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

Joseph Hershkowitz

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US ARMY BALLISTIC RESEARCH LABORATORY
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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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- accidents
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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

*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