shown in Table 5.

TABLE 5. Proposed first year experiments at BEEF.

Number of tests	Charge weight (lbs)	Comments
1	1000	bare charges w/o mitigation
4	1000	bare charges w/ mitigation
1	10,000	bare charges w/o mitigation
4	10,000	bare charges w/ mitigation
2	20,000	cased munitions w/ mitigation

Estimated costs for the experiments depend on whether explosives, equipment, and materials can be borrowed, commercially purchased, or must be fabricated. Also, because BEEF has yet to be fully commissioned (current projected date of full operations at BEEF is February 1996), it is difficult to estimate personnel costs at BEEF for these proposed experiments. While materials for supporting frames, water containers, and aqueous foam containment tents are readily available, the large sizes of the materials needed for containment of very large charges would likely require some custom-made equipment. Silos for sand attenuation have not been used at Site 300 for more than a decade so that no current costs are available. With these caveats, we estimate the range of costs for the above one-year program as in Table 6.

TABLE 6. Estimated first-year costs for BEEF experiments.

Technology Development	\$100-500K
Materials	\$200K
Operations	\$600K
Total Costs	\$900-1,300K

6.0 Conclusions and Recommendations

As stated in Section 2.0, this report documents our pilot study results. We have included effort and cost estimates for suggested/proposed activities, but this document is not a formal proposal for work. Depending on our sponsors' decisions, we will submit formal proposals for any part or all of the herein described activities.

We believe that without the technology design effort, we can only perform validated model development for the traditional OB/OD approach, which we know to be an inadequate approach, and without experimental data for code validation, we cannot guarantee the accuracy of our numerical models. Therefore, we strongly recommend that technology design and testing accompany the code development.

We propose in our first-year effort to develop the technology and numerical modeling capability for OB/OD of one or two of the most abundant types or classes of munitions that *must* be open burned or detonated. The developed technology and numerical models may also be applicable to other types and classes, but the applicability will require further study beyond the one-year effort. Our SERDP sponsor, Dr. Bill Mitchell, has identified the 3.5 inch rocket as the munition that should be considered in our first-year effort.

As mentioned in Section 2, we were directed by our SERDP sponsors to breakdown the required effort and cost for code development into deliverables for 6 months and 1 year project durations for costs of \$250K, \$500K, and \$750K, and to also project long-term efforts. Based on the results of this pilot study, we can make some recommendations on the technological development, experiments, and code development, using the cost and effort estimates in Sections 3, 4, and 5. In Section 4.3, we provided a summary of the schedule, effort, and costs for code development and validation work that was described in detail throughout Section 4. Cost estimates for technology design, experiments for code validation, and field testing of the various technologies were provided in Sections 3 and 5.

6.1 Recommendations for Short-Term Effort

For our short-term (1 to 2 years) recommendations, we present two possible scenarios for the technology approach, experiments, and code development. Other scenarios are also possible, and those presented should be viewed only as possible choices, *not* the only choices.

Scenario #1: Use of water bag, wet sand or aqueous foam technology

In this scenario, the technology would be developed and tested while the sophisticated numerical models are being developed and used to assist in the technology design and analysis. This effort can be completed in one year's time with preliminary design and analysis completed in the first 6 months for roughly half the listed first-year cost. The sec-

ond year's effort will involve the development of the pseudo-empirical model. Table 7 includes the cost estimate for each task.

TABLE 7. Estimated costs for Scenario #1.

Technology development	\$100K-500K
Experiments	
Small-scale (HEAF)	\$95K
Large-scale (NTS)	\$800K
Sophisticated modeling	
Source	\$355K
Blast wave and cloud	\$590K-650K
First year cost	\$1,940K-2,400K
Pseudo-empirical model	\$445K
Second year costs	\$445K

The range of costs for large-scale field testing at NTS is dependent on the number of tests to be performed and the sophistication and amount of instrumentation desired. It may be possible to reduce costs by performing fewer experiments or having some of the experiments done at Army facilities, however, all code development and analysis would need to be done by experienced and trained code developers and analysts at LLNL.

For limited funds of \$250K, we would recommend that the small-scale HEAF experiments be funded along with some preliminary source characterization modeling with the work completed in approximately 6 months. For \$500K, we would include the completion of the source modeling, and for \$750K we would recommend the addition of preliminary technology development with some blast and cloud modeling, with this additional work completed in 1 year. However, it is clear that Scenario #1 would require over the \$750K limit for successful completion.

Scenario #2: A rapid through-put system.

In this scenario, we would design a rapid through-put system as described in Section 3.4 and field test the design. As with Scenario #1, the technology development would be done with the guidance of numerical analysis performed with our sophisticated models. Since the design would most likely be a fully-confined system, modeling of a gaseous cloud would not be necessary. Design, field testing, and numerical modeling would be completed in the first year and a pseudo-empirical model would be developed in the second

year. Preliminary design and analysis results would be available after the first 6 months for roughly half the total first-year cost. Table 8 includes the cost estimate for each task.

TABLE 8. Estimated costs for Scenario #2.

Technology development	\$100K-500K
Experiments	
Small-scale (HEAF)	\$95K
Large-scale (NTS)	\$200K-600K
Sophisticated modeling	
Source	\$355K
Blast wave	\$165-225K
First year cost	\$915K-1,775K
Pseudo-empirical model	\$300K
Second year costs	\$300K

For limited funds of \$250K, we would recommend that the small-scale HEAF experiments be funded along with some preliminary source characterization modeling with the work completed in approximately 6 months. For \$500K, we would include the completion of the source modeling, and for \$750K we would recommend the addition of preliminary technology development with some blast modeling, with this additional work completed in 1 year. Again, it is clear that Scenario #2 would require over the \$750K limit for successful completion.

6.2 Recommendations for Long-Term Efforts

The short-term effort scenarios presented in Section 6.1 are based on destruction of 3.5 inch rockets. The developed technology and numerical models would probably be applicable to other types and classes of munitions, but further study beyond the one-year effort would be required to verify the effectiveness of the technology for destruction of other munitions. Our long-term efforts would include the investigation of other munitions by experimentation and numerical modeling.

Each munition will have different explosives or propellants that will need to be characterized using the HEAF facility and each will need to be analyzed using the source models. Using the developed technology from our first-year effort, the various munitions will need to be field tested and numerically modeled. The experimental and modeling results will then be used to adjust parameters in the existing pseudo-empirical model for use with each of the different munitions.

6.3 Conclusions

In conclusion, LLNL has a suite of numerical models capable of efficiently and accurately modeling and characterizing explosions and their coupled effects on structures or other surrounding media. These numerical models can be directly applied to the OB/OD problem with little if any code development. LLNL also has a highly skilled work force of ana-

lists and designers with the expertise needed for the successful analysis and design of the chosen mitigation technology. In addition, LLNL has three fully equipped and operational test facilities that were built and designed for explosive studies and there are facility personnel with a long history of involvement with OB/OD related activities.

LLNL welcomes the idea of performing this work in collaboration with other government organizations, facilities, or laboratories. We can also provide guidance or assistance in the technology development, experiments, or the usage of LLNL's numerical models.

LLNL would be pleased to assist the SERDP in the OB/OD problem. If desired, we will submit formal proposals for any part or all of the herein described activities.

Appendix A:

Work Plan for Pilot Study

**WORK PLAN
SERDP MUNITION DISPOSAL
SOURCE CHARACTERIZATION PILOT STUDY**

1. BACKGROUND

The Strategic Environmental Research and Development Program (SERDP) is supporting studies to develop and implement technologies for the safe, efficient, and environmentally sound disposal of obsolete munitions and propellants that are stored at various locations across the country. One proposed disposal technique is the open air burning or detonation (OB/OD) of this material. Although OB/OD is viewed as an efficient and cost-effective method for reducing the inventory of unwanted munitions and propellants, questions on its safety and environmental impacts must be addressed.

Current OB/OD operations are conducted on a limited basis using interim Environmental Protection Agency (EPA) permits. These permits are largely based on extrapolation from small scale detonations conducted in "bang-box" facilities or a few larger scale open air detonations. While these demonstrations largely validate certain aspects of the OB/OD technique, many questions that remain on large scale OB/OD cannot be answered in this way.

Specific unanswered questions concerning large scale OB/OD activities include the efficiency with which various munitions and propellants, some of which include casings or packing materials, can be consumed. Other questions include the heat generated, its radiative loss, and the remaining energy available for plume rise. The entrainment of dust (which may constitute the major OB/OD pollution hazard) and the propagation of a blast shock wave are also of concern. Before operational permits can be issued, these important safety and environmental concerns must be resolved. An OB/OD Source Characterization Model is needed to address these safety and environmental issues and to provide bulk source terms (detonation products, the quantity of entrained dust, effective heat released, and initial cloud dimensions) for the dispersion model.

2. THE PILOT STUDY

The SERDP munition disposal source characterization pilot study is needed to evaluate available models that could, with modification, become an OB/OD Source Characterization Model. The pilot study includes several tasks as detailed below:

- a. Task 1. Survey Available Models. Review available literature on relevant models and evaluate the capability of these models to address OB/OD issues.
- b. Task 2. Modeling Requirements Definition. Define model deficiencies and provide recommendations on whether or how to proceed with the development of an OB/OD Source Characterization Model, along with time and cost estimates for accomplishing this task. This should be accomplished in coordination with the contract monitor, who will provide information on the specific bulk source terms needed for input to the OB/OD dispersion model.

3. DELIVERABLES

The deliverable product of this pilot study will be a written report that addresses the two tasks. The report should include sufficient detail to permit an independent evaluation of the reported results and recommendations, and should be written and referenced in a style suitable for publication. Reports will be delivered to Mr. Christopher Biltoft, U.S. Army Dugway Proving Ground, West Desert Test Center Meteorology Division. Mr. Biltoft will be the contract monitor and point-of-contact for this pilot study.

4. PERFORMANCE PERIOD

The performance period for this pilot study is four months after the establishment of a mutually agreed work statement and the delivery of funds.

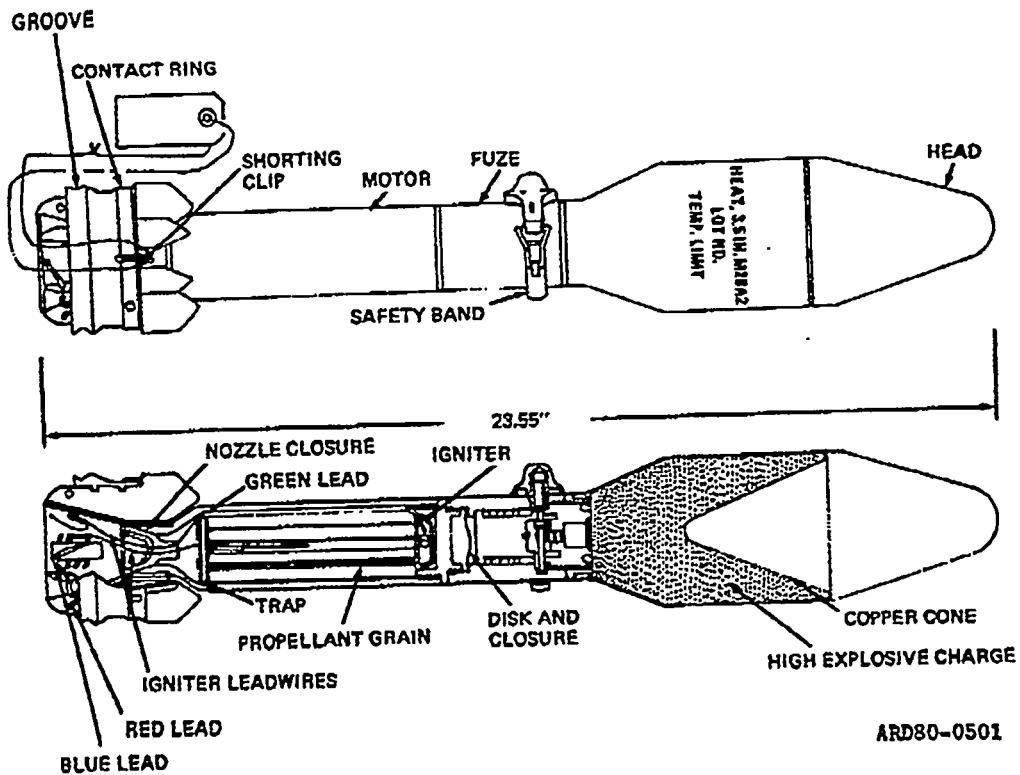
5. FUNDING

Funding for the pilot study will be provided through the Dugway Proving Ground OB/OD program.

Appendix B:

Details on 3.5 inch Rocket

ROCKET, HIGH-EXPLOSIVE, 3.5-INCH: AT, M28A2



ARD80-0501

Type Classification:

STD (LCC-B) OTCM 36841 Jul 58

Usage:

The M28A2 HEAT rocket is used primarily against armored targets, tanks and secondary targets, such as gun emplacements, pillboxes and personnel. It is capable of penetrating heavy armor at angles of impact greater than 30°. In an antipersonnel role, it has a fragmentation area 10 yd wide and 20 yd deep.

Description:

a. The warhead is cylindrical and tapered. The forward end, called the ogive, is thin metal and hollow. The rear end, threaded internally to receive the fuze which is encircled by a safety band. The warhead contains a copper

cone whose apex faces aft and acts to shape the high explosive charge Composition B (Comp B).

b. The base detonating (BD) rocket fuze M404A2 consists of a body which contains the functioning parts; a safety band, a detonator and a booster pellet. The fuze body and safety band are olive drab. The fuze mechanism consists of an activating plunger, a setback spring, a setback sleeve, a firing pin assembly, a detent spring, an ejection pin and an ejection spring. The spring-loaded ejection pin passes through the fuze body.

c. The motor assembly consists of a tube which houses the propellant and igniter. The fin assembly is securely attached to this tube. The front end of the tube is assembled to the base of the fuze. The rear end forms a nozzle. The cylindrical motor cavity is divided into four

sections by two spacer plates which support the grains of propellant powder.

d. Each grain of propellant is 5-in. long and approximately 3/8-in. in diameter. Three grains are placed in each of the four sections formed by the spacer plates. Each lot of propellant is adjusted at the time of manufacture to give standard velocity. The igniter ignites the propellant.

e. The igniter consists of a short, cylindrical plastic case containing a small black powder charge and an electrical squib. It is assembled in the forward end of the motor on top of the propellant, spacer plates. The leads of the electrical squib, running parallel to the grains of propellant, pass from the igniter through the nozzle into the expansion cone. A green lead (ground) wire is connected to the aluminum support ring of the contact ring assembly. A red lead (positive) wire is attached to a pin which is insulated from the support ring, but is in contact with the copper contact band. These connections are positioned 180° apart. Blue lead is used for test purpose only.

f. The fin assembly consists of six aluminum alloy fins and a contact ring assembly. The contact ring assembly, which encircles the fins, consists of three rings. The aluminum support ring, which is innermost, is separated from the copper contact ring by a plastic insulating ring. The fins are spot welded to the expansion cone, and the expansion cone is press fitted to the rear of the motor tube. The M24 and the M66 off-route mines utilizing M28A2 HEAT rockets are described in TM 43-0001-36.

Differences between Models:

The BD rocket fuze M404A1 is similar to BD rocket fuze M404A2. The M404A1 differs principally in minor design changes of the functioning parts and the shape of the safety band.

Functioning:

a. When the safety band is removed, the ejection pin moves outward approximately 3/8 of an inch but still prevents all parts of the fuze mechanism from moving. When the rocket is in the firing chamber, the ejection pin is partially depressed by the chamber, thereby freeing the setback sleeve so it can move to the rear when the rocket is fired. The fuze is still safe, since the ejection pin prevents movement of the actuating sleeve and firing pin.

b. If it becomes necessary to remove the rocket from the launcher, the ejection pin will move outward and re-engage the setback sleeve. This returns the fuze to its original safe condition.

c. When the rocket is fired, the force of inertia causes the setback sleeve to move rearward. It is held in its rearward position by the lockpin. When the rocket leaves the muzzle of the launcher, the ejection pin is thrown clear of the fuze by the ejection pin spring. The fuze is then fully armed.

d. During flight, the firing pin lever and firing pin spring prevent the firing pin from striking the detonator. The creep spring retards the forward movement of the plunger and actuating sleeve. The action of the creep spring prevents the fuze from firing should the rocket strike light objects such as thin brush or undergrowth.

e. Upon impact with a more resistant object, the plunger and actuating sleeve move forward until the sleeve hits the firing pin lever. This causes the firing pin to strike and detonate the warhead.

Tabulated Data:

Rocket:

Model ----- M28A2
 Type ----- Service
 Diameter ----- 3.5 in.
 Length (max) -- 23.55 in.
 Weight ----- 9.00 lb

Performance:

Operating
 temperature
 limits ----- -20° to +120°F
 (-28.6 to +48.4C)

Muzzle velocity
 (at 70°F)
 (approx) ----- 325 ft/sec
 (99 mps)

Warhead:

Type ----- HEAT
 Body ----- Steel
 Color ----- Olive drab w/yellow
 markings
 Diameter ----- 3.5 in.
 Length ----- 10.5 in.
 Weight ----- 4.47 lb

High-explosive train:

Detonator ----- M41
 Booster
 (tetryl) ----- 0.17 oz (4.81 g)
 Filler (warhead)
 Type ----- Comp B
 Weight
 (approx) ----- 1.88 lb (.854 kg)

Fuze:

Model ----- M404A1 or M404A2
 Type ----- Base detonating
 Diameter ----- 2.0 in.

Length:

Overall ----- 3.48 in.
 To shoulder
 (max) ----- 2.94 in.
 Weight ----- 1.16 lb
 Arming
 distance ----- 10 ft (3.05 m)

Motor:

Diameter (at
 fins) ----- 3.5 in.
 Length ----- 10.41
 Weight ----- 3.30 lb
 Thrust ----- 6,000 - 10,000 lb

Propelling initiating train:

Igniter:

Model ----- M20A1
 Charge (black
 powder) ----- 0.13 ± 0.007
 (3.5 ± .2 g)

Electric
 squib ----- M2

Propelling charge:

Propellant:

Model ----- M7
 Type ----- Solvent
 Configuration - Monoperforated,
 cylindrical, extruded
 grains (12)
 Weight ----- 0.44 lb (198 g)

Burning time:

At -20°F ----- 0.05 sec
 At +120°F --- 0.02 sec

Launchers ----- M20, M20A1,
 M20A1B1, M20B1

Packing ----- 1 per metal/fiber con-
 tainer, 3 containers
 per wooden box

Box:

Weight (with
 contents) ----- 53.0 lb

Dimensions:

W/metal
container --- 29-9/16 in. x
14-1/16 in. x
16-19/32 in.

W/fiber
container --- 29-3/16 in. x
13-7/8 in. x
16-19/32 in.

Cube:

W/metal
container ---- 1.6 ft³

W/fiber
container ---- 1.5 ft³

DODAC ----- 1340-H600

Shipping and storage data:

Storage class/

SCG ----- 1.1E

DOT shipping

class ----- A

DOT designation - ROCKET AMMUNI-
TION WITH EXPLO-
SIVE PROJECTILES

Field storage -- Group E

Drawings:

Complete assy -- 9211744 (82-6-22)

Loading assy

(head) ----- 82-16-36

Loading assy

(motor) ----- 9225502 (82-16-35)

Packing (inner) -- 7549038

Packing (outer) -- 7549040

References:

TM 9-1340-222-34

Appendix C:

Detail information on the 10 kg spherical tank

10 KG SPHERICAL TANK INFORMATION

Manufacturer:	<u>CBI Services, Inc</u> Oak Brook, Illinois
Material:	Stainless Steel (304L)
Static Pressure Test Values:	110 PSIG for 40 minutes
Working Static Pressure:	82 PSIG
Tank Qualification Tests:	Began January 1989 Completed February 1989
Test Firing Maximum Weight:	22.2 lbs. (10 Kilograms)
Test Firing Explosive:	C-4
First Experiment Fired Date:	15 March 1991
Inner Diameter:	15.66 feet(4.77 meters)
Tank Entrance Diameter:	8 feet(2.44 meters)
Wall Thickness:	3 inches(7.62 centimeters)
Port Glass and Other Flange Thickness:	5 to 7 inches(12.5 to 17.78 centimeters)
Internal Volume:	2,197 cubic feet(62.22 cubic meters)
Total Weight:	<u>180,283 lbs. (90.14 tons)</u>
Door Weight:	<u>9,500 lbs. (4.75 tons)</u>
Laser Ports:	4 at 8 inches diameter
Camera View Ports:	5 at 6 inches diameter
Thermocouple Ports	2 at 12 inches diameter