Defense Science Board Task Force

on

Munitions System Reliability

September 2005

Office of the Under Secretary of Defense
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ACQUISITION, TECHNOLOGY AND LOGISTICS

13 Sept 2005

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION, TECHNOLOGY, & LOGISTICS)

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on Munitions System Reliability

I am pleased to forward the final report of the DSB Task Force on Munitions Systems Reliability. This effort, chaired by Maj Gen Kenneth Israel (USAF-Ret), reviewed the challenges facing the Department of Defense (DoD) with respect to munitions systems reliability. The Task Force reviewed three main areas of interest:

- Conducting a methodologically sound assessment of the failure rates of US munitions in actual combat use;
- Reviewing ongoing efforts to reduce the amount of unexploded ordnance (UXO) resulting from munition failures, and evaluate ways to improve or accelerate these efforts; and,
- Identifying other feasible measures the United States can take to reduce the threat that failed munitions pose to friendly forces and civilians.

There were two major observations relating to UXO caused by failed munitions: a clear lack of focus, and growing international concern over the impact of UXO to civilians. Several obstacles have limited DoD's post-conflict efforts to mitigate the impact of UXO to friendly forces and civilians, which now requires focus and commitment to address the various factors of munitions failures. The Task Force recommendations coincide with efforts made in the 2003 DSB Task Force on Unexploded Ordnance, expanding the scope and urgency for DoD organizations to take responsive actions. These recommendations emphasize the extent of change required to ensure a more effective approach.

I endorse the Task Force's recommendations and encourage you to review the report.

William Schneider, Jr.
DSB Chairman

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OFFICE OF THE SECRETARY OF DEFENSE
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WASHINGTON, DC 20301-3140

DEFENSE SCIENCE BOARD

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Report of the Defense Science Board (DSB) Task Force on Munitions System Reliability

Attached is the final report of the DSB Task Force on Munitions System Reliability. The report emphasizes that the challenges facing the Department of Defense (DoD) with respect to munitions system reliability must be addressed soon, otherwise a critical aspect of our warfighting capability will be jeopardized and held to even higher levels of scrutiny. This Task Force determined two major observations relating to unexploded ordnance (UXO) caused by failed munitions: a clear lack of focus and growing international concern about the impact on civilians. There is no comprehensive approach to the issue of legacy weapons. Funding for munitions research and development remains unacceptably low. Current acquisition practices have the unintended effect of squeezing fuze and battery manufacturers by relegating them to lower-tier subcontractor status and subjecting them to volatile production rates. A fragmented organizational approach hinders DoD's post-conflict efforts to mitigate the impact of UXO. These challenges limit DoD's immediate and long-term ability to reduce the risks that UXO poses to friendly forces and civilians. They are not insurmountable, but solving them will require a previously unseen focus and commitment to address the factors that lead to munitions failures and UXO.

The topic of unexploded munitions on US ranges and formerly used defense sites was previously examined by the DSB in the 2003 DSB Report on Unexploded Ordnance. The recommendations of this current study are in harmony with this previous effort and have expanded the scope and sense of urgency to take responsive action by DoD organizations. Members of Congress have expressed concern regarding the failure rates of area attack munitions and the impact of UXO on the lives of Iraqi civilians during Operation Iraqi Freedom.

Our recommendations, delineated in the attached report, emphasize the scope of change required across DoD to ensure a more effective and coherent approach. The Task Force urges the senior leaders of DoD to implement the recommendations at the earliest opportunity.

Kenneth R. Israel
Task Force Chairman

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EXECUTIVE SUMMARY

The Defense Science Board Task Force on Munitions System Reliability met from June 2004 to May 2005. The Task Force's charter focused on three principal areas of interest:

- Conducting a methodologically sound assessment of the failure rates of US munitions in actual combat use;
- Reviewing ongoing efforts to reduce the amount of unexploded ordnance (UXO) resulting from munition failures, and evaluate ways to improve or accelerate these efforts; and
- Identifying other feasible measures the United States can take to reduce the threat that failed munitions pose to friendly forces and civilians.

It was not within the purview of this Task Force to examine weapon requirements, but to examine the issue of munition reliability and identify ways to reduce the amount of UXO resulting from failed munitions. Reducing the amount of UXO will lower the risk of casualties among ground forces and enhance their freedom of maneuver in operations following munition use. It will provide greater flexibility for operational commanders who now must consider the risks to friendly forces and potential for collateral damage associated with a particular munition. It will significantly reduce the risks of post-conflict civilian casualties and the challenges that UXO poses to stabilization and reconstruction activities, including winning the "hearts and minds" of local populations. As US global commitments grow, our global responsibilities to ensure safe, reliable and effective expenditure of munitions must continue to grow as well.

Munitions system reliability is a vital area that justifiably requires immediate attention and resources. Senator Patrick Leahy, in a June 24, 2003 letter to Chairman of the Joint Chiefs of Staff General Richard Myers, voiced concerns about the apparent lack of progress in reducing US cluster munition failure rates and the impact of munitions on the lives of Iraqi civilians during Operation Iraqi Freedom. While acknowledging the prohibitive cost of retrofitting the entire stockpile of these munitions, the Senator observed that "the cost of removing duds littering Iraq and Afghanistan may not be appreciably less than it would have cost to retrofit the number of cluster munitions that were used in those conflicts."

A key focus of this study was area attack munitions (often referred to as submunitions or cluster munitions). Owing to the sheer numbers in which these munitions are employed, there is the potential for UXO left on the battlefield to hinder the movement of friendly forces, cause unintended casualties among military and civilians, and deny civilian use of territory and buildings long after a conflict is finished.

Maneuver warfare implies the ability to maneuver unimpeded in time and space to control the entire tempo of an operation by exploiting or attacking critical enemy vulnerabilities. This inextricable link among UXO, munitions system reliability and dominant maneuver must be managed if we are to maximize the potential of joint warfare on tomorrow's battlefield. More precise munitions will help reduce collateral damage while improving lethality. Greater precision systems will, however, complement area attack munitions rather than replace them for the foreseeable future.

The Task Force could identify no comprehensive approach—empirical observation or otherwise—to determine and document operational combat failure rates of US munitions. The available data is inconsistent, largely anecdotal, and often from questionable sources. Area attack munitions in particular—designed to produce dispersed battlefield effects—can be highly effective in combat but difficult to analyze afterward. There is no method in place that can systematically determine and document the reliability rates of a broad range of munitions during combat.

The largest contributors to the UXO problem are legacy munitions, operational factors and fuze technologies. There is an enormous stockpile of aging munitions that will have to be used "as is," retrofitted or demilitarized, but the Department of Defense (DoD) has no comprehensive approach in place to address these legacy munitions. Retrofitting the existing stockpile could easily run into the billions of dollars. Retrofitting is not without other challenges as well, namely meeting revised safety standards and risking the introduction of new failure points in legacy systems never designed for upgrades. The operational question then becomes one of priorities and the cost-benefit analysis of retrofitting older munitions at the expense of developing and fielding more capable, reliable, safe and effective munitions.

Improving the functioning rate of area attack munitions is not the only way to reduce the amount of UXO and the risk it poses for friendly forces and civilians. Incorporating or improving the guidance capabilities of these munitions reduces the amount of UXO (because fewer munitions are needed to service a particular target) and the area potentially affected by UXO (because the guidance capability reduces the radius of error). It is also a less intrusive means of upgrading existing area attack munitions than retrofitting. The Army is currently incorporating a guidance system on its Multiple Launch Rocket System, and the Air Force is adapting its CBU-87 and CBU-97 munitions by adding the Wind-Corrected Munitions Dispenser. While these efforts do not increase the reliability of the systems in question, they provide an immediate and practical way to reduce the amount and distribution of UXO resulting from the use of these munitions, because incorporating guidance results both in fewer munitions used per target and more accurate delivery (i.e., fewer failed munitions and a smaller affected area).

New and emerging technologies offer additional approaches toward improving munition reliability and/or lessening the impact of UXO. Fuzes based on integrated circuits, Micro-Electro-Mechanical Systems (MEMS) and integrated fuzing, targeting and guidance systems can provide greater reliability. The use of radio frequency (RF) tags can be expanded beyond logistics tracking to facilitate UXO remediation for new systems.

If there is one theme, however, that characterizes the challenges facing DoD with respect to the issue of munition reliability and UXO, it is "*lack of focus*." There is no comprehensive approach to the issue of legacy munitions. Funding for munitions research and development is chronically inadequate, and there is no program in place to develop a new generation of area attack munitions that are affordable and highly reliable. Current acquisition practices have the unintended effect of squeezing fuze and battery manufacturers by relegating them to lower-tier subcontractor status and subjecting them to volatile production rates. A fragmented organizational approach hinders DoD's post-conflict efforts to mitigate the impact of UXO. These challenges impede DoD's immediate and long-term ability to reduce the risks that UXO poses to friendly forces and civilians. These challenges are not insurmountable, but solving them will require a previously unseen focus on the factors that lead to munition failures and UXO. At present, no one is positioned to take leadership and overall responsibility for fixing this growing and operationally constraining problem.

The Task Force has researched the status of munitions system reliability efforts and considered other measures to reduce the risks posed by UXO. It identified eleven primary or "key" recommendations and five secondary recommendations. The primary recommendations are outlined below and addressed more extensively in the body of this report. Secondary recommendations are included in the relevant chapters. A classified annex in CD-ROM format provides additional information supporting the conclusions and recommendations of the Task Force. The classified annex is on file at the Defense Science Board Secretariat Office.

KEY RECOMMENDATIONS

Assessing Reliability

1. **The Services, in coordination with the Director of Operational Test and Evaluation, should expand testing of munitions—to include legacy munitions—for the characterization of reliability in a broad range of operationally relevant environments that may cause degradation.** Testing should validate any modeling or simulation. Munitions are expected to achieve effects, independent of the diverse employment environments (such as terrain, firing and launch conditions, weather conditions, etc.). Current testing is often performed in limited environments and does not provide comprehensive knowledge about how the munition will perform in actual environments.

2. **The Chairman of the Joint Chiefs of Staff should develop deliberate planning information-sharing tools for munitions system reliability information exchange.** These tools will capture effectiveness data. Currently, usable information is either stovepiped or is not catalogued.

3. The Chairman of the Joint Chiefs of Staff should establish a munitions expenditure database accessible by all joint components during and immediately after combat operations. This database will identify the type, quantity, and location of munitions expended. The desired results are greater efficiency and effectiveness for ground combat maneuver planning and post-conflict clean-up efforts.

TECHNOLOGY AND DESIGN

4. **The Director, Defense Research and Engineering (DDR&E) should fund new research investments into inexpensive, ultra-reliable fuze development based on integrated circuits, Micro-Electro-Mechanical Systems technologies, and integrated fuze, guidance and targeting systems.** The DDR&E should establish pilot science and technology programs to achieve safety-certified, integrated fuzing, targeting and guidance systems. A reasonable goal would be to have at least two certified IC/MEMS-based fuzes available for introduction by 2008.

5. The **DDR&E needs to drive more joint weapons development efforts with the associated multi-Service research efforts to achieve a critical**

mass of scarce development resources. Organizations such as the Defense Ordnance Technology Consortium are a good start, but are limited because of their voluntary nature; a forcing function and authorities need to be put in place. Further weapon acquisition and weapon research consolidation is necessary in order to maintain a governmental skill base. Joint research targeted at larger joint weapons programs will allow both industry and the Services to maintain a workforce capable of developing and producing state-of-the-art, highly effective and highly reliable munitions.

6. **The Under Secretary of Defense for Acquisition, Technology and Logistics should expand efforts to develop radio frequency tags for munitions beyond logistics tracking to facilitate UXO remediation for new systems.** A DoD goal should be a single common tagging system for munitions of all types. DoD should develop a low cost, integrated RF tag. Economically, it does not make sense to retrofit all area attack munitions currently in storage, since the cost of installing the tags significantly exceeds the cost of the tags and outweighs the effective benefits. However, tagging existing area attack munition dispensers may be a viable method for identifying potential UXO sites.

7. The Services should explore methods to provide operational test and combat operations performance feedback to the acquisition community and the suppliers. This feedback should be used to optimize production methods, ensuring increased reliability through improvements in design and production control methods and documentation.

Acquisition, Logistics and Industrial Base

8. **The Services should support a new, joint family of area attack munitions and upgrade a fraction of the current legacy inventory.** The Services should assess their current operational plans to determine a reasonable number of legacy area attack munitions needed to address future conflict scenarios and develop a plan to reduce UXO in those munitions. This latter step will help ensure that the Services retain a needed capability and sustain industrial capability until a more modern area attack munition matures.

9. **The Services should continue to field munition/dispenser guidance accuracy improvements.** Improvement in munition guidance will reduce both the aggregate quantities of UXO and the areas in which it may be located.

10. **The Under Secretary of Defense for Acquisition, Technology and Logistics should host a fuze and battery industry executive meeting (a "Last Brunch") to discuss future procurement and acquisition policies in order to preserve and optimize our national capability.** The munitions battery and fuze industries are strategic national resources with capabilities that need to be preserved. Without OSD initiative, the industry runs the risk of downsizing "overshoot."

Transforming DoD ERW Abatement Efforts

11. **The Under Secretary of Defense for Policy should transform all functions within his organization related to explosive remnants of war abatement efforts into one single office charged with the responsibility to execute the DoD program and empowered with the commensurate authority.** This will achieve unity of command, unity of effort, and accountability. Sufficient funding already exists, but the current organizational structure prevents effective implementation of DoD ERW abatement efforts.

INTRODUCTION

This report summarizes the deliberations and conclusions of the Defense Science Board Task Force on Munitions System Reliability. The Defense Science Board was asked to assess DoD efforts to improve the reliability of its munitions and to identify whether there are additional steps DoD could take to further reduce the amount of UXO created when these munitions fail to explode. UXO poses a threat to both friendly forces and civilians. It can hinder the movement of friendly forces, cause casualties among military personnel and civilians alike, and deny use of territory and buildings long after a conflict is finished.

Area attack munitions were a key focus of this study, although the Task Force did not limit its review to this class of munitions. Specifically, the Task Force undertook the following assignments:

- **Conduct a methodologically sound assessment of the failure rates of US munitions in actual combat use.** The available data is inconsistent, largely anecdotal and often from questionable sources. For area attack munitions, there is no system in place to determine reliability rates during combat. DoD tracks information on failure rates as determined by lot acceptance and surveillance testing, but there are additional factors that can further degrade the performance of munitions below the levels revealed by testing. These include the age of the munition, conditions under which it was stored, angle and speed of release, range, and the terrain on which the munition lands. There are numerous claims from sources other than DoD allegedly based on observed failure rates in post-conflict environments; however, these are generally based on questionable methodologies. Anecdotal evidence does indicate, however, that failed US munitions create quantities of UXO.

- **Review ongoing efforts to reduce the amount of UXO resulting from munition failures, and evaluate ways to improve or accelerate these efforts.** A few Service efforts are already underway either directly aimed at reducing failure rates or incorporating other improvements to the munition that result in less UXO. The Army is retrofitting a limited number of Dual Purpose Improved Conventional Munitions with a self-destruct fuze. The Army is also moving to a guided version of its Multiple Launch Rocket System, and the Air Force has been adding Wind-Corrected Munitions Dispenser (WCMD) kits to existing area attack munitions systems.[1] Incorporating guidance systems results in fewer munitions used per target and more accurate delivery, which means less UXO

[1] The Task Force notes with regret, however, that Program Budget Decision 753 eliminated funding for WCMD and WCMD-Extended Range procurement.

and a smaller affected area.

- **Identify other feasible measures the United States can take to reduce the threat that failed munitions pose to friendly forces and civilians.** This last assignment was deliberately broad in scope. New and emerging technologies offer the opportunity to demand and obtain greater performance from munitions as well as ways to reduce the risk of collateral damage, and the Task Force considered a number of additional approaches to reduce the risk posed by UXO.

The focus of the Task Force was on improving munitions performance and mitigating the impacts of UXO. The Task Force did not perform a detailed analysis of the military effectiveness of area attack munitions (or any other munition system) and did not attempt to determine whether other munitions can achieve the same effects. Area attack munitions remain highly effective against a variety of targets, especially against dispersed enemy personnel, armor and other vehicles. They can be used to counter mortar and artillery fire, to suppress enemy defenses, and to seal breaches and gaps in defenses during combat operations. Area attack munitions also serve as a force multiplier, enabling a small force to defend itself against a larger force or over a large area. Against these types of targets, area attack munitions offer a number of advantages in comparison to unitary munitions. They require fewer rounds, which both reduces the logistics burden and decreases the tonnage of high explosive needed to attack these targets. They also enable more rapid and effective engagement of mobile targets than unitary munitions. For US ground forces, area attack munitions require fewer shots and permit faster movement. For US pilots, these munitions require fewer sorties, resulting in less exposure to enemy air defenses.

Legal Issues Regarding Munitions System Reliability

The idea of regulating the means and methods of warfare has existed for centuries, whether contained in treaty law, such as the Hague Conventions and the Geneva Conventions of 1949 and Additional Protocols I and II of 1977, or as customary international law. There are four basic principals of the law of armed conflict:

- Military necessity/military objective;
- Distinction/discrimination;
- Proportionality; and
- Humanity/unnecessary suffering.

These four principles must be applied when determining the method of warfare that is chosen, such as the tactics used in the conflict, and the means of warfare, such as the types of weapons used.

The first principle, military necessity, allows those measures not forbidden by international law that are indispensable for securing the complete submission of the enemy as soon as possible. There are two elements to military necessity. First, there must be a military requirement to take the action. Second, the law of armed conflict must not forbid it. Therefore, even if there is a military necessity for taking an action, the target selected must have a military objective. Military objectives are defined as "those objects which by their nature, location, purpose or use make an effective contribution to military action and whose total or partial destruction, capture, or neutralization, in the circumstances ruling at the time, offers a definite military advantage."

The second principle, the principle of discrimination or distinction, forms the basis for many of the Geneva Convention principles of the law of armed conflict. This principle provides that attacks should be directed at combatants and military targets, not at civilians or civilian property. Weapons used should not be employed in a manner that is considered indiscriminate.

The third principle, the principle of proportionality, recognizes that civilian casualties may take place during a conflict. Where an attack is expected to cause loss of civilian life, injury to civilians, damage to civilian objects, or a combination of damage and injury, the test is whether this loss or damage would be excessive in relation to the military advantage to be gained. This principle is only applicable when such an attack has the possibility of affecting civilians. If the target is purely military, with no known civilians or civilian property in the area, no proportionality analysis is required.

The final principle is the principle of unnecessary suffering or humanity. The right of combatants to adopt means of injuring the enemy is certainly not unlimited. Under the Hague Conventions, it is especially forbidden to employ arms, projectiles or material calculated to cause unnecessary suffering. Weapons to which this prohibition relates fall into two categories. First, certain types of weapons that are calculated to cause unnecessary suffering, such as projectiles filled with glass, irregular shaped bullets, and expanding bullet rounds, are illegal. The second are those weapons that are lawful, but are improperly used in a manner that would cause unnecessary suffering.

One specific weapon system type that some have alleged to have indiscriminate effects, and thus to violate the second principle described above, is area attack munitions. This is the principal argument made by various non-governmental organizations and certain members of the international community in arguing that that area attack munitions are illegal, or should at least be regulated. It is alleged that these munitions cannot be accurately employed because of high failure rates, which are claimed to be as high as 20 percent or more. The resulting failed munitions, which become UXO (also referred to as explosive remnants of war or ERW[2]), cannot distinguish between combatants and civilians. Civilians and individuals working for humanitarian groups have been injured, killed, or prevented from providing necessary relief supplies as a result of ERW.

At present, no specific treaties regulate the use of area attack munitions. However, the four basic principles of the law of war do govern their use; they remain lawful weapons under the law of armed conflict. In 2003, the Convention on Conventional Weapons adopted its most recent Protocol on explosive remnants of war.[3] This Protocol is the first multilateral agreement to deal with the problem of unexploded ordnance. Its purpose is to minimize the risks and effects of explosive remnants of war, mainly in post-conflict situations. Explosive remnants of war include ordnance that has been fired, dropped, launched or projected and should have exploded but failed to do so. Under the Protocol, it is the responsibility of the party that fired the ordnance either to clean it up, if it exercises control over the territory where the ordnance is found or, if it does not control the territory, to provide, where feasible, technical, financial, material or human resources assistance to facilitate the marking and clearance, removal or destruction of such explosive remnants. Parties to the Protocol are also required to take precautions to protect the civilian population, individual civilians and civilian objects from the risks and effects of ERW.

The (non-legally binding) Technical Annex to the ERW Protocol contains several suggested "best practices" modeled after US and other States Parties' practices that address pre-conflict situations. The purpose of this Annex is to offer practices that could increase the overall reliability of the munitions, thereby decreasing the chance that they will become ERW. For example, Section 3 provides, in part, that States should, to the extent possible, ensure the following measures are implemented and respected during the munitions manufacturing management: (1) production processes should be designed to achieve the greatest reliability of munitions; (2) high reliability standards should be required in the course of explosive ordnance transactions and transfers.

Other than customary international law principles, which, among other things, require a State specifically to ensure that any weapon is not used in an indiscriminate method, there are no restrictions on the use of area attack munitions. There have been calls by non-governmental organizations in various international fora - specifically in the meetings of States Parties to the Convention on Conventional Weapons - either to ban or restrict the use of area attack munitions, especially in populated areas. The US

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[2] The term "explosive remnants of war" is more inclusive than "unexploded ordnance" since the former refers to unexpended ordnance (such as that found in abandoned arms caches) as well as the latter.

[3] The United States played a significant role in drafting this protocol. The protocol is under review at this time; the United States has not ratified it.

Government has opposed these calls because these munitions, when properly employed, do not cause unnecessary suffering nor are they per se indiscriminate. Area attack munitions serve legitimate military purposes, and in many instances may cause less collateral damage than other munitions.

As noted above, weapons cannot be used in a manner that would cause unnecessary suffering. Armed forces must balance the degree of suffering by the victims that is likely to occur if a particular weapon is used against the military necessity of using that weapon before a weapon is deemed to cause unnecessary suffering. While area attack munitions, as with any weapon, will inflict a degree of suffering on its intended victims, to be unlawful, the suffering must outweigh the legitimate military necessity in their use. It cannot be said as a blanket statement that area attack munitions cause superfluous injury or unnecessary suffering—that can only be determined on a case-by-case basis in the targeting process by military planners, including legal advisors.

Another popular argument against area attack munitions is that they cannot be accurately deployed because the bomblets do not always detonate and the failed munitions create minefields incapable of distinguishing between combatants and civilians. It is important to remember that no weapon will work or be accurate 100 percent of the time. In January 2001, DoD directed that in future acquisition of area attack munitions, the desired goal is to attain a reliable functioning rate of 99 percent. (This policy— see Appendix 3—was developed with future munition systems in mind; it does not compel any changes to legacy systems.) Area attack munitions certainly are not designed to be an indiscriminate weapon, as is attested to by the efforts put into increasing the reliability rates for these systems. Efforts are also made to ensure these munitions are not used in an indiscriminate manner. The evaluation of a target to determine whether an area attack munition is appropriate and whether it will cause collateral damage is done on a case-by-case basis. Technical experts analyze the target, with input from military attorneys, to ensure collateral damage is minimized. The targeting experts not only consider the direct impacts, but also factor in known failure rates to minimize additional collateral damage that may be caused by UXO.

Report Organization

The main body of this report is divided into four chapters: (1) Assessing Reliability, (2) Technology and Design Issues, (3) Acquisition, Logistics and Industrial Base, and (4) Transforming DoD ERW Abatement Efforts. The Terms of Reference establishing the Task Force can be found in Appendix 1. Major General Kenneth R. Israel, USAF (retired), chaired the Task Force; a full listing of Task Force members is given in Appendix 2. The DoD policy memo on submunition reliability, signed by former Secretary of Defense Cohen in January 2001, is provided in Appendix 3. Finally, a classified annex, which provides amplifying detail to the report's conclusions and recommendations, is available separately in CD-ROM format.

Chapter 1. Assessing Reliability

This section will address issues regarding design and observed munitions reliability, specifically focusing on factors affecting reliability, considerations in determining failure rates, and munition life cycle data sharing.

KEY RECOMMENDATIONS

- **The Services, in coordination with the Director of Operational Test and Evaluation, should expand testing of munitions—to include legacy munitions—for the characterization of reliability in a broad range of operationally relevant environments that may cause degradation.** Testing should validate any modeling or simulation. Munitions are expected to achieve effects, independent of the diverse employment environments (such as terrain, firing and launch conditions, weather conditions, etc.). Current testing is often performed in limited environments and does not provide comprehensive knowledge about how the munition will perform in actual environment.

- **The Chairman of the Joint Chiefs of Staff should develop deliberate planning information-sharing tools for munitions system reliability information exchange.** These tools will capture effectiveness data. Currently, usable information is either stovepiped or is not catalogued.

- **The Chairman of the Joint Chiefs of Staff should establish a munitions expenditure database accessible by all joint components during and immediately after combat operations.** This database will identify the type, quantity, and location of munitions expended. The desired results are greater efficiency and effectiveness for ground combat maneuver planning and post-conflict clean-up efforts.

Munitions System Reliability Factors

Reliability means different things to different groups. To the warfighter, a reliable munition is one that consistently achieves desired effects in a predictable manner under a wide range of tactical situations with a minimum number of failures. The munition should do so without undue hazard or risk to friendly forces and civilians. Ideally, it presents the minimum possibility of unintended consequences. A reliable munition should also leave a "clean" battlefield, to avoid hindering the maneuver of friendly forces. It can achieve this through a low failure rate, self-neutralization, or self-destruction.

To others, the most significant factor in determining a munition's reliability is its effect on civilians. Like the warfighter, other groups desire a clean battlefield, but "clean" in terms of safety to civilians. Unlike the warfighter, these groups are not necessarily interested in how effective a munition is in achieving combat effects. The common ground between the two groups is a shared interest in a munition that performs its intended function, but only in the prescribed manner against the intended target.

The Joint Munition Effectiveness Manuals (JMEM) define a munition's reliability as "a measure of the probability of successful detonation." Webster's dictionary defines "reliable" as suitable or fit to be relied on, or giving the same result on successive trials. However, for purposes of discussion, this Task Force recommends: "Reliability describes the expectation of a munition's ability to perform its intended function over successive trials." The intended function should occur in the prescribed manner, which includes the desired time, place, and effect. Reliability is expressed as a ratio of the number of successful expenditures to the total number of expenditures. An equation can accurately portray the mathematical reliability of a single munition round. Such an evaluation may be useful for determining the failure rates of specific munition types. However, the resultant figure will provide only part of the story. In fact, the most complete evaluation of a munition's reliability is on the scale of an entire conflict, either modeled or actual.

The munition system includes a warhead and fuze, and may include a guidance and control section. The warhead consists of the explosive material and a casing that contains the material and provides a source of lethal fragments. The fuze is designed both to initiate the detonation when required and, for safety, to prevent detonation before it is desired. The guidance and control section may include movable fins, a battery, a generator, and electronics to ensure the munition is delivered to the desired location prior to detonation.

Estimates of campaign-based reliability must take into account the total number of munitions expended and whether these munitions achieved the joint warfighting commander's objectives. The reliability of a munition can be expressed as:

$$\textbf{Reliability}_{\text{aggregate}} = \textbf{Reliability}_{\text{platform}} \times \textbf{Reliability}_{\text{dispense vehicle}} \times \textbf{Reliability}_{\text{munition}}$$

Platform reliability is a function of how accurately the launching vehicle can place a munition on the desired target or achieve the required launch acceptability region. The platform's accuracy subsequently affects the post-release accuracy of unguided munitions; once fired or released, unguided munitions must accept the original unguided solution all the way to impact. Guided munitions can overcome this limitation by adjusting the flight solution continually until impact. For the purposes of this report, the reliability of the platform (aircraft, artillery piece, etc.) is considered constant. The dispensing vehicle's reliability is affected by the reliabilities of its structure, accuracy, and dispense fuze. The vehicle must travel to the desired location, sense the desired dispense conditions, and activate the dispensing mechanism.

The reliability requirement of a munition is the product of the effectiveness needed. Effectiveness is governed by the technology available and the cost to develop, field, and maintain the munition. Typical reliabilities for conventional munitions fall in the 95 to 99 percent range. Reliability is subject to statistical confidence bounds. If improperly defined, these bounds either provide too much latitude for performance error or drive acquisition costs prohibitively high. Munition reliability can be significantly affected by such factors as the age of the munition, storage conditions, environmental conditions during employment, and terrain conditions. Reliability is also affected by manufacturing differences both within groups and between groups of the same munitions. Minimizing manufacturing variations reduces reliability variation and makes the effects of age, storage and deployment conditions more predictable.

Potential UXO sources include munitions designed to detonate either upon contact with another object, in proximity to another object, at a set height of burst above ground, or at a predetermined delay set time. Munitions considered in this study are unitary or cluster, guided or unguided. They include both air-to-surface and surface-to-surface systems. This study did not address air-to-air systems, small arms, depleted uranium, and other weapons not specifically designed to explode when employed.

Reliability is ultimately the relationship between munitions expended and the effects created on the battlefield. Until the advent of effects-based operations, assessments of munition effectiveness were based on physical target attrition. Campaign objectives were driven by attrition of a broad target list. Physical damage criteria, such as "catastrophic kill" and "mobility kill," drove campaign planning. Assessment consisted of how well the munition physically damaged the intended aimpoints. Performance measures were driven by accuracy and size of a munition's blast or fragmentation field. These basic criteria remain valuable tools at the tactical level. However, the effects-based operations methodology changes operational- and strategic-level warfare planning. Campaign planning focuses on discovering causal linkages in the enemy's ability to wage war. Detailed pre-strike analysis of the enemy reveals weak nodes and determines the desired effect on those nodes. Systematic attack of those targets disables the enemy. Effects-based operations are military operations deliberately focused on achieving specific strategic, operational, or tactical *effects*, rather than against a particular target set. In effects-based operations, munitions reliability will be judged on the munition's ability to achieve the desired effect on the assigned target. This is munitions effectiveness assessment. It includes both the functional as well as the physical effects of a munition.

Munitions effectiveness assessment is currently limited by several factors. Modern warfare's operational tempo stresses it. The mindset and culture of munitions effectiveness assessment remain based largely on Cold War-era thought, with poorly managed information flow and integration. Figure 1.1 illustrates how high levels of effort early in a campaign stress the assessment process. The targeting cycle continues to compress, but analysis processes are not aligned for the same transformation. The flow of munitions expenditure and reliability data from the theater of operations (for assessment) to rear-located agencies is limited. The flow of ensuing analysis back to the theater is likewise restricted, aggravating real-time incorporation of assessment data back into the targeting cycle.[4]

Although the Services have an impressive array of modernized munitions, the

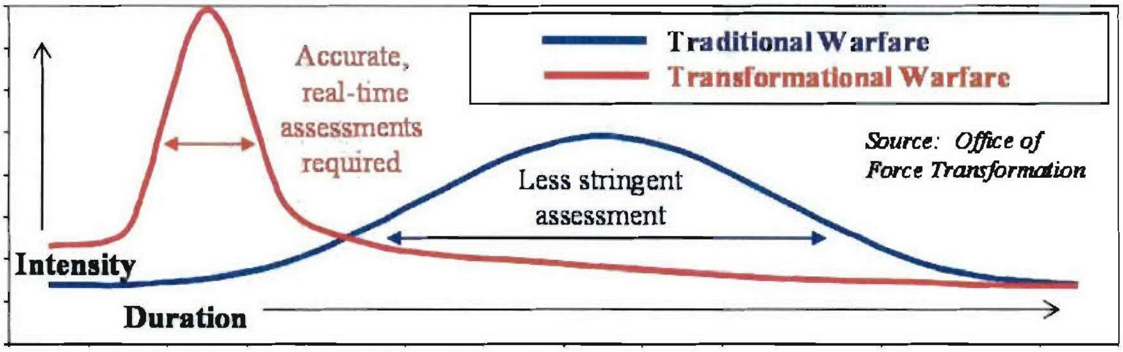


Figure 1. Effect Tempo on Munitions Effectiveness Assessment

Army has the largest legacy system challenge. The Army's primary use of area attack munitions is in its indirect fire support artillery systems. Munition reliability issues, however, are not confined to one Service. Data sharing between the Services can help to identify ways to reduce the amount of UXO resulting from failed munitions and mitigate the effects of UXO.

Determining Failure Rates of U.S. Munitions in Conflict

Just as the nature of assessment and its related tasks has changed with the character of war, the concept of "munitions reliability" is evolving. The result is increasing difficulty in clearly defining and determining the failure rate of munitions in combat. Reliability in combat once referred simply to a munition's ability to function repeatedly as designed. Civilian expectations of the military establishment's abilities in target attack, however, have grown. The public expects the military to sense, locate, and attack targets quickly to win wars swiftly and with minimal collateral damage. The introduction of "smart" munitions into the inventory has changed the military's own expectations. Reliability is no longer simply a matter of battle damage assessment. Each of the Find, Fix, Track, Target, and Engage steps in the kill chain are considered in munitions reliability assessment. As fuzing and guidance capabilities become more integrated, the reliability of target acquisition must be measured and assessed. If the

[4] A more thorough discussion of the challenges facing munitions effectiveness assessment can be found in a Defense Advanced Research Projects Agency (DARPA) study ("Weapons Effects Assessment Study") completed in April 2004 under the leadership of Brig Gen (ret) Buck Adams, USAF.

wrong target is selected because of faulty automated target recognition algorithms, erroneous Global Positioning System (GPS) coordinates, poor analysis or a misaligned sensor, the overall mission impact may be roughly analogous to a malfunctioning fuze sequence. In terms of effects-based operations, planning to strike the wrong aimpoint not only fails to produce the desired chain of effect—it may also yield potentially undesirable secondary and tertiary effects for the warfighting commander.

Battlefield collateral damage will always exist. No class of munition will be faultless in generating undesired battlefield effects. If a munition reaches the intended location, the intended target may no longer be there, but other objects not intended to be targets may remain within the effects field of the munition. The warfighter accepts this situation as normal course of the continual risk analysis process. Imperfections in intelligence gathering systems and methods, actions of the enemy, actions of civilians, and other uncontrollable factors will prevent military forces from having perfect intelligence or awareness of their environment.

There is currently no comprehensive approach—empirical observation or otherwise—to determine and document operational combat failure rates of US munitions. The available data is inconsistent, largely anecdotal, and often from questionable sources. The lack of a rigorous method to determine munition reliability in combat leads to other attendant problems and a considerable amount of misperception concerning their effectiveness. Small quantities of UXO located in a populated area can create the impression of a reliability problem regardless of the actual failure rates. In contrast, significant quantities of UXO in relatively unpopulated areas can go unnoticed, even if they are the result of high failure rates. Area attack munitions, designed for dispersed battlefield effects, can be highly effective in combat yet difficult to analyze afterward. There is no method in place to determine and document systematically the reliability rates of a broad range of munitions during combat.

During non-combat expenditures, DoD tracks information on failure rates as determined by lot acceptance and surveillance testing. These test methods provide accurate munition reliability snapshots at those times and under those conditions. Notably, surveillance testing is normally conducted under conditions ideal for munition to function, such as on desert hardpan soil. Additional factors can degrade the performance of munition below the reliability levels revealed by testing. These include: the age of the munition, conditions under which it was stored, angle, speed and altitude of release; range to target; angle and speed of impact; and type of terrain on which it impacts. The result is an incomplete statistical image of a given munition's reliability. There are numerous claims from sources outside DoD based on observed failures in post-conflict environments. However, these are generally based on unscientific methodologies and cannot be substantiated. Anecdotal evidence does indicate, however, that some munitions can create quantities of UXO. These failures appear to be related to operational factors that are not assessed as part of developmental, acceptance and surveillance testing.

The lack of information regarding actual combat reliability rates reaches beyond munition employment issues. It also impacts operational and logistical planning and execution. The accuracy of munitions reliability statistics directly impacts DoD's ability to plan efficient, munitions-related logistics operations. Munition consumption rates have a significant impact on theater mobility operations. The fewer munitions required for a mission, the less the logistics burden. As indicated above, munition lot acceptance and surveillance testing may establish a statistical baseline, but the factors affecting combat failure rates are broad and vary significantly.

A note of caution regarding reliability and safety—by attempting to ensure a munition will function reliably under all conditions, it is possible to sacrifice safety. As a result, a munition could become less safe to handle, store and load. A munition that never detonates might be perfectly safe, while a munition that functions under unintended conditions may be considered mathematically reliable.

Munition Life Cycle Data Sharing

Munition reliability estimates are generally based on two types of data. The first set of data is the "as-built" reliability developed from testing of serial lot production. As munitions are built, they are grouped into lots that are periodically tested and compared to their requirements. Reliability is one of the qualities tested. If the results of the lot tests demonstrate that the lot satisfies its requirements, the lot is accepted into inventory and is eventually issued to the warfighter. As these accepted lots accumulate, the test data accumulate and provide information on the entire inventory. This information provides an assessment of the readiness of the inventory and includes reliability numbers.

The second type of data is storage or surveillance test data. These data serve as an extension of lot acceptance data described above. Periodically, representative munitions are removed from inventory to assess any degradation in performance resulting from age or storage conditions. This information is extremely important because it assesses the readiness of the munitions, and thus the readiness of the military using it to engage the enemy in combat. It also permits the remediation, elimination and possible replacement of munitions that no longer meet Service requirements. The accumulation of this readiness data provides an assessment of the current state of the inventory of munitions.

Data sharing efforts may be categorized into one of three time-based categories: pre-combat, combat operations, and post-combat. Activities in each phase are linked over time. Through component- and Service-specific processes, warfighting commanders determine current and future munitions capability requirements. Service staffs vet newly identified requirements through the Joint Capabilities Integration and Development System, leading to procurement and fielding. Service munition sufficiency requirements are annually vetted through the Munitions Requirements Process. Munitions are tested and evaluated on a recurring basis through various means, as discussed above.

The data drawn from post-production operational testing are distributed from the evaluating agency into various specialized systems. Though this system transmits data to agencies most directly connected to specific munitions and systems, it lends itself to data stovepiping. Furthermore, the data are not consistently updated in joint manuals. This results in the lack of comprehensive understanding of the expected munitions combat performance. For example, the Air Force's Weapon System Evaluation Program reports contain valuable information, yet are not broadly distributed. The reports are available through a classified website, but no method is in place to notify agencies (outside of the regular distribution list) when new reports are published. Today, each Service has its own weapons index file. An integrated, digital-based system, once put in place, would help ensure a truly joint approach to munitions system issues. The Joint Munitions Effectiveness Manuals and attendant weaponeering software are updated approximately every sixteen months. Updates are accomplished periodically, as often as two to three times between major version publishing cycles. The Joint Logistics Commanders should ensure updates include appropriate munition effectiveness data based on data made available since the previous update.

Combat operations are typically characterized by high-tempo munitions employment. Doctrinally and practically, the Services conduct battle damage assessment and munitions effectiveness assessment in the course of normal combat operations. These are normally focused on target damage and effects against the enemy. Documenting the specific locations and quantities of battlefield UXO is *not* a standard activity. Although air, land, maritime, and special operations components share data, they do not do so in an automated, centralized and coordinated fashion. Established methods do not lend themselves to real-time data call and interpretation.

As noted in the discussion of munition effectiveness, feedback from real-time munitions employment is poorly managed and not integrated. This is the result of a high operational tempo, which stresses the ability to process, interpret and catalog this information. While the impact of this feedback on legacy systems—no longer in production—may be negligible, the feedback on systems still in production, or for which there are planned upgrades, could mitigate design and manufacturing problems during subsequent production. This Task Force's survey revealed that fuze manufacturers have no direct interaction with field commands, nor do they have access to any central theater munitions effectiveness database documenting reliability trends. The inclusion of acquisition-trained officers on theater munitions evaluation teams (both during and after conflicts) will lead to the development of proper feedback mechanisms. Online Joint Munition Effectiveness Manual-based "lessons learned" would be one method for timely distribution of new observations on munitions system reliability performance. These observations could be included as updates to computer-based weaponeering systems, and thus rapidly distributed back to the field as automated "lessons learned."

Post-combat actions consist of data verification and selective clean-up of UXO. Joint commands and the Services develop lessons learned during this phase. This phase may partially overlap in time with combat operations, such as when ground units report observations of air- or surface-based strikes with evaluations of specific munitions effects.

Munitions reliability should be a formal part of munitions effectiveness assessment. As mentioned earlier, there is no real-time methodology in place or in practice that expeditiously and accurately tracks the failure rates of US munitions in combat use. Munitions expenditure assessments are inadequately linked with target-selection processes. Target selection processes are further complicated by the high-tempo targeting cycle preferred by US forces. Post-combat battlefield data collection teams need to include acquisition-trained personnel. These personnel will be able to determine the information manufacturers require during munitions design and production. To the extent declassification allows, manufacturers will be able to use this feedback to improve munitions and munition components.

On the whole, the DoD has a significant opportunity to improve data sharing. This includes inter-Service and military-industry contacts.

Chapter 2. Technology and Design Issues

This section will address the scope of the technology areas associated with overall munition operational reliability. In particular, it will expand the discussion to include target identification and guidance systems, the potential for applying RF tagging to UXO remediation, monitoring operational performance of munitions for design and employment feedback, and the factors associated with the development of electronic and integrated fuzing, targeting and guidance systems.

KEY RECOMMENDATIONS

- **The Director, Defense Research and Engineering (DDR&E) should fund new research investments into inexpensive, ultra-reliable fuze development based on integrated circuits, Micro-Electro-Mechanical Systems technologies, and integrated fuze, guidance and targeting systems.** The DDR&E should establish pilot science and technology programs to achieve safety-certified, integrated fuzing, targeting and guidance systems. A reasonable goal would be to have at least two certified IC/MEMS-based fuzes available for introduction by 2008.

- **The DDR&E needs to drive more joint weapons development efforts with the associated multi-Service research efforts to achieve a critical mass of scarce development resources.** Organizations such as the Defense Ordnance Technology Consortium are a good start, but are limited because of their voluntary nature; a forcing function and authorities need to be put in place. Further weapon acquisition and weapon research consolidation is necessary in order to maintain a governmental skill base. Joint research targeted at larger joint weapons programs will allow both industry and the Services to maintain a workforce capable of developing and producing state-of-the-art, highly effective and highly reliable munitions.

- **The Under Secretary of Defense for Acquisition, Technology and Logistics should expand efforts to develop radio frequency tags for munitions beyond logistics tracking to facilitate UXO remediation for new systems.** A DoD goal should be a single common tagging system for munitions of all types. DoD should develop a low cost, integrated RF tag. Economically, it does not make sense to retrofit all area attack munitions currently in storage, since the cost of installing the tags significantly exceeds the cost of the tags and outweighs the effective benefits. However, tagging existing area attack munition dispensers may be a viable method for identifying potential UXO sites.

- **The Services should explore methods to provide operational test and combat operations performance feedback to the acquisition community and the supplier.**

This feedback should be used to optimize production methods, ensuring increased reliability through improvements in design and production control methods and documentation.

The Task Force has reviewed the technology activities of the Service weapon labs, the ongoing munitions development programs and the various industry internal research and development activities. It has also looked at related technology areas in energy storage and remote sensing. It reviewed munition reliability performance data from monitoring/testing and tried to compare it to operational performance results.

The Task Force's general conclusion is that there is excellent work being performed throughout the munitions community to improve performance and reliability. However, the size of US arsenals and the relatively low level of area attack munition research and development now ongoing means that more reliable munitions will make up a very small percentage of the stockpile available to our warfighters for many years to come.

The Task Force considered several related areas for improvement that reduce collateral damage, fratricide risks and UXO challenges without directly addressing per-unit munitions reliability. Specifically, it looked at improved targeting and target identification, guidance and navigation improvements, theater munitions operations tracking and feedback for munitions design and operational weaponeering, and RF tagging of munitions for improved logistics operations and UXO remediation. None of these related areas contains any "silver bullets" that would transform the need for munition reliability improvement. However, these broader areas of the munitions operational profile can be applied to reduce significantly the unintended consequences of munitions use, and should be considered in a more complete DoD response to munitions reliability.

Critical Technology Areas Related to Munitions Reliability

Precision-guided munitions (which fly to a designated point) and smart munitions (which search for, identify and home on specified targets) incorporate their guidance and navigation functions with the fuzing function. Owing to the overall expense of these munitions, it is economically feasible to employ more sophisticated and expensive fuzes, increasing the reliability of the explosive payload initiation. However, an additional reliability factor will be of concern in achieving the overall battlefield goals of munitions reliability (maximum survivability of US and friendly forces, minimized logistics load, and minimum collateral damage and risk to civilians). This additional concern is that the functions of precision guidance and smart munitions target recognition and acquisition themselves provide input to the fuze. An incorrect target location insertion into the precision-guided munitions, or an incorrect target recognition and homing acquisition may result in the same effect as a direct fuze (explosive charge) initiation failure or other improper function. Friendly forces or civilians might be mistakenly identified as the enemy target, or misdirection or false target indications may defeat the high lethality intent of the munitions.

Munitions reliability in the sense of two important measures—lethality, and risk to friendly forces and civilians—is generally seen as a question of fuzing reliability with associated implications for failure rate and UXO risk. The overall question of munitions systems reliability, however, extends across the entire functional scope of munitions operation. The Task Force focused primarily on reliability issues related to the two important measures of lethality and risk, which are a critical part of the present (and probably continuing) new paradigm for warfighting by US forces, which we suggest may be stated in three parts:

- Very high single-shot kill probability to minimize logistics and time to win;
- Very low to zero US and friendly force casualties; and
- Very low to zero collateral damage to civilians and civil assets.

In this context, the critical technical issues are those of:

- Reliable fuzing (the munitions must go off);
- A high degree of control of the munitions' lethal effects area;
- A very high probability of correct target identification; and
- A very low probability of friendly or civilian targets being incorrectly identified as valid (i.e., enemy) targets.

These issues relate to:

- Reliable fuzing (inexpensive but highly reliable fuze technology);
- Correct target identification (sensor and processing technology); and
- Accurate guidance to the target (both guidance and navigation technology).

The current state of technology in each of these areas will be addressed in the following sections.

Reliable Fuzing

Modern US conventional munitions of the larger calibers (105mm, 155mm artillery and tactical missiles)—both with unitary warheads and NATO standard fuzing—have on the order of 99 percent reliability. Smart munitions and precision-guided munitions also have very high reliability numbers. Both can afford relatively expensive fuzes since the overall cost per munitions unit is high, and the fuze represents only a minimal incremental cost within the overall per-round cost of the system.

Current stocks of area attack munitions and smaller caliber automatic cannon do not have comparably high reliable fuzes. Failure rates are reportedly as high as ten percent and—under some impact conditions (such as sandy or snowy terrain)—may be considerably higher. The low-cost-per-round requirement for these systems means that these fuzes must be very low-cost fuzes. Modern technology provides a basis for the development of low-cost reliable fuzes for these systems. There is a great reluctance, however, to destroy the stockpiles: (1) the United States may need to use a significant number of these systems in the event of a major contingency; (2) replacement systems might not provide the same needed capabilities that the existing systems do; (3) there are insufficient funds to cover demilitarization requirements; and (4) the replacement cost for current stockpiles would be enormous.

Correct Target Identification

Although military forces have been identifying targets for centuries, it has recently become possible to achieve this function from significant distances with very high accuracy. As this ability has become more available and better measured, US forces are beginning to discover the risks and implications of accurate target identification. For direct fire from a weapons platform, target identification is addressed by Identification Friend or Foe systems and man-in-the-loop control. These methods are by no means foolproof, but in recent conflicts (Bosnia, Afghanistan and the two Iraq engagements) direct friendly fire casualties have been low. Improved fire-control systems will result in even lower friendly force risk.

In the case of indirect fires, for which the smart munitions have been specifically designed, the objective is to assure very high single-shot lethality while reducing the exposure of US troops in the process of target acquisition. Unmanned aerial vehicles and other remotely operated target-acquisition assets help in this regard. The smart munitions themselves also incorporate terminal seekers designed to provide final identification of the target and highly accurate homing of a limited-warhead (reduced kill radius) guided munition in order to assure high lethality through a direct or near-direct hit. At the same time, this same accuracy and smaller kill radius reduces the risk of collateral damage.

In the context of the new warfighting paradigm of little or no friendly force risk or collateral damage, the reliability of correct target identification may be expected to become an increasingly important issue, potentially limiting the use of some smart munitions under certain conditions in a similar way to that now experienced with the use of area attack munitions. The Task Force has seen that even single errors, such as the accidental bombing of the Chinese Embassy during Operation Allied Force, can greatly impact overall collateral damage effects in terms of lives and political impact.

The critical technology required to achieve a very high reliability in target identification and homing for these smart munitions is more complex than that required for reliable fuzing. The specific nature of the sensor operation, the observable qualities of target and background for the sensor, and the algorithms used to make target identification decisions (with consequent errors of the first and second kind) will be more difficult to handle and may require significant improvement in sensor data-processing systems.

In any event, following the first priority of obtaining an affordable and reliable fuze, this second reliability risk area may be expected to predominate over the next generation of smart munitions.

Precision Guidance to Target

This is a third and developing area of munitions reliability risk in the context of the desire for little or no friendly force risk and collateral damage. In this case, the indirect fire problem is one of identifying a correct target and a correct target location for attack by remote indirect fires. To do this, remotely operated forward observation means will be increasingly employed. Inaccurate guidance or incorrect target identification will again detract from the desired outcome of killing only the enemy assets. In a denser target environment, problems of this type will grow.

Technologies of importance in this area relate not only to highly robust guidance and navigation systems—particularly to resist GPS jamming—but also to the question of battlefield awareness and target intelligence processing and dissemination. The use of "layered navigation systems" (using sensors, in addition to GPS, to provide positional information to the guidance and navigation system) will assist in achieving such robustness. The technologies of interest to the "Family of Integrated Operational Pictures" system (Single Integrated Air Picture, Single Integrated Ground Picture, etc., functions to be incorporated in the Global Information Grid under the Net-Centric battlefield) will be important, but outside of the scope of specific munitions design.

Target Sensing

This section briefly considers the role of target sensors in munitions reliability—how they may be considered as a part of the fuzing function—and the particular importance of the reliable functioning of target sensors in reducing the risks of fratricide (friendly force risk) and collateral damage (risk to civilians).

For this report, the fuze system is assumed to include the following functions:

- **Safeing** assures that the fuzed munitions are safe to use (very low risk of premature detonation), blocking initiation functions.
- **Arming** assures that the fuze is ready to operate based on arming input from appropriate sensors within the fuze system. Arming input may also include signals received from active communication with outside control means.
- **Target sensing** provides appropriate interaction with the target (not necessarily direct contact) which will cause the initiation (see below) of the munition.

- **Initiation** (of the explosive payload) sets off a train of energetic materials leading to the booster ignition of the main energetic payload, which may either be the explosive charge or an expulsion charge for the ejection and distribution of munitions.

Self-destruction, although not a core function of a fuze, causes the complete detonation of munitions or a complete failure (fire train to booster destroyed). Any remaining explosives cannot be easily set off. Neutralization, in similar fashion, causes the energetic elements of the fuze to become totally inert.

These fuze functions, as applied to conventional munitions, are illustrated in Figure 2.

Conventional Munitions

All munitions fuze systems sense the target in some manner, the simplest by direct impact with whatever object is struck by the munition. Certain smart fuze systems sense the environment during penetration to initiate the fuze at the appropriate depth or distance. These sensors are largely inertial in character. Such smart fuzes are generally combined with precision-guided munitions or smart munitions (see below). Non-impact fuze initiation can be determined by various timing techniques, electronic, pyrotechnic or mechanical. Height-of-burst fuzing (e.g., the Multi-Option Fuze for Artillery, or MOFA, system) can also be initiated by a simple radar or radio-altimeter system. Finally, air target proximity fuzes are initiated by an active (usually RF) detection system that is part of the fuze system. Command-guided munitions systems can also be initiated by direct command to the munitions.

For this class of munitions, the risks to friendly forces and civilians are primarily those associated with the failure rates of the specific fuzing systems and the reliability of back-up self-destruct systems. Owing to the relatively low delivery accuracy of conventional munitions, their use in populated areas carries significant collateral damage risk, both from normally functioning fuzes and from residual UXO.

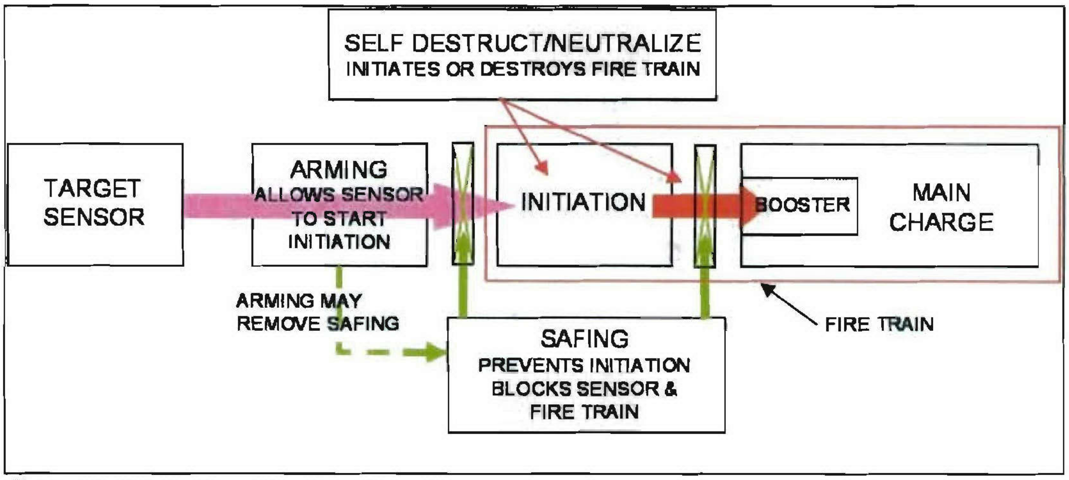


Figure 2. Basic Fuze System Functions

Precision-Guided Munitions

Precision-guided munitions employ active and passive technologies to increase the accuracy with which munitions may be directed to a particular impact point or fuze function point (air burst, height of burst, etc.). These munitions are capable of controlled flight. Coordinate-seeking munitions rely on receiving target position information from the GPS constellation and combining this information with an on-board inertial reference to arrive at a point in earth coordinates defined by the GPS reference system. Designated-homing, precision-guided munitions rely on sensing a homing reference (laser designation, for example) placed on the target by external means to achieve a high-accuracy hit on the illuminated spot. The relationship between the designated point (defined by the earth coordinates or the illuminated spot) and the target itself is a function of—and directly related to—the lethality desired against the selected target. The precision-guided munition fuzing system itself may be no different than those in conventional standard unguided munitions. In some cases, the precision-guidance system itself may be used to supply arming and fuze initiation information to the fuze system.

For precision-guided munitions, the primary risks to friendly forces and civilians remain those associated with the failure rates of conventional munitions fuzing systems and the reliability of back-up self-destruct systems, since these systems are essentially identical to conventional systems, but delivered more accurately. Note, however, that very precise delivery *to the wrong spot* will significantly reduce the overall lethality of a precision-guided munition fire mission against that target. In other words, the increased battlefield lethality of these munitions will only be realized if the target location is known *accurately*.

The potential insertion of precision guided munition input to the fuze is illustrated in Figure 3.

Smart Munitions

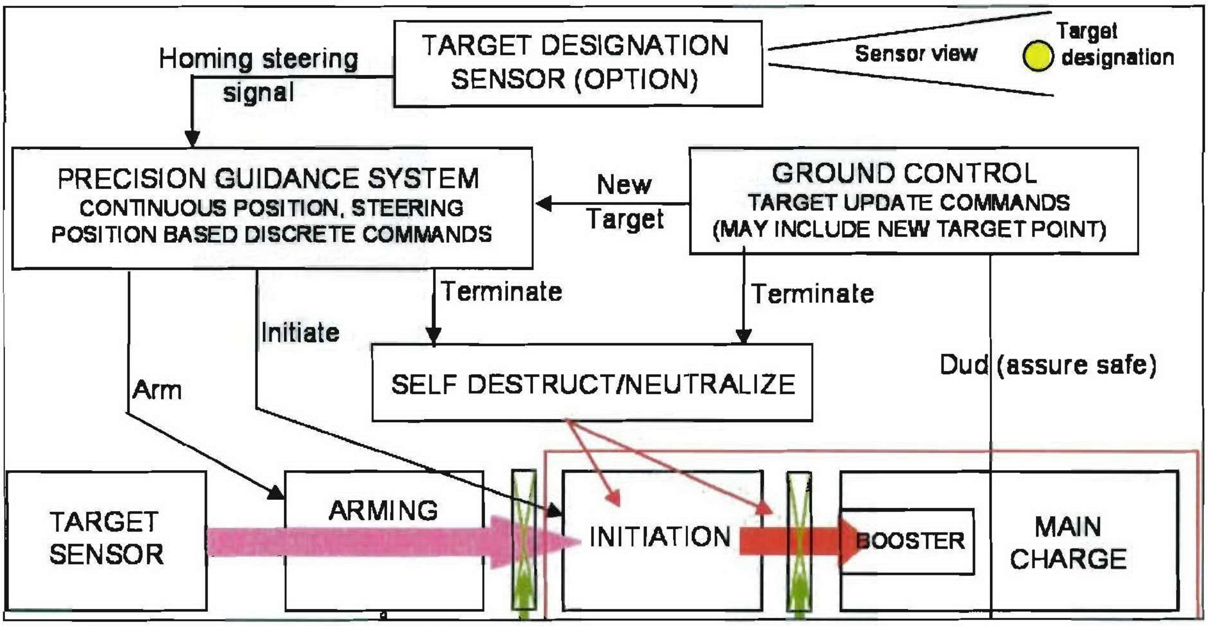


Figure 3. Precision Guidance Input to Fuzing

Smart munitions are generally categorized as those employing a terminal homing means that can both sense and recognize the target. In this case, the general target location is known (GPS coordinates or otherwise) and the smart munitions are directed to that area. Arriving at an "acquisition basket" which encompasses the general target location, the homing sensors on these smart munitions then search for, identify and home on the desired target. Fuzing against the target may rely on a combination of the target homing sensor and other standard fuzing methods.

In smart munitions systems, there is an additional reliability factor associated with risk to friendly forces and to civilians—the risk of mistaken identification. The target acquisition and homing sensors must apply certain built-in tests (computer image processor, for example) for "true target" and, if these tests are "passed" (i.e., the system produces a "true target" indication), the munition then homes and fuzes on that target. As in any formalized decision process, there are potential errors of two kinds: real targets that are not detected, and non-targets that are identified as real targets. It is this latter class that constitutes the additional risk associated with smart munitions. The selected non-targets may in fact be friendly forces or civilians or civilian assets; therefore, a rational set of general considerations of munitions systems reliability may also include the risk of target sensor error and the consequent high-lethality engagement of friendly or civilian assets. The insertion of smart munitions input to the fuzing functions is illustrated in Figure 4.

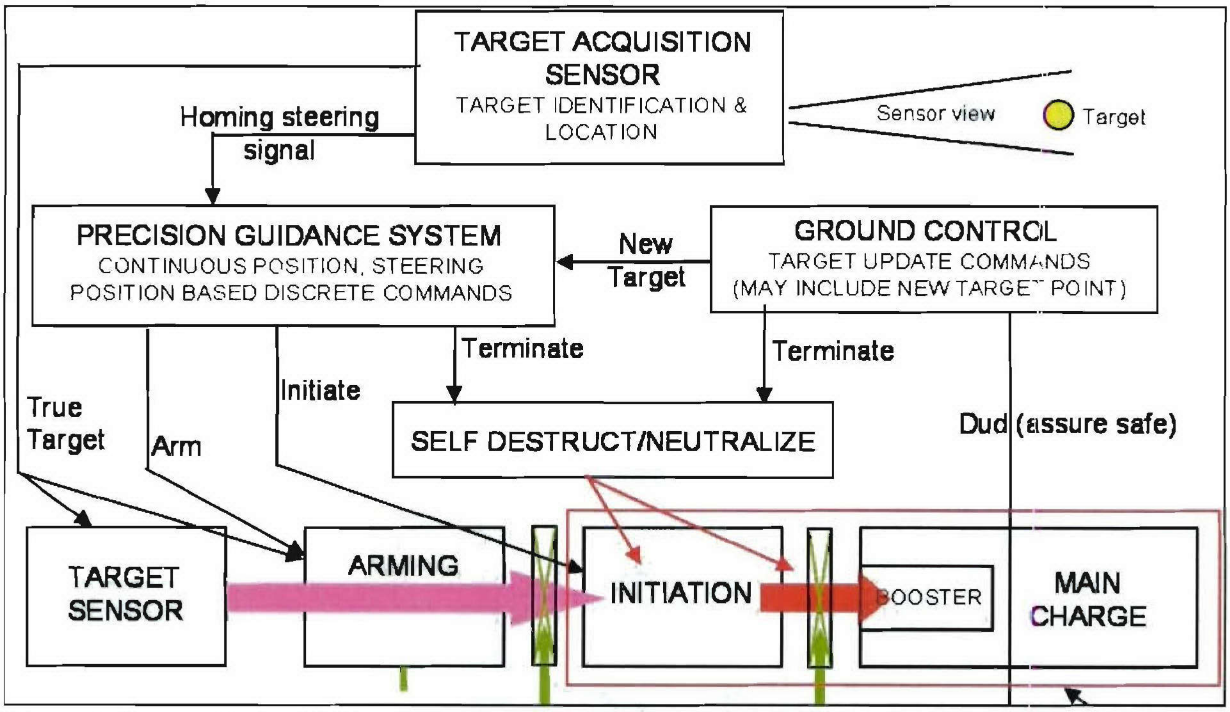


Figure 4. Sensor-Based Fuzing: Target-Based Identification and Homing

Electronic, MEMS, and Integrated Fuzing

This section will address a trend in munitions system design that the Task Force believes will have a significant effect on future fuzing systems and the industry that develops them. The Task Force believes that pressure for increasingly sophisticated munitions systems has created, and will continue to create, pressure for integrating the fuzing function with other parts of the munition, particularly with the guidance and targeting systems. This is likely to change the markets for fuzes of any type, impacting plans for improving fuze reliability and industry production availability.

Traditional fuzes integrate several complex functions while maintaining the primary objectives of providing safety and arming. The more modern fuzes in US inventories typically contain fuze components which include: the target sensor (mechanical or electrical), a reserve power source, a safeing and arming device, and an explosive train.

Current and future warfighting scenarios are driving the need for smarter munitions that have longer range capability, can be placed more accurately on target, and reduce collateral damage. This need for smart munitions is subsequently driving the need to develop more complex munitions that integrate more complex technologies. With the push to integrate more complex functions (such as course correction, GPS, inertial guidance, electronic safeing and arming, and multi-mode initiation) into fuzing systems, there is an increasing need to miniaturize these new technologies as well as the traditional fuze components so that all of these can be packaged into the same space and volume of a conventional fuze. Integrating these technologies should have a significant effect on cost and logistics. Technology integration also affects the fuze industrial base.

Advances in MEMS technology seem to offer the opportunity to achieve reliability through multiple parallel path redundancy, mechanical fire chain interruption, and the general state of IC reliability, with the low cost of such systems, once developed and engineered through the IC/MEMS foundry process. Many current fuze makers recognize this potential line of development, but the "new paradigm" is such that the most capable producers have the best potential of utilizing this new technology. A newly emerging MEMS-based fuze technology may well find its base in firms other than today's fuze suppliers. The implications of such a shift for the fuze industrial base may be profound.

The transition to electronic designs greatly enables integration of the fuzing functions with other munition functions. The technologies for more integrated guidance and fuzing are available but have not been applied fully. This transition promises lower operational costs and improved logistics but requires up front investment for the unique application to munitions systems.

Given the potential for improved performance, lower cost and better reliability, there does not appear to be adequate investment in IC/MEMS fuzing and integrated designs either within munition programs or at the weapon labs.

There are several reasons for the relatively slow pace of change in this area:

- Munition affordability and risk to market drive acquisition executives to use established technology;

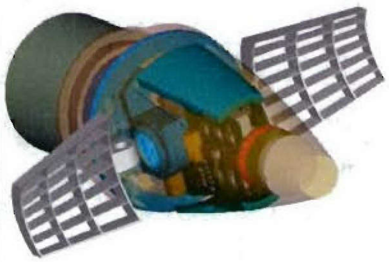
- With fuzes near the bottom of the funding "food chain," less technology investment has gone into the fuze and its integration;

- There is a perception that munition unit cost will grow with improved integration, leading to un-affordability;

- There is a concern that newer "integrated designs" or IC/MEMS-based systems will not be accepted by safety review boards; and

- The effects of earlier munitions development and stockpiling have suppressed demand for new munitions that could more easily incorporate these approaches.

In terms of affordability the Task Force recognizes that adding more complexity will also increase the unit cost of any end item. One might argue that the cost of smart munitions is not affordable but the entire picture must be analyzed. If one smart munition can produce the same effects as 20 traditional munitions—plus reduce the effects of collateral damage and the logistics train to track, transport and carry—then the cost of the system would be justified. For example, the projected cost of a Guidance Integrated Fuze (see Figure 5) is in the $3000 range. It is anticipated that using one of these fuzes may eliminate the need to fire on the order of 20 projectiles with multi-option fuzes. These fuzes currently cost approximately $220 each. The cost savings alone is approximately $1200 (and this does not include the cost of the projectile), plus the additional savings from reduced logistics of carrying 20 fuzes and projectiles. Smarter munitions can actually reduce the number of soldiers and platforms required to gain the same effects.



Guidance Integrated Fuze

Multi-Option Fuze for Artillery

Figure 5. Guided Integrated Fuze and MOFA

The Task Force has seen some programs that have chosen to avoid integrated or electronic fuzes to reduce the risk of passing the weapon safety review. Weapons safety review boards have traditionally made use of certification through comparative design and visual inspections. Both of these proven approaches are challenging to apply to new IC/MEMS or highly integrated designs. Board members have in-depth understanding of traditional separate designs and far less experience with the new approaches. Some examples of successful certification exist (electronic safe-arm devices are now accepted and MEMS safe-arm devices are starting the review process), and others will follow that will provide an experience base in the area and reduce this programmatic risk.

The intensity of munition programs development is clearly well down from the peak of the cold war. This reduced need has led, in turn, to fewer munition programs and smaller numbers in production for each program. This will suppress the broad adoption of electronic or integrated fuzes in two ways. First, the economic case for the change is reduced with smaller production runs. Secondly, there will simply be fewer new munitions relative to our large arsenals for some time to come.

Of course one must consider the effects of reliability on a system when adding more complexity. While added functions will generally cause a system to be less reliable, there are several reasons to believe this can be avoided with integrated fuzing. First, the electronic, MEMS and IC approaches used in integrated fuzes have demonstrated extremely high reliabilities in other applications and are inherently resistant to most environmental extremes and contaminates. More importantly, the cost and size of this technology easily enables redundant functions to improve reliability. Technologies such as MEMS are being considered as a vehicle to integrate traditional safeing and arming functions with electronic fuze functions. The Army and Navy are both developing fuze systems that will integrate multiple fuze functions within a single integrated circuit (Figure 6). It is likely that any new program would consider this option for development, and that many will follow this path.

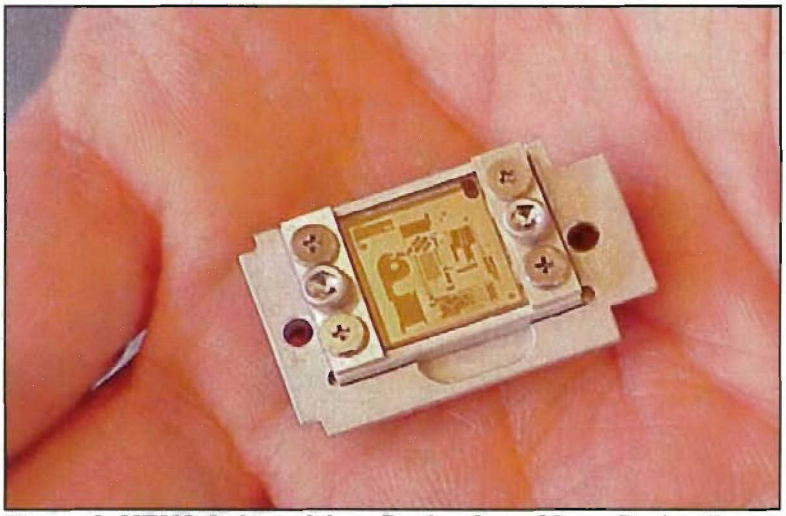


Figure 6. MEMS Safe and Arm Device for a 20mm Projectile

Advances in smart munitions have shaped, and will reshape, the industrial base. As discussed above, more effective smart munitions should reduce the need for the traditional quantities of munitions. This reduction in purchases will most likely affect the shape of the industrial base because manufacturers have to make adjustments to account for a reduced labor force and operational capability. In some instances, out-year purchases of more traditional munitions systems have been cancelled because of the emergence of smart munitions. For example, the Army has significantly reduced its requirement for MOFA fuzes by almost 800,000 from just two years ago because out-year production money was shifted toward guidance-integrated fuzing. This drastic change in requirement has driven the current producer of this fuze to consolidate operations. A sister division is now in jeopardy. The result may be the loss of the only qualified liquid-reserve power source supplier in the US industrial base.

The smart munitions that will be procured will be more sophisticated and produced in much lower numbers. Current suppliers may not be able to transition to a business model that supports higher-end, lower-volume units. They will also have to convert from an electromechanical base to full electronics or integrated hybrids. It is expected that this transition will further erode the industry. The Task Force believes that the end state may be traditional fuze production only for small arms, if at all, and a different mix of contractors building a smaller number of integrated fuze, targeting and guidance systems. DoD's effort should be focused on achieving this transition swiftly because of the improvements in reliability and performance it will bring, but with minimal disruption to necessary munitions maintenance and continued production.

The Task Force therefore recommends that DoD undertake the following actions:

- Fund new research investments into inexpensive, ultra-reliable fuze development based on integrated circuits, MEMS technologies, and integrated fuze, guidance and targeting systems. This will require an overarching investment at DARPA or across the weapons labs in addition to the individual munitions system targeted programs. Specifically, the labs should concentrate on safety-certified, IC/MEMS fuzing while DARPA develops integrated electronic fuze, guidance, targeting devices (a "single chip" munition control). DARPA's efforts should also address safety certification.
- Establish pilot programs in each Service to achieve safety-certified, fully IC/MEMS approaches to integrated fuzing, targeting and guidance systems. OSD should advocate these pilot programs, given the impact that proven, certifiable safety design can have on accelerating the technology transition. A reasonable goal would be to have at least two certified IC/MEMS-based fuzes available for introduction by 2008.
- Consider logistical system modification to support technology-refresh lifecycle strategy. The trends toward integrated fuzing will tax energy storage systems that supported earlier dedicated fuze designs and further undermine production capabilities as numbers needed drop. Consideration should be given to adopting commercial, replaceable energy storage devices (i.e., alkaline or lithium batteries) or the equivalent. While this allows the munitions community to take advantage of improvements in the vastly larger commercial battery industry, it has impacts at every stage of logistics and munition operations.
- Drive more joint weapons development efforts with the associated multi-Service research efforts to achieve a critical mass of scarce development resources. All the trends are for fewer weapons types procured in smaller numbers. Creating efficiencies may require more joint-Service acquisitions of similar if not fully common weapons. Research efforts should also be considered for consolidation, as the same pressure for a smaller workforce drives experience and corporate memory out of the weapon labs. Organizations such as the Defense Ordnance Technology Consortium are a good start, but are limited because of their voluntary nature; a forcing function and authorities need to be put in place. Joint research targeted at larger joint weapons programs will allow both industry and the Services to maintain a workforce capable of developing and producing state-of-the-art, highly effective and highly reliable munitions.

Munitions Tagging

Acting Under Secretary of Defense for Acquisition, Technology and Logistics Michael W. Wynne, in his capacity as the Defense Logistics Executive, issued a tagging mandate in July 2004 intended to address the logistical aspects of tagging. This was in recognition of the benefits of tagging demonstrated by commercial tagging initiatives.

Tagging technology has advanced rapidly in the past few years, leading to a wide assortment of tag technologies. In particular, advances in RF, optical, spectral imaging, and nanotechnology-based tags promise to revolutionize monitoring and tracking. Table 1 provides a summary of some of the current and emerging tagging technologies available in both the commercial and military sectors. In addition, it presents some of the relevant research being conducted by DARPA and others.

Table 1. Tagging Technologies

Tag Type		Sector	Current Applications	Programs
RF Tags	Passive	Commercial	RFID, Theft Protection	Express Pass, E-Z Pass, Railways....
		Military	Logistics	DARPA Digital Dog Tags, DoD Assets
	Semi-Passive	Commercial	Container Tracking	Alien Technologies Backscatter Tags
		Military	Combat ID, Asset Location	PNNL Programs, VESTA/PARD
	Active	Commercial	GPS Locators	GPS Locators
		Military	Radar Responsive Tags	RF STORM, DRaFT, Army RATE
	Passive Radar Reflectors	Military	Tracking and Targeting Tracking Secure Documents	—
	GPS Data Loggers	Commercial	Asset Tracking	Fleet Management, Rental Cars
		Government	Vehicle and Item Tracking	Law Enforcement, etc.
	GPS Beacons	Commercial	Location Reporting	Garmin Rhino
		Military	Personnel Location	Grenadier Brat, CSEL
Optical	Barcodes	Commercial	Product Marketing	Consumer Producets
	Beacons	—	—	IR & UV
	Fluorescent	Medical	Cancer Research	
		Military	Tracking & Targeting	DARPA/SRI
	Retro-Reflective	Military	Location & Covert COM	Dynamic Optical Tags (DOTS)
	Spectral Imaging	Commercial	—	—
		Military	Tracking & Targeting	—
Isotopic & Chemical	Markers	Commercial	Product Tampering	Oil & Gas Industry

As the purpose of this discussion is to focus on technologies suitable to the tagging of munitions, it will focus on those technologies that are suitable to the operational and environmental constraints likely to be encountered by munitions handling.

It would be a mistake to assume that the advances made in the commercial world are directly applicable to tagging munitions. While Wal-Mart seeks to automate inventory control and minimize theft through the use of simple, low-cost tagging technologies, these are largely inappropriate for munitions. Table 2 below provides a generalized comparison between low-cost, commercial tagging technology and the military requirements for munitions tagging. Note that the cost estimates do not include the cost of "installing" the tag. This cost will vary widely depending on the application. For instance, self-adhesive tags can have minimal installation costs, but an active RF tag could require significant effort to install.

Table 2. Comparison of Commercial and Military Tagging Performance

Performance	Commercial	Military
Shelf Life	Days to Weeks	20 Years
Maximum Detection Distance	< 10 Meters	200+ Meters
Security	Little or None	Medium to High
Technology	Optical and Near-Field RF	Optical and Far-Field RF
Environmental	Industrial	Extreme
Cost per Tag	~ $.01 to $2	$.50 to $25 est.

It should also be noted that there is no single solution that will satisfy all the diverse munitions tagging requirements. For instance, optical tags, such as barcodes and beacons, are well suited for many logistical control applications. However, optical tags require line-of-sight access; they are not well-suited to applications such as inventory analysis, theft protection, and UXO detection. For these applications, RF tags provide the best flexibility and performance. Therefore, the remainder of this discussion will focus on the use of RF tags for munitions.

Table 3 provides a perspective of the RF tag capabilities and allocations. In general, RF tags can be grouped into three major categories: passive, semi-passive, and active. Munitions-related applications for RF tags include theft detection, logistics and inventory control, and localization. A side benefit of localization is the ability to locate UXO. Performance characteristics depend on a number of factors, including frequency range, transmit power, waveform and antenna size.

The distinction between the various categories of RF tags can be gray. This Task Force has been shown how energy scavenging could be used in place of a battery to power active RF tags for detection ranges in excess of 100 meters. This eliminates the need for lifetime-limiting batteries.

Table 3. General RF Tag Capabilities Comparison

Type	Effective Range	Battery	Life	Security	Programability	Data Range
Passive	10 m	None	Indefinite	Medium	None	Low
Semi-Passive	150 m	Small	10 Years	High	Medium	Low-Medium
Active	100 km+	Medium-Large	<1 Year (typically)	High	High	High

Research in RF tagging for military applications has been carried out by DARPA and other research facilities such as Sandia National Labs and Pacific Northwest National Labs. These efforts have been largely aimed at Blue Force tracking and high-value asset tracking. DoD has recently committed to tagging all weapons for logistic tracking purposes. This will foster subsequent developments aimed at low-cost munitions tracking that addresses the development, storage and transportation phases of the lifecycle. It does not appear that this effort will extend to operations and UXO recovery phases (see Figure 7). This is of considerable concern and should be addressed before fielding any system.

DoD should expand its efforts to develop RF tags for munitions beyond logistics

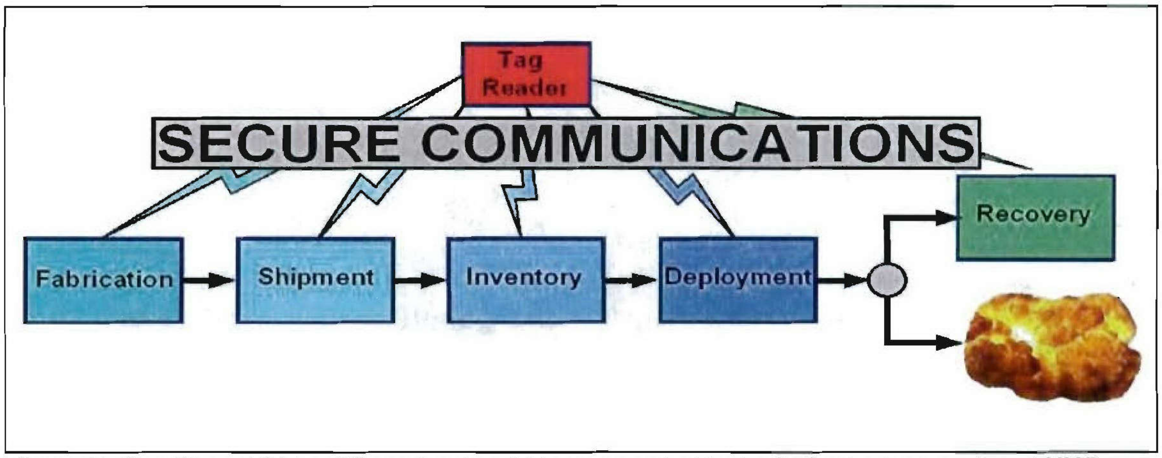


Figure 7. Munitions RF tag lifecycle should be expanded to include deployment and UXO recovery.

tracking to include UXO remediation for new systems. RF tags offer the best performance for tagging munitions, primarily because they do not require a clear line of sight from the reader to the tag. It is highly desirable to have the minimum number of solutions for all classes of tagged munitions in order to minimize the ultimate cost and improve flexibility. A DoD goal should be a single common tagging system for munitions of all types. This requires an operational view that extends across numerous weapons platforms.

In order to achieve low production costs for such a tagging system, DoD should develop a low-cost, RF-integrated chip (RFIC) tag. The system development must include all aspects of the munitions life cycle—in particular the UXO recovery phase. The benefits of tagging could be extrapolated to encompass the entire munitions life cycle. This is consistent with the DoD tagging mandate view of tagging individual, higher-value munitions to enhance force protection. Tagging larger, higher-value munitions makes sense. In addition to the logistical benefits, the tags could be used to ascertain munition effectiveness after deployment.

Economically, it does not make sense to retrofit all munitions currently in storage. The tag and installation costs can greatly exceed the effective benefits. For instance, it can be shown that the cost of tagging individual BLU-97 munitions clearly outweighs the benefits. However, it would make sense to tag the dispensers that contain the area attack munitions. In addition to the logistical benefits, the dispensers can be used to locate the area that might contain UXO after employment.

Precision Guidance and Munitions Reliability Impacts

The justification for acquiring improved fuze performance, as well as the general development of precision-guided and smart munitions, is that of significantly improved lethality per shot or sortie and the attendant savings in the logistics chain and sortie generation. Three areas of particular savings will have a positive effect on combat efficiencies: logistics chain impact, U.S. and friendly force combat survivability, and collateral damage. The fewer munitions required to achieve a particular effect, the less the logistics pre-load and continued munitions flow in battle preparation and engagement. Further, fewer munitions on target to achieve desired battle damage probability will generally result in a higher lethality (less attack-time opportunity for a mobile target to achieve protective cover, for example). Highly reliable and accurate munitions also contribute to a significant reduction in friendly force risk (fratricide) and residual (UXO) impediment to friendly force maneuver. Finally, especially in current and potential future combat scenarios, a critical issue is the avoidance of collateral damage and risk to civilian populations that place in jeopardy the objective of "winning the hearts and minds" of the peoples involved. Smart and precision-guided munitions reduce the chances of collateral damage, especially in confined and urban environments. The added expense per round of the precision or smart munition may well be more than offset by the advantage values gained in these confined areas.

U.S. Forces are in the midst of a revolution in military affairs. GPS and numerous inexpensive and accurate sensors have enabled a broad transition to precision targeting and a substantial drop in the number of munitions needed to prosecute military operations. While the addition of precision targeting and guidance does not in and of itself improve munitions reliability, it provides several tangible related advantages.

- By reducing the number of munitions expended, the quantity of UXO is correspondingly reduced. Air operations have moved from the era of ten or more sorties per target to ten or more targets per sortie in a very few years. Operations in Kosovo, Afghanistan and Iraq have demonstrated air operations effectiveness in excess of any earlier approaches and with vastly less ordnance. Similar improvements will be brought to ground operations with the next generation of missile and artillery systems.

- The use of precision munitions has reduced the area in which UXO may be located. The guidance systems used have proven to be reliable enough that very small amount of ordnance will be deposited outside of tight boundaries around the target area. Even for area attack munitions, this means predictable and smaller areas for potential UXO consideration. While not directly affecting the "percentage failure" of the munitions used, this effort will greatly reduce the number of area attack munitions needed to achieve the desired effect, thereby reducing the amount of UXO.

- The economics of targeting prosecution have been substantially changed by these new guidance and targeting technologies. In addition to vastly reducing the numbers of munitions needed, the new guidance and targeting technologies have reduced the cost of logistic support, training, and operations (e.g., fueling, repairs). These munitions also provide the capability to handle many targets per sortie, rather than many sorties per target to assure target kill, thus significantly reducing the cost of overall tactical operations and cost-per-target kill.

- Certain potential future combat scenarios, however, may require the massed use of conventional munitions for force protection and ultimate defeat of enemy forces. DoD will need to maintain a balance of highly efficient, precise munitions and less precise but very low-cost munitions that are efficient against massed area-wide attacks.

It is the combination of the first two effects that has led to the most substantial recent improvements in reducing collateral damage and the risks posed by UXO in recent US military operations. DoD should consider policy changes that compare the effects of precision guidance on operational UXO issues when assessing compliance with direct munitions reliability performance. If the intention of DoD's submunitions reliability policy is saving the lives of civilians and US forces, it should consider indirect effects (such as guidance) as well as the directly measured munitions reliability.

It is not clear that any further effort needs to be applied to take advantage of these effects. The value of precision munitions is well understood, as is the need to achieve precision or near precision in each new munitions system. It is also clear that the lethality of these accurate munitions has enabled greater use of unitary warheads, which makes it economically and technically much easier to achieve higher levels of reliability.

Recently, many programs facing acquisition milestones have chosen unitary munitions to replace area attack munitions. The Task Force considered a recommendation mandating this transition, but has come to believe that this step is premature because (1) following the recommendations in this report can lead to technically acceptable highly reliable munitions and (2) area attack munitions provide a valuable tactical capability that cannot at present be replicated by other munitions.

Operational Performance Assessment of Munitions Reliability

During this review, the Task Force repeatedly tried to review operational performance data for the munitions of interest. It was clear that there is no structured mechanism for tracking munition reliability in combat operations. Some munitions reliability data can be inferred from strike assessment reporting, but this can only bound the failure rate.

Modern production techniques, especially flexible precision manufacturing, can be set up to maximize the effectiveness with which feedback information on reliability (test and field performance) may be inserted into the production and quality control process to improve product reliability. The Task Force has, however, found that there is no effective mechanism in place to provide this feedback to the munition or fuze manufacturer, and that the manufacturers do not receive timely or useful information about the types and nature of operational failures experienced in use.

It should also be possible to provide improved munition performance predictions with this type of data. It is understood that many of the most problematic munitions have higher failure rates when used during or after precipitation, or when targeted at areas that may not trigger their contact fuzing as designed (such as trees, marshes and areas with heavy underbrush). However, no specific guidelines for taking into account the reduced effectiveness of these systems under these conditions have been developed or offered to mission planners. Although anecdotes abound, there is no statistically significant data on munitions reliability outside of proving ground conditions, and no efforts ongoing to generate any.

Figure 8. BLU-97 Munitions in orchard near Kandahar, Afghanistan, 2001. *(Photo courtesy of William M. Arkin, Matthew McKinzie and Sarah Sewall)*

Unfortunately, former Secretary Cohen's guidance on munitions reliability may be having an unintended negative effect in this area. By targeting munitions reliability as measured in performance lot tests, all efforts are concentrated on high-reliability measures. Consequently, this makes capturing data on non-pristine operational scenarios risky, as the expected lower reliability could be misinterpreted as non-compliance with the guidelines.

Steps necessary to quantify reduced performance effects owing to target conditions will require some combination of more representative operational testing and better maintenance of area attack munition performance data in combat operations. This information will help mission planners determine when to use or to avoid using these munitions. Therefore, these scope-determining tests should not be excluded from any identification of anticipated munition reliability.

Note that the type of data required for munitions effectiveness assessment is not necessarily the same type of data needed for production feedback leading to improved reliability. In the case of the former, information is sought to improve the accuracy of JMEMs. In the case of the latter, information on causes of failures will be essential in order to relate reliability to the production and lot acceptance process. It is the latter type of information that the fuze producers said they were not getting and that would be useful to a responsive production system.

The overall point for the JMEMs is that the insertion of actually achieved target effects provides a much higher confidence in the guidelines for future munitions allocation and operational use.

The overall point for industry feedback is that the producer needs to understand the relationship between production process/lot testing and failure mechanisms actually experienced in the field, if improved production processes and testing are to be identified and inserted into the production and acceptance line to improve reliability.

The Services should explore methods to provide operational test and combat operations performance feedback to the acquisition community and the suppliers. This feedback should be used to optimize production methods, ensuring increased reliability through improvements in design and production control methods and documentation.

SECONDARY RECOMMENDATION

- **Consideration should be given to (1) whichever target characteristics could yield unacceptably high failure rates and (2) mechanisms for monitoring and anticipating those conditions in operations.** Given the dependency on such factors as foliage, soil types, and recent weather, this is likely to be a complex undertaking. However, it is just these environmentally related failures that lead to a substantial portion of the misinformation about these munitions. Addressing these failures directly through anticipation and an alternative weaponeering could greatly reduce their contribution to UXO and any negative connotation attached to their use. This data should be made available as quickly as it can be generated and validated to weaponeering operations through direct contact with the affected mission planning operations. By directly and rapidly responding to munition performance limitations in certain scenarios, DoD will improve operational effectiveness while avoiding pockets of UXO that could lead to collateral damage or fratricide and be misrepresented as indicative or broader operational use of that munition.

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Chapter 3. Acquisition, Logistics, and Industrial Base

This section will address the areas of acquisition, logistics and the industrial base, focusing in particular on the issues of legacy inventory area attack munitions, the deteriorating fuze and battery industrial base, and the acquisition policies that impact our national security.

KEY RECOMMENDATIONS

- **The Services should support a new, joint family of area attack munitions and upgrade a fraction of the current legacy inventory.** The Services should assess their current operational plans to determine a reasonable number of legacy area attack munitions needed to address future conflict scenarios and develop a plan to reduce UXO in those munitions. This latter step will help ensure that the Services retain a needed capability and sustain industrial capability until a more modern area attack munition matures.

- **The Services should continue to field munition/dispenser guidance accuracy improvements.** Improvement in munition guidance will reduce both the aggregate quantities of UXO and the areas in which it may be located.

- **The Under Secretary of Defense for Acquisition, Technology and Logistics should host a fuze and battery industry executive meeting (a "Last Brunch") to discuss future procurement and acquisition policies in order to preserve and optimize our national capability.** The munitions battery and fuze industries are strategic national resources with capabilities that need to be preserved. Without OSD initiative, the industry runs the risk of downsizing "overshoot."

There is nothing more certain than change, and change has been rampant in the world of fuzes and related fire train requirements.

There is an increased emphasis on dominant maneuver, precision engagement, small-unit operations, focused logistics and force protection in US combat operations. At the same time, there are heightened public expectations that US forces will be able to conduct clean and precise operations that pose minimal risk of collateral damage. The result is an increased cost associated with UXO both in terms of effects on military operations and on growing sensitivity to humanitarian risks. Reaction to these changes has been throttled by lack of recognition at the highest levels and a severe shortage of funding for those solutions that have been identified. This is not meant to be an indictment, but rather a critical review of what has evolved since the paradigm shifts evidenced by the fall of the Berlin Wall, Bosnia, Desert Storm, Operation Enduring Freedom and Operation Iraqi Freedom, as well as the defense industry consolidation initiated by then-Deputy Secretary of Defense William Perry in 1993 and the follow-on assignment of overall Total System Performance Responsibility to system or prime contractors ("primes") that has followed.

Not to be forgotten is that the current preferred munitions are precise and smart. These munitions have redefined acceptable performance as well as drastically improved warfighter survivability with their accuracy, stand-off capability, lethality, and reduced failure rates. The new measure of effectiveness is "targets per sortie" rather than "sorties per target," coupled with minimal collateral damage. This trend favorably reduces the number of munitions that need to be stockpiled, pre-positioned and supported. However, this reduced demand magnifies the problems of excess production capacity and lagging manufacturing technologies in the fuze sector of the munitions industrial base.

The discrete fire train elements— batteries, fuzes, etc.—have been challenged to meet their technical requirements and retain their identity owing to the need for miniaturization and the high levels of integration, as well as the reduced quantity of munitions being procured. This is further exacerbated by the inherent safety concerns of such integration. No relevant or comparable commercial standards for safe-arm devices exist.

The end result is that the dominant fuze manufacturers (L3, Kaman and ATK) have been forced to downsize even after consolidation. The risk to national security is that the entire industry could implode. This phenomenon is exacerbated by the reduced involvement of—and funding support to—the government in-house laboratories (Picatinny, China Lake, Eglin, Indian Head, etc.). It appears that recognition of the fuze industry's plight has been shrouded by the success of new munitions systems.

Before detailing the issues and programs underway and recommended, it should be noted that there is a massive inventory of munitions that were designed, developed and produced using decades-old technology.

Legacy Munitions

The largest contributors to the UXO problem are legacy munitions, operational factors and fuze technologies. With regard to legacy munitions, current munitions employment procedures emphasize using our best munitions systems first, then systematically expending less modernized munitions as the conflict progresses (i.e., last in—first out). Accordingly, there is an ever increasing stockpile of dated munitions that will either have to be used "as is," retrofitted or demilitarized. A large percentage of area attack munitions are past their respective design life. Retrofitting the existing stockpile could run into the hundreds of millions of dollars or more for the BLU-97 alone. Retrofitting is not without other challenges as well, namely the question of meeting revised safety standards and the risk of introducing new failure points in legacy systems never designed for upgrades. The operational question then becomes one of priorities and the cost-benefit analysis of retrofitting older munitions at the expense of fielding more capable, reliable, safe and effective munitions systems.

Retrofitting is not the only option for addressing the issue of legacy munitions and UXO. Incorporating or improving the guidance capabilities of these munitions—through the application of GPS or Inertial Navigation System guidance to the delivery vehicle—can also help reduce the quantity of UXO and its impact on friendly forces and civilians. Adding accuracy improvements results in less UXO because fewer munitions are needed to achieve the same effect against a given target. It reduces the area subsequently affected by UXO because reducing the guidance capability reduces the radius of error. It also provides a less intrusive method of upgrading existing munitions than retrofitting, thus avoiding the expense and risk of the latter. The end results are a smaller logistics load, greater freedom of maneuver, reduced risk for both friendly forces and civilians, and less UXO.

The Services have unanimously stated the need for area attack munitions. That said, there appears to be no plan addressing the future of these munitions, particularly as legacy systems age. It is clear that legacy munitions in the Service's inventory have caused the UXO issues leading to the initiation of this Task Force. The ongoing Quadrennial Defense Review is an excellent opportunity to address the issue.

The Services should assess their current operational plans to determine a reasonable number of legacy area attack munitions to address future conflict scenarios and develop a plan to reduce UXO. This will help ensure the Services retain a needed capability and sustain industrial capacity until more modern area attack munitions are developed and fielded.

This should be accomplished through a measured technology update program. The first and least invasive step is to increase the guidance accuracy of the munition canister. With the increased accuracy of the dispenser, dispersion of UXO will be reduced. Given the requirement and resources available for upgrade, some portion of the munitions (e.g., BLU-97s) could also be upgraded to further reduce UXO. This hybrid action will address both the potential for further loss of industry capability and the employment of the legacy inventory of area attack munitions.

The Task Force focused its research on US munitions. With the growing emphasis on coalition operations and multi-national acquisitions, munitions reliability considerations will need to include foreign-produced munitions and components as well as those produced in the United States.

SECONDARY RECOMMENDATION

- **The Services should establish a sunset plan to phase out non-retrofitted, grandfathered munitions by 2020, consistent with Joint Vision 2020 and long-range Service planning.** The sunset plan will make allowance for the Services' ability to replace legacy munition capabilities.

Optimizing the Fuze and Battery Industry

The Addressable Market

There is a handful of struggling fuze manufacturers today, and in interviews with the top four, they all expressed concern about the long-term economic ability to produce fuzes for military purposes. Three corporations account for over 80 percent of 2003 fuze sales, with the remaining sales spread among half a dozen other suppliers.

There are significant issues with the munitions fuze and battery production base. Munitions fuzes and reserve batteries are a niche market exclusively dependent on military demand. They are also critical elements with respect to munitions reliability. The fuze and power source industries have significant excess capacity; volatile production rates have an almost crippling effect.

Using joint-Service production requirements for tactical general-purpose bombs as a benchmark, Figure 9 depicts a chronic instability in production requirements. Each bomb produced requires at least one fuze when employed. The timespan of 1990 through 2010 shows that there were huge surges in demand coinciding with both Gulf Wars, followed by rapidly declining requirements with "get-well" production forecasts in the out years. Such cycles are highly destabilizing for ammunition manufacturers and their component suppliers. They inhibit the achievement of a financially healthy, robust and modernized fuze supplier base to support warfighter needs.

The risk of not achieving an acceptable return on investment (because of an unpredictable market) discourages fuze and battery suppliers from investing to modernize manufacturing processes or to improve designs to enhance reliability. During production valleys, line shutdowns are likely and result in the loss of critical skills and manufacturing know-how. The need to replace critical suppliers—forced to exit the market because of low volume—adds schedule risks, quality concerns and component requalification costs. Nevertheless, fuze suppliers historically have met the needs of the warfighter, including surge requirements. This has made it difficult for warnings of a growing systemic weakness in the fuze and battery sectors to receive adequate top-level attention within DoD. The changing operational environment makes it essential that these warnings be heard.

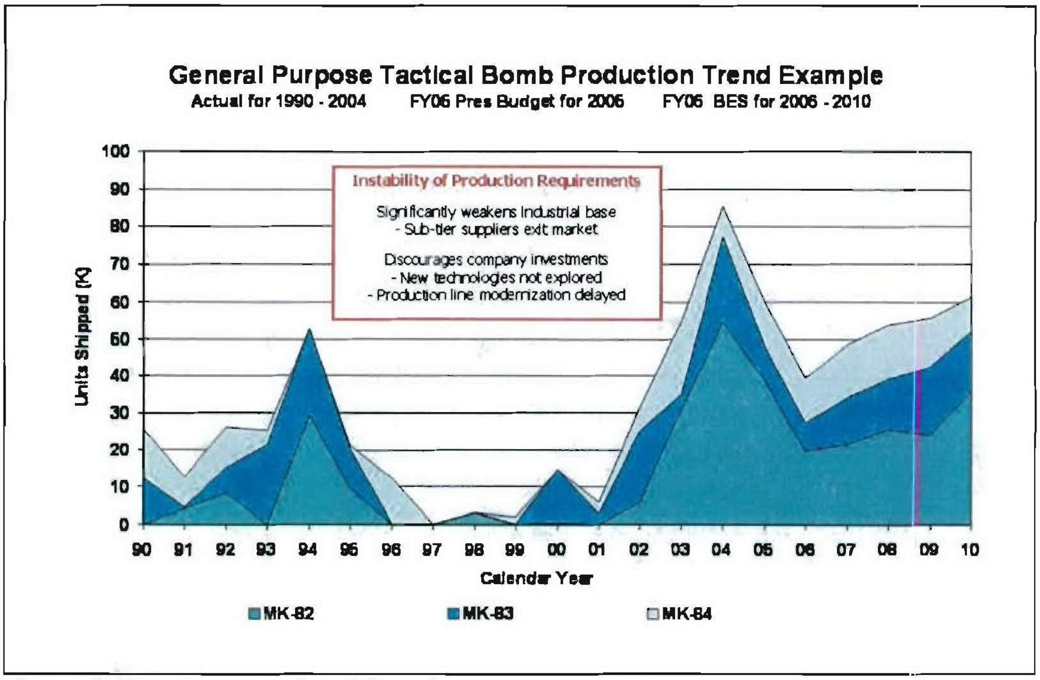

Figure 9. Bomb production drives fuze requirements.

The emerging dominance of precision-guided munitions in air ordnance is driving a paradigm shift in what is needed from the fuze industrial base. During the Operation Desert Storm, over 220,000 general-purpose bombs were employed from about 1,300 US combat aircraft. Approximately 9,000 bombs or 4 percent of the total were precision-guided. During Operation Iraqi Freedom, about 24,000 general-purpose bombs were employed from about 700 combat aircraft. In this latter conflict, 63 percent, or about 15,000 bombs, were precision-guided. That is nearly twice the number of precision-guided munitions and one-tenth the total number of bombs than in Desert Storm. While the air campaign requirements for the two wars were different, the dominance of precision-guided munitions is unmistakable and irreversible as the number of combat platforms decrease over the long term.

The continuing use of precision-guided, general-purpose bombs will sustain a need for bomb fuzes, but not in the massive quantities previously required. However, the need for high-reliability fuzing is increasingly important when only one bomb is being dropped per target. This evolution in war fighting, combined with reduced production demands in the post-Operation Iraqi Freedom surge environment, enhances the likelihood of a major restructuring of the fuze and battery industrial base sectors. Recent studies confirm that a shakeout is impending.

A multi-Service DoD panel participated in a study led by the Department of Commerce on the munitions battery industry. The study, published in February 2004, determined that the reserve battery industrial base should be part of the mobilization base, and that the industry was economically stressed and needed to be strengthened. A study of the fuze industry, led by the Defense Contract Management Agency, was completed in December 2003. The study generally found that these manufacturers were suffering from marginal business, severe competition and significant overcapacity. The Task Force is concerned by the lack of positive action to resolve these critical findings. Some level of government interest and guidance is needed to maintain this critical capability until the next-generation integrated fuze—guidance, targeting, etc.—has matured.

It is clear that defense acquisition strategies not tailored to shaping the desired industrial base end state have brought about significant challenges for the suppliers of munitions batteries and fuzes. These challenges include: company consolidation; reduced research and development spending, resulting in loss of workforce expertise; lack of technology for new designs; inefficient procurement practices, resulting in volatile production rates; and acquisition policies focusing on systems and relegating battery and fuze suppliers to a subcontractor status to the prime contractors. The likely result for essential batteries and fuzes will be delayed production, production of suspect quality, or no production at all. This will adversely affect DoD's ability to meet future mission requirements, including minimizing UXO.

Acquisition Policy Impact

Acquisition strategies and procurements will drive the future state of the fuze and battery industrial base sectors. All the studies and best intentions cannot supplant the fact that the fuzes and batteries DoD actually buys, and the contracting techniques it employs, will determine the future of these industrial base sectors. These strategies and contracts must be incentive-based in order to motivate industry to invest in the capital equipment and processes to create efficient, flexible and responsive manufacturing capabilities. Modernized, financially healthy fuze and battery suppliers are critical to achieving highly reliable munitions.

Fuzes are sophisticated devices that must meet high safety standards using components and techniques with few (if any) commercial analogies. A systems approach, rather than a commodity approach, is required to assure delivery of a reliable product. Unfortunately, acquisition strategies for fuzes frequently do not recognize this fact.

To meet small and disadvantaged business goals, for example, acquisition officials—both government and contractor—have often broken fuze procurements down to the component level to ensure these businesses could qualify. The unintended result is that fuze components were produced without a complete understanding of how they would be assembled or what functions they performed, and without the appropriate quality control. The consequence is poor fuzing reliability.

As previously discussed, feast-or-famine procurement requirements also have a deleterious effect on the fuze and battery industrial base sectors. This situation is exacerbated by annual fiscal-year contracts. There is little motivation for contractors to invest in modernization when the return on investment is unpredictable. Part of the reason government acquisition planners have not addressed this situation may be attributable to different perceptions of risk. Government personnel primarily view risk in terms of cost, schedule and product performance. While these factors are all important to industry, an additional factor for contractors is achieving financial objectives and meeting their fiduciary responsibilities to shareholders. To be successful in transforming the industrial base, government acquisition strategies must recognize how both prime and subcontractors perceive risk.

Current government acquisition strategies (Total-System Performance Responsibility) emphasize the use of systems contracts managed by prime contractors. The objective is to provide well-integrated solutions to government requirements, with the prime contractor assuming the risk of developing and providing the total system. In recognition of this risk, prime contractors are often awarded cost-plus-fixed-fee contracts. However, to control their risks, prime contractors frequently require fixed-

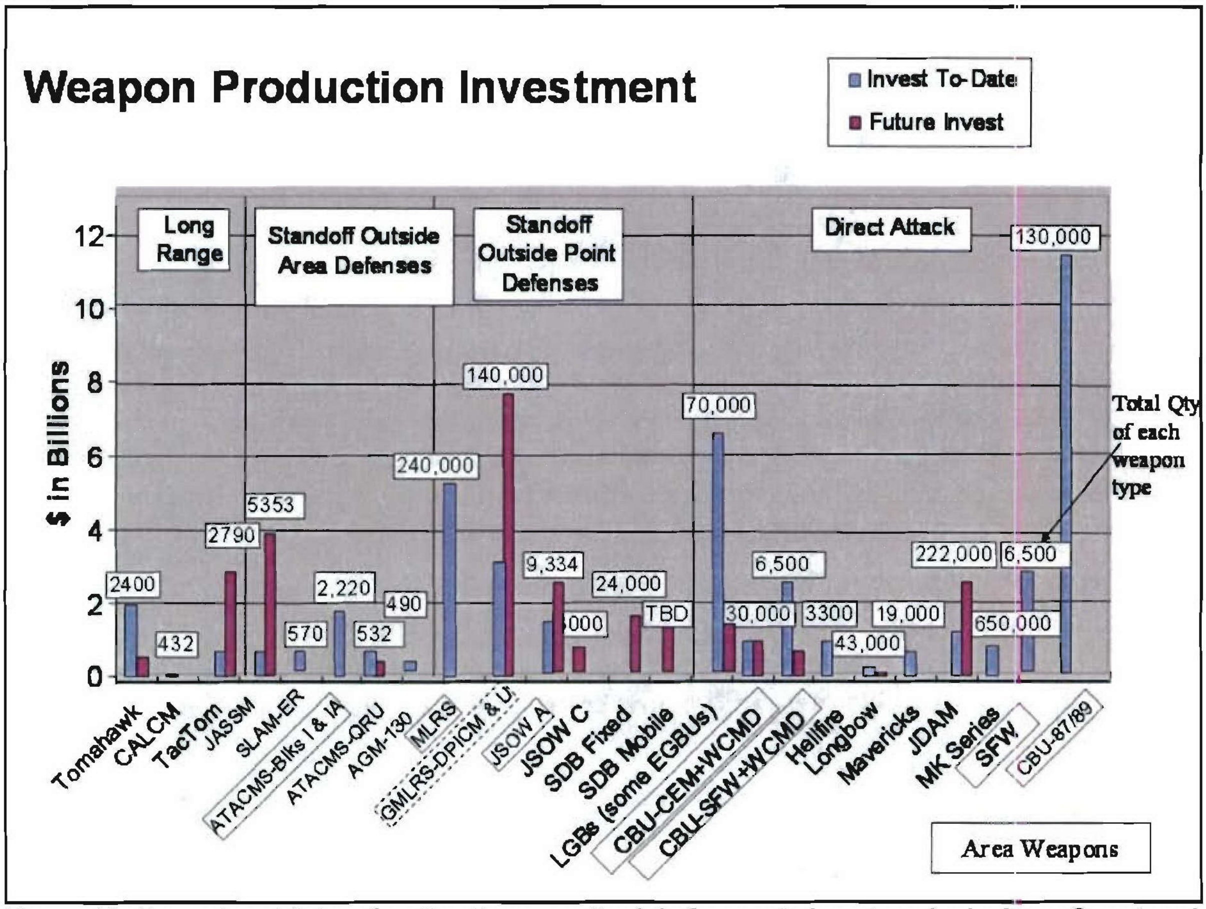

Figure 10. Current and future funding for area attack is focused almost exclusively on Smart and Precision munitions.

price development contracts from their subcontractors, including fuze manufacturers. With few new programs offering production opportunities, and with excess production capacity, fuze suppliers have little choice but to acquiesce to the prime contractors. This situation creates significant risk for fuze manufacturers in the area they consider most important—achieving their financial objectives. As currently implemented, well-intentioned total-system contract strategies are not effectively addressing the unique needs of the financially stressed fuze and battery industrial base, and will not facilitate the needed transformation of these sectors.

Assessing the Outlook for Industry

It is not a secret to anyone that the industry has suffered. Consolidation has taken place, and some companies are still facing a bleak outlook that dictates further consolidation and downsizing.

With acquisition strategies tending to treat fuzes as a commodity, there is no top-level recognition that munitions battery and fuze industries are strategic national resources with capabilities that need to be preserved. The current emphasis on systems contracting does not help the situation. Prime contractors are interested in making progress on their programs with minimal risk and cost. This results in more economically stressed fuze and munition battery suppliers and little emphasis on advancing technology.

The Darwinian influence of the marketplace cannot be avoided, and a virtual safety net needs to be established through enlightened policy. Without OSD initiative, the industry runs the risk of downsizing "overshoot."

Current acquisition strategies are not effectively addressing the unique needs of the fuze and battery industrial base, despite the warnings of knowledgeable study groups and experts in the field that there are systemic problems in both areas. The long-term health of these at-risk sectors is crucial to producing reliable munitions. While studies and experts can sound the alarm, suppliers will only respond to what DoD customers actually buy and the contracting methods used for the purchase. Therefore, acquisition strategies and contracts are the primary tools for transforming these sectors into a financially healthy and responsive national asset.

Because of their stringent performance requirements in a demanding operational environment, fuzes must be managed from a systems perspective, whether that be as end items procured by the government or as a part of a larger total system managed by a prime contractor. Government and prime contractor acquisition strategies must be tailored to support this reality.

Currently, fuze and battery manufacturers are not motivated to invest in upgrading manufacturing capabilities or developing innovative new approaches to improve reliability because the financial rewards are too uncertain. This situation is a major contributor to the systemic weakness of the industrial base and is driven by a volatile market, single-year contracts, excess capacity, too many producers, and contracts not tailored to address the supplier financial risks.

The Under Secretary of Defense for Acquisition, Technology and Logistics needs to arrange a meeting with the fuze and battery industry executives to provide guidance on the future government requirements so they can make the necessary business decisions. This would be similar in nature to the "Last Supper" hosted by then-Deputy Secretary of Defense William Perry in 1993. As part of this process, DoD should identify required in-house and industrial base capabilities and develop acquisition policies and strategies to maintain them.

Subsequent to this, DoD must increase its support of fuze and battery technologies. A forthcoming DoD Fuze Integrated Product Team Technology Plan is expected to identify approximately $120 million needed by both industry and government labs over the next ten years—above the current baseline—in order to support fuze technology. While the Task Force does not endorse a specific investment level, it is critical that DoD maintain complementary in-house and industrial base capabilities.

SECONDARY RECOMMENDATIONS

- **The Defense Systems Management College should immediately form a Red Team to develop policy recommendations for OSD to provide to program executive officers and program managers.** The recommendations should focus on improving acquisition strategies and guiding the transformation of the fuze and battery industrial base.

- **The implications of advanced precision-guided and smart munitions system designs for safety design approval, design certification, and lot acceptance testing must be examined in order for these systems to move forward into their System Development and Demonstration and initial production phases in a timely manner.** This is particularly important because such advanced munition designs provide close integration of guidance and target sensing with the fuzing function. Because of this, the design balance between munitions safety and munitions reliability is likely to be shifted away from current safety board concerns based on mechanical and electromechanical safety designs. In any event, the design and per-unit cost of these precision and smart munitions will assure high fuzing reliability. The critical performance criterion for these sensor-integrated fuzed munitions will be the effectiveness of these systems in achieving per-round lethality objectives against the mission target set.

The section below provides a number of options addressing fuze and battery community procurement issues.

An Acquisition Policy "Tool Box"

Suppliers need to be rewarded for managing the risks inherent in the fuze and munitions battery industrial base sectors. These rewards can be a combination of economic and non-economic incentives. When fuzes are part of a larger total-system contract, primes should be rewarded for employing similar incentives for their fuze and battery suppliers. There are numerous possibilities including:

a. Contract Length. Long-term contractual relationships are very beneficial in strengthening the industrial base. Five years should be the norm. While multi-year contracts are coveted by industry, base-year contracts with multiple priced options are viable alternatives. The key point is that long-term contracts reduce risks in achieving adequate returns on investment for projects that improve munitions system reliability. They also:

    - Reduce the likelihood of production breaks, which can contribute to the loss of skilled workers and the costly need to re-qualify processes or suppliers;
    - Reduce costs through long-term purchase agreements and economic-order quantity savings;
    - Allow time for supply chain streamlining efforts to take hold;
    - Secure contractor commitments to remain in the industry; and
    - Reduce contracting administrative workloads, allowing government acquisition personnel to concentrate on other mission tasks.

b. Price-Quantity Curves or Tables. An important element of long-term contracts is a commitment by government and contractor to pricing for varying quantities. This provides the government with needed flexibility to handle changes in requirements while assuring the contractor a favorable price as quantities fluctuate. Minimum and maximum quantities and delivery rates should be identified. Agreeing to long-term pricing versus various quantities also facilitates stability in Service budgeting, since the cost impact of quantity fluctuations is visible to planners up front in the budget process.

c. Economic Price Adjustments. When fixed-price contracts are employed, the government should recognize and allow price adjustments when there are components or materials for which there is significant market risk or cost volatility. Such adjustments are important in managing financial risks arising from long-term contracts.

d. Performance Incentives. Fuze and battery suppliers should be rewarded for both demonstrated and sustained improvements in reliability.

e. Schedule Incentives. Fuze and battery suppliers who exceed delivery expectations should be rewarded. This includes both long-term, sustained, on-time delivery and demonstrated responsiveness and flexibility in responding to new government requirements.

f. Robust Manufacturing Award Fees. Fuze and battery suppliers should be rewarded for their modernization efforts that balance current requirements with responsive surge capabilities and disaster-recovery planning. Rewards for effective programs in areas such as Lean Manufacturing and Six Sigma are also appropriate in that these programs contribute directly to improved product reliability.

g. Supply Chain Management Award Fees. Reliance on small and disadvantaged businesses is one of the hallmarks of federal acquisition policy. While acquisition strategies to procure fuzes must take a systems perspective, contractors should be rewarded for effective utilization of these important sources of innovative solutions. This includes mentoring small and disadvantaged businesses to improve their manufacturing capabilities using tools such as Lean Manufacturing and Six Sigma teams.

h. Partnering Initiatives. Establishing a partnering environment promotes teamwork, cooperation and good-faith performance. Partnering involves bringing stakeholders together from across industry and government in a structured framework to share information and establish common goals and objectives. For example, partnering can be used to provide a forum for fuze and battery suppliers to receive direct feedback from warfighters on the reliability of their products. In an effective partnering environment there are no surprises for government or industry, especially regarding product reliability.

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Chapter 4. Transforming DoD ERW Abatement Efforts

This section will address recommended changes to DoD's organizational structure to improve its capability to address ERW issues.

KEY RECOMMENDATION

- **The Under Secretary of Defense for Policy should transform all functions within his organization related to explosive remnants of war abatement efforts into one single office charged with the responsibility to execute the DoD program and empowered with the commensurate authority.** This will achieve unity of command, unity of effort, and accountability. Sufficient funding already exists, but the current organizational structure prevents effective implementation of DoD ERW abatement efforts.

The Terms of Reference directed the Task Force to identify other feasible measures—beyond improving the reliability rates of its munitions—that the United States could take to reduce the threat that failed munitions pose to friendly forces and civilians. Most recommendations in this report concern technical changes and improvements in targeting, fuzing, batteries, and the acquisition process itself. However, there is another category of "feasible measures" the United States can undertake—establishing a robust, well-synchronized and effective ERW abatement program. A DoD effort exists, in multiple entities, but it lacks unity of effort and unity of command, thereby limiting its potential contributions to establishing safe and secure environments in future stabilization, reconstruction, and counter-insurgency operations.

Achieving 100 percent munition reliability is arguably neither economically feasible nor technically realistic; therefore, a prudent assumption is that there will always be US-origin UXO populating battlefields where American forces have engaged opponents. Furthermore, much of the UXO afflicting countries worldwide is not of US origin, and US efforts to reduce the amount of UXO resulting from its own operations will have no corresponding effect on foreign-origin UXO. Consequently, there will continue to be a demand for capabilities and resources to address these remnants of war.

In addition, it is very significant to note that high reliability rates alone will not solve the UXO problem. For example, even a near-perfect 99 percent munitions reliability rate can yield nearly 80 pieces of UXO in less than a minute from just one volley of a multiple launch rocket system—an area attack munition system found in dozens of countries world-wide.[5] A more probable 95 percent reliability rate applied to a single tactical engagement—a battery of six launchers firing two volleys—would produce over 4600 pieces of UXO.[6] Consequently, there will continue to be a demand for capabilities and resources to address these explosive remnants of war. The daunting time and costs associated with the clean up the UXO produced by these two volleys further illustrates the need for an aggressive effort to address ERW. The 4600 pieces of UXO would typically be scattered over three square kilometers, the area covered by a six-launcher strike.[7] Assuming a clearance rate of two square meters per hour per man, it would require a 300-man demining unit approximately five years to clear the area to international standards.[8] The cost could easily reach tens of millions of dollars. The time and costs could be further increased depending on the soil type, vegetation, slope, ground clutter, saturation level of ERW, and surrounding habitation and infrastructure.

Fortunately, the resources, training base, facilities, and, for the most part, the personnel necessary to support abatement efforts currently exist, but responsibilities for these efforts within the Office of the Secretary of Defense are not organized in a coherent and streamlined manner.

The US Government's Humanitarian Mine Action Program is an interagency effort led by the Department of State. It is an active and vigorous program—and the largest in the world. US support for mine action since 1993 totals approximately $1 billion—representing over 60 percent of mine action contributions worldwide during the past dozen years ($1.7 billion).

Despite the title "Humanitarian Mine Action Program," these interagency efforts necessarily address *all* explosive remnants of war—not just landmines. In reality, contaminated areas often contain a mix of landmines, mortar shells, artillery rounds, grenades, booby traps, bombs, weapons caches, improvised explosive devices, and area attack munitions. DoD recognized this reality and last year obtained a change to its legislative authority (Section 401 of Title 10, United States Code) broadening its humanitarian mine action efforts to include ERW.

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[5] 1 launcher x 12 rockets x 644 munitions per rocket x .01 failure rate = 77 pieces of UXO.

[6] 6 launchers x 12 rockets x 2 volleys x 644 munitions per rocket x .05 failure rate = 4636 pieces of UXO.

[7] 1 launcher firing 12 rockets attacks an area target covering 500m x 500m = .25 km^2. At this rate of coverage, 6 launchers x 2 volleys x .25 km^2 = 3 km^2.

[8] One deminer can clear to international standards at an approximate rate of 1-3 m^2 per hour. The costs range from $1-$80 per m^2. The rate and costs are dependent upon many factors, including: soil type, extent of vegetation, slope, ground clutter, saturation level of ERW, extent of surrounding habitation and infrastructure, competency of deminers and demining program overall, and local labor rates. For the example cited: 3 million m^2 ÷ (2 m^2 cleared per hour x 30 hours per week effective clearance rate x 48 weeks work per year x 200 deminers) = over 5 years. 200 deminers equates to an organization of at least 300 personnel based on 1 supervisor per 2-3 deminers plus medical personnel and supervisory staff.

US ERW abatement efforts have supported programs in over forty countries and regions. DoD's contribution to the effort totals nearly $270 million, of which approximately $120 million has been spent on research and development (mostly to develop mechanical demining technologies). DoD's efforts focus on the following: "train-the-trainer" programs to establish indigenous demining and medical response capacities; mine-risk education efforts; underwater explosive ordnance disposal; technical assistance with ERW removal; establishing, training, and equipping national mine action authorities; provision of personal protective equipment for deminers; satellite imagery and map products; and mechanical demining technology, testing, training and equipment.

Unfortunately, DoD efforts fall short of their potential because of organizational inefficiency. Figure 11 highlights the fragmented nature of DoD efforts. Component functions are assigned to multiple offices within the Office of the Under Secretary of Defense for Policy. This organizational structure *lacks unity of effort* and *unity of command*, and is consequently devoid of synergy. As a result, DoD is missing a significant opportunity to exploit a means of engagement and humanitarian assistance in support of present and future stabilization, reconstruction and counter-insurgency operations.

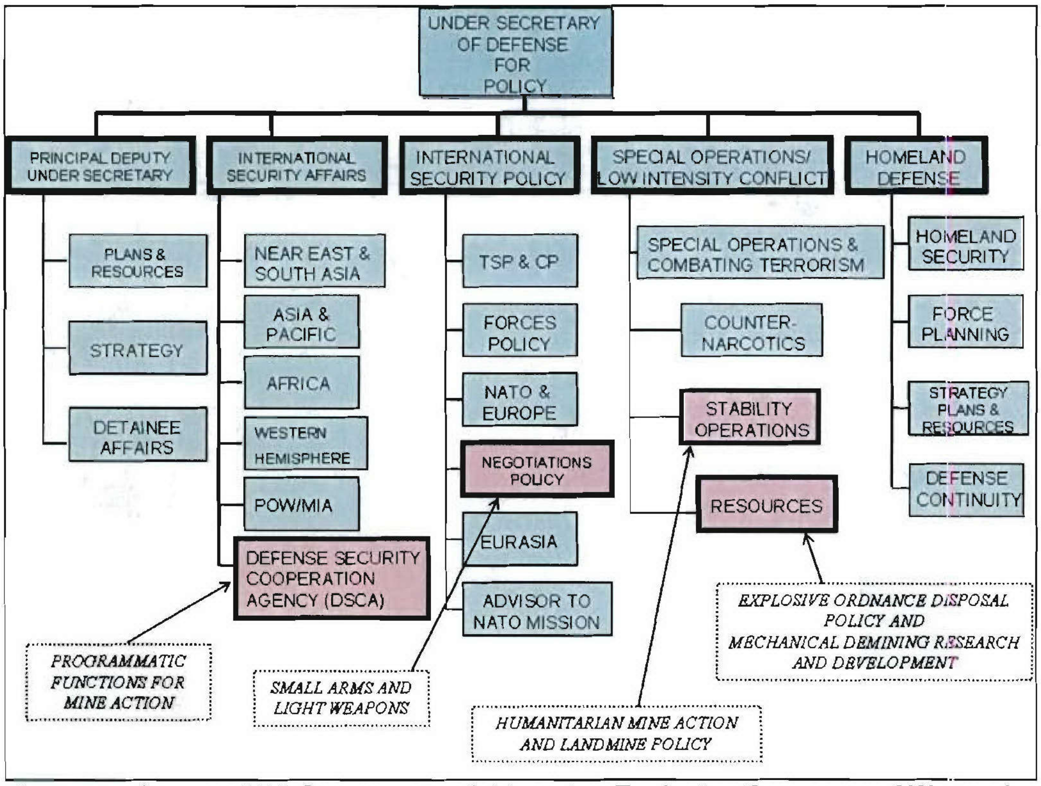

Figure 11. Current OSD Structure for Addressing Explosive Remnants of War and Related Issues

Ironically, the Department of State has the very unity of effort and unity of command that DoD lacks. Its Weapons Removal and Abatement Office has responsibility for ERW abatement policy, program management, public outreach and decision-making authority, allowing it to achieve a level of consistency and focus that DoD at present cannot match.

Therefore, in order to make effective use of its ERW resources, DoD should transform all functions related to ERW abatement efforts into one single office charged with the responsibility to execute the DoD program and empowered with the commensurate authority. This will achieve unity of command, unity of effort, and accountability, and will place DoD's efforts on par with those of the State Department.

Embracing this recommendation, DoD's ERW abatement efforts could be poised to achieve the following:

- Significantly increase the effectiveness of its interagency contributions resulting in reduced danger to US and allied military personnel and civilians alike from US- and foreign-origin ERW.
- Demonstrate that, while area attack munitions remain militarily effective and continue to provide a needed capability, the United States is not indifferent to the potential dangers they can pose to civilians.
- Lead future DoD efforts in the establishment of a safe and secure environment in stabilization, reconstruction, counter-insurgency, and humanitarian relief efforts, all of which will consume an increasing role of future military engagements. Stabilization operations are vastly improved when the hazards of mines, captured enemy ammunition, UXO and other remnants of war are controlled or eliminated.

The United States maintains an aggressive interagency humanitarian program, as previously detailed, to assist other countries with their indigenous ERW—the vast majority of which is of neither US manufacture nor delivery.

This stands as an impressive contribution and commitment to the eradication of threats posed by ERW—not equaled by any country or organization in the world. This point is often overlooked amid the periodic barrages of criticism that DoD receives for keeping landmines and area attack munitions in its inventory.

Leadership in future DoD efforts in stabilization, reconstruction, and counter-insurgency efforts will depend on establishing and maintaining a safe and secure environment. Achieving this requires the safe removal of all

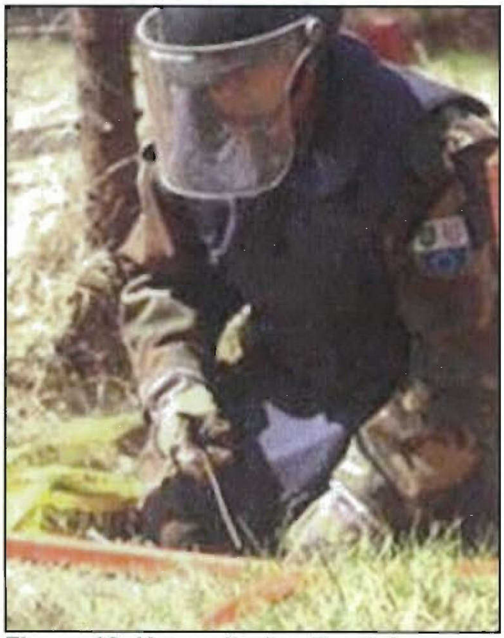

Figure 12. Humanitarian Demining

ERW that threatens military operations or civilians. Therefore, once the recommended DoD organizational structure is in place, DoD should provide specific guidance—in the form of a Directive—focusing its ERW abatement efforts in support of broader stabilization, reconstruction and counter-insurgency efforts. At a minimum, this guidance should address the following:

- Resourcing of training missions. The supply of US military personnel able to support these efforts evaporated in the face of War on Terrorism demands. A legislative initiative permitting DoD to use its civilian personnel for these missions is under review in Congress.
- Combatant Command support of program. Currently, some Commands strongly support and embrace DoD's ERW efforts and others don't. The guidance should reiterate that ERW abatement efforts constitute an important security cooperation tool and need to be employed as such. From a functional point of view, Commands should adequately resource a small, dedicated ERW staff to facilitate operational support. This staff could be teamed with an Explosive Ordnance Disposal (EOD) cell to oversee doctrine development, joint tactics, techniques and procedures, EOD training, and employment on ERW abatement missions in support of the Command's security cooperation goals.
- Organization of DoD ERW abatement office, mission, resources, and linkage to the Security Cooperation Guidance. Currently, not all of DoD's ERW efforts directly support this guidance.
- Using the Secretary's Transformation Planning Guidance as direction and the Doctrine, Organization, Training, Materiel, Leader Development, Personnel, and Facilities process as a structure for analysis, address EOD joint operations, training and realignment of the funding for joint EOD technology. There is currently no single organization responsible for developing EOD doctrine, training or tactics, techniques and procedures, and no single organization with the authority to make needed changes. This must change in order to support ERW abatement efforts.
- Funding appropriated by Congress for mine action but susceptible to diversion to other humanitarian projects. Mine action and other ERW programs involve training people to do a dangerous task—a very perishable skill—and often involve significant lead times (working with the host nation government, interagency coordination, etc.) to plan and execute missions. Diverting funding away from planned ERW missions to address foreign disasters or other priorities creates significant disruptions and calls into question DoD's long-term commitment to these efforts. Resources to support these missions cannot ebb and flow if they are to provide effective support to broader stabilization, reconstruction and counter-insurgency efforts.

DoD has made impressive contributions to ERW abatement. Nevertheless, the Task Force recommends a transformation of these efforts so that DoD can contribute effectively to the interagency humanitarian effort, thereby reducing the threat to military personnel and civilians alike, and helping establish safe and secure environments for US military operations.

SECONDARY RECOMMENDATION

- **DoD should provide specific guidance—in the form of a Directive—focusing its ERW abatement efforts in support of broader stabilization, reconstruction and counter-insurgency efforts.**

Appendix I. Terms of Reference

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

APR 30 2004

ACQUISITION, TECHNOLOGY AND LOGISTICS

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference – Defense Science Board Task Force on Munitions System Reliability

You are requested to form a Defense Science Board (DSB) Task Force on Munitions System Reliability.

Unexploded ordnance created by munitions failures poses a threat to friendly forces and noncombatants alike. It can hinder onward movement of friendly forces, cause casualties among military personnel and civilians alike, and deny civilian use of territory and buildings long after a conflict is finished. The United States is already taking some steps either to improve the reliability and performance of some munitions systems (such as the development of self-destruct fuzing for certain submunitions containing systems) or otherwise reduce the number of submunitions weapons used (such as adding guidance systems to improve weapon accuracy, thereby reducing the number of weapons required to achieve a given military objective). The Department of Defense should assess its efforts thus far to improve the reliability of its munitions systems and identify additional steps it can take to reduce the amount of unexploded ordnance resulting from munitions failures.

To inform future policy and programmatic decisions regarding U.S. munitions design and development, the Task Force should:

1. Conduct a methodologically sound assessment of the failure rates of U.S. munitions in actual combat use – a key subset of this effort should focus on submunitions system reliability. To the extent feasible, results of this assessment should be unclassified so they can be used to confirm or refute claims made about U.S. systems containing submunitions.

2. Review ongoing efforts to reduce the amount of unexploded ordnance resulting from munitions system failures, and evaluate whether there are ways to improve or accelerate these efforts.

3. Identify other feasible measures the U.S. can take to reduce the threat that failed munitions pose to friendly forces and noncombatants. These measures can include: (1) further efforts to improve munitions fuze system reliability (e.g., secondary pyrotechnic fuzing or self-neutralization), (2) changes in

employment practices and/or procedures (including training) to minimize failures, and (3) technical modifications to munitions to facilitate the location and safe disposal of unexploded ordnance items. In considering these additional measures, the Task Force should take into account the efforts of other countries to mitigate the effects of munitions failures.

Where applicable, the Task Force should also take into account recommendations of related DSB Task Force efforts (Unexploded Ordnance, Integrated Fire Support in the Battlespace, etc.).

The Study will be sponsored by me as the Acting USD(AT&L) and the Assistant Secretary of Defense for Special Operations and Low Intensity Conflict. MGEN Ken Israel, USAF (Ret.) will serve as Chairman of the Task Force. Mr. Marc Cheek, OASD/SOLIC, will serve as Executive Secretary, and CDR Dave Waugh, USN will serve as the DSB Secretariat representative.

The Task Force will operate in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DoD Directive 5105.4, the "DoD Federal Advisory Committee Management Program." It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of Section 208 of Title 18, U.S. Code, nor will it cause any member to be placed in the position of acting as a procurement official.

FOR

Michael W. Wynne
Acting

Appendix II. Task Force Membership

CHAIRMAN

MG Kenneth Israel (Ret)	*Lockheed Martin Integrated Systems*

MEMBERS

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Col Paul Brandenburg, USAF (Ret)	*General Dynamics*
Mr. Danny Brunson	*EG&G*
Gen Chuck Horner (Ret)	*Private Consultant*
Mr. Kent Hutchinson	*Private Consultant*
Mr. Lanny Lancaster	*Private Consultant*
VADM Denny McGinn (Ret)	*Battelle*
Mr. Cliff McLain	*ARES Corporation*
Mr. Alan Moore	*The MITRE Corporation*
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Dr. Allan Steinhardt	*Booz Allen Hamilton*

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LTC Jeffrey Brock	*Joint Staff*
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Appendix III. DoD Policy Memo on Submunition Reliability

THE SECRETARY OF DEFENSE
1000 DEFENSE PENTAGON
WASHINGTON, DC 20301-1000

JAN 1 0 2001

MEMORANDUM FOR THE SECRETARIES OF THE MILITARY DEPARTMENTS

SUBJECT: DoD Policy on Submunition Reliability (U)

Submunition weapons employment in Southwest Asia and Kosovo, and major theater war modeling, have revealed a significant unexploded ordnance (UXO) concern. The following establishes the Department's policy regarding submunition weapons acquisition. The policy applies to systems delivered by aircraft, cruise missiles, artillery, mortars, missiles, tanks, rocket launchers, or naval guns that are designed to attack land-based targets and that deploy payloads of submunitions that detonate via target acquisition, impact, or altitude, or self-destruct (or a combination thereof). It is the policy of the DoD to reduce overall UXO through a process of improvement in submunition system reliability–the desire is to field future submunitions with a 99% or higher functioning rate. Submunition functioning rates may be lower under operational conditions due to environmental factors such as terrain and weather.

Program Managers shall include the non-recurring cost of increasing the overall functioning rate; the operational use costs, including the cost of clearing UXO on test and training ranges in accordance with DoD policy and operational requirements; and disposal costs, as part of the life-cycle costs of all future submunition weapons. The Program Manager should establish submunition functioning thresholds and objectives that advance the process of improvement in system reliability, and that take into consideration the benefits from reduced UXO (i.e., a cost-benefit analysis of increasing the functioning rate (cost) and the resulting reduction in UXO (benefit)).

The Services may retain "legacy" submunitions until employed or superseded by replacement systems in accordance with the above policy. The designation "legacy" would apply to submunition weapon acquisition programs reaching Milestone III prior to the First Quarter of Fiscal Year 2005.

The Services shall evaluate "legacy" submunition weapons undergoing re-procurement, product improvement, or block upgrades to determine whether modifications should be made to bring them into compliance with the above policy.

The Services shall design and procure all future submunition weapons in compliance with the above policy. A "future" submunition weapon is one that will reach Milestone III in FY 2005 and beyond. Waivers to this policy for future ACAT I and II submunition weapons programs, shall require approval by the JROC.

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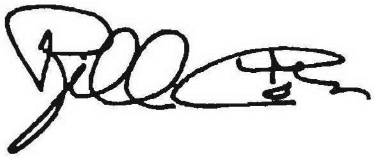
This policy applies to all acquisition category submunition weapons programs. Compliance with this policy shall be assessed by the Component or Defense Acquisition Executive, as appropriate.



Appendix IV. Briefings Received By the Task Force

June 25, 2004

Maj Darren Cochran, *SAF/AQPW*

MGEN Ken Israel, *Lockheed Martin*

Mr. Milo Serreyn, *HQDA - G4, Munitions Division*

Mr. Anthony Kress, *(OUSD)AT&L's IDS/LW&M*

July 8 - July 9, 2004

Mr. Rene Kiebler, *Combat Ammunition Systems*

Mr. Leon Springer, *US Army, Fuze Mgmt Office*

LTC Stephen Lee, *US Army*

Dr. John Pletcher, *US Air Force, Eglin AFB*

Mr. George Clessas, *US Navy*

Mr. William Delaney, *MIT Lincoln Laboratory*

Ms. Diane Wright, *AT&L*

LTC Charles Kelly, *J8*

Dr. Allan Steinhardt, *Booz Allen Hamilton*

August 19 - August 20, 2004

Mr. Philip T. Gorman Jr., *ARDEC/RDECOM*

LTC Kevin Jennings, *PM Demilitarization*

Mr. Anthony Kress, *(OUSD)AT&L's IDS/LW&M*

Mr. Felix E. Cruz, *PM CAS*

Mr. Lawrence Fan, *Indian Head Division, NSWC*

Mr. Robert L. Lillard, *US Army Artillary Center, Fort Sill*

COL Thomas Torrance, *JCS J5*

LTC Keith Angles, USA (Ret), *US Army Corp of Engineers*

Mr. Thomas McKimm, *Fuze Division, FPAT, AETC, RDECOM-ARDEC*

September 21 - September 22, 2004

Mr. Perry Hamlyn, *Mitre*

Dr. Allan Steinhardt, *Booz Allen Hamilton*

Mr. Andrew Chester, *DCMA*

Mr. Ed Cummings, *Department of State*

COL John Jordan, *OSD-Policy/SOLIC/Stability Operations*

COL Al Vosburgh, *OSD - SOLIC*

October 28 - October 29, 2004

Mr. Dave Cole, *KDI*

Mr. Dave Fine, *Alliant*

Mr. Steve Robillard, *Alliant*

Mr. Harry Hutchins, *Kaman Raymond Aerospace Corporation*

Mr. Jerry Hawkins, *Kaman Raymond Aerospace Corporation*

Mr. Joseph Homko, *BT Fuze*

Mr. Edward Cooper, *BT Fuze*

Mr. Scott Pomeroy, *NSWC DL*

Mr. Randy Cope, *Fuze and Warhead Division*

Mr. Lawrence Fan, *Indian Head Division, NSWC*

Mr. John Kunstmann, *NSWC IH*

Mr. Roger I. Swanson, *QE Program Manager, NOSSA*

November 22 - November 23, 2004

Maj Gen Robert Chedister, *AAC/CC*

BGen David Edgington, *Combined Air Operations Center (CAOC)*

Dr. John Pletcher, *US Air Force, Eglin AFB*

Mr. Brian Rutledge, *Direct Attack Systems Group*

Mr. Russ Howard, *Air-to-Ground Munitions Systems Wing*

Capt Steve Clark, *Shaw AFB*

Capt Kevin Halicki, *Shaw AFB*

Col John Croghan, *US Air Force, Eglin AFB*

Mr. Anthony Kress, *(OUSD)AT&L's IDS/LW&M*

RADM Rondeau, *NAVPERSDEVCOM*

Ms. Carolyn Holland, *AAC/ENA*

Lt Col Raegan Echols, *US Air Force, Eglin AFB*

December 22, 2004

LTC(P) Michael W. Meier, *Joint Staff OCJCS-LC*

February 2 - February 3, 2005

Mr. Dave Janiec, *Naval Air (NAVAIR) Weapons Division*

Captain Dan Lee, *US Navy, NAVAIR*

Mr. Roy Hageman, *NAVAIR Weapons Engagement Office*

Mr. Mike Wirtz, *NAVAIR Weapons Engagement Office*

Mr. Clint Housh, *NAVAIR Joint Standoff Weapon Office*

Mr. Forrest Lloyd, *NAVAIR Weapons and Energetics Office*

Mr. Ken Hayes, *NAVAIR Weapons Prototype Division*

Mr. Steven Fowler, *NAVAIR Department for Energetics*

Mr. George Hennings, *NAVAIR* Fuze Development Office

Mr. Randy Cope, *NAVAIR Ordnance System Division*

Mr. Dave Riggs, *NAVAIR Safe Arm Development Branch*

March 30 - March 31, 2005

Mr. William (Bill) Arkin, *The Carr Center*

Mr. Matthew McKinzie, *The Carr Center*

Ms. Sarah Sewall, *The Carr Center*

Howard Russell, *PEO for Weapons*

Keith Sanders, *PEO for Tactical Aircraft and Strike Weapons & Unmanned Aviation*

Brent Pope, *PEO for Missiles and Space*

Jim Sutton, *PEO for Ammo*

Carl Campagnuolo, *PEO for Special Programs (SOCOM)*

Richard Bowen, *PEO for Integrated Warfare Systems*

Scott Allred, *US Marine Corps, Ammunition Program*

Gregory DuChane, *US Marine Corps, Ammunition Program*

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Appendix V. Acronym Index

AGM	air-to-ground Missile
ATK	Alliant Techsystems Inc.
BLU	bomb live unit, submunitions for cluster bombs or dispensers
CALCM	conventional air-launched cruise missile (US DoD)
CBU	cluster bomb unit
CD-ROM	Compact Disk - Read Only Memory
CEM	combined effects munitions
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research and Engineering
DoD	Department of Defense
DOTS	Dynamic Optical Tags
DPICM	Dual Purpose, Improved Conventional Munition
DRaFT	Digital Radio Frequency Tag
DSB	Defense Science Board
DSCA	Defense Security Cooperation Agency
EGBU	Enhanced Guided Bomb Unit
EOD	Explosive Ordnance Disposal
ERW	Explosive Remnants of War
GMLRS	Guided Multiple Launch Rocket System
GPS	Global Positioning System
IC	integrated circuit
J3	Joint Staff, Operations
JASSM	Joint Air-to-Surface Standoff Missile
JDAM	joint direct attack munitions
JMEMs	Joint Munition Effectiveness Manuals
JSOW	Joint Service Stand-Off Weapon
LGB	Laser-Guided Bomb
MEMS	Micro-electro-mechanical system
MLRS	multiple launch rocket system
MOFA	Multi-Option Fuze for Artillery
MSR	Munitions Systems Reliability
NATO	North Atlantic Treaty Organization
OSD	Office of the Secretary of Defense
PNNL	Pacific Northwest National Laboratory
RF	radio frequency
FRIC	Radio Frequency integrated chip

RFID	Radio Frequency Identification
SDB	small diameter bomb
SFW	sensor fused weapon
SLAM-ER	Standoff Land-Attack Missile - Expanded Response
TacTom	Tactical Tomahawk
TSP & CP	Technology Security Policy and Counterproliferation
US	United States
UXO	Unexploded Ordinance
VESTA	Valuable Enterprise Services in Technology Achievement
WCMD	Wind-Corrected Munitions Dispenser