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A REVIEW OF SAFETY PRACTICES AND SAFETY TRAINING FOR THE EXPLOSIVES FIELD

Joseph Hershkowitz

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Various safety practices and the content of selected training programs emphasized at several major installations involved with explosives and explosive devices are reported herein.

The report is divided into independent sections, each of which addresses a commonly encountered facet of explosives safety. Supplemented by a safety file consisting of regulations, references, documents, videotapes, and cassettes

(cont)

19. KEY WORDS (cont)

- standing operating procedures
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- firing/grounds/shielding
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- sensitivity/explosiveness
- accidents
- philosophy

20. ABSTRACT (cont)

(all listed in an appendix) and suggestions for presentation and demonstrations (also included as an appendix), the report can be used as the basis for a modular training course. It is being used in this mode by the Ballistic Research Laboratory (BRL) in the production of a video training tape which, ultimately, will be made available to those working in the field of explosives.

Although the report provides the reader with a comprehensive view of many of the safety practices currently in use at representative installations, it is not an endorsement of any of the safety practices described nor does it supersede existing safety regulations at any installation. In all cases, the safety regulations at the individual installations continue in effect until formally altered.

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1. INTRODUCTION

A. Need and Response

Installations working with explosives and munitions have always been concerned with safety. Unfortunately, through retirement and normal attrition, many of these installations are losing personnel well-versed in safe practices, who are taking with them the accumulated wisdom of many years. There is an urgent need to capture the knowledge and viewpoints of these experienced senior personnel (including those already retired) while this rich source of information from the past is still available. There is also a pervading interest in providing new employees with new and improved training media and practices. This report attempts to satisfy both these needs.

While visiting representative installations, each of which provides training for its special needs based on the relevant agency (e.g., DOE, DOD, etc.) regulations, the author interviewed line and safety personnel and acquired related documents. Emphasized safety practices and selected content of training programs obtained were organized into this report.

Not in itself a training course, the report recounts what those interviewed considered important and includes substantiating backup material in a format that can accommodate supplementary material in the future. It is virtually a "corporate memory" of explosives safety and, as such, inevitably contains differences of opinion and different approaches to the same problem. All of the varying options have been included not only to realistically reflect actual practices in the field, but to provide the reader with as much diversity as possible to help him in accommodating different specific needs. If the adoption of any of these practices leads to changes in existing procedures, such changes can only be authorized by the organization concerned, and unless (or until) changes are formally made, the existing safety regulations at each installation must be followed.

B. Organization and Content

This report is divided into sections (modules) which represent areas of interest from which a selection can be made to fit the needs of personnel with different duties and backgrounds. Fundamental information such as chemistry or detonation theory has not been included. The need is recognized but should be incorporated as either separate or introductory modules for particular sections. This report concentrates only on the safety practices.

The Safety File at Ballistic Research Laboratory, BLT(A) (app A) consists of the documents, cassettes, videotapes, and references gathered or ordered as a result of the visits made to the installations listed in appendix B and delivered to Dr. Howe at BRL.* There is some overlap between the categories of the safety file; material filed under SOPs and TRAINING necessarily includes information on the other topics (e.g., PRESSING, MAGAZINES, and FIRING). These two categories should always be consulted in seeking information on any topic.

The suggestions for presentation and demonstration (app C) serve an overwhelming need to make training effective. Problems of presentation of content and the use of visual aids are dealt with, and a list of suggestions, keyed to each section, of possible demonstrations is included. (The paragraph within the body of the report most pertinent to a particular suggestion in appendix C has the corresponding suggestion number at the end of that paragraph.) Selection from these presentation ideas or provision of those more appropriate for the needs of the installation is considered essential to maintain interest and make the points remain long after the course is completed.

2. RAW MATERIALS (H)

A. Adequate Description

Until the experimentor has recognized an explosive in the sense of knowing all the hazards in the planned operations with it, he must consider and treat it as a sensitive primary explosive. If it is identical with one that has been used previously for the same application, then the existing standard procedures may be followed. If it is not identical, or if the application is changed, it becomes necessary to do tests to establish the significance of the differences. In many cases it is essential to know precisely the chemical composition and physical attributes of each particular explosive material. It is equally necessary to be aware of the presence of chemical residues and to remove foreign materials. Finally, the sensitivity properties of the specific explosive material must be known or established.

To communicate information on an explosive, a designation is needed which is sufficiently unique that tests made on samples with that designation may be considered representative. It is necessary to include by that designation all parameters that may have a bearing on sensitivity. One might think that an explosive description could be adequately provided by just the composition, by the details of the process by which it is made, or by the results of sensitivity tests. It will be seen that combinations of these and other descriptors are necessary. Explosive compositions are assigned a name or designation that usually includes letters and numbers (e.g., PBX 9404, COMP B4, H6) and an explosive specification is associated with each explosive. The addition of a letter E to a Navy designation (e.g., PBXN-107E) indicates that a change in process of manufacture has been made or a substitute material used (app C, H1).

*Requests for individual materials should be addressed directly to the source.

The chemical name or composition is totally inadequate to specify the explosive. TNT can be pressed, cast as a liquid, or be a single crystal, cracked or whole. There are isomers of TNT and polymorphs of HMX, etc., which must also be specified. Most often, mixtures of explosive and nonexplosive ingredients are used as practical explosives. COMP B4 contains weight percentages, RDX 60/TNT 40. COMP B has the same ratio but adds 1% of wax and has a different particle size of RDX. COMP B can be cast or pressed and the particular wax or substitute for the wax also changes the sensitivity.

A mechanical description must be added to the chemical description (formulation). The particle size distribution of the explosive is a most significant factor for both cast and pressed forms. In a composition there may also be microdefects (e.g., cracks) that affect the sensitivity. The density of the explosive in relation to the theoretical maximum density (TMD) plays an important role. It has also been shown that the sensitivity to shock initiation decreases markedly when very close to TMD. Some explosives have additives or binders added to one or more explosive constituents. The overall sensitivity is very dependent on the properties of the binder/additive in relation to the explosive constituents (app C, H2, 3, 4).

PETN sensitivity is very much a function of surface area, surface states, particle morphology, and distressed crystals so that "superfine" must be distinguished from regular.

Lead azide, a primary explosive, has a sensitivity that depends on the crystal habit modifier used in its preparation, so that dextrinated lead azide is distinguished from "service" lead azide (nucleus of lead carbonate) and from polyvinyl alcohol (PVA) lead azide. The addition of graphite or CAB-O-SIL to lead azide further changes the sensitivity. Lead styphnate, a sensitive primary, is currently used in dead-pressed form as a delay element. This requires care as to mechanical state, e.g., crumbling would make it hazardous.

It should be clear now that in using information on the explosive-at-hand, one must know the specifics of which explosive it is and, from the safety viewpoint, be sure that no modification has been made in formulation, processing, or mechanical makeup which has not been evaluated with respect to the effect on sensitivity.

B. Quality Assurance

On all explosives, it is necessary to do a "powder" inspection on received explosives as foreign matter is often present. Nails, wood, etc., have been found in COMP B. A moving belt with a magnet and visual inspection is effective. This screening should be part of a quality assurance (QA) program on incoming material.

The QA program should include some sensitivity and chemical tests to be sure that the received material is correctly identified. A case occurred in which a material identified as TATB really contained some HMX which had been inadvertently mixed in during reworking. This was discovered when an impact test was run on the received material and a "GO" occurred. If the received material had been handled as TATB, an incident might have occurred.

Statements made by others are not always reliable. The individual himself is responsible for knowing what he is working with. A supplier has been known to honestly give wrong information (i.e., there can be a mixup). In one case, the material received was so sensitive that body static was adequate to set it off, but the manufacturer did not know it. When notified, the manufacturer conducted tests which confirmed the condition.

Chemical reactions that are unexpected can occur due to a residue from manufacture within a constituent used to make a composite explosive. For example, residual acid in TNT by one method of manufacture can, when TNT is used for Pentolite, lead to nitrogen dioxide fumes due to autocatalytic decomposition of PETN. The residual acid content in TNT is limited by current agreement to less than 0.02%. This is important when TNT is used with Pentolite boosters because excessive acid leads to generation of nitrogen dioxide fumes. If TNT with excessive acid were furnished for manufacture of Pentolite (e.g., for use in munitions by our NATO allies) it could be a major safety hazard. More than a decade ago a Naval Surface Weapons Center (NSWC) report recommended that residual acid in TNT be reduced to less than 0.004% for all TNT earmarked for Pentolite manufacture or for TNT that would be in intimate contact with Pentolite boosters.

C. Allergic Reactions and Toxicity

The presence of residues is also important and should be identified because of the possible reactions of human beings to those chemicals. In the manufacture of RDX and HMX, it has been proposed that dimethyl sulfoxide (DMSO) be used. However, DMSO is one of the strongest skin penetrants known. If there were to be residual volatiles of DMSO in COMP B, for example, then on contact it would carry RDX, which is soluble (as is HMX) in DMSO, directly into the skin. The change in manufacture to the use of DMSO instead of cyclohexanol also changes the particle shape and size distribution of the RDX and HMX. This can change explosive properties, which again stresses the need for full characterization, not just the name of the explosive. DMSO recrystallized RDX and HMX have been checked in plastic-bonded explosives (PBXs) and propellants and, in several cases, have exhibited abnormal process and end-use behavior (app C, H5).

The problem of allergic reactions and toxicity can exist with respect to both the residues and the materials involved. TNT can cause allergic skin reactions; tetryl is toxic and is still used overseas and in the United States. Although tetryl is being phased out in the United States, many years' supply remains to be used. Urethane systems used in making polyurethane based PBXs use toxic raw materials. When plasticized, polyurethane binder explosives burn, they may produce cyano and cyanide combustion products (app C, H6).

When disposal by burning is used, the fumes generated can be hazardous. Even without burning, operators exposed to explosive fumes have a health hazard [e.g., lead from lead azide; mercury from mercury fulminate; nitroglycerin (gelatin dynamite) fumes are a powerful vascular dilator; TNT has systemic effects]. Therefore, working with explosives in confined spaces can be hazardous. Ventilation and vacuum used to draw fumes from the top of a kettle are essential safeguards. When regularly casting TNT explosives in the past, operators received blood tests every 6 months. Skin reactions, headaches, and other physical reactions require immediate action to protect personnel. Protective clothing is often required.

Because of the toxic hazard from mercury vapor, a facility must be designed to take care of mercury spills. In running vacuum stability, a mercury manometer is used which can shatter occasionally. Smooth floors that have no cracks and are tilted should be used and have a trough for collection of spilled mercury. Vacuum should be applied to surfaces to remove residual mercury.

D. Preliminary Sensitivity Test

Before any experimental work is started with a new explosive or explosive mixture for which sensitivity and stability data do not exist, small quantities of the explosive or explosive mixture should be subjected to sensitivity tests (including at least spark sensitivity, impact sensitivity, vacuum stability, and/or chemical reactivity), thermal tests such as DTA, and pyrolysis tests. Preliminary tests with up to 5 grams of secondary explosive may proceed if justified by the results of these tests. Standards for proceeding beyond 5 grams are set up by an SOP. Quantities for primary explosives are always maintained at very low levels (SENSITIVITY and app C, H7).

3. PROCESSING (O)

This section contains safety problems related to the equipment used for processing the raw materials including some of those common to casting and pressing operations.

A. Drying Ovens

Drying ovens are used to prepare explosives for further processing; e.g., PETN, HMX, and RDX are stored under water and required quantities dried for use when needed. The following paragraphs indicate some associated safety features:

There was an incident in which an oven with a backup safety device that had been incorrectly wired by the manufacturer led to the loss of some equipment. Routine checkups on safety devices on ovens and a regular scheduled maintenance program are necessary (app C, O1).

There was also an incident in which a control on an oven malfunctioned and the temperature continued to rise causing runaway. An additional temperature-limiting device is required to be set at 5° to 10°F above the thermostat setting or to a value well below the critical temperature. This increases safety by providing dual controls. With two temperature controls in use, it is beneficial to incorporate a switch so that each is used alternately as primary and backup. This insures proper maintenance of both.

If there is an interruption of power, the power should not go back on again automatically, because solid state control circuits may not function correctly. The controls must be manually reset.

At one installation the gages, located in the hall outside the room containing four ovens, are reviewed before entering. The room is isolated, has a blast door, and each oven is isolated from the others by chain-mail curtains.

Steam ovens* are preferred to electrical types. However, even with steam ovens, care must be exercised (e.g., nitrocellulose can be ignited by steam temperatures).

Magnetic door latches are used on ovens for ready venting if a "blow" occurs. No exposed wiring or heating element is allowed within electric ovens.

B. Mixers of Different Types

Before a kettle is used, the interior is checked to assure that it is clean and contains no foreign material. The kettle wall thickness is also periodically checked as abrasion wears down the wall. The agitator blade clearance must be checked before placing melt constituents into a kettle. A blade clearance test should be run after the empty kettle is equilibrated to the melt temperature, and the clearance should be checked in four patterns, 90 degrees apart. The kettle cannot be used unless this check is passed at specified values. Use of a gage designed for the test is recommended. Some kettles need more attention to clearances than others. The emphasis is that the agitator will not rub the kettle wall directly. It is also necessary to be sure that there is no excessive friction in the packing glands of the shafts. If the material added is in big chunks, it tends to move the agitator; therefore, material must be added in small pieces and in increments as the previous additions melt, so that the agitator is not overloaded. Some constituents of a mix (e.g. anticaking agent, dodecylbenzene which is insoluble in ammonium nitrate) may have a tendency to pile up on the walls of the kettle. The increased friction combined with higher than normal kettle temperature could possibly cause local decomposition constituting a serious hazard (app C, 02).

It is always necessary to go to more sophisticated shearing mechanisms as the viscosity increases to a level set by the needs of the mix. A first step

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*Available as Precision Scientific Model 959, Type B, Chicago, Illinois or equivalent.

from the "candy" kettle type is the use of swirl blades to reduce drag. For higher viscosity mixes, however, a blender such as the Baker-Perkins hi-shear type (B-P) is used. As the viscosity increases more energy is put into the mix which must be considered with respect to blending speeds and tolerances in equipment and temperatures. Also, the viscosity in the pot depends on the particular size and shape distribution of the solid content; therefore, tolerances are required on these parameters as well. The B-P kneading action can take several hours; samples must be pulled during this time to check for uniformity. In this type of blender the bearing must be exceptionally rigid to avoid scraping the wall due to bending. (The only bearing is at the top; there can be none in the explosive.) Since hi-shear type blenders introduce extra energy to overcome the viscosity of the mix, the operation must be done remotely. High shear type blenders are used for PBX; candy kettles are used for cast TNT base explosives.

Each time, before explosive constituents are put into the B-P, it is run empty to check the clearances. A change in particle size could alter the clearance required. Therefore, the tolerances of the equipment and the tolerances required so that the mix does not bind must be known. If particles of inert material bind in the clearances of the blades or of the blade and wall in the presence of the energetic material, a hazardous situation also exists.

At NSWC, the processing group uses B-P mixers in 1-gal, 1-pt, and 1/2-pt sizes. As originally furnished by the manufacturer, the bowl is on wheels and positioned so that a platen operated by a double-sided hydraulic ram lifts and lowers the bowl. This system has been modified because of the concern that the bowl might hang up if the vacuum line clogs or for other reasons that it would not follow the platen and would then drop a distance thereafter, possibly tilting (cocking) in the drop. The modification at NSWC involves locking pins between bowl and platen to provide positive up-and-down motion and removing the wheels. However, the machined parts used must be very precise and there must be no alteration of clearances or binding to the blades as the bowl is lowered. This modification has been discussed with the manufacturer but has not been adopted by the manufacturer at this time.

The planetary head of a B-P has many gears. Full vacuum is normally maintained in the standard unit on the enclosure which contains these gears as well as on the bowl interior itself. However, at NSWC, the vacuum line to the gear chamber has been closed off. (Vacuum gages should be located to avoid plugging and consequent erroneous readings.) The motive is to prevent explosives from being drawn up into the gears by the vacuum by means of the rotating shafts. This is considered preferable to the risk of grease making its way down the shafts to the explosive. In general, hazard considerations for all processing equipment should assess the risk of flow of constituents along rotating shafts whether horizontal or vertical.

To be effective the deluge system for a Baker-Perkins vertical mixer must be positioned so that the deluge output is directed to the mixing kettle. An inadvertent shutdown of a mixer containing a blend with catalyst present can lead to local reaction and can build up to ignition so that prompt use of a deluge system may be required. Note that deluges are not uniformly accepted. It has been asserted that they function more often than mixers catch fire which leads to other hazardous situations (e.g., freezing of TNT in candy kettles, water reacting with isocyanates and aluminum in B-P mixers).

The B-Ps are observed during use by remote TV. The control room is also linked to the processing area by an audio-communication link. This link is essential for safety to assure that no accidental operation of the B-P can occur during clearance checks. A local switch to operate the B-P is not available so as to prevent any "short-cut" use while the operator is not safe in a remote bunker, thus necessitating the audio link.

In performing a chemical analysis of PBX-type explosives under contact conditions, begin with a maximum of 2 grams in dissolved or diluted form and work with it on a bench or in a hood depending on what is underway. Later, in a scale up, a quart mixer or a 1- to 2-pound maxima is used in various other equipment within a cell of a 6-cell barricaded building. There a camera is used to observe the pot remotely.

C. Permissible Parameters

At the Naval Weapons Station (NWS), tests are done to establish the matrix of permissible values of processing variables that are safe to use. A specific set of processing variables is selected in the "center" of the matrix to provide a margin of safety consistent with practical considerations. The result is called Navy Munitions Data (NMD) for the combination of the weapon and the explosive. The point here is that one should be aware that there are safe and unsafe domains of process variables, and if these are not known, the process must be approached with initial small steps, etc. The safety parameters in processing are constituent parameters (e.g., particle sizes), temperature, rate of rotation, vacuum level maintained, type of agitator used in relation to viscosity of mix, clearance, and set time (app C, 03).

When energetic materials are government furnished (e.g., RDX from Holston), the accompanying certification is normally accepted. Similarly, vendor certification is often accepted. At other times, samples from lots are used. In processing with furnished materials, viscosity of a pilot batch is checked in the laboratory. The end of mix viscosity is checked to determine the time to finish use. Also, when the warhead is being poured, the pour specimens are simultaneously taken for hardness, tensile strength, and uniformity to indicate what is being achieved in the warhead (app C, 07).

D. Chemical/Static Hazards and Indicators

The need for knowledge of chemistry of constituents and explosives in processing and other handling in order to avoid accidents shows up repeatedly. "White" compound is formed as an intermediate in the continuous manufacture of TNT. This compound can, in time, plug the line connecting two reaction vessels. To have the reaction continue, the plug was mechanically pushed through. On one occasion a rubber hose was used as a pusher and penetrated into the second reaction vessel, and the rubber reacted violently with the concentrated acid in that vessel leading to an incident. Another example relates to troughs which are sometimes used to convey TNT. This leads to build-up of a layer of TNT on the surface of the trough. A less knowledgeable individual learned that TNT was soluble in alkali and was ready to use strong alkali to clear the trough. Fortunately, the attention of a senior scientist led to a laboratory small-scale experiment to demonstrate that violent burning would result (app C, 04).

Knowledge of chemistry of constituents and explosives must be supplemented in processing and formulating work by knowledge of indicators of hazardous chemical change, but any appearance of unexpected color, odor, etc., must be considered hazardous. In this connection, a chart that lists properties of 38 principal explosives has been compiled so that individuals would be aware of these for processing purposes and characterizations. These properties include formula or composition, color, use, method of loading, drop test, bullet impact, reaction with steam, melting temperature, detonation temperature, burn under water, reaction with metals, hygroscopicity, solvents, and stability in storage (app A and app C, 05).

Continuous processing equipment is now being used for low viscosity blends and is being considered for the high viscosity PBX blends. In order to provide a 4- to 6-hour pot life in the Baker-Perkins equipment, only 0.019% catalyst can be used. Since a short blend-life to setup time can exist in the continuous process, 1% catalyst can be used and entered further down the blending column. The chemical timing has been changed which requires reconsideration. Safety problems in this area are not yet fully defined, and in the presence of a larger quantity of catalyst, the effect of an inadvertent shutdown is an important consideration (app C, 06).

The pouring of powders is a source of static electricity. This and the general hazard with handling explosives particularly in dry regions requires that the humidity must be controlled to reduce static hazard (app C, 08).

4. CASTING (C)

A. Melting Temperature

In melting or casting, the explosive local temperature depends on the thermal properties of the liquid phase as well as those of the solid phase. The temperature distribution is linked to the temperature of the kettle and the local self-heating of the explosive. Temperature-controlled water is used in the jacket because this gives fine control for melting and freezing of the explosive. If the stirrer stops during melting, blending, or casting, explosive accumulates, self-heating is altered, and the heat transport to the jacket is different. This can be a hazard; therefore, temperature limits must be maintained on the melt. An accident that resulted in four fatalities may have occurred in working with Pentolite where the agitator may not have been running. It is essential to watch the melt temperature and have shutdown procedures keyed to limits. In this connection, a mix that is allowed to remain for a considerable time at a reduced kettle temperature is subjected to a long induction period that can lower the explosion temperature (app C, C1).

A thermal lag can exist in controlling kettle product temperature resulting in fluctuations of 10°C. For less thermally stable materials such as Pentolite, this could be dangerous. If the thermal lag is due to an insufficiently sensitive temperature sensor that controls steam injection, it should be replaced with one with a more rapid response. A good approach is to prepare the melt by using steam in the kettle jacket and then by switching to a controlled-temperature circulating, hot water system as soon as all the TNT has melted. At Los Alamos National Laboratory (LANL) steam is not used; instead, pressurized hot water is used to heat the kettles. This gives better control over melt to make high quality casting and provides the needed control of freezing patterns. Accumulation of resolidified explosive on kettle surfaces or on the agitator is prevented by correct heat transport (app C, C1).

For TNT type explosives, the viscosity is approximately 100,000 centipoise and the use of a candy kettle approach is satisfactory. It is important not to add large chunks of riser, for example, that can get jammed between agitator and wall.

B. Equipment Hazards

Chemical change can occur with time; therefore, changes in properties can occur that can lead to a hazard. Solid TNT is compatible with isoprene (rubber); however, in reaction with molten TNT over a long time, the isoprene is embrittled. Therefore, a valve made of isoprene operated by pressure of liquid TNT would fail in time. Some plastics also react over a period of time, so that the need for always verifying long term compatibility is necessary prior to use.

When a vacuum cast kettle is modified for a vacuum melt capability, the use of butterfly or ball valves for bottom or side discharge creates a potential hazard. Instead, a commercially available sphincter or diaphragm valve with high temperature, operating capability should be used (app C, C2).

Ground glass in TNT is a combination equivalent in sensitivity to lead azide. For this reason, one should not use glass thermometers to check the melt temperature. If breakage occurs, a serious hazard is suddenly generated in the kettle. Similarly, safety glasses should be held in place on the head by safety straps. Watches, pens, and badges have made their way into explosives. The use of tools or equipment that can fall into a melt kettle during the preparation of a melt must be avoided. Bolts and other parts of melt cast kettles that could fall into the melt should be securely fastened.

In cleaning up, one cannot use live steam without evaluation of the consequences. On Baratol, this led to a reaction. Dry steam can give sparks from static. A mixture of live steam and water is usable, but high pressure steam with low pressure water cannot be used. A commercially available device to match pressures is needed. Note that loading plants have a 15 psi limit on steam used in kettle jackets (app C, C3).

Cleaning a kettle with acetone is hazardous because of the possibility of a fire since acetone has a low flash point and because of the health problem of repeated and prolonged exposure to acetone vapors. The health problems require equipping the operators with masks. It is still preferable to avoid acetone for cleaning by installing a steam-hot water, mixing valve where feasible (app C, C3).

In casting, hot explosives are poured and kettle connections transmit 10 pounds of steam. There is a distinct safety hazard with respect to getting burned or scalded. It is important to be sure that the steam has been turned off before disconnecting the hose. Gloves and aprons are used to protect against contact with hot explosives. Safety glasses and, if necessary, face shields are used for protection against splatter.

In the casting room, equipment is grounded, floors are usually made conductive, and nonsparking tools are used. Where the hazard of dropping a billet of explosive is greater than that of static charge effects, floors may be covered with a surface that leads to reduced skid-friction hazard.

In the casting plant, the liquid explosive is transferred into a volumetric loader that has multiple orifices on the bottom. At one time, between flows into the munitions, the holes were plugged by a set of metal corks aligned to close the holes. The metal-to-metal contact shearing explosive (especially containing solid particulates in liquid) was the wrong thing to do and may have been the cause of an accident in which a building was lost with all inhabitants. Plugs are now coated with a selected KEL-F or other yielding polymer.

C. Cast Explosive Hazards

When loading is done vertically with a riser, it is necessary to remove the riser. This can be hazardous unless the riser explosive is designed for easy removal. On occasion, poor design leads to snap/crackle/pop as the riser is struck by a mallet. This requires redesign to avoid an accident. The use of risers that require the fracture of large cross-sections of explosive during the stripping operation should be minimized. Casting molds should also be designed with no screw threads that can be contaminated with liquid explosive during the casting operation (app C, C4).

In spite of proper processing as checked by pour specimens, etc., the actual situation created in the warhead may be very different. In casting TORPEX, when the explosive is poured too hot from the kettle into the munition which is then laid on its side, a safety problem might arise. This could be the result of a concentration of aluminum grit and RDX on one side due to settling which makes the side more sensitive. A warhead hit by a fork truck in this sensitive area may have led to an accident by the described settling mechanism (app C, C5).

After blending, a castable explosive is sometimes poured onto cookie sheets (panning) to form a thin layer. To break it up, a rolled leather mallet is used gently. If a piece of explosive is to be broken because it is too large to put directly into the kettle, it is held by hand and the mallet is used, or it is broken by using both hands. In all cases, only limited force is applied and care is exercised that the force is never concentrated on a small region of the explosive (app C, C6).

Reclaimed explosives are sold for commercial use or are reused directly within the government. When reused, these explosives require recharacterization to ascertain the changes in sensitivity to various stimuli. Proportions change (e.g., riser has less solids) so that it may be necessary to reconstitute the correct proportions. Changes in sensitivity may have occurred with chemical or mechanical methods used to remove the old explosive from munitions in demilitarization steps.

5. PRESSING (P)

A. Remote Operation

Contact operation, when permitted, is limited to TNT base explosives where there is 40 years of experience and appropriate safety precautions are well established. PBXs are always run remotely, since lots of energy can be generated during pressing, and experience is still limited. In some installations all pressing is always done remotely.

When a small quantity of explosive, even 1 gram, is being pressed and is therefore confined, explosion can lead to fragmentation (miniature pipe bomb). If pressing with small quantities of explosive is done using only a shield to protect the operator, then that shield must provide for all the consequences of explosion during pressing. The use of a shield that requires an operator to expose an arm while the explosive is either being pressed or under pressure is not an acceptable operating procedure. Optically transparent shields made of polycarbonate in a steel frame are inexpensive and effective (app C, P4).

Red warning lights and gates should be used to alert personnel when pressing operations are underway and to block access to dangerous areas such as the rear of buildings where blowout is a possibility.

Molds capable of being heated, of applying vacuum to the molding powder, and of ejecting the pressed explosive charge, all under remote operation, should be used to maximize safety and product quality.

B. Tooling and Pressing Facility

In pressing, it is essential to have proper die design which is a complex subject in itself. Installations may even approach the subject with different philosophies. Hardness of parts, clearances scaled with dimensions, tapers, finishes, and choice of materials, all enter into achieving the final design for a specific application.

Pressing dies are visually inspected for damage, deformation, and cleanliness prior to use. If any question exists, parts are subjected to tests such as x-ray, magnaflux, and ultrasonic examination to verify condition. Tooling should be tested by the preceding technique after no more than every 1000 pressing cycles and preferably more often (app C, P2).

Press-blows are thought by some to be caused by powder between the ram and the wall leading to frictional initiation. Tools and dies for pressing operations should be only matched sets to assure an accurate fit (app C, P1).

Oil in the vacuum pumps used in high explosive operations is tested for the presence of high explosive at periodic intervals not to exceed 6 months. If high explosive is detected, the oil is changed.

In the pressing area, a new conductive floor paint was applied to a deteriorating conductive concrete base.[1] It is gray and is not supposed to wear off. An electrician is assigned to all floors to check conductivity spot-by-spot. He also does regular checks of the ground girdle, measuring resistance of many points including floors directly to the main ground post.

C. Parameters and Stress Concentration

In pressing, one must consider temperature of powder, number of increments, powder-ram adhesion ram speed, ram pressure, dwell time, and clearance.

An important consideration in all processing is to avoid concentration of mechanical stresses. To do this, pinching by moving parts is avoided in the mold design for pressing. Cleanliness is part of this because foreign matter can serve to concentrate forces. Similarly, binders can serve to spread the force exerted on the explosive crystal or convey it to the crystal depending on properties. In trying to press dry RDX to crystal density, a mold exploded, perhaps due to crystal-on-crystal concentration. However, Bridgman, et al, subjected pure explosives to extremes of pressure without incident, which supports the view that press-blows are related to cracks, metal chips (i.e., to concentrators), and to rate of pressing. All powders should be pressed slowly to allow them to equilibrate.

The role of the binder in cushioning particles is important and this role can change with temperature, altering sensitivity (e.g., KEL-F 800 is a waxy soft, whereas KEL-F-3700 is a more rigid elastomer, so that they differ in force transmitted onto an explosive crystal). A binder may also change properties with temperature where there is a phase change. In one case, Estane/HMX, PBX 9011, changes mechanical properties as temperature (T) changes. At low T, it becomes

[1] "Elimostat" from Walter G. Legge, 122 E. 42nd St., NY, NY, 10017. (Products are available from other sources as well.)

rigid and is shown to be significantly more hazardous. This is contrary to the popular idea that all hazards are always less at low temperatures (app C, P3).

In pressing operation, Class A RDX was changed into Class E (finer). This was shown by taking axial core specimens and chemically removing the wax of the COMP A3 and remeasuring particle size properties. No differences were found when COMP A3 was made by using either Class E particles of RDX or Class A starting material. It is concluded that particle sizes can change in pressing. In casting, crystals can also grow in size in the melt (e.g. RDX in Cyclotol, HMX in Octol).

6. COMPATIBILITY (B)

A. Sources of Information

Compatibility of explosives with various items to be encountered in the environment is a very broad subject. There is a large body of reference material, computerized (COMPAT) and reports issued by PLASTEC (app A), that provides guidance as to combinations to avoid. These are invaluable to the designer selecting materials to be used and also should be referred to by the explosive scientist or technician preparing an experiment (e.g., assembling an explosive train) where adhesives are used or where different materials come in contact (app C, B1).

A knowledge of chemistry can be most helpful to create an awareness of possible hazards. A nonchemist always needs advice from an explosives chemist with respect to potential incompatibilities. No adhesive, solvent, or combination of materials can be envisioned or selected without such consultation. If a new or modified explosive or other constituent is involved, the chemist can perform small scale tests to identify any potential hazards (app C, B2).

An awareness of chemical warning indicators can be helpful. If you smell an odor, any odor, a chemical reaction or a vaporization may be underway. If you detect gas bubbles emanating from a mix, a chemical reaction is probably underway. If there is a color change, a chemical reaction is very likely to be underway. If you hear a noise (fizzing, sparking, crackling, etc.), a reaction is underway. Use both your eyes and ears and do not wait to investigate if you even suspect an unforeseen chemical reaction is underway--clear out (evacuate). Shut the operation off on the way if this is part of the procedure and then consider what to do after isolation is achieved (app C, B3).

B. Some Problem Areas

A sealed ampule of a strong oxidizer (nitronium perchlorate) was unlabeled and led to a painful accident. When broken, clean up was attempted with water and then acetone which reacted explosively with the oxidizer. Only the small quantity involved prevented serious injury.

In handling liquids (i.e., fuels and chemicals), leaks or spills must be prevented in confined spaces. Liquids mixing with air can provide a combustible mixture. Acetylene (used in lab) is very dangerous; it is detonable both alone, especially under pressure, and mixed with air. Actually, acetylene forms a more sensitive mixture with air than hydrogen. Mixtures of aromatic hydrocarbons with nitrogen dioxide can easily detonate. The general remedy is to keep fuels and oxidizers separate, to avoid premixing by leakage, and to store compressed gases outside or with ventilation so that small leaks will not lead to accumulations.

Lead azide and copper can lead to the formation of copper azide which is most hazardous. Copper or copper alloys are not allowed in the safing and arming (S&A) unit or on the booster side of the S&A in new design fuzes. It is not unknown for copper azide to form on laboratory alligator clips when exposed to certain chemical atmospheres. These clips then "pop" when connected to a voltage source. It is best not to use copper clips in such situations. Compatibility problems also exist between epoxies and oxidizers and between aluminum and teflon (fluorine in particular attacks aluminum). Outgassing of plastic materials is a source for contaminating connectors. Chemical reaction comes into play when foreign objects from the workplace [e.g., from workers or implements (PROCESSING)] can get into the explosive being processed (e.g., into melt or pressing powder).

Many investigators run a compatibility test between a cured PBX explosive such as a polyurethane type and other components of a given piece of ordnance which will come into direct contact with the PBX. This ignores potential compatibility problems between the same ordnance components and the as yet unreacted PBX (or polyurethane) ingredients. For example, the cured explosive may well be compatible with various liners, paints, gaskets, etc. in the warhead, but the isocyanates, alcohols, plasticizers, etc. from which the PBX is manufactured may not be compatible. Since final cure or polymerization takes place in the warhead and not in the mixer, these potentially reactive materials could also enter into side reactions with the lines, gaskets, etc. The main reason most people do not stop to think of this is that in most melt cast, TNT-based explosives only phase differences exist (i.e., between ingredients before and after solidification). These are the explosive types with which they are most familiar. In any case, the hazard here is not impurities in the components but the as yet unreacted components themselves.

7. CLOTHING AND EQUIPMENT (J)

Safety offices maintain an ongoing awareness of products available and should be consulted. The following should be considered for use depending on the circumstances: safety glasses; face shields; conductive, electrical, or chemical sole shoes; ear plugs; ear muffs; gloves; conductive cloth coveralls; wrist grounding strap; respirators; rubber aprons; hair nets, etc. To these must be added the caution that personal clothing can be a source of static electricity (app C, J1, 2).

A. Safety Shoes

There is often a need for a choice between wearing safety shoes with conductive soles versus electrical insulating soles. When working on electrical equipment on a wet surface, conductive-sole shoes should not be worn. When working with static sensitive materials (e.g., primaries, low energy detonators), conductive-sole shoes are required. In one laboratory/manufacturing facility for secondary explosives, conductive-sole shoes are not used and the floors are also not conductive because they do not work with static sensitive materials. They do use resilient floors because they consider that the most serious hazard they have to contend with is dropping billets of explosive. The dividing line as to usage of conductive floors, tables, etc. according to application should be clarified.

Safety shoes with conductive soles should be worn only in the appropriate workplace to avoid an added hazard (e.g., conductive shoes with electrical equipment) and embedding grit into soles. They should be checked regularly. This is done daily at the processing site. To assure correct use of conductive-sole shoes, the individual wearing them is required to step on the shoe tester, check the value, and sign the logbook while standing there.

In processing, bays are washed down with water. To avoid slipping, conductive-sole shoes must have nonskid surfaces on the bottom as is present in the Lehigh brand but not in some others.

Proper fitting for safety shoes is necessary and it has been asserted that this cannot be achieved by ordering by size only; however, some installations do order by size. A shoe store or other means of obtaining a correct fit is preferable.

Visitors must wear conductive-sole shoes, booties, or straps or given hand-held brass canes to be kept in contact with the conductive floor where required because there is a static hazard.

B. Clothing re Static Electricity

It is advisable to wear cotton socks and underwear when handling explosives. Outer garments that generate static electricity should also be avoided. It is difficult, but possible, to locate cotton underwear and socks. Some operations may require very high cotton content, but tests were run that show one cannot measure the difference in static generation for 50% or 100% cotton. These tests were run using military field jackets. On this basis one installation currently accepts 80% cotton content as adequate (app C, J3).

A coverall with metallized threads in the cloth was tried. It was found to provide flame protection, was cooler, and it was asserted at one laboratory that it did not generate static. (This assertion has been questioned so that further tests are required.) However, even though cotton fiber coveralls wear out faster and require re-impregnation with a flame retardant, a study indicated that the cost of using cotton fiber coveralls was still cheaper than the cost of metallized thread coveralls. Since the cost has come down, the results of the study are now being reconsidered. At another installation the use of metallized thread coveralls is not disapproved but also not recommended.

C. Clothing re Chemicals

For handling some materials (e.g. isocyanates), it is necessary to use a fresh-air-supply respirator in which the air is predried so as not to steam up glasses. Protective clothing, including gloves and coveralls, is also needed for skin protection. Immediate decontamination of the protective clothing follows each use to prevent transfer from the clothing to the individual or other surfaces.

In operations where chemicals such as nitric acid are used, face masks, gloves, and aprons are required for protection (app C, J4).

The following protective apparel should be used during high explosive pouring and hot-water washdown operations because of the high probability of splashing: face masks, rubber aprons, rubber gloves, and rubber boots. For other operations, eye protection and gloves should be used as required. A respirator should be worn while working with dusty powders, solvents, and adhesives as required.

Containers, kettles, and vats containing strong oxidants or acids may react strongly if a fuel is accidentally introduced. For this reason, loose articles of clothing such as cloth cap or even carrying a cloth that could fall into the container carelessly could lead to an accident. Precautions observed include the using of covers and the mounting at a higher level other than on the floor.

D. Equipment and Instruments

Equipment used in explosive areas must be selected carefully. Underwriters' Laboratories (UL) approval is not adequate. Dust-tight or vapor-proof enclosures are used in explosive areas. For machining, use watertight electrical hardware to prevent the slurry of explosive and coolant from getting into the equipment. When commercial hardware is purchased, it should be tested for suitability for the application. In some cases equipment approved for an application is available, e.g., for explosive dust and vapor environment. Further testing for special uses may still be required.

Inexpensive devices are available for handling small quantities of explosives at distances up to 1 meter to avoid finger contact and to interpose a shield. Major remote facilities exist for manipulating secondary explosives, munitions, or large scale processes behind a major barricade with viewing by remote TV or by optical systems. In general, processing is done within barricaded enclosures. Testing at a field site is normally done by placing the instrumentation and personnel within a barricaded area and functioning the explosive/munition outside.

Nonsparking tools should be used on units containing explosives as well as in handling explosive materials directly. Tools containing a small quantity of beryllium in a nonferrous alloy are commonly used for nonsparking application. They are available from most safety equipment firms.

Each laboratory should be equipped for chemistry work with a ventilated chamber or hood that is adequate to contain the explosive test and fumes when closed. It should have a blow-out back and high top (with blow-out to rear), good ventilation, and sliding panels for blast and fragment protection. Materials used in hoods must be chemically inert with respect to all chemicals including fumes to be used or generated within the hood.

Two position, toggle switches sometimes lead to a situation in which the switch could be left in the wrong position creating a hazard. In such cases, the switches should be the momentary contact type so that when released they automatically go to the safe position. Redundancy should be built into equipment and procedures to provide extra protection against equipment and human failure.

Explosive facility design is usually a combination of strong reinforced walls to protect personnel and weak blow-out walls to allow channeling blast waves (venting) out of the firing room preventing higher pressures from being built up.[2] Some other features requiring consideration are explosive allowances, spacing of buildings, compatibility of functions, and contents.

There is concern with atmospheric static, particularly in low humidity geographical regions. Voltage-gradient meters are located at firing sites and other places so that personnel can become aware of approaching electrical storms. Work is suspended if there is visual evidence of an approaching storm or if the static gradient reaches 2000 volts/meter. The grid of meters feeds a computer which is programmed to provide a full data display or a warning. Very low humidity can be combined sometimes with windblown sand which can lead to generation of additional static charges by the blowing sand. In this case, the voltage gradient is measured first as described below. The shutdown value is 2000 volts/meter. If the source is a dust storm, then each setup must be further considered by how it is affected by a dust storm. [For indoor activities related to explosives, the Army requires a minimum of 55% relative humidity (RH). The approach is to humidify in order to reduce the hazard.]

There are two types of sensors used to detect voltage gradients: (1) a radioactive isotope source which will not respond correctly to wind as the emissions are distorted, and (2) a Field Mill [used at the Naval Weapons Center (NWC)] which consists of a rotor of pie-shaped plates that rotates past a parallel spaced similar stator.* It takes the d.c. induced between rotor and stator and

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[2] "Structures to Resist the Effects of Accidental Explosion," Army TM 5-1300.

* The device was invented at the University of Minnesota on an ONR Contract by Professor Olson.

converts it to give a reading proportional to d.c. gradient in volts per meter. A less expensive commercial version of reduced dynamic range and accuracy can be purchased and is a possible alternate.* Since only a GO:NO-GO indication is needed, lower cost is important particularly as the goal is to have a geographic distribution of many meters to provide early warning of the arrival of a hazardous voltage gradient.

E. Working with Primary Explosives

Working with electrically sensitive primary explosives is an entirely different world from working with secondary explosives and requires extreme care and attention to details if it is to be safe.

For work with primary explosives in small quantities, a LEXAN (or equivalent) shield is used. This shield should be coated with an electrically conductive material. The use of an evaporated metal film is recommended as being superior to an antistatic liquid coating. In one case where the antistatic liquid coating was used, it did not provide adequate leakage to ground. An electric discharge to a lead azide loaded detonator with a graphite bridge occurred and led to hand injuries. The coating should be checked periodically for effectiveness (app C, J6).

In making small quantities of detonators, stab and electric low energy threshold devices (LED), a small press is used. The press is within a complete enclosure but has a front face which can be raised and lowered and is interlocked so that it must be closed to operate the press. The ram of the press is operated hydraulically. The two switches that operate the ram are located at the top of the enclosure, left and right. Both hands are needed to operate the two switches. This is done so both hands are in a safe location when pressing is underway. A similar arrangement to protect the hands is used in a testing device for stab detonators (app C, J5).

Manufactured stab detonators are placed in a nonpropagating box for storage and transport. If one detonator functions in this box, the others are not supposed to be set off. In handling detonators, the output end of the detonator is always faced away from the operator and held by leads. Electric detonators should be in bunches wrapped in aluminum foil or within a fixture with a metal strap (app C, J7).

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* Can be purchased from Electrofields, Inc., P.O. Box 523722, Miami, Florida [1811 SW 98 Avenue, 33165: Tel: (305) 552-6280].

8. CHEMICAL LABORATORY, NEW SYNTHESIS (K)

A. General Rules

For laboratory scale operations, the following rules are observed:

1. Keep quantities small, no more on-hand than actually required for immediate use.

2. Treat all new substances as if primary explosives.

3. Never leave anything unlabeled and do not use codes.

4. Dispose of energetic waste by safe/acceptable means. Pouring material down the sink should never be allowed. It should be accumulated in containers for disposal pickup on call.

5. Establish a way to properly receive a sample submitted for testing, storing, and separating the small quantities required for individual tests.

6. Designate containers to carry explosives within the laboratory. Other containers are used for storage and transport outside the laboratory. Procedures for transporting materials-in-process within the laboratory must be established according to the risks.

7. Ventilate on the basis that the material will explode. Protection is required not only for blast but also for fume leakage to adjacent areas. Fragments (jets) must be protected against.

B. Secondary (Main Charge) Explosives

The organic chemist uses the following approach to synthesize and evaluate a new material anticipated to be a secondary type explosive. The maximum initial quantity made in a hood is 100 mg, without a hood is 30 mg. A pinch of this material is put on a hard surface and rubbed with a spatula to see how it responds. If there is no indication of unusual hazard, a "match" test is made by putting a little of the material (no more than a few milligrams) on a broad stainless steel spatula and heating it by holding the spatula a few inches over a bunsen burner. The response differentiating between burning with bright flame, flashing, or flashing with noise is noted. If there is no indication of unusual hazard, a "hammer" test is made by placing a pinch on a firm steel base and hitting with a ball-peen hammer. This test must be done several times as the sample may not respond unless hit "properly." This serves as a crude preliminary impact test, but for the reasons stated (not hit properly), a negative result may not be conclusive. If the decision is made to continue to evaluate this new material, an additional quantity is then prepared for standard sensitivity tests. These tests will typically include an impact test using Type-12 tools for drop heights above 10 cm and a ball-drop test for lower heights, a 5-sec explosion temperature, and DTA. At this point, it is decided if more extensive characterization is needed (app C, K1).

When reaction conditions permit, synthesis is performed in dilute solutions so that the quantities of the explosive constituent being handled are buffered by the carrier. Note that characterization and the quantity being produced go together. If a decision is made to proceed further, friction and static sensitivity tests are added to impact, DTA, and explosion temperature. At this stage, if the material is similar in response to TNT, then 10 to 20 g may be made in small lots. The next step may involve pressing small pellets.

When explosive hoods are not used for explosive synthesis (e.g. when a building was not designed for the current application), then shields must be used and quantities appropriately limited. Protective clothing, gloves, eye rinse facility, and fire blankets must be available. Quantities used in one such case are reduced to a 30-mg limit for secondary synthesis. New employees are instructed to do their work safely in the absence of a hood by working with a senior scientist and they are taught to always be aware in advance of potential consequences of any action before proceeding.

Synthesis up to 100 mg (30 mg where a hood is not available) of energetic compounds has safety considered as the responsibility of the scientist and his immediate supervisor. At one installation, SOPs are not used in this level of secondary synthesis work. The emphasis is on selection of qualified individuals and development of a strong safety consciousness by apprenticeship and training.

C. Primary Explosives

In dealing with new primary explosives, extremely small quantities are used and many extra precautions are observed. Preliminary information about a new primary, such as an organic azide, was obtained as follows. It was found that heating the material in a thin capillary to determine the melting point showed evolution of gas and color change to brown. However, when a small pinch was subjected to a "match" test which has a more rapid rate of heating, the material melted and then detonated. It was also found that it responded to a low dropheight in an impact test (app C, K2).

9. MACHINING (M)

A. Remote Operation

The machining of explosives carries with it a distinct hazard. Depending on the particular explosive involved, there are normally a set of machining parameters that will reduce the hazard to a minimum. However, this minimum hazard may still be too high to allow for contact machining; therefore, remote operation is required. Comprehensive information from NAVSEA OP 5 VOL I, sections 7-3.4.2 and

7-3.4.3, shows a multitude of factors to be considered and is suggested reading for those interested in machining. The type of information contained is illustrated by the sentences below (selected from the full text of some of the subparagraphs):

7-3.4.2 General Requirements

a. Only certified personnel may perform energetic material machining operations and must be thoroughly briefed by their immediate supervisor prior to the start of a new operation.

b. Where machining with coolant is required, positive automatic interlocking devices shall be provided to ensure that machining cannot be started until coolant is flowing. These controls must also be capable of stopping the machine if the flow of coolant is interrupted.

c. Special care must be taken to prevent energetic material-laden coolant water from contact with explosion-proofed electrical enclosures which are not waterproof and only designed to contain interior vapor explosions.

d. Sensors are recommended to detect tooling malfunctions or other potentially hazardous abnormalities, particularly for remote controlled operations.

e. Cutting tools must be chemically compatible with the energetic material to be machined and capable of maintaining sharp cutting edges throughout the machining cycle. If a cutting edge inadvertently attains an excessive temperature during machining, it poses the maximum hazard when machining is stopped and continuous contact with the energetic material is maintained. It is therefore essential that coolant flow to the cutter continue until the cutter is removed.

h. Depths achieved with twist drills must not impede the flow of chips and coolant in the flutes. The drilling of small holes (1/4 inch or less) and any size multiple drilling must be performed by remote control.

n. The remote control station must provide the capability for manual activation of an emergency water flush on the energetic material being machined. In addition, the remote controls must be capable of starting and stopping all cutting or rubbing action of the cutting tool on the energetic material.

p. When using compressed air as a coolant, only low pressure (10 pounds or less) may be used and then only when an approved vacuum system is implemented to reduce the broadcasting of energetic material particles. The coolant line shall have a metallic tip or nozzle that is grounded to the machine in such a manner as to eliminate any static charges.

q. In all cases the conducted hazard analysis for a specific machining operation should provide additional guidance for specific operating conditions and procedures.

7-3.4.3 Explosives Machining

Explosive charges, cased or uncased, may be machined by conventional machine tools to physically remove explosive, if standard regulations concerning personnel, facilities, and equipment for explosives processing, and the following additional guidelines are adhered to.

a. Sufficient experience with the following explosives justifies permitting their being contact-machined (operator at machine): TNT, explosive D, Picratol, PBXN-4--with air (or water, if appropriate) as a coolant; Cyclotols (RDX/TNT) and Octols (HMX/TNT) with less than 60% RDX or HMX with water used as a coolant. All other compositions must be machined by remote control with a coolant, air or liquid, directed to the contact point of the cutter and the explosive.* In the selection of coolant, the explosive must be neither reactive with nor soluble in the coolant. Consideration should be given to residual water compatibility with corrosive materials and metal parts.

c. Machining operations combining the removal of metal and explosives, as in demilling, must be performed by remote control using water as a coolant.

e. For sawing, the following shall apply:

(1) Particular attention must be given to sawing operations to prevent the work from plunging into the saw blade, and secondly, ensure that chips are removed from the saw teeth prior to their next cutting pass.

(4) For reciprocating saws (hack-saws)--the blade shall contain 4 to 6 teeth per inch and the maximum blade speed shall not exceed 800 inches per minute.

f. For other nonrotational machining such as shaping, planing, broaching, etc., the maximum relative speed of cutter-to-explosive shall be 210 surface feet per minute, and the depth of cut shall not exceed 3/16 inch per cut.

When a new explosive or a device containing explosives requires machining, a separate determination must be made before using the machining parameters. This determination may require some small scale experiments, well-instrumented, and remotely controlled. Experimental explosives must always be handled remotely until confidence is established on its properties.

In machining, as in handling, there is always the problem that the explosive piece may be jammed or dropped. Therefore, criteria in regard to use of remote

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* At BRL, all machining of explosives shall be done remotely.

machining or handling should include the consequences based on the mass of the explosive involved. This influences the decision as to contact machining (drilling excepted) and level of barricades/isolation required. Special care must be taken if metal-to-metal contact can occur when machining explosives (app C, M1).

In addition to the TNT based explosives approved for contact machining (7-3.4.3a of NAVSEA OP 5), a DOE laboratory is currently contact machining some PBX explosives in which TATB is the major constituent with selected machining parameters. Certain other PBX explosives are sometimes contact machined in special circumstances under a waiver granted after complete review.

B. Drilling

Drilling small diameter holes in explosives can be so dangerous that it is outlawed. To put a probe in PBX 9404, a small diameter hole was needed. When tried, the charge detonated leading to two fatalities. Steel is a poor conductor; explosives are good insulators. A belief existed that the hole could be drilled because early tests had been made. However, these had used a high rate of advance. In the accident, drilling was "extra careful" with a slow rate of advance. In this case, when the drill bit advanced quickly, the site of the heat generation correspondingly advanced; when the drill bit was advanced slowly, the heat accumulated at a small site leading to explosion (app C, M2).

In drilling small holes in explosives, the maximum heating may not be at the tip of the drill bit, but may occur where a chip lodges (jams) on the way out of the hole. For this reason, specially designed tools with flutes that effectively remove chips and reduce jam potential are essential.

An energetic binder can considerably alter the sensitivity of the explosive. This is made evident in drilling small holes in explosives with different binders.

An accident occurred during a radial arm, drilling operation using a core bit which consisted of a stainless steel tube with teeth on the end. A 4-inch core was taken from an explosive charge. A vacuum was applied to remove chips, and the operation was viewed remotely. It was noticed that the operation was proceeding slowly and that the light went on to indicate the correct depth had been reached. However, at this time the video screen showed smoke at the drilling site; therefore, the work area was not entered. It then blew up destroying the building. It was concluded that the core bit had reached a crack in the explosive, dislodging a piece of explosive which blocked the vacuum hose. The following are important lessons that were learned:

1. Closed-circuit TV monitoring is essential to safety.

2. The vacuum must be monitored so that, if suddenly more vacuum is pulled or if vacuum is lost, the existence of a problem can be recognized.

3. A valve should be present that would permit water to be sent to the boring site on first evidence of overheating.

4. The tool enclosed in the explosive should be fully withdrawn before the operator enters the area.

5. With TNT type explosives, melting at the cutting site would have absorbed heat and lubricated the cut. Similarly for COMP A3, the wax would have done the same. This type of mechanism does not exist for PBX.

C. Optimum Parameters

Reports are available that detail results obtained in studies to determine the parameters to be used for particular machining needs. Devices also have been developed for determining the optimum machining parameters to minimize explosive response (app A). One study used a thermocouple to measure temperature under the cutter to continuously monitor chip temperature during cutting. If the temperature rose, it would mean the cutter had become dull and should be changed. Other sudden temperature rises could be used to warn of a hazard. It is envisioned that by using feedback to control cutting parameters in accordance with applicable equations, optimum parameters consistent with safety could be achieved.

10. MAGAZINES/DECONTAMINATION/DISPOSAL (Z)

A. Receipt, Storage, and Issue

The attitudes with respect to magazines should be positive, i.e., to make it convenient but consistent with safety. Procedures for the use of magazines are fitted to the individual organization's needs. Some examples of different procedures used are as follows:

1. In one installation, shipping and receiving are made to igloos that also serve for long-term storage of explosives. Issue of explosives is made with the permission of the safety organization and limited to use with an SOP. If explosives are ready for test firing, they go directly to the firing area; if not, they go to an assembly/disassembly building that has storage cabinets nearby with assigned limits. Explosives are held here for about a week, but they sometimes accumulate due to interruptions in schedule. The storage cabinets consist of a piece of culvert pipe covered with earth. The pipe has a 4-ft diameter with an 8- to 10-ft length that is plugged on one end and has a control wall at the other end that contains a metal door. There are explosive vaults that are made of concrete with pullout drawers. No overnight storage is permitted at the test site; explosive material is returned each day to a magazine. Inventory cards are used for all explosives and explosive-containing items and an annual review and inventory is made. One person should be given control of contents and documentation of a particular magazine to avoid abuse. Older powders in an igloo must be periodically rechecked and considered for disposal (app C, Z1).

2. At another installation, a centrally located magazine provides charges or items to a ready magazine at the firing site. Only the items to be actually fired that day are released. There is a computer maintained inventory of all explosives, initiators, and explosive containing devices which is kept current by daily changes noted by the ordnance technicians as they do the day's work.

3. Elsewhere, the overall magazine system starts with the main explosive storage area that is run by a separate department and delivers requested material to the site. The keys to the magazines must be obtained from the Branch Office. A continuous running inventory is kept in a book, but the inventory for the processing area is maintained on a computer. Wall-to-wall inventories are made approximately once a year. The firing site has one large magazine and four smaller ones. Adjacent to the door of the large magazine there is a metal-top table and a metal stand-on plate used for dividing explosives. The ground wire is clipped to the table. A rolling metal table with a long wire clipped to the ground wire is used at the smaller magazines. An underground common ground runs between all the magazines and connects to a building ground. These precautions are important because the area is dry and both wind-blown sand and personnel can easily generate a static charge (app C, Z2).

4. The procedure at still another installation is that only charges and detonators needed that day are delivered. Host organization magazines are used for field tests or special arrangements are made. The charges and detonators are separately secured and protected but may be transported within the same vehicle when the vehicle is equipped with separate compartments. A request is made to a separate magazine group for delivery and pick-up of explosives. This group maintains records of issues and receipts. Magazines are important for security as well as for safety. (Security is an extensive subject not treated here, e.g., "hardened buildings.") An inventory control on explosives produced, scrapped, and those remaining is made each day at buildings where large quantities are involved. Heavy duty locks are used and the keys are locked up, signed for, and returned promptly.

B. Long Term Storage

The control of contents with regular reviews and disposal is necessary to counteract the "pack-rat" tendency of the engineers and scientists. However, a balance must be reached between retention and disposal. The following examples show how this is handled at various installations:

1. Any explosive that goes into a magazine is assigned a storage review interval which then sets a review date. After this date, unless recertified, the storekeeper cannot issue the explosive. To recertify, a small sample is abstracted and re-evaluated. (The tests required for recertification depend on the explosive involved.) The system is intended to prevent use of deteriorated explosives. It does not lead to destruction at the end of the storage review interval, just no issuance. Destruction may follow at a later review (app C, Z3).

2. Every explosive is tagged and dated. If older than 6 months, the individual must justify the retention regularly. If he leaves, the explosives must be disposed of or transferred.

3. All experimental charges and/or processed explosives, if not specifically justified and claimed for further retention, are destroyed within 6 months.

Energetic materials and explosive devices should only be accepted for storage when it is known in advance that there is no hazard associated with the planned storage. The following examples show why temperature and humidity cycles are important with respect to safety: (1) after gelatin dynamite was stored under uncontrolled environmental conditions for a year, nitroglycerin had exuded onto all surfaces, and (2) ammonium nitrate stored in contact with copper in the presence of slight moisture can form a salt that is as sensitive as a primary explosive. At the time of storage, special handling instructions should be furnished and made part of the record, and materials should be labeled. Plans should be made to limit storage to less than a certified lifetime.

Contents of magazines should be controlled, particularly with respect to aging energetic materials. On one occasion, a magazine door was found open. A stored material had created enough gas to create adequate pressure to force the door. Fortunately, there was no explosion.

C. Disposal and Decontamination

The procedures for destruction of explosives vary between organizations and even between departments within an organization. Explosives are destroyed by using a detonating charge or an explosives burning ground. Burning of cased ammunition can be extremely hazardous.

The disposal of waste material from processing and machining requires special care. Solids and recoverable machining waste go directly to a burning ground. Liquids containing energetic materials are conveyed by a spillway to a sump located outside of the building. Solids suspended in the liquid settle out and are wetted down. The spillway and sump are dredged (or flushed, depending on safety considerations) periodically as well as before a change in process that might lead to incompatible chemicals arriving into the waste system. The effluent water goes from the sump to a large charge of activated carbon. The sump has consecutive settling chambers separated by walls so that as the liquid rises in the first chamber it overflows into the next. The last overflow leads to the carbon column. The column is checked periodically for safety and residual effectiveness. The usual check is for concentration of explosive in the effluent. Very efficient columns will pick up explosives almost completely.

Decontamination of metal parts that contained explosives requires that the temperature of the metal part be monitored by thermocouples to assure that the metal (not just the oven) has been maintained at the prescribed decomposition temperature for the specified period. In one case, a large metal mass was not monitored and did not achieve the needed high temperature. Subsequent welding of a crack in that metal piece led to an explosion and a fatality (app C, Z4).

The large scale gap test uses an explosive cylindrical charge that is a slip fit into a confining steel cylinder. A sample that had been shocked but had not gone off was unlabeled as to history and had not been disposed of due to a problem of explosive control. An operator, trying to remove the charge, applied a strong force with fatal results. The shock had locked the charge to the wall which led to high friction at the interface. This incident highlights the need to eliminate handling of NO-FIRE test assemblies. At one installation, such items are destroyed at the test site by detonation (app C, Z5).

11. DETONATORS (D)

There is a universal opinion that in using electro-explosive devices (EED), low energy threshold detonators (LED) should not be used. Instead of LEDs, exploding bridge-wire detonators (EBW) or slapper types should be used. An essential difference in current EEDs is that LEDs use primary explosives and EBWs and slappers use secondary explosives.

Primary explosives can be initiated by a very low energy thermal impulse generated by friction, by heat due to passage of electrical current, or by impact. Examples of primary explosives are: lead azide, mercury fulminate, and lead styphnate. Some of these explosives serve as the first component in an LED because they build rapidly to a full detonation and are energetic enough to initiate a secondary booster charge. However, the overall safety is then determined by the most sensitive primary component.

Secondary explosives require higher energy stimuli for initiation, generally supplied by a primary (initiating) explosive or by an intermediate booster for effectively initiating a main charge. Examples are: PETN, RDX, HMX, etc. PETN is a borderline explosive often used as an initiating explosive in EBWs and slappers to achieve a high level of safety. (RDX and HMX can also be used in initiators but require significantly greater electrical energy concentration for initiation.)

A. Characteristics of Different Types of Detonators

Among the LEDs, a hot-wire detonator has a metallic wire or film through which current passes. A carbon-bridge detonator contains a deposited layer of carbon between the lead wires. In a conductive-mix detonator, the electrical current passes directly through a conductive first-fire pyrotechnic mixture. Hot wire, carbon bridge, or conductive mix all cause chemical reactions by rapidly heating a small volume of the ignition material (app C, D1).

EBW detonators burst the wire or foil bridge causing a combined thermal and shock stimulus to the explosive to initiate reaction. Slapper detonators use only a shock. EBW and slapper detonators do not require the use of primary explosives to achieve a transition from burning to detonation as in hot-wire devices. (A comparison of the characteristics of EBW, slapper, hot-wire detonators is shown in table 1.) There is a military requirement that all detonators that use primary explosives (LEDs) be "out-of-line" in the fuze train system so that, until properly armed, there is no direct path between the initiator and the rest of the fuze train, boosters, and main charge.

If current (I) is plotted against time (t), a variety of growth curves can be drawn, any of which will cause ignition of an LED if there is enough ohmic heating. For an EBW, the threshold is dependent on the power history deposited in the wire and is extremely selective. The EBW design is matched to the inductance (L), capacitance (C), and resistance (R) of the firing circuit and connecting wires so that the waveform provides ignition. The resistance of the bridge rises sharply as it vaporizes and then, as the voltage rises further, the gap breaks down and the resistance drops. The design is made so that the firing circuit produces a pulse that would not be found in nature (app C, D2).

The slappers require an even sharper signal to function which eliminates more potential accident scenarios (e.g., if 0.5 function probability is 700 volts, then there is practically zero response at 690 volts and 0.999 at 710 volts.

EBWs require a 1/4-joule pulse minimum, but usually more is used (e.g., 1/2 microfarad and 2 kV which is 1 joule). Note that high-voltage pulse circuitry is required. Slappers can be made to work with 1/10 joule but need fast rise and low inductance. Slappers have initiated HNS with 1/10 joule showing potential for future use in munitions.

Hot-wire detonators are normally 1 ampere, 1 watt no-fire design, that is, they require that the initiator shall not fire within 5 minutes when subjected to a current of 1 ampere with an associated power of 1 watt. To function within 50 ms, a 5-A direct current is required. While the military attempts to adhere to the 1-A/1-W no-fire criteria for LEDs, they cannot always meet this goal because of the reality of system power constraints. The Navy, Air Force, and Army routinely use LEDs with 7,000 ergs (0.0007 joule) all-fire and 100 mA no-fire. Some systems even have 1000 ergs all-fire initiators. The current tube launched, optically tracked, wire-guided (TOW) missile uses a carbon-bridge detonator that functions at 10 to 15 ergs (MK-48). The United Kingdom routinely uses conductive-mix bridges that are also in the few-erg category. In general, carbon-bridge and conductive-mix systems are unpredictable because the no-fire thresholds change with environment and during quality assurance testing. The minimum firing current for blasting caps and igniters varies from 70 to 500 mA with special circuit-testing igniters having a firing current of 250 mA. Standard blasting caps will usually fire with a current of 340 mA at 0.75 V. Electric primers will fire at currents as low as 5 mA at approximately 3 V.

Representative detonator parameters of the three types are listed in table 1.

Table 1. Comparison of detonator characteristics

	Detonator					
	Hot wire		Exploding bridge wire		Slapper	
	Threshold	Operating	Threshold	Operating	Threshold	Operating
Current (A)	>1	5	250	800	3,000	6,000
Time (μs)	-	1,000	-	1	-	0.25
Power (-W)	>1 W	5 W	225 kW	1 MW	4 MW	8 MW
Voltage (V)	-	1	900	1,250	1,300	-
Energy (J)	0.001	0.005	0.25	1.0	1	-

Hot-wire detonators cost up to $10 each.* EBWs commercially sell for $3 to $12 based on quantity.** Slappers are still not commercially available in the highest quality and the cost is about as much as for EBWs. The DOE cost of a slapper is about $450 because the required timing and reliability is very high.

An all-secondary explosive, hot-wire detonator (ER345) is under development (Safety File has sketch). It uses HMX and is completely spark insensitive. The ER345 will satisfy 1-A/1-W no-fire and 2.5-A all-fire. Further study on its limitations is being completed. Due to current use of glass-metal seals in the header, the cost is about $40 each (app C, D3).

B. Electrostatic and Induction Hazard

Electrostatic discharges, stray electrical currents, and electromagnetic radiation (lightning, galvanic action, high tension power lines, radio frequency (RF) from radio, radar, and television transmitters, microwave transmitters, etc.) can all cause accidental initiation of low energy electroexplosive devices containing primary explosives. As is the case for all explosive items, they also react to severe heat, flame, and mechanical shock.

The general criterion for electrostatic sensitivity is that a detonator not initiate when subjected to the simulated maximum human body electrostatic energy.

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* Reference to money is 1984 dollars.

** One commercial source for EBWs (RP80 and RP1) is Reynolds Industries, Inc., 5005 McConnel Avenue, Los Angeles, CA 90066, (213) 823-5491. They also make an associated firing circuit for their EBW detonators.

DOD criterion is specified in MIL-STD-1512 and MIL-I-23659C as 25 kV, 5000 ohm, and 500 pf at 5 μH. Sandia uses a comparable 20 kV, 500 ohm, and 600 pf, but the Institute of Makers of Explosives (IME) uses the Bureau of Mines criterion of 10 kV and 300 pf (0.015 joules) for commercial items.

The electrostatic safety relies on the 25 kV or similar test leading to noninitiation. A possibility that has not been investigated is that at the high test voltage, breakdown may follow an external path in air from leads to case; whereas, at 5 kV or less, the path may be internal through the explosive. Normally, pin-to-pin and pin-to-case safety tests should both be done. If the path followed by the current is a function of the applied voltage, then these tests have to be done at different voltages.

The basis for the accepted electrostatic safety of EBWs using PETN is a comparison made with human-generated, electrostatic charge. The minimum requirements for spark initiation of granular PETN pressed to 50% of crystal density were found to be that there exists in the early stages of spark formation a current amplitude of at least 150 A concurrent with a time rate of change of at least 3×10^9 A/s (app A, D). To determine the characteristics of sparks drawn from personnel, individuals were charged to electrostatic voltages as high as 40 kV and discharges were obtained from a metal tool held in the subject's hand. The maximum discharge currents observed were approximately 70 A. The spark discharge characteristics of the human body were approximated as those exhibited by a critically damped LRC circuit. It was then shown that the generation of sparks from the human body capable of initiating PETN required initial body voltages exceeding 70 kV. Body potentials of this magnitude normally cannot be sustained due to corona discharge and therefore are not expected in practical situations. In conclusion, although PETN can be spark initiated under certain conditions, the necessary characteristics of the spark required for initiation are not met by typical electrostatic sparks drawn from the human body. Therefore, it is very unlikely that EBWs that use PETN would be accidentally initiated by electrostatic sparks from personnel (app C, D4).

One laboratory uses an ARC-211 detonator which is insensitive to static by virtue of a painted external leakage surface.

C. Tests With LEDs Versus EBWs

Tests with low-energy detonators (LED) have to be run since the Army still uses them in fuzes because of limited available power. EBWs (exploding bridgewire detonators) are definitely preferred for firing setups. However, the interference spikes that can be generated by the electrical discharge used to fire the EBWs can introduce sporadic pulses into sensitive instrumentation. In some cases this also makes it necessary to use LEDs.

In one facility, EBWs are used for routine work. Hot-wire initiators are used only when they are part of the equipment design, and each case requires the special approval of the department head. When a fuze to be tested has a hot-wire initiator, the fuze is rebuilt to use an EBW or to use remote arming and firing. No setup is worked on in which a hot-wire initiator is in-line within a munition.

No initiator is used which is more sensitive than an Engineers Special (no. 8 blasting cap) or than those meeting the 1-A/1-W criterion for no-fire.

In another laboratory, use of an EBW or slapper is recommended. If this is not possible, an LED must be developed to meet the following requirements:

1. No reaction or dudding when subjected to the electrostatics of a simulated human body in both pin-to-pin and pin-to-case discharge modes.

2. No-fire criteria of 1-A/1-W 5-minute no-fire, if possible, but as a minimum, the commercial requirement of a 0.250 A no-fire.

3. Eliminate primary and static sensitive explosives if at all possible.

4. Prohibit carbon—bridge and conductive—mix low energy-initiator systems.

The interaction of personnel with detonators is given special attention. Personnel who normally work with EBWs and then are required to do a test with LEDs must be retrained because of the major differences in the approach to these two types of work. Hot-wire devices require a special SOP for each application and work under this SOP is limited to specially trained personnel. The trained technician uses a conductive wrist strap and wears safety glasses. Hazardous sources of radiated electromagnetic energy are eliminated. All firing leads are shorted and checked for stray voltages and currents by using a special detonator ohmmeter before they are connected. This equipment must be periodically checked to verify that the current through the detonator (serious deviations have been found) is really the low design value. Circuitry and access to the meter should prevent tampering. In explosive assemblies, a barrier is always used between the detonator and the main-charge explosive to prevent the main charge from being initiated if the detonator fires accidentally. The barrier is removed remotely before the assembly is test fired. The individual setting up the shot carries with him the means to set it off (e.g., a handcrank firing unit). Before each shot is set up, it is considered in detail with respect to shorting and grounding to be used for leads, case, and other units and with respect to the presence of common grounds, ground loops, and any other safety issues.

D. General Precautions

In general, detonator wires should be twisted as well as shorted to minimize inductive pickup. The twisted leads reduce to a minimum the area of the loop that can intersect electromagnetic fields.

In handling a detonator, it should be held by the leads, never on the body of the detonator, and should be aimed away from everyone. Working close to the ground reduces drop height. Do not hand a detonator from one person to another; put it down, let the other person pick it up.

A detonator-transport box made of plywood with a felt liner that can fully contain detonation of contents is used to store and move detonators. Initiators can also be carried in a metal box with a ground strap which is connected to a main ground line. The interior of the box should prevent propagation between detonators and be strong enough to protect the person carrying it, if initiation occurred. The operator should wear cotton coveralls, with a fire-retardant additive, that are reimpregnated after laundering. Attention should be given to having a common potential for people, equipment, components, etc.

In fuzes, leads are always soldered for reliability. To protect against the heat reaching the explosive in the detonator, clip-on heat sinks and special soldering irons are used. A decision must be made whether to ground the soldering iron, float it, or disconnect the hot iron before applying.

A special problem when EBWs are used with underwater shots is that the EBW must normally be within 200 feet of the firing unit. An electronic package, with a discharge unit that can be put close enough to the charge while the rest of the circuitry is further away, is available from Reynolds Industries, Inc.

E. Parallel Path Hazard

The possibility of currently finding an unanticipated way to pass through the primary explosive is important for LEDs. If the two leads are shorted, it must be remembered that they are still imbedded in the primary explosive. If the primary explosive is in a metal case (of the detonator) and is not connected to one of the leads, a path is found through the explosive from the case to the leads. Therefore, if the leads were grounded even though they are shorted, and a potential (by a voltage on metal connected to the case or by electrostatic charge) was applied to the case, the detonator could initiate. If a conducting detonator case is connected through the fuze to the metal of a shell which is grounded, and a voltage is placed on the shorted but ungrounded leads, it will send a current through the explosive. Even if there is a connection from one lead to the case, a hazard can still exist since there are two parallel paths; one leads to the case by the intended connection the other is through the explosive. The resistance of each path is of low value (fractions of an ohm). If adequate voltage is applied, the parallel current through the explosive path may be enough to set it off. It should now be clear why it is so essential to make a full analysis of how an LED is to be used in terms of its properties and the application to assure safety (app C, D5).

The hazard of parallel paths can exist in the circuitry. In one such case, it led to a fatality. A shell went off during an experiment in which the deflection of the wall was to be measured by establishing contact to a pin spaced a distance from the original position of the shell wall. The pin (with power on the instrumentation) accidentally touched the wall, and the item went off. It was not recognized that even though the shell wall was thought to be at ground potential, the distance to the bunker and the lead resistance to ground provided two parallel paths to that ground, one of which went through the detonator. The arrangement and equivalent current are shown in figure 1.

The shell and detonator were connected at A and to ground at B. B and C were connected to provide a short across the detonator and to provide grounding. When the pin switch touched the shell wall, putting 90 V to it, the circuit including wire resistance can be seen in the equivalent circuit to the right. There were two parallel paths, one from A to B directly and the other from A through the detonator via C to B. Although lead resistances are low, so is that through the detonator. When a fraction of the total current went through the detonator, it was adequate to set it off. The parallel path danger must always be guarded against. NEVER USE FIGURE 1 CIRCUIT ARRANGEMENT. After the accident, a one-megohm resistor was added between points D and E; a different initiator with double pins both insulated from the detonator case was used and grounding was revised. The parallel path problem remain .

A similar accident involving an unrealized, two parallel, path situation occurred when an item was heated by nichrome wire wound over asbestos insulating the item. The root cause was that the direct connection from item wall to ground had broken off (fig. 2). When a short occurred through the asbestos, the current again had two parallel paths, one leading through the detonator explosive and the other through the detonator case to the lead connection.

The question of using a connection from one lead to the case has led to the following policy in one laboratory: The case of the munition must be firmly grounded and the detonator must have one leg internally grounded to the case of the detonator. If a special case exists where the bridgewire is isolated from the detonator case, the detonator must not initiate when a charge of 20 kV on a 600-pf capacitor is applied through a 500-ohm resistor between the shorted leads and the case. This requirement is based on the static charge that can occur from an individual. Meeting this requirement again emphasizes the advantages of the use of EBWs or slappers instead of LEDs. The need for an analysis of the short and ground situation before LEDs are used must be stated again. Note also that having the explosive within an insulating material case instead of a metal case is a possibility to be considered.

In the effort to resolve the hazards of electric detonators, a "nonelectric" detonator has been developed that has a central cotton core with black powder that is confined and leads to a layer of primary explosive (igniter). However, this nonelectric detonator sometimes has been initiated by a static discharge which followed the core to the surface layer of the explosive.

12. FIRING/GROUNDS/SHIELDING (F)

To assure safety in firing shots, scientists, engineers, and technicians must be provided with procedures to follow and electrical and mechanical safeguards to use. These needs have been approached in a variety of ways at different installations to meet their specific situations. Although there are many features in common, sharp differences exist between setups used with low energy initiators and with those using EBWs.

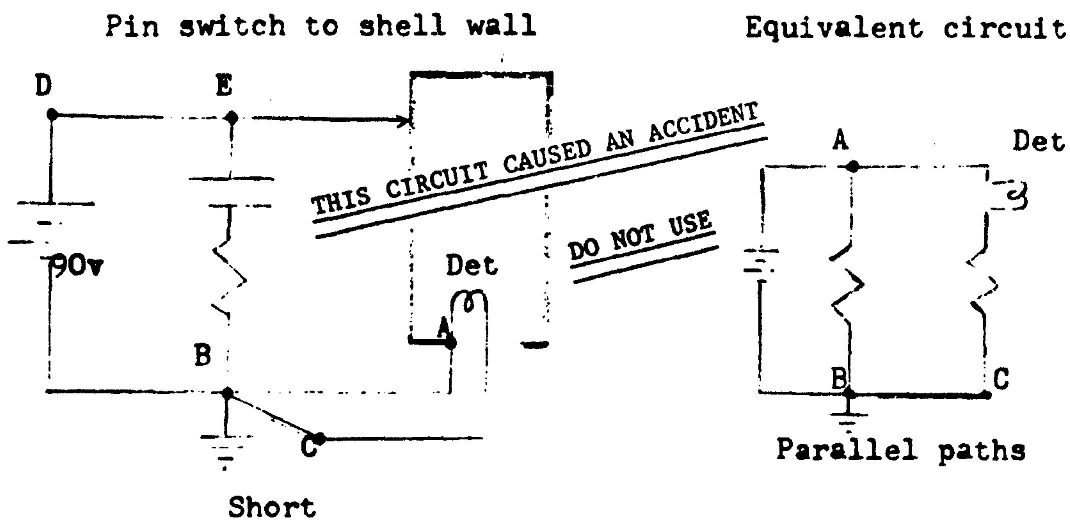

Figure 1. Parallel path hazard - pin switch contact initiates item

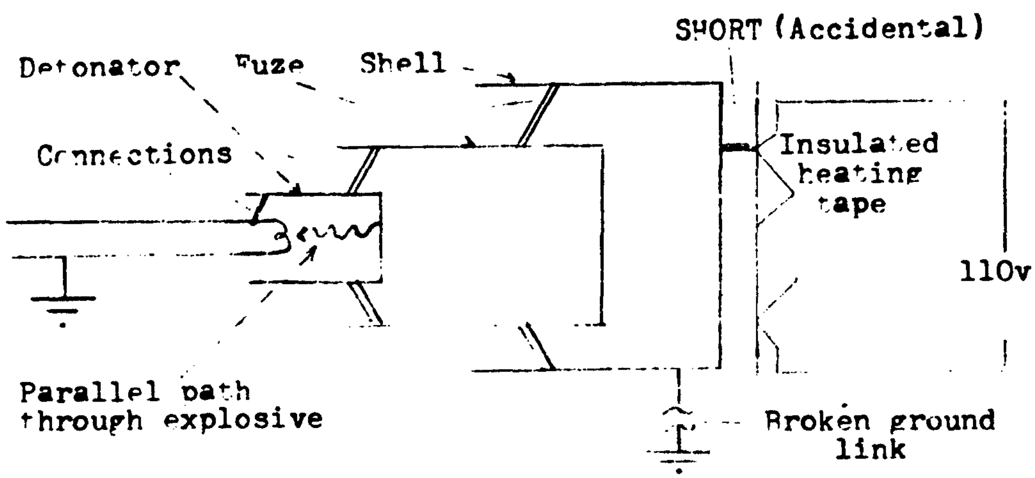

Figure 2. Parallel path hazard - short to wall initiates item

A. Individual Responsibility

One individual, clearly designated, should have prime responsibility at an experiment/firing site. This is necessary since more senior personnel may arrive to observe and assist and lines of authority could become muddled. The "key-holder" has his responsibilities but he reports to the one responsible individual. The idea of a key-holder is that the person who is physically involved in setting up the explosive device has on his person the means essential to set it off, so that no other person can set it off accidentally. Some variations of this procedure are as follows:

1. Each individual working on the explosive experiment has a key and all of the keys must be inserted so that the shot can be fired.

2. An exclusive key is not used. A firing site leader is issued a key and can fire a shot at any site. (This is now being changed to an exclusive key for each site.) When the key is inserted, warning lights operate and the shot cannot be fired for 5 minutes. With the envisioned unique key system, this 5 minute delay will no longer be used.

3. Sometimes the safety provided by the key is replaced or supplemented by carrying a vital piece of the equipment needed to fire the shot. The individual setting up the test at a firing facility carries a jumper cable with an attached key. The key opens a box into which the jumper cable is inserted to complete the high voltage from the pulse source to the setup. For tests out in the field, the firing line is disconnected and put in a different locked box to which the handler has the key. The firing line is painted so that it can be distinguished from other lines and not erroneously connected to a source of voltage.

B. Site Safety

The key-holder precautions are always supplemented by mechanical and electrical safety devices on-site. For example, when the firing controls are in a room where the surroundings of the firing site cannot be seen, another individual is stationed at a "deadman" switch which must be closed to fire the shot. Other safety features include an interlock on a vent to assure that it is closed, horns and lights to warn of an impending shot, and firing control switches linked to the equipment for the shot. A maximum of three personnel work in the "bombproof," one operates the "deadman" switch, and two operate the controls to fire the shot (app C, F1).

Limiting access to the site to those directly involved can be difficult. For example, at a site within a building that was used for small shots, it was found that signs, chains across entry, bells, and lights did not work. It was necessary to close and lock the door to the building from the inside. Since this prevented access to the building in case of accident or fire, a key was placed in a break-box outside the door. In another case, a shot being fired in the field at a remote site was ready to be fired but the firing officer made a final check. As he exited the bunker, he saw a person on horseback riding over to take a look.

The following is a set of coordinated precautions:

1. At entry point, the arriving individual must call the bunker for permission to enter.

2. Call is recorded.

3. Caller must sign in.

4. The pin at entry point that is needed to complete the system so that firing can occur is added when the last man leaves the entry point with the pin.

5. If two firing sites are in the area, they must be coordinated.

6. Call for permission to leave the site and call when departure is achieved.

7. Observer on nearby hill watches for low-flying aircraft and must approve firing the shot.

8. Key system is used and power cannot be turned on unless the key is used and the last man into the bunker carries the key.

9. All personnel must be accounted for.

In contrast to the above large scale, open firing site with a control bunker, some installations have single level smaller firing sites. In one such firing area, up to 2 lb can be fired in an inside chamber and 5 lb at an outside chamber. Both chambers are viewed through mirrors by the same cameras. The inside firing chamber is reached through an electrically operated, interlocked safety door and a labyrinth. There is an emergency exit from within the labyrinth by means of a large kickout panel which is adjacent to the safety door and leads to the outside. There is an adjacent assembly room and camera room. The standardized lockbox and the firing sets are in another small room in the building. To fire a shot the interlocks must be closed on the assembly room, firing chamber, and camera room doors, and on the street safety barricade. No one is in the camera room when the turbines are activated.

At an installation with an indoor site for up to 2 lb of explosive, protection is provided by the following: ring of keys carried by operator, siren, access gate locked, sliding door , complete circuit remotely operated, and venting, firing circuit, switching devices key-operated. The sliding door of the firing site is operated from within the instrumentation room that is isolated from the firing site. The door opens to over a 3-ft gap. The door and frame have a set of male and female blades that interconnect when the door closes. When the door is open, the firing lines are automatically shorted and grounded.

The general rule being followed is that unless the operator is in a safe place, power cannot be available to any point in the system. If electrical checks must be done at the firing site with the power on, the detonator and charge must first be removed from the firing site. If problems are encountered with a test setup, respond cautiously. Follow prearranged procedures and do not go out to the pad without shutting off the power and being sure that sources of a voltage such as charged capacitors have been discharged.

The firing site must start out clean. When the setup is fired, it can, in some cases, scatter explosives around the firing site. Starting with a clean site enables the effect of the firing to be seen and makes cleanup safer.

In addition, the following have general applicability:

1. Have a high fence around firing area so that no unauthorized entry is possible.

2. Recognize that the noise of the shot can produce fright if unexpected and cause a secondary type of accident.

3. Stop operations during a lightning storm.

4. No boisterous activity between operators.

5. Keep work areas clean, no clutter, adequate space for items and work to be done.

6. Take time and be thorough even for a small modification. A hazardous situation always exists when a modification is made in an experimental setup and adequate time is not taken to reconsider the situation.

7. Teach new personnel to respect, not fear, explosives; recognize that knowledge is the key to safety.

8. Hold a Monday-morning meeting each week among firing personnel to discuss planned work and anticipated problems.

9. Be sure that each worker is given a job and has adequate education and training to safely do the job he is assigned.

10. Be aware that a particular fear by an individual could generate a hazard (e.g., fear of snakes could lead to the dropping of an item in the field).

11. Protect against blast, fragments, jets, fire, and gases as the result of firing of a shot. In particular, in setting up an experiment involving a shaped charge, the safety must be provided for the jet produced. It can penetrate vehicles, structures, etc., at considerable dist ces.

12. Do not leave an explosive setup in an outside firing chamber overnight if firing cannot be completed; it can be left in a secured inside chamber.

C. Firing Devices

Each installation, in addition to providing site-safety and assuring clear responsibility to prevent personnel error, also uses firing procedures and equip-

ment to prevent an accidental initiation in the presence of personnel (app C, F2).

In one installation, an out-of-line technique is used completely for LEDs so that at no time is a detonator placed, or a connection to a detonator made, while it is in line with a secondary charge. If necessary, the fuze is replaced or modified to permit this out-of-line safety. The safety block which is used has an out-of-line sliding section that holds a no. 6 blasting cap away from a channel containing a detonating cord line until a retaining block is remotely pulled out causing alignment to take place. The safety firing block is supplemented by a lockbox in which the connecting electrical cords are placed for the firing set power, for the meters, etc., with the key in possession of the ordnance technician. The lockbox is an open steel, mesh box which makes the contents visible. A typical procedure using these two safety devices with an initiator is:

1. Check all explosive connections and safety block
2. Connect explosive train (fig. 3) to safety block
3. Check continuity of electric cap
4. Plug in firing line
5. Reset sequences
6. Arm sliding firing block
7. Ready to fire.

When finally connected, the train to the explosive event is by detonating cord rather than by long electrical lines (except when an EBW is used). The nonelectric system starts from the safety firing block. Only the out-of-line no. 6 cap is electrically initiated after being sequenced in-line during the SOP. The nonelectric train typically consists of

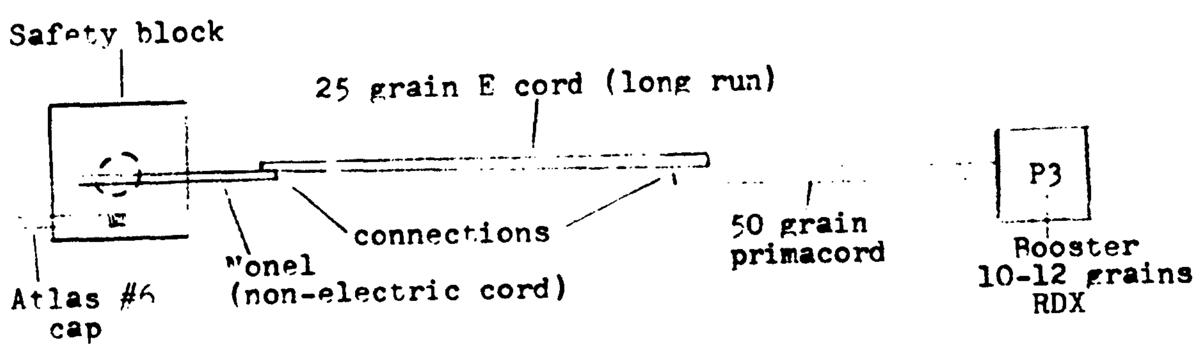

Figure 3. Out-of-line and non-electric firing system

At the same installation, when using EBWs, a specially designed firing set is used that is preferred to the commercially available Reynolds unit. The connecting cord to power the firing set, the cord to the meter that will show the voltage in the capacitor, and the cord that will connect to the firing set from the EBW are all placed in the lockbox. It also contains the cord which will close the safety switch in the firing set. After connections have been made to the EBW, the lockbox is unlocked and a sequence for the use of the cords is followed to set up for firing the shot. This includes checking and monitoring the status of the firing-set capacitor. Reynolds EBWs are used.

At all other installations visited, a firing safety block was not in use; therefore, electrical connections were made to an in-line system, or a connected initiator was placed in-line. Typically, the laboratories using interrupted, shorted, electrical lines for safety would have a lockbox near the firing circuit and a transfer box in a sheltered location closer to the pad where the event was to be fired. The line from the firing circuit into the lockbox would not be connected to the line leading to the transfer box except as a last step before firing. The line within the lockbox going to the transfer box would also be firmly shorted until ready to fire. At the firing lines transfer box, a combination of a DPDT and SPST switch can be used to provide shorting and grounding as shown in figure 4. The DPDT switch is first transferred from the short, then the SPST switch is opened. The grounding here is through a resistor.

Low energy initiators should be avoided if at all possible. Instead, EBWs or equivalent initiators should be used. Each of the following paragraphs is preceded by either (EBW) or (LED) to avoid confusion and to assure adequate extra precautions with LEDs. The inclusion of safety procedures for LEDs is necessary for completeness and is not to be interpreted as endorsing their use. Precautions listed for LEDs are often equally applicable or desirable for EBWs. Those listed for EBWs must be reconsidered before application to LEDs. The principles followed and details observed at various installations are described.

(LED) The detonator should not be placed into a setup until all other steps have been completed and the detonator has been connected to a shorted, verified, safe-firing line in a safe location away from the setup. This connection is made with the detonator in a protected region (safety confinement) so that, if it went off, no damage would occur. For example, the detonator can be in a heavy metal pipe with leads brought to the outside. This procedure provides protection against the main charge going off when in spite of all precautions, a detonator fires when connection is made to the leads (app C, F2).

(LED) Firing lines are double shorted at all times, one of the shorts being at the LED. Before connection of the firing line to the shorted LED, the line is checked to assure that it carries no voltage and is shorted. After the hookup of the firing line to the shorted detonator, the shorted pigtail is cut off. Depending on the nature of the event, the detonator may have been made part of the event before connection of the firing line. This is done only in cases where it is considered awkward to try to insert the detonator into the event in the firing chamber or after connections have been made. In other cases, the detonator is fully connected while isolated from the main charge for the added safety in the event the detonator functioned. It is recognized that the isolated detonator approach is preferable and special permission is obtained where the former (deto-

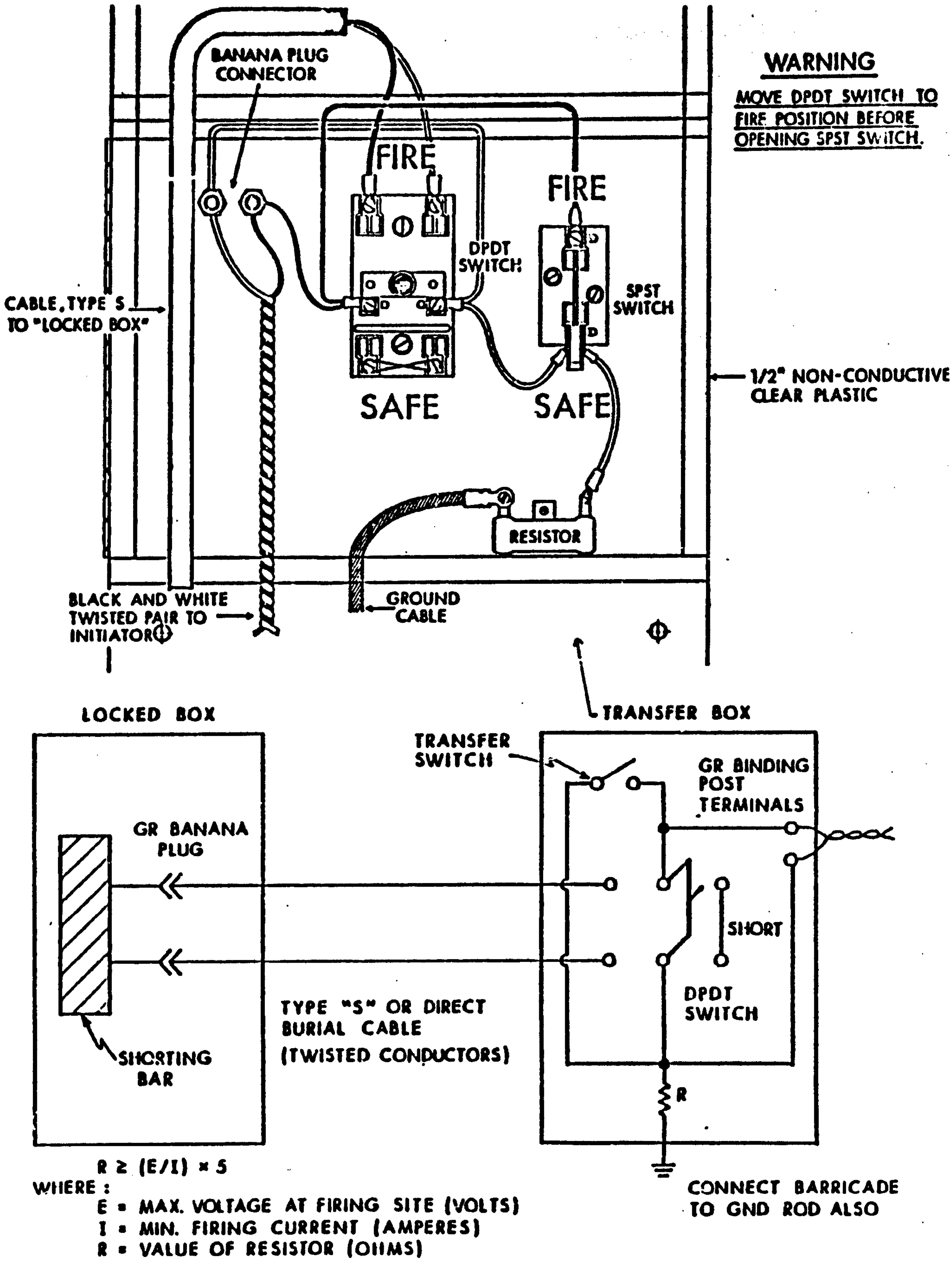

Figure 4. A firing system at Ballistic Research Laboratory

nator in item at the time when the firing line is connected) is to be used and is then limited to a maximum 100-g item. A flak vest and shield are then used in handling the item.

(LED) In all cases, the firing line that is connected to a detonator is not connected to the source to activate it and is protected by means of shielding, shorting, and grounding. The means to achieve the protected state of the firing line at time of connection to an initiator varies as to detail at various installations. The firing line, transfer box is a major element to assure safety. It contains a row of shorting plugs to which the connectors from the firing lines are attached. When these connections are made, and the box is closed and locked, the connections to the shorts can be seen through a window. This door key and the firing system power key are on a ring with a big red, rectangular tag and is kept in the possession of the person working on the setup. When the door is opened, a red light goes on above the box and in the nearby building where the instrumentation for firing is located; an audible warning also goes on. If a firing line connector is removed from the shorting plug of the transfer box and attached to one of the corresponding row of plugs from the firing circuits located below the row of shorts, the box can no longer be closed as the lower plugs extend further out. When working on a setup with the box still closed, a yellow warning light goes on instead of the red. The firing line transfer box is located so that the individual is fully protected if the explosive setup went off when the firing line was connected to the firing circuit. When the firing line is removed from the shorting plug and before it is connected to the firing circuit, the resistance to the initiator is measured using an ignition circuit tester and is recorded.*

(EBW) All detonator firing leads end on a shorting bar. Several leads are connected to a shot because some EBWs may be used to function items at different times. The resistance of each is checked before it is connected. All capacitors used for firing the EBWs are inside the bunker. If a shot does not fire, a second try is made. If this is not successful, then all cables are reconnected to the shorting bar, capacitors are drained, and the TV camera is elevated. The resistance of each lead is checked individually. If the necessary corrections cannot be made within the bunker, then one-half hour after shot time (recorded within one minute), one person will go to the shot to look it over while a second watches from the doorway. At one firing site, the control switches in the firing set for the EBWs have been made redundant. One switch shorts the firing capacitor and the other completes the circuit to the EBW. These extra switches are mounted in a box with a glass front adjacent to the firing switch so the operator can see the status. This was done because the firing set was furnished by another group and the redundancy was considered worthwhile.

(LED) The use of a safety transfer box that is based on a plug transfer is also used. The firing line has a special plug at one end that normally is connected to a shorting bar within the locked box. No ground is used in the short box. After the detonator has been connected to the other end in the safety con-

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* Alinco Model 101-5BFG by MB Electrics or equivalent.

finenent and placed in contact with the booster, the handler opens the lockbox and transfers the plug to the terminals that will then be used to send the firing pulse. Grounding is achieved when the connection is made to the firing unit. In a more elaborate system where the door is closed remotely, the shorts are opened and the firing lines are simultaneously connected to the instrumentation room with the key. The firing key is a single key that is carried by the operator and needed for all safing devices. It closes an air switch which operates an air-activated solenoid that completes the firing circuit (between door and firing unit) and operates a siren that has a 20 second built-in delay that precedes firing of the shot. The same key also applies the voltage.

(LED and EBW) Although the safety in each case lies in the use of the lockbox and/or firing transfer box, all auxiliary lines are disconnected while people are on the pad and are hooked up when they reach cover. Each low voltage, hot-wire initiator case is separately analyzed to maximize safety and is incorporated in a request for approval to proceed.

(LED and EBW) Before a set of leads are connected to any electro-explosive device, a voltmeter with a diode bridge to detect a.c. and d.c. is used to test between the leads and from each lead to ground. A discernible deflection is produced by 15 mV, and the needle is not damaged by 110 V.[3]

D. Shielding, Grounding, and Shorting

(EBW) To introduce the subject of shielding, grounding, and shorting, a specific example of a firing-line system should be considered. The firing-line length to the detonator is limited to 100 ft. Reynolds Type C coaxial cable is used, and the shield is connected at both ends. A leakage line is used and runs in the same metal conduit (for physical protection) to the firing pad. The connection is to the leakage line as shown in figure 5 (app C, F3).

The criterion for safety is that all personnel must be protected when the transfer of the firing line is made to the firing circuit since the setup can accidentally fire. With the shield side of the firing unit tied to ground, it is recognized that there can be a ground loop to the firing pad through the shield. The detonator used is a two-wire detonator with no connection to the case. However, the detonator must be able to have 500 V applied from either lead to the case without going off.

(EBW) The best possible termination of a long line to be connected to an EBW that would minimize the effect of induced fields was considered by Sandia Corporation. The concern was whether an open or shorted line was preferable. A transmission line, computer program was used as part of the theoretical study and concluded that it would be best to terminate the transmission line in 10-K resistance. This is how the 10-K resistors (fig. 5) were arrived at.

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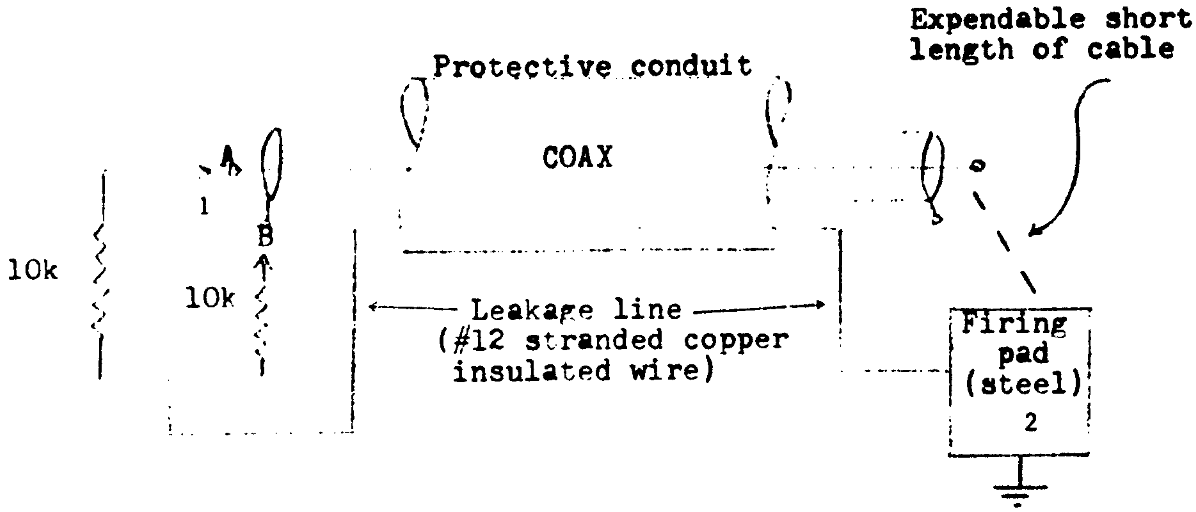
[3] Michael R. Osborn, "No-Voltage Meter," NWC TP 5822, February 1976.



[1] In the safe position, A and B are connected within the firing transfer box to the resistors. For firing, connections A and B of the coax are made to the firing circuit plugs.

[2] The setup is done at the steel firing pad. However, the detonator case may or may not make electrical connection to the steel pad.

Figure 5. A grounding and shielding system

(LED) The changes in the circuit (fig. 5) for a low voltage, hot-wire initiator are as follows:

1. The single conductor coax is replaced by twisted-pair shielded and the three conductors are each connected through a 10-K resistor to the drain line when plugged into the shorted position in the firing transfer box.

2. The shield at the end nearest the pad is terminated open (no connection) and is insulated from the leads so it cannot accidentally touch ground.

(LED and EBW) The following rationale with respect to resistive termination is used at another installation (BRL): Grounds are connected to the firing lines in order to drain off static electric charge. At the same time, a system must be included to prevent drawing current from ground in the event of a poor ground and presence of an electrical fault. To meet both requirements, firing lines will be connected to ground through a resistor. The size of the resistor is determined at this installation as follows:

$$R > (E/I) \times 5$$

where

R = the value of the resistor in ohms

E = the RMS value of the electrical service at the firing position volts

I = the minimum firing current in amperes of the most sensitive detonator used at that firing position.

Note that electric primers will fire at currents as low as 5 mA at approximately 3 V. This formula calls for 3,000 ohms; therefore, a typical bleed resistor (fig. 4) is 10,000 ohms in the leakage line circuit (app C, F4).

(LED) A ground loop cannot always be avoided (e.g., if a thermocouple goes to the item or if a transducer goes to a charge amplifier, one side of the a.c. will be grounded). Even though the possibility of having ground loops is recognized, it also must be stated that they are clearly undesirable. Normally, a shield on a cable should only be connected to ground at one end. Care should be taken so that shields do not electrically connect at both ends to connectors that are plugged into a grounded chassis. In each electrical situation, LEDs must be analyzed with respect to possible paths for pickup and for possible paths leading to explosive initiation by grounding or making lead connections.

(EBW) A ground loop is tolerated if it is shorted until ready to be fired. A single lead coax with a shield grounded through a firing set by a connector can be used in this manner. However, the twisted, unshielded leads with one leg grounded at the firing pad to a firm ground and kept shorted until ready for use is the preferred mode at one installation.

(EBW) At another installation, the instrumentation has a common ground. The EBW has neither side grounded normally. The leads from the setup are shorted and grounded at the lockbox until the connection is made; the lockbox is in a safe location with respect to the shot setup. A relay is used to complete the firing circuit. When the relay is not activated, the leads are terminated in a discharge resistor. Instrumentation on the setup must be shorted and grounded while personnel are in the bombproof. The lockbox also interrupts the leads to the light source used for the shot. The firing line that is used has two conductor armoured cables with no shield and no connection to the armor.

(LED) With 1-A/1-W detonators, a load resistor is used across the detonator so that when the detonator functions, the instrumentation does not show an open circuit. The resistor also serves as a leakage path.

(LED and EBW) A ground made at the firing bunker (blockhouse) with long lines to the detonator can be a hazard. In one case, such leads were led to the distant firing site within a conduit, but adjacent power lines were found to be inducing a current.

(LED and EBW) Unnecessary interlock/safeties should be avoided because by malfunctioning they can lead to circuit difficulties. There should be no hidden connections. One well-established, positive lockout may be safer than several if the status of any is in doubt. At one installation, the vital connection or its absence is made evident by location in a LEXAN box so that status is always visible.

(LED) In considering sources of electrical fields, it should be recognized that at military installations, powerful radars exist and are a dangerous source. At one installation, the test site is about a mile from a radar. It is necessary to ground the cable before attaching the detonator. Otherwise, it will immediately fire due to pickup if the radar unit is operating. In general, the electrical level of the trigger pulse required for initiation should far exceed the electrical noise level present.

(LED and EBW) Normally, if an explosive is on the pad, there is no power. If an explosive is being heated and power is on for this purpose, then everyone is under cover. When a dry run is made with power, the explosive is in the transportation truck next to the firing table. Since power lines are not normally out on the firing table, preparatory work is done with battery powered drills, etc.

(LED and EBW) If thermocouples go to the table (or shot), they are plugged into a special safing box in the bunker that prevents the power from inside (e.g., from a recording instrument) charging the thermocouple (app C, F5).

(LED and EBW) When a multiple detonator application is fired, the circuitry can set off others because firing is by a strong pulse. The coupling can be resistive, inductive, capacitive, or due to the parts of the circuitry that are not recognized as being there. One such source is circulating ground currents; two grounds can have different potentials. In one unusual case, a connection at one building stated to be a ground had a 35-V difference in potential to the stated ground of an adjacent building. Grounds must be carefully located and verified periodically. Circuitry and connections must be checked for possible ground loops. The considerations as to grounds and ground loops are critical for LEDs but less for EBWs. For LEDs that have resistance of about one ohm, small currents and parallel paths create a serious hazard. Because of the possible existance of unrecognized coupling, a system in which a sequence of events occurs should not be checked one at a time because the possibility of interaction is ignored. The sequence should be checked with dummy loads and instrumentation to check for interactions but without explosives. Detonators alone can be used as indicators of proper sequencing in the absence of main charges and with proper safeguards regarding detonator action.

(LED and EBW) Reliance on shielding must be accompanied with a realization of the limitations of the shield-in-use. Even screened rooms can have limitations. A Faraday cage need not be of fixed potential to prevent entry of electric fields from a static surrounding field. However, a dynamic external field can induce currents in a Faraday shield which will lead to induced fields inside the shield unless fixed at all points in potential.

(LED) The output of electric detonators is tested in a screened room that has an interlock-protected door, and operation is from the outside. The detonator with two shorted-twisted leads has the leads spread apart between the detonator and the twisted section. Alligator clips which emanate from heavy shorted leads are then attached. After the connections have been made, the twisted section of the leads are clipped off using grounded cutting pliers. For a detonator with one wire emanating, the clips are attached to the wire and directly to the cup. The short of the massive leads is removed only after the operator has left the screened room, closed the interlocked door, and is ready to run the test.

13. SENSITIVITY/EXPLOSIVENESS (I)

A. Definition of Terms

The use of the words sensitiveness and explosiveness in relation to the use of words such as sensitivity, initiability, and growth have been considered by NATO participants. In late 1984, the results will be issued in NATO Allied Ordnance Publication No. 7 (AOP 7), "Explosive Materials for Military Use." This document will have definitions and tests used by each country. Currently the British have agreed not to insist on use of sensitiveness. Sensitivity has been defined as: "Sensitivity is a parameter which determines how easily a fast reaction can be initiated in a sample, usually at normal temperature and pressure."[4] The definition is related to starting chemical reaction (perhaps including activation energy as one parameter). Explosiveness is related to building up to some violent response and is enhanced by rapid burning which depends on particle size and pressure coefficient. If an explosive does not have low sensitivity, the overall response may still be lowered by reduced explosiveness. The dividing line between sensitivity and explosiveness is neither sharp nor clear.

The words sensitivity and explosiveness should be properly applied to an explosive system because of the role of factors such as quantity, confinement, contacts, and shape of explosive. Lead azide, properly packaged, could be carried around with no fear. AN in large quantities as in the shipboard disaster exceeded critical mass, therefore, representing a continuous real hazard. However, AN is insensitive and lead azide very sensitive in standard sensitivity tests. A system description is needed to assess the hazard not just the result of sensitivity tests.

Explosives have intrinsic properties (such as thermokinetic parameters) and extrinsic parameters that govern behavior. A mechanical stimulus acts on the explosive through extrinsic properties that are alterable to cause initiation through the intrinsic property. Therefore, an explosive with CAB-O-SIL will respond differently to a mechanical stimulus than one without. Wood in the form of a solid block ignites differently than sawdust. Flour, grain, and coal in the form of dust are more sensitive than explosive dust. The details of the explosive and nature of its embodiment in the systems must be considered in order to characterize the explosive response to a stimulus to the system (which stimulus is transmitted in modified form to the energetic constituent).

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[4] Energetic Materials, Vol I, edited by H. Fair and R. Walker.

The rate of reaction of an explosive (centuries, years, seconds, or microseconds for significant chemical change) is strongly linked to temperature. The rate is proportional to the quantity (first order kinetics) and the proportionality factor has a coefficient called the frequency factor which multiplies the base e to the power: activation energy (A) divided by the product of gas constant and absolute temperature. A decrease in temperature will increase the exponent. A small change in temperature can increase the reaction rate several orders of magnitude, depending on the value of activation energy. A 10-degree increase can lead to an exotherm which could then cause an explosion. This is why the DTA test proceding an operation (e.g., pressing) is so important. The DTA is done on a very small quantity of the explosive. In the operation, a much larger quantity will be used and heat accumulation at a temperature below the exotherm temperature measured by DTA, can very quickly lead to explosion. Therefore, an exotherm in the vicinity of the proposed operation temperature is adequate to disqualify the planned operation and to require a system analysis and smaller scale tests to establish a safe operating temperature. An accident occurred in pressing PBX 9404, in which lead had been incorporated, because indications of a change in an exotherm with lead addition were ignored and one pound was pressed with disastrous results. The reactivity of a material also depends on the physical state (e.g., melting causes change in activation energy and frequency factor leading to very quick response to temperature).

B. Critical Temperature

Thermal tests should be distinguished from others because they can be a measure of explosiveness as well as sensitivity. In particular, the concept of critical temperature is related to explosiveness and requires care in its use. It is a property of the system depending on dimensions, shape, insulation, etc. Curves for various explosives of critical temperature are shown for diameter of spheres of explosive (fig. 6). The route that has to be followed for extrapolation involves geometry, kinetics, and transport. The critical temperature is the minimum temperature at which a system of a given configuration takes off due to catastrophic self-heating and depends on both intrinsic chemistry and the system parameters. Below this temperature it may still burn, but not run away (app C, I1).

Thermal sensitivity is measured by DTA, TGA, etc. which determines the temperatures at which changes in phase are initiated. Kinetics are deducible from explosion temperature tests that involve time to react versus bath temperature for a particular configuration. Computer simulations with kinetic data and transport parameters can then be used for critical temperature calculations to assess explosiveness.

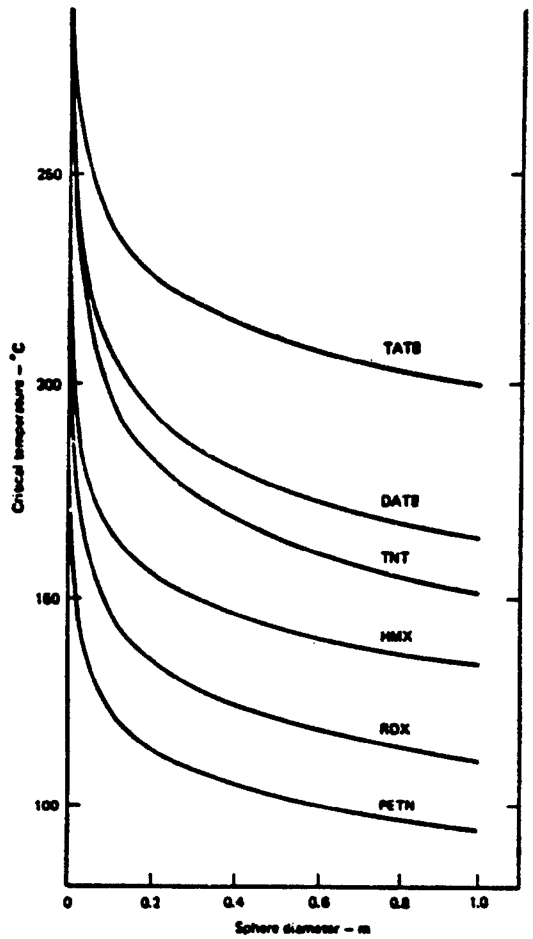

Figure 6. Critical temperature for explosive spheres

C. Use of Results of Sensitivity/Explosiveness Tests

One test for sensitivity to a particular type of stimulus (e.g., impact) does not lead to extrapolation from that test to the results of another test, even for the same stimulus. Many sensitivity tests need to be made for different stimulus. Sensitivity tests have limited use for characterizing an explosive as regards real stimuli. Explosiveness tests permit extrapolation in some cases (e.g., Susan and skid results correlate). However, safety tests are not done to get precise prediction data. They are to assure that we are within limits that represent a safe domain. They are for interpolation not extrapolating into the unknown (e.g., require that a new explosive shall be no more sensitive than PBX 9404 and use the results of many tests to arrive at a decision).

There is a need for a series of tests and for evaluation of the results in light of the application. Two similar sensitivity tests can invert the order of the same explosive. Thallous azide and RDX were tested by drop impact using type 12A tools, and it was found that thallous azide was no more sensitive than RDX. After experiencing surprising behaviors, a retest with type 12B tools (without sandpaper) showed that thallous azide could be distinctly more sensitive than RDX under different conditions.

The type 12 drop test poses problems in obtaining reproducible results and correlating these with previously obtained values. New Navy explosives are tested at NWS because their equipment reproduces old values. Tests currently used for drop impact have been adjusted so that the order of sensitivity agrees with factory and field experience on behavior of common explosives: TNT at top, HMX near the bottom, ammonium picrate, TATB, and nitroguanidine off the machine top. By interpolation, the impact test places an explosive qualitatively in this ranking linked to experience in the field.

The use of sensitivity tests requires caution. If a single test is stated to be significant for a particular use of the explosive, some guidance is received, but the identification may be incorrect or incomplete. Some consider it best to always use the full matrix of sensitivity tests as a general guide, adding some particular cautions. Others think one should try to provide a closer link to particular hazards by designing a simulation test, e.g., the skid test was designed to simulate a drop onto a concrete floor (app C, I2).

Sensitivity is not understood quantitatively. However, qualitatively it can be used to represent the results of a series of tests (sensitivity/thermal/explosiveness) as a basis for comparing a new explosive with standard ones. For an unchanged system, whose behavior is known with standard explosives, a new explosive can be located within the basis and provide estimates as to behavior in the system (e.g., all tests showing an explosive to fall between TNT and Octol justify using this in a system that is safe with both TNT and Octol). Extrapolation outside the basis to predict behavior of a new explosive is not possible. An explosive may have a particular type of hazard associated with it (e.g., dropping, static). The nature of the stimuli acting on the system as compared to the results of the sensitivity/thermal/explosiveness tests must be considered. Sensitivity tests are used to locate new or altered explosives from a safety viewpoint with respect to other explosives for which there is a large body of experience. These tests are questioned in terms of the history and preparation of test samples in a brief set of case examples.[5] To achieve a general appraisal of relative safety, a combination index has been developed.[6] The results were made up into a color chart of Hazard Index values for 69 explosives. The overall

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[5] Paper by L. R. Rothstein and W. McBride presented at Standardization Conference at Picatinny Arsenal, 21 June 1977.

[6] R. Petersen, "Susceptibility Index of Explosives to Accidental Initiation," NWSY-TR-81-6, October 1981.

index does not eliminate the need to evaluate the response to individual stimuli, particularly those that will occur in the application.

The corollary problem of explosiveness must also be considered. Thermochemistry of explosives underlies runaway to disaster. Decomposition reactions accelerated by autocatalysis are particularly dangerous. The theory and relation to reality involving thermal explosions has been reviewed.[7]

D. Hazards Not Revealed by Tests

The supposition that if an explosive is not disturbed it will not go off by itself is not always true. Consider the following cases:

1. Items containing lead azide desensitized with freon and with a water getter included, exploded while in storage.

2. Ammonium nitrate-type explosives, each 12,000 lb, used for helicopter landing pad formation were stated to have a 3-year life. After 5 years, they started to explode.

3. A large, single crystal of PETN, grown from a seed crystal in ethyl acetate solution of PETN by slow evaporation, was left to dry after pouring out the liquid. It went off. (There is a suspicion that ethyl acetate residual vapor migrated to a nearby refrigerator, ignited, and set off the PETN crystal.)

There is an awareness of the extra hazard that may exist when an explosive is in the form of a large single crystal or is being grown to form one. The following mechanism was advanced as one cause of potential hazard. Residual solvent on the surface or within the crystal may lead to cracking. The crack will propagate causing high stresses at the crack-tip and high local temperatures. The formation of a crack creates fresh surfaces; therefore, instability and stress concentration can feed on each other to initiate the crystal. There are some steps (app A, SOP) that can be used to reduce hazard. One such example is to slow the evaporation process and so reduce mechanical and thermal shock potential by having some of the same solvent in the container in which the grown crystal is drying.

It should be recognized that sensitivity tests are usually done at room temperature, whereas, usage can be at high or low temperatures. In addition, sensitivity of the solid phases differ from liquid phase. Separate testing is required to assess the hazard of a phase change or of handling the solid or liquid phase at elevated temperatures.

Some reference material on this section is included in appendix A.

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[7] R. Peterson, L. R. Rothstein, and John H. Smith, "Thermochemistry and the Demilitarization of Explosives," NWSY-TR7-TR76-2, July 1976.

The following examples are cited in a paper by L. R. Rothstein and W. McBride (app A) to show that prior sample history can influence both test results and end product quality or performance when either the neat explosive itself or a specific warhead configuration is under evaluation:

1. In the adiabatic sensitivity test of a cast plastic-bonded explosive (PBX), test samples cast and cured-in-place did not blow the pressure relief plug at maximum drop-weight heights, while cured samples with freshly cut surfaces did.

2. A cast PBX increased 30% in drop-hammer sensitivity after accelerated aging. A PBX increased in bullet-impact sensitivity with aging.

3. COMP B manufactured with a Grade B wax met all military specification requirements for the neat explosive and proved slightly less sensitive in at least one gun-type test than did COMP B formulated with Grade A wax. However, unlike the Grade A wax, the freezing characteristics of the Grade B wax were altered sufficiently to cause excessive critical defects in 105-mm projectile loads.

4. Impurities are different in TNT manufactured by the continuous versus the batch process. Test data relevant to TNT growth, cracking, or exudation must be identified with the TNT source since they also will differ.

5. The HMX content in RDX varies with the manufacturing process of the RDX and vice versa. It is critical that burning rate data, particularly of propellant formulations, be identified with the history of the RDX or HMX that is used.

6. It was demonstrated conclusively that density, particle sizes, and whether or not an explosive has been pressed or melt-cast loaded all materially influence gap sensitivity and DDT (deflagration to detonation transition) test results (app A, D. Price, et al). The system under investigation has not always been precisely defined with reported results.

7. Several compounds, such as desensitizing waxes, have been known to change their thermal properties, as measured in DSC (differential scanning calorimetry) tests, if they are heated and cooled more than once.

8. A Navy PBX, which passed all other WR-50 qualification tests as a fill for 5-in. projectiles, failed by premature initiation after temperature and humidity cycling because of its unique coefficient of thermal expansion characteristics. Similarly, an Air Force PBX, which proved a successful load for one type missile, failed as a 5-in. projectile alternate fill because of crack formation even at ambient cure which was the result of the mismatch in expansion coefficients between it and its container.

9. The density-sensitivity graphing of solid charge test results is essential to conveying that data in a useful form.

10. Pressed-test charges are more sensitive in some tests than the cast charges of the same composition--each type must be given a separate, distinct identity.

11. Response in drop-hammer impact (type 12 tooling) is overwhelmingly influenced by the most sensitive ingredient in an explosive mix; therefore, it should not be expected to correlate well with most solid-charge tests.

12. Any deviation from a standard test procedure (i.e., impact on solid chunks versus powders) should be reported with the test result.

14. ACCIDENTS (A)

The causes of accidents are not always known and may be the result of a combination of circumstances. It is possible to categorize the probable causes of accidents and to use these as a guide for stressing safe procedures (app C, A2).

A. Operating Procedures

Accidents are frequently due to violation of operating procedures, to oversights in creating the procedures, or to careless handling with respect to prior inspection or in assembly as can be seen from the following recorded probable causes extracted from accident reports:

1. The firing tank door is hinged and is secured around the surface by seven stud bolts. The door failed during test firing because three nuts were just barely engaged on the bolts; one nut was not in place at all, and one bolt was missing. (730-12)*

2. Operating personnel did not actuate the switch which closes the hydraulic latches securing the firing chamber door. A pressure sensing interlock should have prevented the shot from being fired but was found to have the diaphragm stuck and the microswitch closed to allow completion of the firing circuit. (730-7)

3. An operator left out the mushroom plate that seals against loss of water in a hydrostatic press. The bag collapsed and crushed the billets against the lower surface of the backup plate. (730-18)

* The numbers in parenthesis refer to file numbers of more complete descriptions in the BRL safety file.

4. Waste explosives do not normally accumulate in the trench, but small foreign objects in the trench prevented proper flow and allowed a buildup of explosive material. The welder had moved his operation to a portion of the building not approved for work with spark- or flame-producing tools and ignited the accumulated waste in the trench. (730-13)

5. Four parts of the mandrel were left out of the shell/mandrel assembly so that shear action initiated the explosive. (730-4)

6. Some pieces of tooling were left out and allowed the explosive to move as pressure was applied. (1530-1)

7. The attempt to burn PETN in thickness over the maximum allowed. (730-36)

8. Samples used were four times the normal size and were not purged with an inert gas as is normally required. (730-33)

9. A welding spark ignited dust on the floor which contained high explosives. (730-25)

10. An operator made an error in connections. (730-19)

11. Coolant flow lowered, the tool was not rewashed and cleaned at required intervals. (730-17)

12. The attempt to destroy explosive-contaminated waste in a condition which was not compatible with the existing disposal procedures. (730-40)

B. Mechanical Action on an Explosive

This category of accidents can occur in pressing operations where an explosive is highly stressed, or it can occur in handling explosives in a way that imposes a local high stress. The following probable causes of accidents were extracted from reports which illustrate this category:

1. High explosive material between metal portions of press. (1530-2,3)

2. Friction and pinching with improper clamping. (730-20)

3. Dropping a billet of explosive or moving it across a surface is equally dangerous. Such incidents in England and in France had fatal consequences. The following prior incident illustrates the hazard and the value of reporting such misses: A block of explosives was being relocated by use of a chain hoist. The chain was at an angle to the vertical. As the explosive left contact with the surface, it swung to make the chain vertical, rubbed on a surface, and ignited. Under limited stimulus and no confinement, it burned but went out as the sprinklers came on. A major accident was fortunately prevented. This incident was not made known to personnel at AWRE (England) where a similar skid

mechanism later led to two fatal accidents. A chain-fall hoist was not located vertically over the assembly when it was raised causing the assembly to strike the floor with a pendulum motion. A three-legged stand which tilted easily was being used to support the 500-lb assembly being hoisted. The skid test is used to measure sensitivity to this type of hazard. Where billets of explosive are handled, floor and table surfaces are selected to provide minimum skid and impact sensitivity (app C, A1). (730-27)

4. Explosive billet was initiated when dropped onto gravel or metal equipment present on the pad. (1530-4)

5. Pinch point at one of the locating pin holes where a square shouldered, locating pin had been used. (730-38)

6. A burr on the surface of the aluminum curing fixture could have contributed to the burning. (730-37)

7. Friction between mortar and pestle. (730-30)

8. High-explosive chips subjected to pressure and/or impaction. (730-28)

9. High explosive in the threads or between the pins of the wrench and nut was impacted. (730-26)

10. High-explosive chip impacted by gauge arm striking the part being gaged. (730-24)

11. Pressure exerted on the high explosive with the pipe. (730-23)

12. Impacting high explosive with unauthorized tool. (730-2)

13. Possibility that some explosive extruded around the insert during the first pressing cycle and moved upward when the press was opened. On the second cycle the extruded material could have become very hot due to compression and friction, thereby causing ignition and ultimate detonation. (730-5)

14. Probable flowing of TNT. The 12-lb billets pressed previously to the one that exploded showed evidence that some of the surfact TNT had melted and resolidified. Any movement of the press ram at that point could cause the explosion. (730-21)

15. Ignition of a dry titanium particle by friction caused by insufficient blade clearance in mixer. The particle size of the powder ranged from 39 to 78 mils, while the blade clearance was only 48 mils. (730-43)

16. Combination, or one of the following is probable: (1) Extrusion between laminations, (2) extrusion into the space between the stainless steel plug and the distributor. Either of these could cause pinching or shearing. Plugging could have caused an excessive extrusion rate. (730-35)

17. Metal fastener from the barium nitrate hopper dropped into the mixer bowl and was caught between the revolving agitator and the bottom of the mixer bowl. (1530-6)

18. Incorrect sizing and setup of equipment led to pressing tetryl powder to a size which would give a density approaching the theoretical maximum of 1.73 g/ml. The powder probably extruded into the small die clearance resulting in frictional heating and ignition. (730-41)

19. Contamination by a trace of titanium powder that remained in the die from the previous pressing. Friction between ram and die might have initiated a reaction between a titanium particle and adjacent explosive. (730-39)

20. Frictional heating inherent to mechanical pressing operations generated additional undesired heat. (730-15)

C. Incompatibility of Materials

The following probable causes of accidents illustrate this category:

1. Order of mixing of the TNGU and pyridine can lead to explosion. When a small quantity of pyridine was poured on a small pile of powder, there was an explosion, but when the powder was added to pyridine, there was no visible reaction.

2. The knowledge of the disposal personnel was not sufficient to anticipate the chemical reaction of sulfuric acid on excelsior. (730-40)

3. Excess of catalyst and/or a poor mix in the Furane gave an earlier exotherm than usual. Cavities in the explosive bond area had resulted in the use of excessive amounts of adhesive. The resultant, quick heat buildup within the interstices ignited the explosive when left to harden overnight. (730-10)

4. Exothermic reaction between lead, nitrocellulose, and chloroethylphosphate led to a thermal runaway during pressing. All three of these reactants are required; combinations of only two of them do not react. (730-11)

5. Reaction between the azide and the glue used on the plug may have occurred. (730-14)

6. A small piece of wood in excelsior or a concentration of kerosene at some point close to the MDF (medium detonating fuze). (1530-7)

7. Impurities in the explosive lowered the "safe" temperature for pressing. (730-15)

D. Malfunction of Equipment

This category of accidents stresses the need for preventive overdesign, maintenance, and inspection. The following probable causes (from accident reports) illustrate this category.

1. The 80-mesh screens which cover the vacuum port were clogged. (730-29)

2. The viscous flow of the XTX-8003 through a small orifice screen (200 mesh) caused heating and eventual ignition. The plastic parts used to separate the explosive from the screen either ruptured or were not adequately cleaned from a previous operation. (730-6)

3. Malfunctioning temperature controller permitted the circulating fluid that was used for heating the die to rise to 34°C above the specified pressing temperature. (730-15)

4. Exothermic reaction was caused by electrical heater failure, low liquid level (below electric heater element), and temperature excess over 200°C. The 50-liter glass reactor developed a crack or an unknown catalyst was present to cause polymerization reaction. (730-1)

5. Stoppage of coolant flow was caused by clogging, shaft breakage, or inadvertent shutoff. Some 470 similar operations had been conducted without incident since early 1958. (1530-5)

6. Pump became clogged with foreign material and high explosive. A contributing factor was the length of time the pump was out of service causing settling of high explosive in the pump. (730-32)

7. Internal voids with some water contained could have developed enough steam pressure to rupture the molds. (730-22)

8. Fine heat-powder dust collecting on the filter of the vacuum cleaner underwent a reaction probably caused from the moisture in the air. (730-3)

9. Dust buildup at the cutting tool probably ignited from heat buildup through friction or hitting a hot spot in the part. Twenty parts had gone through three separate machining operations before the incident. The fire propagated into the dust-air mixture in the collection system resulting in an explosion at the vacuum cleaner. The vacuum cleaner had water in the bottom to wet all powder collected, but enough dust was present to blow the top off the cleaner. (730-42)

E. Other Probable Causes

Drilling holes in explosives is dangerous. Two accidents are described in detail under MACHINING (Drilling) and are not repeated here, but should be reviewed at this point.

Mechanical hazards can involve explosive moving inside a metal confinement, as well as externally. The large-scale gap test uses a cylindrical explosive charge that is a slip-fit into a confining steel cylinder. A sample that had been shocked, but had not gone off, was unlabelled as to history. An operator, trying to remove the charge, applied strong force to it with fatal results. The shock had locked the charge to the wall leading to high friction at the interface.

A mechanical hazard can be created when casting is done at too high a temperature which leads to excessive settling. TORPEX is essentially COMP B with aluminum substituted for part of the RDX. It was involved in a major blow where it was hypothesized, not proven, that a forklift hitting an item loaded with TORPEX set it off due to a sensitive concentration of explosive at the wall. In casting, the explosive may have been poured at an excessive melt temperature from the kettle into the munition which was then laid on one side. This was hypothesized to have led to a concentration of aluminum grit and RDX on one side which makes that side more sensitive. When hit by a fork truck in this sensitive area, the accident may have followed.

When casting in the plant, the liquid explosive is transferred into a reservoir that has multiple orifices on the bottom side. At one time, between flow from the reservoir into the munitions, the orifice holes were plugged by a set of metal corks aligned to close the holes. The metal-to-metal contact shearing explosive was the wrong thing to do and is hypothesized to have led to an accident in which a building and all inhabitants were lost. Plugs are now coated with KEL-F or other yielding polymers. The durability of this solution requires monitoring.

Cleanliness of explosives and the surfaces contacted is important; the accumulation of foreign matter on a surface must be avoided. The hazard exists in handling and machining. One possible explanation that was advanced for a serious machining accident was that the mallet used for tapping the charge on the lathe was coated with sand from the surface it had been lying.

An accident occurred after an item impacted the ground from the air and did not function (dud). This was now an item of unknown properties and sensitivity. A full analysis was needed before any step was taken toward disassembly. The situation is normally covered by an SOP including a required authorization for action. Unfortunately, in one case, a project engineer decided to salvage a part and lost his life and that of another.

An administrative decision was made to temporarily close an area used for disposal of explosives. This and the unrelated decision to clean out a magazine led to an accident. With the disposal area closed, the operator improvised with fatal consequences; there was no SOP.

An accident can also occur by not complying with an SOP with good intention of being helpful. In such a case, the SOP required that reject parts be put aside to be worked over under a separate SOP. The individual decided to make the necessary correction on the spot to reduce the number of rejects. The item involved could function if dropped; in trying to improvise a correction, it did drop and did function. Deviations from an SOP are never to be improvised. Careful consideration and consultation with an authority are a prerequisite.

Accidents can occur because of the lack of knowledge of the details of the item being handled. In one case, although the safing and arming device (S&A) would only arm if the item was spun like a top, the operator handled it negligently and let it roll which armed it and led to the item functioning. In another case, the same item came through armed, and again rough handling caused it to function. Knowledge of the status and properties of an item being handled is essential. It is essential that when handling a device that could contain explosives or that supposedly is inert, the operator should be certain that it is inert. Cases exist where explosives were found in small items that were supposedly inert and had been handled over a period of time. Parts that are sometimes sold for scrap could cause an accident if incorrectly labelled. Inert markings are a minimum; a signed certificate that is properly arrived at after investigation is preferable. Labelling should be clear and permanent.

An infrared (IR) flare under test in a flare tunnel blew up (a most unusual event). After burning for 6 seconds it detonated as evidenced by the fragmentation of the case; the force displaced cinder block walls. The overhead design of the tunnel permitted gases to vent into an adjacent office. The incident points out the need to design structures for the worst case and also led to reconsideration of the hazard classification of flares.

An accident occurred when, in haste, power to instrumentation was not shut off, and the experimenter went out to make adjustments of the probes (part of the instrumentation) in the setup on the firing pad. There was a defective circuit arrangement and the item went off resulting in a fatality. NEVER WORK ON LIVE INSTRUMENTATION ON A FIRING PAD.

A shell went off during an experiment in which the deflection of the wall was to be measured by contact to a pin that was spaced a distance from the original position of the shell wall. The pin accidentally was moved to touch the wall and the item went off (DETONATORS, Parallel Path Hazard).

A similar accident involving an unrealized, two-parallel path situation occurred when an item was heated by nichrome wire wound over asbestos around the item. When a short occurred through the asbestos, the voltage had two parallel paths, one leading through the detonator (DETONATOR, Parallel Path Hazard).

About ten years ago there was an accident that led to a fatality in which a mini-det being placed into an explosive was set off by static charge from clothing. It is now a set policy of the organization where this occurred that only EBWs can be placed in contact with explosives by one of their personnel. The importance of cotton clothing was also learned from that accident. Sliding across the bench seat of a car can also generate static electricity. The supervisory ordnance technician who drives between sites and handles explosive setups has a cotton seat cover on his vehicle.

There was an incident in which an individual entered a walk-in oven and could not get out, which resulted in a fatality. Walk-in spaces now have panic release facilities and means to notify those outside. In the dark, a fluorescent latch indicates location for escape purposes.

There was an incident in which an oven control malfunctioned and temperature continued to rise, causing runaway. In addition to the thermostat, a temperature limiting device is now required. There was also an incident with an oven that had a backup safety device incorrectly wired by the manufacturer. This led to the loss of the vibrator machine. Routine checkups on oven safety devices and a regular schedule maintenance program have resulted.

Accidents are caused by some of the following:

1. Change from a set situation; sometimes because an individual did not see need for a step

2. Oversight

3. Safety characteristics of material (i.e., it was not well characterized before scaling up)

4. Communication--message given not same as message received (e.g., "Have you rotated your tires?" Response: "Why should I; they rotate whenever I drive the car.")

Liquid explosives can be very dangerous even in small quantities. One accident occurred when a thin film of nitroglycerin on the edge of a plate was impacted as the plate fell and hit concrete. In another case, a micropipette holding a very small quantity of liquid explosive went off when the tip brushed the interior surface of the test tube as it was being withdrawn.

Thallous azide was the explosive involved in a fatal accident. It had been drop-weight impact tested using Type-12 tools which include sandpaper and anvil. The equipment was an advanced unit using an instrumented detection of a GO. On this equipment, thallous azide was found to have a 50% value of 24 cm compared to RDX with 22 cm. No other test indicated the existence of a trap, but during an operation it exploded. It was subsequently discovered that azides are more sensitive in a test without sandpaper, i.e., on bare steel. Thallous azide was far more sensitive than RDX. Further, the notebook of the operator indicated that there had been some low-order reaction at low heights in the impact sensitivity tests which were not counted as GOs by the instrumentation and were not reported. Finally, the 50% point does not indicate the behavior at the far lower level of probability which is of interest. This point stresses the need for protected small-scale steps to corroborate sensitivity test indications.

Accidents occur because the relevant hazard feature of the explosive is not known or discovered. Astrolite is a very sensitive explosive that contains hydrazine and when put in contact with tetryl (a booster), a hypergolic reaction occurs (i.e., it burns immediately on contact). It produces ammonia as a byproduct so that a hypothesis for the cause of the accident was that ammonia-air had accumulated and was set off by a spark. Another hypothesis was that hydrazine had reacted with the iron-oxide in a rusty pipe. Nitromethane can give off methane gas leading to the hypothesis that a tank-car explosion was started by a methane gas explosion. Tetranitromethane is a powerful oxidizer. When mixed with fuel, coordination or additional compounds are formed. Tetranitromethane with benzene took nine lives. Detonators using lead azide had aluminum cases. A change was made to brass for one application. With just a little water, lead azide forms hydrazoic acid which attacks the copper in brass forming copper azide. This azide is much more sensitive than lead azide because of the electronic structure of the copper. Some of these detonators became potential time bombs, dangerous to handle or destroy.

Another potential cause of accidents is the unusual memory property of lead styphnate with respect to a static electricity or voltage stimulus. If an electrostatic sensitivity test is run on lead azide and results in a NOGO, the material then behaves on a subsequent test as though the first test had not been done. This is not the case for lead styphnate. Lead styphnate behaves as though it is integrating the effect of individual stimuli toward a GO. Thus a NOGO specimen of lead styphnate is more sensitive after the test than before (i.e., the subsequent threshold for a GO is lower). With respect to a lot where the history is unknown, the sensitivity of lead styphnate is not known since it may have been previously subjected to electrical stimulation. Samples from each and every lot of lead styphnate must be separately tested for electrostatic sensitivity to establish the lot sensitivity and the NOGO samples destroyed.. This history effect of lead styphnate was responsible for a magazine blow.

To avoid accidents, the following general listing of DOs and DON'Ts was provided at one installation:

- Don't use threaded joints around explosives. Use C clamps.

- If threaded, don't use solvents like acetone, etc., which can carry explosives into a joint, but DO use lubricating oil.

- Never weld, torch, or fire any pipes with elbows or whenever there is no line-of-sight even if assured that "its been steamed out and decontaminated." This applies to duct work, fume hoods, etc. where TNT or other subliming type explosives can build up.

- Never tear up explosive contaminated floors or walls which are cracked and may contain residual explosives; particularly avoid use of jack hammers.

- Avoid indiscriminate use of strong acids, alkalies, amines, etc. for cleaning or washing without thorough knowledge of contamination that exists (e.g., sodium azide which was poured down lead pipes in a hospital caused an explosion at a later day by lead azide). Acid and sodium azide forms hydrozoic acid which is spontaneously combustible and detonable.

15. PHILOSOPHY (U)

A. Limits on Content

Although many of the safety procedures included in this report are common to a variety of energetic materials, no attempt has been made to make this coverage comprehensive. Specifically, the scope has been limited by the exclusion of propellants, pyrotechnics, and primers for gun firings. The report is also limited to the material provided by the personnel at the installations visited (app B) which are primarily research, development, and testing organizations. Future expansion and improvement of the content could be achieved by soliciting additional input from representative, large scale, production facilities (e.g., Pantex, IAAP) and several additional facilities such as IITRE, Safety Engineering, BuMines that have worked on improving safety in handling explosives.

B. Safety Office Relation to Operating Activities

Each installation faces the problem of dividing the responsibility for safety between a separate safety department and the operating activities. Each organization solves this problem differently according to its needs; there is neither a correct or incorrect method. However, a review of the approaches used by different organizations may provide ideas worthy of consideration by another.

At an installation that deals with small quantities of explosives, but principally primaries and sensitive secondaries, the safety organization has been given a major role and staffed accordingly, with personnel, some at MS and Ph.D levels, experienced in explosives. It assigns these individuals to work fulltime serving particular divisions, and to write the SOPs in consultation with the line personnel involved. The philosophy of the safety organization is that it is a service organization with responsibility to help, but that the ultimate responsibility for safety resides in the line organization. It is clearly not an adversary relationship, but a strongly cooperative one.

At another organization involved in research and development studies, the safety office provides a general contribution for the field of overall safety. Reliance for the specifics appropriate to explosives is placed on the operating personnel, publications, regulations, and a safety committee which includes a spectrum of experience. A safety committee of technically competent individuals can be effective in improving the safety status for explosive and explosive item handling.

To be effective and maintain interest, the safety office must be given strong administrative support. In particular, when a safety office is administratively located so that the decision-making is several organizational steps removed from the operating segment, a hazardous communication problem can exist. Administrative decisions as to procedures, materials stocked, and difficulty to get approvals or required safety devices can in themselves lead to an accident. This can occur because the operating scientist, engineer, or technician feels thwarted in getting his job done and improvises a means to do so.

C. Personnel for Particular Functions

With respect to the type of personnel authorized to work with explosives (e.g., measuring properties, setting-up and firing tests), there is a dichotomy of viewpoints that seems to relate to the function of the organization and the quantity and magnitude of work involved. One viewpoint is that in research with explosives, scientists and engineers are the ones who do the training of the technicians and have a broader knowledge, hence properly certified they should be a party in setting up the shot. The other viewpoint is to only use individuals specifically trained for the operation involved (e.g., firing officer) and to minimize direct scientist involvement. In both viewpoints, SOPs are used to impose on people a need to think through what they are going to do from a safety viewpoint and have other people who are knowledgeable think through it with them as well. People who do loading and firing should be sufficiently educated to serve as strong links in the system.

Explosives are sometimes an incidental part of a test, i.e., they serve as a source of a switch action, blast, flying plate, etc., and in testing a nonexplosive item, the test personnel may have limited experience with explosives. In such cases (and it has merit for others), whoever designs the explosive aspects of the experiment must be on-site when the experiment is conducted. In one organization where such cases are common, there are two scientists who devote themselves to helping or conducting experiments involving explosives where the explosive is incidental. They are experienced, have strong backgrounds, and provide an important measure of safety.

In installations or parts of organizations responsible for firing many shots, often of large magnitude, specially trained firing officers assume the responsibility for setting up shots and firing. The professionals who designed the test and are interested in the results are not entrusted with the setup or the firing. Quantities are minimized at the firing location by magazines convenient to the site. As part of this arrangement, the experimenter/scientist/engineer has no say as to what happens in the bunker. The people operating the facility are under separate supervision and will not undermine safety to accommodate schedules, etc. This division of control is important for safety. The firing officers are sometimes in a separate group, and an engineer/scientist cannot become a firing officer unless he is transferred to the group. The position is that an engineer/scientist who is responsible for a project will tend to give priority to timely completion of the project as opposed to strict adherence to safety precautions. The firing officers are trained by formal courses such as those at the Safety School at Crane, Indiana and by other training set up by the Safety Office.

This concept of separate responsibility for firing shots is handled similarly in another organization which devotes a major portion of its personnel to large-scale field testing. Explosives are handled only by ordnance technicians with extensive explosives-handling experience, most often from the military (e.g., demolition). As a matter of policy, the professionals, do not set up shots. However, the know-how of the professionals is used in designing the setups and in formulating safety procedures. Although regulations are used, great stress is placed on the competence, the interest in safety, and the practical experience of the ordnance technicians. These men live their jobs. They know they are important to the organization and are well regarded. Acting safely is important to maintaining their self-esteem and the esteem of others. The result is self-generated stress on safety in a small group (5 individuals) that is open to consider new means of assuring safety. This strong dependence on the individual may not be as suitable for larger organizations where the formal regulations that are applicable are more extensive.

D. Emphasis on Training

In training personnel who do the hands-on work with explosives, there is again a dichotomy of philosophies. On the one hand, there is a reliance solely on SOPs and operational experience. Others strongly believe that a basic understanding of explosives serves as a necessary prerequisite for safety, and provides an awareness of safety traps. In both approaches, safety instruction should include actual incidents to bring home the point. Each situation requires careful consideration in designing training appropriate for each individual concerned with explosives.

Disaster plans are an important part of safety and should be part of safety training. Such plans include: definition of a disaster, personnel direction to assemble in defined places, reaction in case of building fires. For a local fire, if convinced that it can be extinguished quickly and there is no damage to other setups by fighting it, and if no toxic fumes are involved, then use of a hand extinguisher can be attempted briefly. Otherwise the fire department must be called and mass evacuation started.

It is important not to overreact to information about accidents. Safety requires doing what is scientifically justified, but recognizing that explosives handling will always have some risk. Every new explosive has at least one built-in trap. The problem is to identify it in advance of an incident and proceed so that no harm will result when the trap surfaces. Therefore, a new explosive should be physically accompanied by the results of the sensitivity tests and handling precautions. The overall philosophy is to work with the safest explosive and the safest initiation system that will do the job. This is why EBWs are used instead of low energy initiators, if at all possible.

General rules for working with explosives are: keep quantities small; separate quantities of explosives or explosive devices to provide isolation from each other; assume that an explosion will occur, and design procedures, facilities, and devices that will minimize materiel damage and prevent personal injury in the event of an unanticipated initiation. If something unusual, unexpected, or simply different than that covered by an SOP or usual procedure occurs, do not proceed; instead, consider, reconsider, and consult more experienced personnel and the chain of authority in such situations. Accidents can be caused by proceeding instead of stopping and reconsidering. The approach should be "do not believe anybody; do not trust anybody." Verify personally "word of mouth" information (e.g., "this is inert," "not hooked-up," "firing circuit is off," etc.). A request for work to be done with explosives must be accompanied with all the details. The features that could introduce a hazard should be identified.

The biggest hazard is complacency, i.e., that which is used on one occasion is assumed to be safe in another without questioning or thinking. This complacency can have the form of feeling that some questionable procedure has been done often enough without leading to a bad consequence to be acceptable. This is false thinking. A questionable, doubtful, wrong, or unsafe procedure will ultimately lead to an accident.

The fact that an explosive material has been handled without incident for some time does not necessarily mean it is safe to do so. (At the Sixth Detonation Symposium it was reported that liquid nitric oxide which had been used regularly in distilling nitrogen 15 had resulted in an explosion with 50 grams. Tests then showed that it was as sensitive as nitroglycerin.)

It is important to realize that contrary to other interactions with our environment, explosives rarely give advance warning of hazard. The environment in which people live generally provides warning of possible accidents (horns blowing, etc.) and near misses. These provide conditioning to maintain alertness to avoid accidents. Explosives handling differs in that there are generally no warnings of imminent explosive accidents. Hence maintaining alertness and persisting in safe practices requires extra effort that must be supported by safety programs. The principal causes of accidents that involve alertness occur when things begin to be routine; mistakes are made. Obsession with one thing can lead to ignoring another.

Explosive on threads is dangerous. No internal threads should be used to join two pieces. The riser used in casting should not be threaded into the item. It can be held down by external shafts away from the explosive. At the same time, riser design should avoid pinch points. When an explosive does not quite fit into a mating part, it should not be forced. It should be obvious that when a fit is lacking, trying to use a razor blade to adjust dimensions for a slip-fit can be extremely dangerous.

Explosive simulants can look like explosives and each must be clearly labeled. It is easy to be confused. In one case, efforts were made for a week to fire a "charge" that turned out to be a simulant. Labeling of explosive components is a must. A canister which contains live components cannot be labeled inert.

Duds require specialized experience and special handling and constitute an unfamiliar hazard for the explosive scientist/engineer. One should be aware that the fuze of a dud may be armed or have been made defective.

Finally, although pyrotechnics are outside the scope of this report, there is an important caution worth noting. For a flash fire in a pyrotechnic, if the fire cannot be doused immediately, evacuate the building because there may shortly follow a heat pulse (flash of heat) which will cause instantaneous death. Note also that many pyrotechnics, particularly smokes, dyes, etc., are carcinogens and should be treated accordingly, both in handling dry, in solvents, or breathing vapors.

The goal for new explosives must be to achieve the desired performance with equal or less sensitivity than for the old explosives. Hazard exists not only with a new explosive but with new applications of old explosives. In any application, the problem is to be wary of a sensitivity to a particular stimulus that exists in a specific application; i.e., to be wary of a trap. To avoid the trap, do the test that counts, the right test that reveals the hazard. An approach follows:

1. Use previous experience to decide if an operation is possible.

2. Talk to experienced people of various backgrounds about it.

3. Impart as little energy to the high explosive as possible.

4. Add energy to the explosive as slowly as possible. Beware that a slow physical action can lead to accumulation of heat at a local site; e.g., slow advance in drilling a small hole (MACHINING, Drilling).

5. Conduct a fault-tree analysis. What stimuli will the high explosive be exposed to? Which are the most critical stimuli?

6. Conduct or establish a test to simulate, as closely as possible, these critical stimuli.

7. Assess the risk versus benefits of the operation, application, or substitution of explosive. Consider the consequences of the risk being incorrectly assessed, the penalties for failure and a change to a different, less hazardous experiment.

8. Use redundant or overlapping safety measures. Multiple layers of precautions, interlocks, etc., are important to protect against failure or infraction of one of the layers, especially when consequences are severe.

9. If all else fails, minimize the consequences.

16. STANDING OPERATING PROCEDURES (S)

Each individual is responsible for his safety and for the safety of those around him. Rules in the form of SOPs are there to guide him. The SOP is the result of applying safety principles, practices, and experiences gleaned from knowledgeable individuals to the need to provide a safe procedure. An SOP cannot be so general as to leave room for errors leading to accidents. On the other hand, the SOP cannot be made so specific that an excessive number of SOPs are necessary to meet operational requirements or that the SOP is used beyond the real domain of validity. The overall approach is to provide SOPs of three types: general rules, repetitive operations, and specific functions. Each organization has a procedure for preparing and approving SOPs which includes some form of periodic review. Many SOPs limit the personnel authorized to use them to those qualified by prescribed training. At several laboratories, a procedure also exists for obtaining authority to deviate from an SOP which by-passes the full route used for a new SOP. The Safety File at BRL contains a collection of representative SOPs from different organizations which reflect the three basic SOP types.

In each branch of the Defense Department and in DOE, there is a comprehensive safety manual concerned with explosives (e.g., DARCOM-R 385-100 for the Army, OP5 for the Navy, AF Regulation 127-100, and DOE/EV/06194-2 Rev 1). Within each organization (e.g., BRL, NWC, LLNL) there are manuals (SOPs) specific to that organization or some subdivision of it (e.g., at BRL--Explosives Safety and Field Firing Instructions). In each subdivision of the major organization there are SOPs devoted to a specific area of activity (e.g., at LLNL--Explosive Operations Building 222 Complex) or to a specific type of function (e.g., at LANL--Pressing Operations). These are supplemented by SOPs devoted to a single activity (e.g., at ARDC, Dover--Detonation Velocity Testing including Sample Preparation at B1612).

The number of SOPs at all the installations visited (app B) is very large. The few selected for inclusion in the safety file at BRL as representative constitute a stack over 4 inches high.

A. Generation and Review

The first step in generating an SOP is understanding the reasons why one is needed since this establishes the objective (app C, S1). The SOP must:

1. Reflect the plans and operational requirements in a concise, complete, and logical manner. This requires that the person responsible for planning or conducting the test or operation has reviewed the complete project.

2. Firmly establish the procedure for conducting the operation. The responsible person will not be issuing impulsive or improper instructions. Thus, the possibility of omitting an important step and causing hazardous consequences will be reduced because a logical sequence of operations will be followed.

3. Specify the safest location, the number of persons required, and the proper equipment needed for the test or operation.

4. Reflect on how the work will affect the health and safety of operating personnel as well as others who may be in the vicinity of the operations.

5. Be reviewed by more than one person, each from his own perspective. Consequently, more safeguards will be considered, with the result that there will be less likelihood of omitting an important safety consideration.

6. Establish procedures for the necessary actions in case of an abort, misfire, power failure, or other contingency.

The draft of a proposed SOP is usually written by the engineer/scientist/technician/project leader who is closely related to the operation and bears responsibility for the safety of all concerned. In preparing the draft, he works closely with those individuals who have contributory knowledge or experience and seeks advice as required. In one organization, the SOP is drafted by an SOP communications specialist to whom the line engineer conveys the nature of the operation and the required safety content. This maximizes the clarity of the draft and relieves the engineer of the writing chore but not of the responsibility for the content.

The review of the draft SOP and its modification into an approved SOP follows a prescribed course of obtaining approval signatures. There is first a peer review in the sense that the reviewers are familiar with the subject and can offer technical recommendations for necessary changes. This level of review may include a dry run with inert material. This first review varies from organization to organization. Sometimes the technical review of the draft is limited to the immediate supervisor. In some cases the originator or supervisor circulates the draft to other experienced personnel to obtain concurrence. The draft may be submitted to a safety committee comprised of individuals of differing backgrounds (sometimes with short-staggered terms) for concurrence. After the draft has been modified (if necessary) to obtain concurrence, it proceeds up the line of authority for a "management acceptance of risk" review. How far it proceeds is determined by the nature of the operation, the quantity of explosive, or the area in which the operation/firing will take place. The role of this second review is to provide an awareness of the planned activity and to assure that it is in accord with the mission of the unit involved. The third type of review is done by safety personnel and can occur in conjunction with either the draft technical review or the management acceptance of risk review, or both. In some installations, an assigned member of a safety organization works with the writer of the draft and participates in the review processes at the early stages. In other installations, the safety office only formally enters the approval procedure after the line organization submits the proposed SOP.

When the SOP is prepared for work sponsored by an outside organization, it goes to the sponsoring agency for review and concurrence because the agency may be aware of features of the munition that would bear on the content of the SOP. If an operation is done by one segment for another of the same organization and the originating segment has a current SOP, the receiving organization may not accept that SOP for use, but may initiate a full SOP review procedure. This is done because conditions (e.g., grounding, circuitry, and personnel training) may be different in one organization than in another.

Except for those that are well established, SOPs are normally updated annually. The updating consists of a review and the incorporation of necessary modifications, usually as a supplement but sometimes as a complete rewrite. In one installation, SOPs are required to be reviewed annually but are rewritten only once every three years.

The user of an SOP must also review it, though he may not have participated in either the generation or the approval procedure. This is essential because, unless the SOP content can be followed easily, it is useless. In some organizations, the user (often the technician) is consulted when the draft is prepared. However, sometimes an explosives operator first sees an approved SOP just prior to use. In all events, he is required to read it carefully before commencing the operation. At one plant the potential user must read and sign the SOP on initial use. For critical operations at this plant the operators are required to take annual exams on the content of the SOPs which emphasizes awareness of the content. In some installations, the user must sign that he has read the SOP each time he uses it. It is important to realize the key role of review by the user. He must know and follow the content. It must be emphasized (and he must be told) that there is an alternative: if he considers any action unsafe, he has the right (and duty) to decline to do it. He should be asked to explain why he considers the action unsafe, and his views should be given careful consideration.

Superimposed on the SOP generation and internal review procedure, one organization has created a separate safety working group that reviews in detail the operation of the SOP system including verifying that the SOPs are being followed and discovering hazardous events not covered.

B. Modification

Situations will arise which are not covered by a current, approved SOP but could be covered by modifying the SOP. Since issuing a new SOP is a lengthy process, either a waiver of the requirement or a modification in the SOP is sought. This is achieved at different installations by means that vary from low level, local, informal agreement to requiring formal authorization for the change at a high level. Often the nature of the required approval procedure is related to the nature of the change sought. At one installation, approval of an Interim SOP, valid for one time, 10-day-only use, can be obtained with the signature of the test director, one other senior scientist, and the safety office. To meet future needs, the basic SOP can be rewritten or supplemented using the standard approval procedure (app C, S2).

Another installation has an analagous approach to meeting a need for a deviation when the need is pressing. If all present agree on the procedure to be followed, the safety office can be called and the cognizant individual in that office consulted to give permission for the deviation. The deviation must be documented by a follow-up memo. The deviation can be followed only once after which, if it is to be repeated, an addendum to the SOP must be written and approved by the standard approval procedure.

In another installation, the need for deviations from established SOPs occurs so frequently that there is a procedure called the Prior Approval Procedure, to supplement or substitute for the established SOPs. It is intended to serve as an SOP in a laboratory research environment where comprehensive SOPs are impractical. It achieves close administrative control of small scale experiments while permitting flexibility, innovation, and efficiency. It also covers deviations such as changes in the type of explosive, the weight of explosive, and in small, nonrepetitive operations. The vehicle is a Prior Approval Form (copy in safety data file) filled out by the user, who then must locate three individuals with relevant experience from a list of about a dozen with different backgrounds to sign-off after discussion and, sometimes, going through a dry run. It is then good for only 60 days. The Safety Office does not have to give individual case approval again since that office has already participated by setting the scope of the Prior Approval Procedure. It generally takes about an hour to get the approvals required. The use of the prior approval route is not abused. It is treated as a means for decision at the technical level. The deviation details are recorded in a logbook with the approval signatures also entered to represent assumed responsibility.

In the same installation there is also a different form used to supplement the general SOPs for large scale firings at a remote firing site. It is a type of prior approval in that it provides information to the site personnel beyond that in the SOP. The approval signatures required vary according to the quantity of explosive and the nature of the proposed test. A copy of the form is included in the safety data file.

For some operations, a department manual on safety may use the words "shall" and "should" to distinguish mandatory and advisory regulations. Where "shall" is used, a waiver can only be issued by a committee in the Washington office; where "should" is used, the local people can generate a waiver.

In another installation, within a research department, there is provision for professionals working on a small scale to proceed without an SOP under conditions established in the department manual on assignments and in a manner reviewed by the branch head.

An entirely different approach is used in preparing SOPs at still another installation, where SOPs are generated for particular operations, but not for a particular explosive formulation, (e.g., a general SOP for a particular press). The SOP is written for the worst possible formulation, so that the worst case is protected. It is recognized that some limitation must be imposed on the scope of the formulations to be included; e.g., an SOP for TNT loading could be used for COMP B, if written for the latter insofar as safety is concerned. This approach is valuable if the experimental program involves slight changes in formulation, each of which depends on the results of the previous experiment. Hence, the next formulation evolves after the previous one is completed. If an SOP must be written and approved for each change, excessive delay occurs. This approach is used only for research and development and considered appropriate there when used with adequate safeguards. There are differences of opinion on this approach.

Unfortunately, if a system is made too restrictive, particularly if an item among the prescribed actions appears unjustified or is not understood, human nature is such that there is a tendency to circumvent the restrictions. The importance of SOPs to safe operation is so great that a system for readily obtaining approval for deviations is essential. Equally essential is an approval procedure for new or modified SOPs that is not unnecessarily time-consuming.

The value of having an SOP together with a Prior Approval Procedure (or equivalent) as compared to a general SOP is that it accommodates the fact that there is no complete set of rules that always hold. Situations will arise that either require a different response or in which the risk is sufficiently reduced to justify a less restrictive approach. In the absence of a procedure to readily adapt the SOP, the individual judgment may be substituted for a protective procedure for deviating from an SOP. For example, there are some situations, depending on the explosive and other features, in which hand drilling a hole in an explosive can be done in a particular way. However, this can be authorized only on an individual basis, since a change in any one feature of the situation could change the hazard immensely. Another example is using a knife blade to cut explosive. There are forces at the cutting edge of the blade that can generate high, local, tip temperatures (as high as 500°C) and create high mechanical stresses. The hazard, again, depends on the feature of the situation, e.g., the hardness versus the softness of the explosive. A general SOP can rule against cutting explosives except for some specific, carefully delineated exceptions. When a new situation arises, there must be a means in place to deal with it. The comparatively long approval procedure for a new or revised SOP can be complemented by faster means such as a Prior Approval Procedure to deal initially with new situations, and so prevent unauthorized risk. On the other hand, the deviations authorized by a corollary method, such as the Prior Approval Procedure, can be reviewed for inclusion in the general SOP to update it.

C. Content

The mass of valuable safety information (over 3000 pages) found in only the sample SOPs placed in the safety file at BRL cannot be reproduced here. When a new problem requires an SOP to be prepared or modified, the problem may very well be that the scientist/engineer/technician never reads it, so that he prepares the SOP unaware of the experience of others. A future goal may be to prepare an overall index to the safety file (not only the SOP section) that will enable the reader to quickly find safety information on a specific subject. For the present, data retrieval is best done guided by a combination of titles and tables of contents of reference material and talking with experienced and knowledgeable personnel.

A set of SOPs should be selected to acquaint the individuals working with explosives with the contents of typical existing SOPs and to encourage their use (app C, S3). The following is a set selected from the safety file (number in parentheses is the safety file index number):

1. LANL M-3 re Charge Preparation, SOP 16.15 and app 4.5, details on adhesives and their use (1340)

2. ARDC FREL Safety Manual, details on chemical hazards (3570)

3. BRL Field Firing Instructions, aimed at personnel engaged in the conduct of firing programs (180)

4. LANL WX-3 High Explosive Development, traces the testing at each state of the development and evaluation of new explosives and new explosive mixtures (1470)

5. LLNL B222 Complex Explosive Operations, provides guidance for a center doing a large variety of operations; includes the Prior Approval Procedure and has an excellent index (680)

6. DOE Explosives Safety Manual (DOE/EV/06194-2 Revision 1), an example of a general agency standard. (The Army, Navy, or Air Force documents DARCOM R-385-100, OP5, or AF 127-100 may be used as examples instead.) (580)

Subject areas singled out for inclusion in SOPs, by the experienced personnel interviewed, are described below.

Five individuals at different installations stressed provision for misfires. The SOP must include procedures for responding to emergencies, definition of local responsibility, notifications to be made, and steps to be taken. The key point is that what to do must be clearly defined; who is in charge must be established, and the limitation on his authority stated.

Deviations from an SOP are never to be improvised. There is often an unrecognized trap. Consultation and review on the proposed deviation, however simple it may seem to be, is always appropriate.

Remote operation, but with the use of video observation and recording, eases the hazard level and is sometime essential when electrical equipment is being used with explosives, for example. Other cases exist in processing, firing, etc.

Hot-wire devices and other LEDs should be covered by a special SOP for each application to stress the hazard level which far exceeds that of EBWs. In one installation, only two individuals in the entire organization are "qualified" to use such devices. The key point here is that LEDs should be avoided. When they have to be used, users must be aware of the hazard. The preferred use of EBWs was stressed repeatedly.

When components sensitive to electric noise are being handled, there should be a list of prohibitions for the jeopardy period (e.g., no CB radios, no trucks, vehicles arrive/depart/start/repair, etc.). AFR 127-100 Chapter 6 on electrical hazards details limitations on radio transmitters near areas in which detonators are being used.

A weakness sometimes found in SOPs is that, when prepared by a very capable high-level individual, it can only be followed by his peers. The language of the SOP should be geared to the level of the user. Thus, the successor to the original user should have no problems in using it. This criticism is particularly pertinent to research level SOPs.

An SOP can introduce a hazard in two ways: by requiring a faulty hazardous step, i.e. falling into a trap, and by being so unclear that a hazardous action is performed. It should be recognized that SOPs may contain provisions that are important to the success of the operation that are not safety related. In one SOP, there are restrictions on materials that have vapor access to detonators. Glues, sealants, greases are not allowed to make contact. It is known that vapors of Eastman 910 in particular will poison low density PETN. Here, there is a performance requirement assured by following the SOP. The point made is that such requirements should not be allowed to obscure the hazard avoidance steps o an SOP. SOPs should be as short as possible with emphasis placed on detailing those steps that involve danger. Perhaps a "safety SOP" should be a separate document or the hazardous features should be accented in some way.

The following additional DONT'S are cautions reiterated by several senior individuals:

- DON'T take a system into the field with which you are unfamiliar.

- DON'T expect another person to do what they have been told to do. Check and ask to be sure.

- DON'T be impatient. Do not hurry if it is not going smoothly.

- DON'T fire the shot before repeating visual checks of the firing area after it has been cleared. Unauthorized entry can occur at any moment.

17. TRAINING (T)

Training personnel in the various aspects of safe interaction with explosives and munitions containing explosives is an ongoing activity at every installation. Each installation sees a need for improving its training program and many have recently added or revised courses or are in the process of doing so. There is an overriding desire to prevent injury and property loss. It is also recognized that administrative reaction to an accident leads to major expenditures in time and funds, and restrictions on activities to prevent a repetition of the accident. Training costs are thus seen as a most worthwhile investment. The problem is to provide training that is effective. An extensive collection of training material provided by participating installations has been made part of the safety file (app A).

A. Role of the Training Course

The function of training is to provide personnel with the information and attitudes they require to prevent accidents. A "course" whether by videotape, film, or live presentation is only a part of a training program which may also include safety tours and demonstrations as well as a period of apprenticeship with senior personnel. Every installation uses a training program as a requirement for qualifying an individual for certain activities. (Details of qualification procedures are presented later.)

The safety training program is only a part of the overall safety program, which also includes SOPs incorporating the collective knowledge of the organization and uses personnel who have responsibilities for safety, both in the safety office and in the line organization. By its attitude and support, the administration of the installation establishes the level, content, and effectiveness of the safety program. The rapport between safety office and technical personnel in the line organization is an essential part of the program. The ready availability of safety information and protective devices is emphasized in the safety program.

B. Effective Training

The language and ideas used in training must be understandable to the user. The level should be that of the nonprofessional new employee unfamiliar with the subject. The density of information provided must be limited in an initial presentation; if too much is included, it will turn off the reader. Capsule information on accidents with emphasis on lessons to be learned should be used to make points and provide emphasis. More detail can be provided by readily available reference material, such as the safety file, or in later, more specialized presentations to a more limited audience.

The organization of a training course should be modular. It should be possible to select specialized areas for use in a single training session according to the individuals participating. Some areas (e.g., RAW MATERIALS) may be applicable to all individuals, whereas others (e.g., FIRING or CASTING) may be appropriate to different individuals. Within each area of a training course by videotape, consideration should be given to dividing the presentation into two parts, a general, simplified-language introduction and a more specialized follow up. This enlargement of the modular approach would broaden the selections available to match the needs for the participants.

The modular concept of training by videotape is recognized as potentially the most efficient approach. However, the execution requires great effort to avoid poor communication. A videotape showing an average speaker using a blackboard or following a text or presenting dense tabular data or many equations loses the audience. The videotape must compete with good live presentations by using demonstrations, circuit diagrams, tables, charts, and recorded interaction between the audience and the speaker. The videotape should be complemented with tours as part of the overall training program.

There is a limit to the quantity of material that can be transferred effectively by a single training course. The modular approach functions within that limit by tailoring the course to match different needs. At a more advanced level, background and needs differ and only a few people can be trained at the same time, requiring recourse to individual study of reference material (such as the safety file).

C. Language

Language used must be consistent within each area and between areas, particularly in describing the nature of the response of an explosive to a stimulus. It has been suggested that "threshold of detectable reaction" be used instead of sensitivity and that "explosiveness" be used to indicate the extent to which a following reaction occurs when the threshold is exceeded. The words "sensitivity tests" in this approach are limited to results of a measurement providing a result characterizing the reaction for a particular applied stimulus in a particular way. With respect to language for the action of the stimulus producing explosive reaction, it has been suggested that the term "local site" be avoided and mechanical stress concentration, microdefect, or hot spot be used as applicable. Finally, the words "accident" and "incident" need consistent use. A distinction would be that a safety incident becomes an accident when it involves bodily injury, consequent illness, or property damage.

D. Contents of a Training Course

There are essentially two schools of thought on the content of a training course. One philosophy is to provide comprehensive training including fundamentals of explosive behavior to all, including technicians and explosive operators. It is considered necessary to assure a better, safer job. On occasion, by virtue of this training and direct involvement, the technician is expected to "see what has not even occurred to the engineer." The other philosophy is that comprehensive training tends to confuse the individual and obscure the specific safety knowledge he needs to do his job. Training in this second philosophy considers fundamentals as a separate course (or group of modules) and concentrates on safety aspects of procedures in specific activities involving explosives. To satisfy the varying needs of personnel at different installations, various combinations of these two philosophies are used. In this report, exploration of the fundamentals of explosive behavior is considered as either a separate course or as additional modules to be incorporated later for use for selected personnel. That fundamental knowledge necessary to clearly present safety aspects has been included.

The sections in this report (e.g., RAW MATERIALS, DETONATORS) represent areas that clearly need to be addressed from the perspective of safety. Subjects and demonstrations specifically recommended by those interviewed for inclusion in a training program are described below.

1. Guidance on how to use or interpret the results of sensitivity tests is needed. One viewpoint is that sensitivity tests are intended to flag dangerous situations. One should not try to use these tests for more quantitative judgments beyond that flag (e.g., drop hammer results in the range of 35 to 100 cm height are the same for all practical purposes).

2. A need exits to make personnel aware of the damage inflicted on the hand by a detonator. Firing one imbedded in a frankfurter shows the effect on fingers, as does a photo of a mannequin's hand missing fingers after a hand-held detonator functions.

3. The static hazard can be demonstrated by donning and removing a plastic raincoat, then touching the leads of an electric match.

4. Demonstrations should be included on how much heat is required to initiate an explosive; e.g., end of cigarette, drill bit turned by hand or by motor, etc.

5. In a firing officer course, the lecturer drops a 1/8-in.-diameter steel ball-bearing a height of 0.72 in. to demonstrate the amount of energy that is 1000 ergs. This energy level approximates the no-fire level of the sensitive hot wire initiators, MK 70 and MK 71.

6. Inerts and explosives should be shown side-by-side to illustrate that explosives can look inert. A machinist unwittingly used a block of blue material (actually 9404) thinking it was plastic to make a handle for his fishing rod. (The error was fortunately brought to his attention by a colleague before an accident occurred.)

7. To introduce new hires to the field of explosives, a set of analogies between common experience and principles involved in explosive behavior can be drawn, e.g., twirling a sharp pointed stick in a small hollow in another piece of wood generates heat as does drilling small holes in explosives.

8. The life cycle of "new" explosives from small scale up to pilot plant should be included.

9. The hazard classification of explosives and the use thereof regarding handling, segregation for storage, and transportation should be included.

10. Understanding must be provided so that the right questions can be asked (e.g., for fuzes: what is in it, what are its properties, and what is the related significance?).

11. It is necessary to introduce the differences between primary and secondary explosives in terms of stimuli to initiate and stress that there is an overlap range of stimuli where explosives can be initiated whether primaries or secondaries.

12. It should be noted that there are widely used chemicals that are really explosives (e.g., AN, picric acid) with safety depending on how they are treated.

13. The operator should be thoroughly indoctrinated in circuitry in terms of inherent dangers--function of switches, meaning of lights, connectors, possible voltage sources, etc. He should not be expected to do anything unless convinced it is safe.

14. The need to clarify the limits of safe and unsafe domains in applying a particular stimulus to a particular explosive is emphasized. Temperature, pressure, and rates of load application have different safe and unsafe domains for each case.

15. Individuals handling explosives and explosive containing devices must be warned not to become so intent on one hazard-avoidance action as to neglect another one.

16. Talks on the nature of the explosives, compatibility, shear, combination of sensitivity tests, thermal behavior, chemical reactions, assembly, hazard build-up, and the parameters of hazard are included.

17. The specific items suggested by an explosives operator and an engineering technician were: packaging, forms, procedures for shipping explosives by different means of transportation; instructions on permissible field modification

of dimensions of explosives to achieve a fit (e.g., by lapping) and means for safely doing so; electronic hazards; handling procedures and safety with argon gas and compressed air; instruction on band-saws and other equipment used for setup preparation not involving the explosive itself; proper storage of explosives; personnel protection in the use of flash x-rays; chemicals and photodevelopment.

18. Work on fuzes should include:

a. Characteristics of explosive materials (make-up, use, sensitivity)

b. Demonstration of output (primers, detonators, leads, boosters)

c. Sensitivity (detonators, stab, percussion and electrical initiation, boosters, delay elements, and propellants)

d. Safety principles for operations involving explosives work areas (limits, benches, shields, floors, shoes, clothing and glasses, tools, electrical instruments)

e. SOPs

f. Compatibility (explosives, metals, and others)

g. Explosives in fuzes.

19. With respect to outside courses such as those by duPont or Franklin Institute, it was found that a follow-on session was needed to make the material specific for needs at each installation. Such courses are valuable because the instruction is safety intensive for 5 days (a few hours each day) and cross-discussion occurs.

20. An excellent production facility in which to observe melt-cast and pressing operations is the Iowa Army Ammunition Plant (IAAP). This plant has a special line for the production of shaped charges using vacuum melting with atmospheric casting and modern pressing technology.

E. Requirements for Qualification/Certification

An individual must be qualified to work with explosives. The degree of formality associated with being declared "qualified" varies from supervisor approval to a prescribed training course followed by an examination and the granting of a certificate. The training requirements for qualification are, in all cases, related to the duties to be performed. The training requirements are, therefore, different for a synthesis chemist than for an explosives operator; although there are areas of instruction in common for all new employees.

There is often a core program to introduce new employees, whatever their duties, to the field of explosives. In one installation, there is a safety office orientation geared to technicians (2 hours) followed by electroexplosive devices (2-hour lecture and 1 hour hands-on laboratory instruction). Live demonstrations or videotapes are also included. At another installation, the new employee must go through a series of safety videotapes, then view the technology tapes (such as those for firing officer training) which begin with general material on explosives.

For those personnel firing shots for research studies only, an apprentice system is often used for a period set by the supervisor who recommends to the certification board that the employee be certified when he is considered ready for a particular type of operation. In addition, at least annually, each individual must have an additional safety training course and his certification must be reviewed. During the apprentice period he may be trained by an assigned teacher who decides when he is to be permitted to sign off on a particular SOP and to use it without the teacher being present. The teacher then recommends the associated formal certification to the supervisor where this is required.

For those personnel firing large shots, there is always a formal procedure. One installation requires an apprentice system for only 6 months, followed by certification and annual review. In another installation, the firing is done only by firing officers who are given several levels of training. The first level is certified as "general" which requires familiarity with safety policies and operation procedures. A certified "general" is permitted to work along with someone who is certified "skilled." To be certified skilled one has to have first been certified general, then trained in the particular SOPs in which the certification will be earned. In addition, demonstrated experience, capability, and the ability to assume overall responsibility for assigned duties are required. To become a firing officer, the employee must satisfactorily complete an additional special course and be certified on an official form by several higher administrative levels that review the training and record of the individual.

Between the two extremes described in the previous paragraph are the following typical in-between procedures:

1. New technicians are not allowed to handle explosives for at least 4 months during which they are trained by the apprentice system. They receive 6 months additional hands-on training and are then rated by a training qualification form (reviewed annually). Safe execution of duties is achieved by then relying on the technicians to know operating procedures and follow them. Where site leaders are used, it takes a minimum of 3 to 4 years to complete training. In the last 10 minutes before firing the shot he is in full control, like the captain of a ship.

2. The firing-officer course is given when required to qualify selected individuals, but it may be attended by others at the same time for professional growth. It consists of three half-days of lectures and includes demonstrations. The course is supplemented by further training on site in the increased responsibilities of a firing officer.

3. Personnel who handle the explosives and set up and fire the shots are either technicians or engineers. Ordnance people may be available to handle explosives, but their number is limited, so they are called upon only for special

needs. The engineer in charge of the project can handle explosives, but he must have been trained properly just as a technician or explosives operator would have been trained. About 80% of the qualified project engineers participate in their own shots.

Recommendation of personnel in firing activities for certification or recertification is often predicated on additional training courses as well as on-the-job training. Sometimes standard courses such as those given by duPont, Franklin Institute, or the Safety School (Crane, Indiana) are used. Otherwise, in-house courses are used which include pertinent special topics such as underwater tests and blast in large scale field tests.

Few new personnel are introduced to the processing field each year. Those who are accepted are integrated into the workforce by first reading guides such as SOPs, then working with trained and experienced personnel. After some practical experience they are required to reread the guides. Their progress is reviewed periodically to determine the point at which they are qualified, which may take as long as a year. (Some are simply dropped from the program.) This process will soon be formalized, including documentation with signatures and dates.

At another installation, the policy is to certify on a card signed by a supervisor that the individual is adequately trained for a particular job. In addition to reading OP5, he attends weekly safety meetings at which specific topics are discussed. The emphasis is not on fearing explosives, but rather on handling them with respect. It is stressed that just because one has done something hazardous once and suffered no consequences, it does not mean that the procedure can be repeated without incident or threat. Also, it is stressed that one cannot extrapolate from one explosive to another or from one situation to another; one can only interpolate on the basis of the explosive's behavior under certain conditions.

Training may be adjusted to accommodate different types of personnel from blue-collar explosive operators and foremen to lead GS technicians. The former are expected to do specific jobs following oral and written instructions; the latter (GS) do the same but with a deeper understanding of the scientific and engineering basis for the instructions. Blue-collar foremen who exhibit extra capability are encouraged to join the GS ranks where there is more growth potential. There is a salary problem in that blue-collar workers receive hazard pay, while GS workers encountering the same hazards do not. The training for both categories is initially the same, but additional, more fundamental training is given to the GS technicians.

If explosives have to be transported, a special vehicle is used (with strapped-down containers) and the driver must have a special driver's license earned after training.

Specialized activities devise their own training. For example, the mines and torpedoes group is concerned with weaponry, but incorporates a safety group that works with weapons designers. The mines and torpedoes group try to design units that indicate whether or not the S&A device is in a safe position. They work on designs to detect and eliminate conditions that might endanger those handling explosives or explosive-containing devices, using standards such as MIL

STD 1316. The safety group participates in training employees in explosives handling through courses similar to that offered by duPont but modified to emphasize electro-explosive devices and to de-emphasize processing. Written material is handed out for study, and a written test is given. Candidates who do well are recommended for approval by the certification board. Certification must be renewed once-a-year.

The training for chemists generally includes a core course in explosives, but then relies on on-the-job training under experienced personnel. As for other professionals, the individual scientist and engineer is expected to use reference materials to train himself to assure the safe execution of his duties.

F. Core Syllabus for a Training Course

This discussion on training has so far focused on an overall safety program and has reported the items stressed for inclusion by employees in the field. Any training course would make use of the material in the previous sections (RAW MATERIALS, PROCESSING, etc.) and would supplement the content of those sections with that in the safety file and other sources (current holdings in the safety file are listed in app A). Those holdings in the training section of the safety file that have many features in common were used to establish the core syllabus listed below.

One procedure for generating a training course would be to create a course outline based on the core syllabus which follows by expanding it to meet the particular needs of the installation and implementing the outline using the content of this report and that of the safety file.

The core syllabus presented be' v is organized according to the sections used in this report and in the safety file (the numbers following headings refer to related index numbers of items in the TRAINING section of the safety file at BRL.

G. Core Syllabus*

RAW MATERIALS (K) - 560, 900, 1520, 2980

- Explosives by Definition--High energy, rapid reaction, extensive gas production, examples

- Chemical Explosives--Air and gases, air and dusts, solid materials

*The topics referenced in the safety file should be complemented by the same topics in the body of the report.

- Explosives by Function--Initiating, transfer, booster, main charge primary, secondary

- Military Explosives

- Commercial Explosives

- Toxicity

PROCESSING (O), CASTING (C), PRESSING (P), MACHINING (M) - 720, 1520

- Remote--Pressing, drilling, high shear mixing, milling, extrusion, ball milling, grinding, machining (unless approved for contact).

- Contact--Slurry mixing, casting TNT base, lapping wet, wet machining on approved explosives, sieving small quantity, microtone or sharp blade cutting of soft material

- Storage of Energetic Materials

- Disposal of Energetic Waste Materials

CLOTHING/EQUIPMENT (J) - 3000

- Electrostatic Hazard

- Protective Clothing

- Ear Protection

- Shields

- Barriers

- Barricades

- Hand Tools

- Respirators

- Ventilation

- Exhaust

- Hoods

- Safety Showers

DETONATORS (D) - 1520, 1680, 2200A

- Construction
- Operation
- Characteristics
- Theory
- Examples--hot-wire, exploding bridgewire, slapper, low energy
- Modes of Initiation--Stab, flash, electric, thresholds, output of initiators

FIRING (F) - 2200B

- Firing Lines
- Transfer Point
- Checking Bridgewire Resistance
- Periodic Inspection
- Grounding
- Stray Voltages
- Cable Damage
- Connections
- Misfires
- Electrostatics
- Clothing

SENSITIVITY (I) - 1520, 2460

- Tests--Drop-weight impact, time-to-explosion, friction, spigot, SUSAN, small scale gap, skid, bullet impact
- Stability--Self-heating, critical temperature, long term decomposition, incompatibility, change in sensitivity with age, stabilizers depletion over time

- Rate Dependence--Spatial and temporal

ACCIDENTS (A) - 900, 1520, 2460, 3000

- Energy Stimuli--Sparks, compression, shear, friction, impact, shock, chemical

- Examples

- Precautions

SOPs (S)--See appendix A for extensive holdings

ACKNOWLEDGEMENTS

The initiator and sponsor of this project was Dr. P. Howe of the Ballistic Research Laboratory, TBD. The personnel interviewed at the installations visited (app A) have been generous with their time and attempted in every way to make this project worthwhile. The author has faithfully reflected the information provided and has not written it as his own views of the subject matter. Dr. Howe anticipates that a training course in the form of a videotape will be prepared using this report, and arrangements will be made to make it available to participants and others working in the field of explosives.

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APPENDIX A

SAFETY FILE

RAW MATERIALS (H)

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APPENDIX B

INSTALLATIONS VISITED AND PERSONNEL INTERVIEWED

Ballistic Research Laboratory, APG, MD 21005

P. Howe	W. Hilstrom
R. Frey	L. Van Dekieft
J. Watson	J. Waddell
V. Boyle	O. Lyman
J. Trimble	F. L. Weaver

Armament Research and Development Center, Dover, NJ 07801

R. F. Walker	A. Sutton
H. Matsuguma	G. Ziegler
E. Gilbert	R. Collett
W. E. Voreck	H. Pebly
L. Avrami	R. Moss
E. Dalrymple	

Naval Surface Weapons Center, Silver Spring, MD 20910

J. Proctor	J. Short
T. Austin	R. Bernecker
J. Forbes	J. Leahy
A. Brown	R. Schmiech
R. Baker	J. Diehlmann
L. J. DeSabla	J. Walsh (Dahlgren)

Naval Weapons Station, Yorktown, VA 23691

L. R. Rothstein	E. Y. McGann
J. A. Zehmer	H. D. Matney
R. Petersen	R. W. Coakley
J. H. Smith	L. J. Merrill

Naval Weapons Center, China Lake, CA 93555

T. Joyner	R. Smith
D. C. Lind	M. Osborne
C. Greene	A. Wiruth
[illegible] Amster	A. Owens

Terminal Effects Research and Analysis, New Mexico Institute of Mining and Technology, Socorro, NM 87801

L. Kempton
P. McLain
D. Wilson
D. Hunter

Sandia National Laboratory, Albuquerque, NM 87115

D. Anderson
J. Kennedy
P. Cooper
S. Kurowski
B. Van Donnelen
R. Doyle
W. Benedick
P. Wilcox
A. Fine

Los Alamos National Laboratory, Los Alamos, NM 87545

J. Ramsay
W. Campbell
I. Akst
M. Urizar
H. Flaugh
A. Popolato (retired)
W. Meyer
R. Rogers
C. Mader
T. Chandler
F. Jackson
G. Fritz

Lawrence Livermore National Laboratory, Livermore, CA 94550

M. Finger
S. Cochran
H. Hornig
R. McGuire
P. Urtiew
E. Lee
E. James
L. Green
M. Jaroska
R. Guarienti

APPENDIX C

PRESENTATIONS AND DEMONSTRATIONS

INTRODUCTION

The mode of presentation and the use of dynamic demonstrations are critical to the effectiveness of communication. Because training courses are usually written by people with academic backgrounds, they tend to follow the lecture/exhibit format or, reflecting the form of the author's presentations to his peers, rely heavily on viewgraphs. Neither approach is suitable for a training course in safety which should, for maximum effect, recreate live situations, illustrate step-by-step procedures, and simulate accidents as realistically as possible. This is best accomplished through the medium of videotape, complemented by the lecturer and the interspersion of other visual aids, both still and animated, developed during the presentation of the program. Instead of introducing a completed schematic, for example, the lecturer can encourage the student to follow along with him as he develops the circuit, element by element. Items can also be added to a table or curves to a figure, one at a time. Color highlighting can shift from region to region. A moving arrow can direct attention to a pathway. The course designer must isolate the points he wishes to make and use the animation and demonstration techniques which most enhance their presentation.

The suggestions for training demonstrations given below are under the same headings (e.g., RAW MATERIALS, PROCESSING, CASTING, etc.) as the main body of the report, and are each identified by an alpha-numeric symbol (H1, C3, etc.). These symbols are cited in the report in the corresponding section at the close of the paragraph to which they most closely relate. A modular (mix and match) training program combining the applicable demonstrations with the lecturer's comments and auxiliary visual aids can be tailored to fit any given safety area. The videotape format also permits the inclusion of additional demonstrations as funding permits.

RAW MATERIALS (H)

H1 - Lay out on a table several secondary explosives, some inert materials resembling explosives (e.g., TNT and Octogon soap, which looks like TNT), and some simulants. Identify the explosives individually by name. Use a brief chart of some property, e.g., drop-impact or thermal sensitivity, to show how different the response of similar-appearing explosives can be. Compare explosives to inerts and simulants.

H2 - Use a chart to show how explosives with the same name can have different properties with different additives, impurities, and particle shapes and sizes. Use macrophotos followed by scanning electron microscope photos to illustrate the internal appearance of explosives. These macrophotos can also be used to discuss forces and thermal flux to crystals as modified by binder properties.

H3 - Prepare a list of unobservables to reinforce the point that there is no way to judge an explosive by appearance and that sensitivity and explosiveness data for the stimuli to be encountered must be determined in advance. Mention "traps" and select an example or two from the ACCIDENTS section to illustrate the need for applicable-to-the-situation results.

H4 - Complement the negative attitude of examples H1, 2, and 3 by showing the availability of data on explosives. Use a chart of properties; show the source. Scan reference material laid out on a table. Show the safety file. Explain how to get information on the response of explosives to stimuli by testing and indicate that the course will amplify this subject later.

H5 - Use paper chromatography to show the rapid penetration of DMSO. Use the progressive color change of a cross-section of a mannequin hand made of appropriate materials to simulate DMSO's penetrating from the surface inward.

H6 - Show the smoke immediately following a shot at both indoor and outdoor sites. A chart of concentrations in the smoke of unconsumed explosives, intermediate and final products should be referred to. Concentrations versus time-to-clear or exhaust fan action can be referred to as the basis for the waiting time before entering the site.

H7 - Incorporate a capsule version of key tests used for initial data to distinguish explosives with respect to response to stimuli. Refer to the more extensive treatment in the SENSITIVITY/EXPLOSIVENESS section.

PROCESSING (O)

O1 - Show an oven with temperature controller and backup, temperature controlled shut-off switch or valve. Explain the importance of a slight change in temperature. Recount oven accident(s). Go over routine checks and procedure for putting an oven into service. Indicate external temperature monitoring device and its use, if present.

O2 - Indicate the clearance between the blade and the wall in a kettle. Go through the procedure of checking the clearance demonstrating the use of a gage. Relate to viscosity of material by showing these checks for both a kettle for TNT base explosives and a Baker-Perkins blender. Position an oversized wedge of inert crushable material in the blender so that the blade will jam it as it turns. Discuss the effect on clearance on the opposite side in terms of the support bearing "play." Turn the blender on and show the pieces of simulant created by the jam. Consider using a small piece of pyrophoric (not explosive) material so that starting the blade motion will create flash and smoke. Connect clearances to the granulation of the material to be worked on and drag.

O3 - Explain the concept of safe domain of operation by using two properties (e.g., the rate of rotation and the viscosity of mix) to show an area of the x-y plane that can be used for a particular explosive blend. Stress the interrelation. Now add a third property (e.g., granulation) and indicate that the safe domain is now in three dimensions, illustrate this by a sketch of a safe domain within a set of x-y-z coordinate axes. Again stress that a single point within the domain involves a choice of all three processing parameters and must be within the domain to be safe. Explain that the extension goes on to all other relevant parameters so that the safe domain can have more than three coordinates.

04 - Select a foreign material that will react violently if accidently dropped into a particular mix. Using very small quantities handled remotely behind a transparent protective screen, create a miniaturized version of an accident. Orally extrapolate to the much larger quantities used in practice. Relate the specifics of some accidents of this type or error and the disastrous consequences.

05 - Use step-by-step addition of data to a table to show the varied properties of explosives. Do not "create" the entire table. Instead refer to the full table in the safety file and scan the file. Dwell on the compatibility documents and indicate that they will be discussed later in relation to data retrieval by computer.

06 - Demonstrate pot-life versus percent catalyst by using an excess adequate to cause early hardening in an inert transparent simulant (e.g., use 5-minute epoxy) in a beaker. Rotate a wire mesh in the hardening mix to illustrate the loads due to unanticipated early viscosity in a Baker-Perkins. Pose the question of clean-up. Mention accidents due to excessive catalyst. Note that the real solution is the use of the correct catalyst and timing of operations.

07 - Take a pour specimen and measure viscosity in seconds for TNT and COMP B. Show the effect of solids percent of RDX in the latter or for a range of Octols. Relate the viscosity to settling of solids. Use cross-sections of specimens prepared in advance to indicate how RDX or aluminum concentration is altered if the casting temperature is too hot. Explain how sensitivity can depend on RDX concentration. Tell of a possible cause of the fork-truck accident along these lines.

08 - Demonstrate electrostatic charge generation by powder flowing through an orifice of an electrically isolated small metal funnel. Use an electrometer to show the rising potential to ground. Introduce other means of generating static such as sliding across a carseat in winter or walking across a rug. Refer to the demonstration of the hazards of static initiation of explosives and the description of tests to measure response of explosives to static coming up later in the course. Provide information on static related accidents.

CASTING (C)

C1 - Using an inert material in a kettle, set temperature gages in the material and on the wall. Show the effect on temperature of variations in the heating control parameters. Note time lags and the effect of agitator stall. Relate the observed temperature rise (beyond that intended) to the possibility of runaway reaction using hypothetical results for thermal tests of the material.

C2 - Show the discharge valve on a kettle, then show a sketch of different types of valves and the mechanisms involved. Relate to the danger of pinching explosives creating shear between hard surfaces. Extrapolate to the plant accident involving metal plugs inserted into metal discharge nozzles.

C3 - Demonstrate good practice for clean-up. Discuss the dangers of dry steam, acetone, etc. Show on a very small scale how acetone will flash at a low temperature.

C4 - Show a riser. Explain why it is part of casting. Explain the potential hazard of improper design requiring application of great force to break off the riser. Show removal of a riser. Use sketches to illustrate the features of good riser design.

C5 - Use an inert transparent liquid matrix whose viscosity depends strongly on temperature, adding solids to show how settling occurs as a function of temperature. If possible, show the effect of size, shape, and quantity of solid particles.

C6 - Demonstrate panning and break-up of cast explosive. Consider the use of peanuts in honey as the inert medium. A touch of humor can be injected by eating the product and a lead provided into toxicity and allergic reaction to explosives.

PRESSING (P)

P1 - Make up a transparent analog of a piston in a cylinder for pressing. Using a contrasting fine material (e.g., carbon, or aluminum dust) show how powder can be forced between the piston and the cylinder. Show the actions that occur when an additional increment is added and pressure reapplied. Make a series of aluminum powder pellets in a press, cross-section these in advance and take microphotos to show the density variations. This will assist in explaining the wall action in supporting the ram (piston) during reconsolidation.

P2 - Show pinch points in pressing by using the transparent piston and cylinder together with shaped inserts to simulate forming desired shapes. Use a filling material that is transparent and will reveal stress patterns when viewed through crossed polarizers. Relate to mold design and avoiding press-blows. Describe pinch points due to damaged molds. Use this as an entry to the need for regular inspection of molds prior to use and periodic replacement.

P3 - Show a drawing of a crystal in a binder. Explain how an externally applied force is transmitted to crystal surfaces and the net force across the crystal. Place the crystal next to a rigid wall and compare the net force with the previous. Introduce a second crystal and examine the forces between the two crystals depending on orientation and contact areas. Show a sketch of many crystals in a binder and trace a supporting path through crystals to a rigid wall. Relate forces on individual crystals to the concentration of filler and the properties of the binder as isolating, coating, or lubricating. Discuss the wax in COMP B and various KEL-F binders. Mention the accident in which a rigid binder was a contributing cause.

P4 - Give statistics on "blows" when pressing primary explosives into detonators. Note that secondary explosives may also initiate during the "dwell" period. Relate the dwell to temperature-vs-time properties of explosives and note presence of strong confinement. Indicate that the explosive pellet must be ejected remotely from the die and allowed to relax physically and thermally before entry.

COMPATIBILITY (B)

B1 - Show how data on compatibility is obtained using a computer terminal linked to the PLASTEC data bank.

B2 - Demonstrate an incompatibility that gives a prompt indication, e.g., expoxy with TNT turns red. Show samples that deteriorated due to long term incompatibility, e.g., migration of plasticizer, final cure in munition.

B3 - Explain the need to respond promptly to indicators of danger. Use this as an opportunity to demonstrate standing operating procedures. Describe accidents in which rapid action has saved a life.

CLOTHING/DEVICES (J)

J1 - Display on a table the various protective devices available. Demonstrate correct use. Show a chart indicating when use is required.

J2 - Demonstrate the protection afforded by a protective device. A detonator can be allowed to go off held by a mannequin and compared to result when a handling device is used, or even to being held by the wire ends by the mannequin hand.

J3 - Show the static discharge from a finger tip with and without a grounded wrist strap when static is generated by rubbing hand across a plastic surface. Use an electrometer to show levels developed by a variety of charging possibilities. Show the effect of wearing conductive sole shoes. Rub nylon socks together. Rub nylon shorts and undershirts together.

J4 - Show action of acid on wood. Refer to holes from battery acid. Place a layer of heavy cloth, simulating clothing, over another material simulating flesh. Then allow a drop of hot COMP B to fall on the cloth. The COMP B will penetrate the cloth and char the surface below. Do the same with the cloth covered by the material of protective apparel to indicate how the hazard of a burn from splatter of explosive during casting can be avoided.

J5 - Show a protective enclosure in which the door must be electrically closed using both hands simultaneously to operate two separate switches in series before the operation within the enclosure can be activated. This is used for pressing of experimental detonators and for some tests on detonators.

J6 - Demonstrate the protection afforded by a LEXAN shield. Use a megohmmeter to compare the surface leakage of charge provided by a solution-applied graphite film to an evaporated metal film. Show the time required for charge dissipation using a standard charge from a capacitor and an electrometer. Compare this time with the time involved in a single operation.

J7 - Demonstrate the protection provided by a carrier box for detonators by remotely setting one off inside. Show the interiors of a non-propagation box and demonstrate its effectiveness.

CHEM LAB/SYNTHESIS (K)

K1 - Provide a flow diagram showing the steps in the safe synthesis of a new explosive or for a new route to obtain an existing explosive, e.g.:

1. Listing all steps, materials, and equipment required for the safest path.

2. Fault tree analysis of possible hazards in proposed safest path.

3. Information obtained by corollary tests to check possible hazardous steps.

4. Decisions made on magnitude of a very small quantity to be prepared initially and safety precautions required.

5. Proposed work discussed with at least one other senior scientist in same field and with supervisor. Decision made on whether to proceed and need for SOP or other authorization.

6. Preparation of initial very small quantity.

7. Miniscale tests.

8. Decision on whether to proceed to make additional material using the same process already used.

9. Accumulation of adequate material for sensitivity tests; testing in order of significance as material becomes available.

K2 - Show a set of miniscale tests being performed; e.g., match test, capillary test.

MACHINING (M)

M1 - Prepare a videotape segment showing how explosives are machined in an explosive machine shop. Use the demonstration to note the coolant, the chips, tool selection, etc. Use the occasion to raise and discuss the question of what can be done outside the machine shop, by whom and with what authority.

M2 - Drill holes in clear plastic to show effect of drill bit size, speed of rotation, rate of bit advance, chip removal, force applied. Show how heat accumulation at one spot can melt the plastic. Repeat for a second plastic material chosen to give different results. Relate the demonstration to explosives and make it evident how hazardous drilling a small hole in an explosive is. Discuss machining accidents.

MAGAZINES/DECONTAMINATION/DISPOSAL (Z)

Z1 - An animated schematic should be prepared that shows step-by-step the life cycle of explosives--from receipt or manufacture, through storage, issue, use, cleanup, and decontamination, to disposal. Forms necessary for each stage should be displayed and explained.

Z2 - Show the various magazines used. Explain the types, limits, safety, and security controls. Show the special features of carriers and vehicles used to transport explosives. Explain the absolute prohibition on the use of a personal vehicle for transporting explosives.

Z3 - If possible, show an overloaded magazine. Examine individual items. Note identification, original date of storage. Consider the alternative of retention or disposal for each item and the consequences of each. Show examples of deterioration in storage; e.g., exudation, cardboard containers, loss of labels.

Z4 - Recreate accident scenerios where decontamination was not done; e.g., machinist, welder, carpenter.

Z5 - Recreate by a safe simulation with inert material the accident that involved improper disposal of a shocked large-scale gap specimen. Use this to stress unknown features, remote disassembly, and use of standard disposal facilities.

DETONATORS (D)

D1 - Show cross-section drawings of hot wire detonator, carbon bridge detonator, conductive mix detonator. Identify the ingredients on the drawing, draw attention to the component that detonates. Show a sketch of an explosive train in which the detonator is used. Show a cross-section drawing of an EBW. Again draw attention to the detonating component and the use in an explosive train. Do the same for a slapper detonator. Discuss the physical differences.

D2 - Present the threshold signal waveforms for LEDs, EBWs and slappers one at a time and then compare. Introduce the all-fire characteristics of each type. Show the energy sources necessary to initiate each. Use table 1 in the text for numerical comparison.

D3 - Show the sketch for ER 345 (available in the safety file). Explain features. Use this to introduce DOD problems that have prevented incorporation of EBWs in existing munitions. Relate to out-of-line requirement. Flag the need for caution in handling duds and components.

D4 - Demonstrate that the electrostatic energy that a person can accummulate can set off a low energy threshold device. Do this for several types, and extend the experiment to EBW and slapper types. Exercise care so that the demonstration does not cause an accident.

D5 - Show possible paths through the explosive constituents other than that intended by using the cross-section drawings of D1 above. Draw a sketch to show the problem of a parallel path that could cause initiation. Use figures 1 and 2 in the text to describe how these accidents occurred. Stress the need for analysis in advance to avoid parallel paths and describe component modifications made to isolate the explosive from a parallel path or to provide an external leakage path to protect the explosive.

FIRING/GROUNDS/SHIELDING (F)

F1 - Provide views of physical safety precautions used at each site. Cover "key holder," incomplete firing circuit provisions (include fig. 4 in text), limited access, interlocks, quantity limitations, safe location for personnel, camera location, warning sirens, etc.

F2 - Explain in detail each step of the procedure for setting up and firing a shot; i.e., show how each of the firing facilities at an installation is used. Do this separately for each type of test. In particular, distinguish the differences in procedure when LEDs are used from that when EBWs or slapper type detonators are used. State the responsibility and the limits on duties and on authority for each participant in a shot.

F3 - Present the details of a firing line system that achieves grounding through a leakage line (fig. 5). Calculate the time constant for dissipation of static charge. Note that if the firing line is treated as a transmission line, the induced voltage depends on the terminations. Point out the ground loop caused by one side of the firing circuit's being grounded. Trace the path from leads to detonator case and note the need for the requirement of withstanding 500 volts from either lead to the case without initiation. Show the changes made for firing LEDs.

F4 - Treat the case of single point connection to ground through a current limiting resistor. Compare this case to the previous one.

F5 - Show the various auxiliary equipment; e.g., flash x-ray, thermocouples, strobe or argon flash, and discuss safety aspects.

SENSITIVITY/EXPLOSIVENESS (I)

I1 - Use the curves (fig. 6) for critical temperature vs sphere diameter to stress that critical temperature applies to a specified system. Explain that threshold response to a stimulus is followed by growth of reaction in terms of both intrinsic kinetics and transport. Point out the role of confinement in determining pressure in a rate law. Mention transition from deflagration to detonation.

I2 - By animation, create a chart by introducing one sensitivity test at a time. Supplement the chart with a schematic which shows what the test does. Mention the limitations on stimulus, condition and quantity of explosive, and the number of tests conducted.. Return to the chart for each sensitivity test to add a term describing the stimulus and a few words of comment on limitations. After listing about four tests, point out the need for a battery of tests, the lack of correlation to real situations, and the danger of traps. Follow this with the positive value of using tests to stay within a known framework of threshold responses to stimuli and growth patterns. Conclude with the need to treat new situations cautiously by relating cases of some accidents due to traps such as thallous azide, rust in the bore hole, and examples of situations outside the normal use of sensitivity tests; e.g., aging, different constituents, and foreign matter. This presentation can be expanded, if desired, to include additional tests, more information on each, demonstrations, and a tour.

ACCIDENTS (A)

A1 - Using an inert billet, show how a chain hoist lifting at an angle would drag the billet sideways across the surface. Use this to relate the story of the corresponding accident. Mention a second accident involving glancing action in a drop. Introduce the skid friction tests as a simulation type of sensitivity/explosiveness test. Explain the details of the test including categories of results that go beyond threshold reaction. Note that the safety lesson is that explosives are not to be moved across surfaces, certainly not under load, rapidly on rough surfaces. They are to be lifted off directly and put down gently on surfaces. Observe that where skid is a hazard, surface coatings for floors and tables are chosen not for conductivity properties but for minimum skid friction. The greater hazard dominates.

A2 - Prepare a chart showing the categories of accidents listed in the body of the report under ACCIDENTS. Then for each category, list several selected accidents. Briefly describe each, but omit description in cases where that accident has already been covered under the cognizant section. The point is to indicate the value of becoming aware of accidents as a means of preventing repetition. Stress that accidents can be prevented and indicate how in each case either the accident need not have occurred or injuries could have been minimized.

SOPs (S)

S1 - Prepare a sequence showing how an SOP is generated. Explain the need for an SOP. Show how the problem is discussed initially (at the point of origin) and how the assignment to prepare one is made. Question the guidance available and respond with a chart showing how to block out the content by deciding how to do the job safely. Provide another chart showing the goals of SOPs and discuss it. Have the writer seek information from senior personnel, other SOPs, this report, other reports, and the safety file as he seeks the safest way to do the job, e.g., the videotape clip on using the computer regarding compatibility can be reused. Show a part of the proposed action being tested with an inert material. After the technical decisions are made, show an outline of the general SOP format. Show a typical paragraph being prepared. Indicate how language can be simplified to remove ambiguity. Follow the course of the first draft through the steps leading to the issue of the approved SOP. Continue by showing it being read carefully by the user including discussion of several instructions. Give examples of how SOPs benefit the user.

S2 - Show a problem arising in the course of planning an operation or in the operation itself that requires a modification of the SOP. Show how the proposed modification is arrived at and how approval is obtained. Explain the importance of not modifying an SOP without following the procedure for it. Discuss the time delay in getting the job done versus the value of safety. Present methods used in other installations to modify SOPs to meet immediate needs (e.g. prior approval procedure) to a selected audience and encourage audience interaction and film it. Try to convey the idea that there is a consensus of opinion which supports the proper procedure in modifying SOPs.

S3 - The preparation of videotapes of SOP's that are used often or are used by many people or that involve particular hazards would be valuable, not only in a training course, but as a supplement to the written form of the SOP. The user could follow the videotape step-by-step as he reads the SOP as preparation for later using only the written version at the site of the operation. The safety aspects of individual steps could be stressed in the course of following the SOP.

GLOSSARY

A	activation energy
AN	ammonium nitrate
ARDC	Armament Research and Development Center
AWRE	Atomic Weapons Research Establishment
B	COMPATIBILITY
B-P	Baker-Perkins hi-shear type blender
BRL	Ballistic Research Laboratory
C	Capacitance
C	CASTING
CAB-O-SIL	a flow additive
D	DETONATORS
DDT	deflagration to detonation transition
DMSO	dimethyl sulfoxide
DOD	Department of Defense
DoE	Department of Energy
DPDT	double pole, double throw switch
DSC	differential scanning calorimetry
DTA	differential thermal analysis
EBW	exploding bridgewire detonator
EED	electroexplosive device (detonator)
GO	initiate
GS	general service--a civil service category

HE	high explosive such as PETN, TNT, RDX, HMX TATB, TORPEX, HNS, TNGU, BTF, AN
HNS	a high explosive
I	current
IAAP	Iowa Army Ammunition Plant
IME	Institute of Makers of Explosives
IR	infrared
ITTRE	Illinois Institute of Technology Research and Engineering
J	CLOTHING/EQUIPMENT
K	CHEMICAL LABORATORY, NEW SYNTHESIS
KEL-F	binder used for explosive
L	inductance
LANL	Los Alamos National Laboratory
LED	low energy threshold device (detonator)
LLNL	Lawrence Livermore National Laboratory
M	MACHINING
MDF	mild detonating fuze
NO-GO	not initiate
NMD	Navy Munitions Data
NSWC	Naval Station Weapons Center
NWC	Naval Weapons Center
NWS	Naval Weapons Station
O	PROCESSING
ONR	Office of Naval Research

P	pressing
PBX	plastic bonded explosive
PETN	a high explosive
PVA	polyvinyl alcohol
QA	quality assurance
R	resistance
RF	electromagnetic (radio) frequency
RH	relative humidity
S&A	safing and arming
SOP	standing (safe) operating procedure
SPST	single pole, single throw switch
t	time
T	temperature
TATB	a high explosive
TGA	thermogravimetric analysis
TMD	theoretical maximum density
TNGU	a high explosive
TOW	tube launched, optically tracked, wire-guided missile
UL	Underwriters' Laboratory approved
Z	MAGAZINES/DECONTAMINATION/DISPOSAL

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