SAFETY CONSIDERATIONS FOR CAST AND PRESSED WARHEAD DESIGNS

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ABSTRACT

The authors have performed safety assessments of several cast and pressed warhead designs. Each evaluation consisted of considerable research into the behavior of explosives as they relate to safety. Based upon research and discussions with explosive experts, necessary design criteria was developed to minimize or control the risk of accidental explosion and other hazards associated with the warheads.

This paper presents a discussion of the major hazards that were identified during the system safety analysis and safety assessment of several cast and pressed warhead designs. The discussions are intended to assist warhead designers and safety engineers in the identification and control of hazards during the development of new warhead designs. A bibliography is provided for further information on the hazards discussed.

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SAFETY CONSIDERATIONS FOR CAST AND PRESSED WARHEAD DESIGNS

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INTRODUCTION

Over the past five years, the authors have evaluated several cast and pressed warhead designs. Each evaluation consisted of a considerable amount of research into the behavior of explosives as they relate to safety. Based upon research and discussions with explosive experts, the warhead designs were evaluated to identify necessary design criteria to minimize or control the risk of accidental explosion and other hazards associated with the warheads.

Based upon the research and evaluations, it became evident that the number of new concerns identified during each subsequent analysis steadily decreased. Much of the information generated on previous analyses could easily be adapted to new warhead designs.

This paper discusses the general concerns that were identified and addressed. Discussions of control procedures are presented. Examples have been included for clarification.

SCOPE

This paper addresses many of the explosive safety concerns that should be addressed during the development of a new cast or pressed warhead design. The paper does not address safety and arming devices or other initiation systems beyond interface considerations.

TYPICAL WARHEAD DESIGN

A typical warhead consists of a main explosive charge that is enclosed in a shell. For the purposes of this paper, the main explosive material is either cast or pressed into its final configuration within the shell. The shell provides structural integrity and environmental protection for the explosive material. Depending on the type of warhead, there will be additional features or components necessary to perform its function. For example, a fragmentation warhead will have fragments, and a hard target penetrator or shaped charge warhead will have a shaped charge liner and cavity. Figure 1 illustrates a typical shaped charge warhead.

In addition to the main charge explosive, there is typically a booster and initiating explosive. The initiating explosive is contained within a safety and arming device. The booster explosive is generally a secondary explosive that may or may not be in direct contact with the main charge.

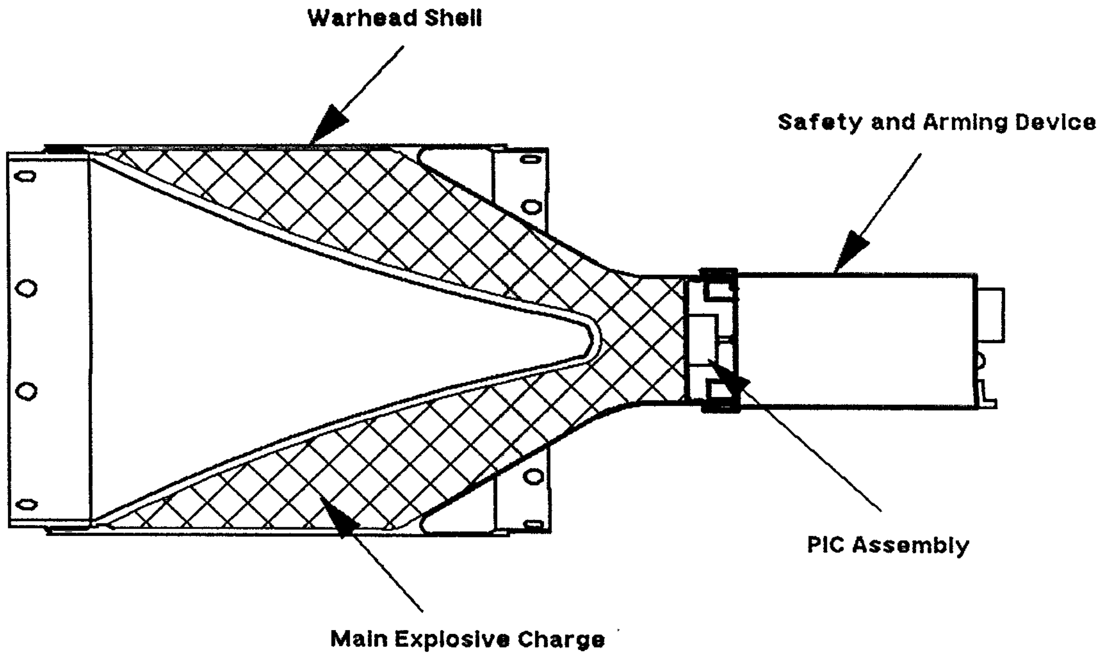

Figure 1. Typical Shaped Charge Warhead

PRELIMINARY HAZARD LIST

Not surprisingly, nearly all of the significant hazards associated with a warhead design either leads to or is a result of the deflagration or detonation of the explosive materials within the warhead. Table 1 provides a list of many of the common hazards associated with a typical warhead. Each of these hazards will be discussed in greater detail within this paper.

Table 1. Preliminary Hazard List

HAZARD	POTENTIAL CAUSE
Deflagration or Detonation	Direct Mechanical impact of explosives Electrostatic Discharge Increased Sensitivity; - Thermal expansion - Explosive enters joints - Inclusions in explosives - Age induced degradation - Incorrect explosive formulation - Bubbles or voids in explosive - Incorrect thermal conditioning - Sharp edges in contact with the explosive Exposure to external heat Lightning induced electrical discharge Explosive dust or fumes Sympathetic Detonation Transportation vibration Friction ignition Fire
Toxic Materials	Seal failure Toxic materials used on exposed parts Explosive by-products
Flying Fragments	Normal during test
Blast overpressure	Normal during test
Heavy objects (Handling)	Weight exceeds allowable limits

HAZARDOUS CONDITIONS

Major identified hazards include explosion, fire, flying fragments, toxicity, and noise. Mechanical hazards such as pinch points, or crush points are considered minor as compared to the other hazards and have not been included in this paper.

In addition to the above listed hazards, there are several causes that could lead to an accidental explosion. These causes include material incompatibility, mechanical shock, spark ignition, electromagnetic radiation, friction, heat and pressure.

Both major hazards and potential causes of explosion are considered major hazardous conditions. Included in the discussion of the hazardous conditions is a brief description of controls that can be considered during the design and manufacture of explosive warheads to minimize the risk of mishaps during later life cycle phases.

MATERIAL INCOMPATIBILITY

> *Material incompatibility hazards can be controlled in design by selecting materials that are known to be compatible with the explosives. It is best to select those materials for which long term compatibility data is available. Material selection should include both materials used in the warhead, and materials used during manufacturing of the warhead.*

Material incompatibility is not generally a hazard by itself, but can often lead to hazardous conditions that could result in a mishap. For example, if incompatible materials increase the sensitivity of an explosive, a mishap could result if an unsuspecting handler moves the explosive in a manner not suitable for the more sensitive explosive. Hazardous conditions that could result from incompatible materials include increased sensitivity of the explosive, self initiation, reduced mechanical strength, and leakage of toxic, corrosive, and sensitive chemicals from the warhead assembly.

Material incompatibility induced changes can be slow to manifest themselves and can occur during long term storage. If the warheads absorb water, or are subjected to biological attack, they may change properties and become hazardous during storage or subsequent operations. Corrosion from the outside of the body could eventually penetrate and expose the explosive to environmental conditions and corrosion products. These effects must be considered during the design and selection of materials for the warhead.

The actual material interfaces between all materials within the warhead, including all coatings, lubricants, glues, cleaning solvents, or other materials used during manufacturing must be considered when selecting materials and developing processes for the warhead. All of the materials in the warhead must be shown to be compatible with one another during long term storage, including hot, cold, and humid storage environments. Compatibility must also exist between different phases or polymorphs of the explosive and material interfaces. Synergistic effects that might occur when three or more materials come into contact should be considered when determining material compatibility.

When relying upon materials compatibility data, the data must be specific to the exact materials used within the warhead. This includes verifying that the chemical composition of the materials being used are identical to the chemical composition of the materials that were tested to create the materials compatibility data. Very little data is available where three or more chemicals have been tested for synergistic effects. The interfaces of three or more chemicals should be kept to a minimum and the probability of synergistic reactions should be investigated.

When the warheads are to be stored in a sealed environment such as a launch tube, there is a potential for gases from adhesives or other materials to accumulate. Any such gases must be compatible with the explosives. Synergistic effects of different gases may also be an issue. This is a system level issue and should be addressed at the system level. Consideration should be given to allowing adhesives and paints to cure prior to placing the warhead into a sealed environment.

MECHANICAL SHOCK

> *Accidental explosions caused by impact of an explosive that meets insensitive munitions requirements is unlikely. However, special precautions are necessary to ensure that a design defect cannot increase the sensitivity of a qualified warhead design.*

All explosives are shock sensitive. Therefore there is some risk of inadvertent ignition caused by impact of the explosive or item. The impact can be the result of dropping or hitting the explosive. For explosive items that have passed insensitive munitions requirements, mechanical shock impact is not generally a concern for normal environments. However, a mechanical shock impact hazard exists if some condition has increased the sensitivity of the explosive so that an impact that would normally be acceptable, could ignite the warhead. For example, many explosives become more shock sensitive when they are heated or confined under pressure.

Inclusions, grit, bubbles, contaminates, residual internal stresses, or variable average particle size introduced into the explosive material during manufacturing operations can increase the shock sensitivity of the explosive. Explosive cracking can increase a warhead's sensitivity to mechanical impact. Cracks can be introduced in all life cycle phases. Thermal extremes, vibrations, radiation or manufacturing defects could potentially introduce explosive cracking.

An effective quality control program can prevent the receipt of contaminated materials and can prevent the introduction of contaminates or manufacturing defects. It is important that manufacturing processes be performed that result in clean, uniform materials that do not have excessive, residual internal stresses or cracking of the explosive.

SPARK IGNITION

> *A warhead should be designed to shield all explosives from both mechanical and electrical sparks or electrostatic discharges. This is demonstrated by Electro-Static Discharge (ESD) and Electromagnetic Radiation (EMR) testing of the warhead during qualification. Sparks should never be present when explosive materials are exposed.*

Spark ignition can be caused by mechanical or electrical sparks. Static electricity sensitivity of an explosive can be increased if it is in the form of dust, or if it is fractured or sensitized by factors such as contact with incompatible materials. Spark sensitivity can be controlled by designing and manufacturing the warhead to prevent cracks or fractures in the explosive material, preventing the presence of incompatible materials, and by providing conductive shielding around the warhead.

Many secondary explosives are not considered sensitive to electro-static discharge. However, beware of ESD sensitivity data. There are several different ESD sensitivity testing techniques. The values reported by the different tests can vary by orders of magnitude. In addition, most of the testing techniques rely on a small statistical sample size (10 trials). The number reported is the maximum energy level tested that did not produce a "reaction" in 10 trials. The explosive samples are typically in a powder form and may or may not be confined. Test results do not provide statistical probability of reaction an lower energy levels that those reported.

ELECTROMAGNETIC RADIATION

> *All explosive materials within the warhead should be enclosed within a continuous conducting container that shields the explosives from strong EMR fields. EMR testing should be conduced to verify the design. Quality assurance inspections should be developed to verify that parts are properly bonded. Long term affects of corrosion and incompatible materials should be considered to ensure that conductive shields do not fail over time.*

Some explosive devices and materials are sensitive to initiation by electromagnetic radiation. This can be in the form of Radio Frequency (RF), X-ray, microwave or other radiation. RF radiation can produce a spark, or heat a conductor, if the field is sufficiently strong and an antenna circuit is present. Microwaves can heat the interior of explosives enough to cause auto-ignition.

FRICTION

> *Friction hazards can be introduced by manufacturing defects. These hazards will be controlled through proper design, processes, and quality control of the warhead assembly.*

Explosives can be ignited by friction. The friction can be generated between the explosive and other objects, or between two pieces of explosive. Ignition can occur whenever the explosive is trapped, crushed and heated by friction. For example, friction ignition can occur if explosives are caught in threads that are screwed together, inside of holes that have pins inserted into them, or when explosives are trapped in metal interfaces that move relative to one another. Ignition can also occur at explosive interfaces where two explosive come together, or where a piece of explosive breaks off. Any of these conditions can lead to ignition of the warhead when it is exposed to shock or vibration environments that would normally be acceptable.

THERMAL

> *There are three basic safety concerns relating to thermal effects on the explosives. Temperature extremes can increase explosive sensitivity, differential thermal expansion can cause cracks and increase sensitivity, and extreme temperatures can cause ignition. Each of these conditions should be considered in design and controlled through design, processes, quality control, and by following proper handling and storage procedures.*

Overheating is the main cause of accidental detonation of explosives. Overheating bulk explosive material can directly lead to ignition or explosion or it can indirectly lead to ignition or explosion by increasing the sensitivity of the explosive to the other types of ignition sources. Pressing or casting operations can be especially critical because of the necessity to work with heated, sensitive explosives.

Some explosives can change chemical properties as a result of being exposed to high temperatures. For example, the temperature at which spontaneous exothermic decomposition will occur in HMX is decreased if it is overheated during the pressing or casting operations. HMX has several possible polymorphs. The beta form is relatively stable and is used in explosive manufacturing. Beta HMX can convert to the less stable alpha HMX (solid to solid phase transition) when it is heated above 217°F for an extended period of time. It is difficult to determine that the conversion has taken place because there are no obvious indications of the change, such as a change in color or appearance.

The rate at which the Beta to Alpha solid to solid phase transformation occurs is dependent on the temperature of the HMX. For example, at the threshold temperature of the transformation, it may take several days or weeks to detect a phase transformation. An increase in temperature over the critical temperature is likely to accelerate the transformation rate. Therefore, the overheating of HMX during pressing or casting should be prevented. However if heating above the transition temperature is necessary, then monitoring of the temperature and the durations will become critical to ensure consistent sensitivity.

Most explosive materials react with hydrocarbons such as lubricants, oils, and plasticizers. The reaction often decreases the temperature at which the explosive will undergo spontaneous exothermic decomposition. Manufacturing processes and controls must prevent the contamination or contact of explosives with these hydrocarbon materials during manufacturing. The warhead design should be sealed to prevent the introduction of these materials if they should be involved in later sources of contamination such as having oil or hydraulic fluid spilled on the warhead.

Assembled warheads can be affected by exposure to external heat sources such as heaters, solar radiation, or contact with hot objects. This exposure can directly result in the ignition of the explosive materials, or indirectly by changing the chemical structure or composition of the explosives resulting in an increased sensitivity of the explosive to future events.

Differential thermal expansion of the explosive and its enclosure must be considered during design. As an example, LX-14 has nearly three times the coefficient of thermal expansion as compared with copper or aluminum. Elevated temperatures may compromise the structural integrity of the explosive enclosure. In addition, elevated temperature can result in the migration of explosives into warhead joints or mechanical interfaces. The migration can either occur from extrusion of the explosive into the interface or from exudation of liquid explosive into the joint. The likelihood of either extrusion or exudation will depend on the explosive and the design of the warhead.

Lowered temperatures may induce cracking in the explosive if it shrinks around a material that has a lower coefficient of thermal expansion. For example, a precision shaped charge with a copper liner may develop cracks when the explosive shrinks around the liner. Low temperatures may also cause the explosive charge to become loose within its enclosure. This could result in an increased risk of ignition by friction, or could result in other hazardous conditions.

EXPLOSIVE DENSITIES

> *Explosive densities must be controlled in the design of the warhead and the loading process. Means for ensuring consistency in loading densities and eliminating bubbles and voids must be included in the loading operations. Appropriate quality control inspections are necessary to verify that production warheads are the same as the warheads that were qualified.*

Pressing operations under vacuum are less likely to produce air pockets, bubbles, or voids than casting operations. However, improper pressing cycles (temperature or dwell time) can result in improper overall explosive density. Depending on the characteristics of the specific explosive material, variations in explosive density could change the impact sensitivity of the warheads.

The configuration of each warhead, including pressing time and pressure history, must be the same as those of the samples used to qualify the warheads. It is recommended that the time/pressure history of each warhead be included as part of the quality control acceptance criteria for pressed charges. Pressing dies must also be inspected for damage, deformation and cleanliness prior to use. Quality control of explosive pressing can be enhanced by properly choosing material hardness, clearances, tapers and finishes.

Casting operations must include provisions to minimize the occurrence of entrained air, bubbles, and voids within the final explosive warhead. Bubbles and voids can increase the impact sensitivity of the warheads by increasing the risk of ignition through adiabatic heating of the gases in the void. In addition, it is conceivable that crystal fracturing on the surface of a void could release very fine explosive particles into the void.

BLAST OVERPRESSURE

Consequences of a high explosive shock wave must be controlled by range safety during testing and by allowing safe separation during training and operation of the weapon. Range safety data is usually obtained as part of the qualification program for a warhead subsystem.

A high explosive shock wave will be produced upon detonation of the warhead. Detonation will occur as a result of the use of the weapon and during static firing of the warhead. The high pressure shock wave can cause whole body injury to personnel, damage to structures and can cause serious hearing injury. Blast overpressures should be maintained to acceptable levels during controlled tests. Hearing protection will be required to prevent hearing damage.

Pressure waves can also be reflected to produce damaging effects that are greater than expected. Weather conditions can cause reflections and combining of pressure waves that will break windows and damage property at much greater distances than the pressure wave would have directly.

FLYING FRAGMENTS

Exposure of personnel to flying fragments during training and testing must be controlled by test procedures that include personnel protective structures, and/or adequate separation distances.

Flying fragments and debris are of major concern when the warhead is detonated whether during testing or accidental detonation. All flying fragments or debris from the warhead must be contained within a controlled area during testing. This can be accomplished by controlling the fragments or by allowing sufficient distance between the test site and any populated areas and providing protection for test personnel within the established surface area danger zone. Aircraft flying overhead should also be considered during training and testing.

HAZARDOUS MATERIALS AND COMPONENTS

An evaluation of the hazardous materials within a warhead, and possible by-products from a detonation must be evaluated for each new warhead design.

Recent studies have shown that many explosives do not produce highly toxic by-products by themselves. For example, LX-14 contains mostly organic compounds that contain carbon, oxygen, nitrogen, and hydrogen. The products that can reasonably be expected to result from the explosion of LX-14 include carbon dioxide, carbon monoxide, oxides of nitrogen, hydrocarbons, and some water vapor. However, because the warheads contain other materials that make up the shell and other features, the by-products of a warhead detonation can be highly toxic. Other products might include aluminum fumes and dust, and by-products of binders, adhesives, products from the initiators, adhesives, and any other materials.

The use of composites in warheads may also produce adverse health affects as a result of releasing small respirable fibers. Health studies of carbon fiber composites indicate that more single fibers are reduced when the composite is involved in an explosion. They also indicate that the fibers can cleave in a longitudinal direction resulting in an increase in respirable fibers under explosion conditions. Additional study is necessary to study the characteristics of carbon fiber composites under detonation conditions.

CONCLUSIONS

The discussions in this paper provide a "hazard list" to help identify many of the major concerns associated with cast and pressed explosive warheads. The bibliography provides a selected list of reference materials for further information on some of the issues discussed.

This is the first step in performing a hazard analysis for a warhead system. Once these hazards are identified, the real work begins. Each specific warhead design must be evaluated to ensure that all of the identified concerns are adequately addressed and controlled in the design of the warhead. The controls for the specific warhead should be integrated into an effective hazard tracking system and provided to the designers as design requirements. The requirements must be tracked to ensure they are included in the design and that new hazards are identified and resolved as the development of the warhead matures.

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