DEPARTMENT OF DEFENSE

DEVELOPING CRITICAL TECHNOLOGIES/SCIENCE & TECHNOLOGY (DCT/S&T)

SECTION 2: ARMAMENTS AND ENERGETIC MATERIALS

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PREFACE

Developing Critical Technologies/Science & Technology (DCT/S&T) is a product of the Defense Critical Technologies Program (DCTP) process. This process provides a systematic, ongoing assessment and analysis of a wide spectrum of technologies of potential interest to the Department of Defense. DCT/S&T focuses on worldwide government and commercial scientific and technological capabilities that have the potential to significantly enhance or degrade U.S. military capabilities in the future. It includes new and enabling technologies as well as those that can be retrofitted and integrated because of technological advances. It assigns values and parameters to the technologies and covers the worldwide technology spectrum.

DCT/S&T is oriented towards advanced research and development including science and technology. It is developed to be a reference for international cooperative technology programs. A key component is an assessment of worldwide technology capabilities. S&T includes basic research, applied research and advanced technology development.

SECTION 2—ARMAMENTS AND ENERGETIC MATERIALS TECHNOLOGY

Scope

Highlights

- Achieving the Joint Chiefs of Staff (JCS) vision of full-spectrum dominance is predicated upon an ability to protect U.S. forces at all levels and to engage and attack enemy forces and capabilities precisely, with overwhelming effectiveness.
- A military force that cannot credibly threaten its adversaries with destruction cannot control the tempo of an operation to a successful conclusion. A posture of full-dimensional protection cannot be sustained indefinitely from a purely defensive stance.
- Developing critical technologies for conventional weapons provides the foundation for the decisive military capabilities needed to support Joint Staff Future Warfighting Capabilities (JSFWC) in Precision Force, Strike Warfare, Joint Theater Missile Defense (JTMD), Military Operations in Urban Terrain (MOUT), and Joint Countermine.

OVERVIEW

Conventional weapons technologies encompass munitions (bombs, rockets, guided missiles, land and undersea mines, launching systems, guns, mortars) and their lethal mechanisms (warheads and specially designed initiation subsystems). Conventional weapons traditionally have focused on technology and systems to destroy enemy personnel, materiel, and infrastructure, and recently a growing emphasis has been placed on incapacitation through nonlethal weapons (NLWs).

This section does not include either directed-energy weapons (DEW) (addressed in Section 6, *Directed and Kinetic Energy Systems Technology*) or electronic warfare (EW) (covered in Section 10, *Information Technology*).

The revolutionary rate of advance in digital electronics and materials have resulted in highly visible improvements in command, control, communications, computers, intelligence, and information (C4I2) and military platforms. Although these applications have gathered the lion's share of press attention, the underlying technologies also enable a wide array of less visible but equally important advances in weaponry.

The emphasis on information superiority and operations implicitly contains—but unfortunately tends to obscure—one critical point. Making it work requires assured lethality. A military force that cannot credibly threaten its enemy with destruction cannot control the tempo of an operation to a conclusion. The ability to protect forces so that they can operate with impunity cannot be sustained indefinitely from a purely defensive stance. An adversary that does not suffer consequences from the use of force will simply continue to attack with increased intensity, sophistication, or both.

Two other factors come strongly into play:

1. The rapid spread and proliferation of advanced technologies.
2. The erosion of national and institutional barriers that, in the past, would have inhibited access to knowledge of how the technology could be applied.

The net result is to increase dramatically the potential for technological surprise on the battlefield.

BACKGROUND

Conventional weapons technology provides the foundation for the decisive military capabilities needed for cost-effective system upgrades and next-generation systems in support of the top JSFWC. Specifically, conventional weapons directly support the areas of Precision Force, Strike Warfare, JTMD, MOUT, and Joint Countermine.

These demanding military objectives depend upon the continual advancement of the technologies that support and enable these weapons systems. Unlike weapons of mass destruction (WMD), which effect indiscriminant damage over a large area, conventional weapons are designed for specific effects on specific targets or for defined effectiveness against a relatively small target area. Only a few nations currently have the wherewithal to seriously threaten the global superiority of U.S. conventional forces. However, the proliferation of advanced technologies and critical developments described in this section pose a credible threat to individual force elements.

Global trends that will continue to increase the availability of military capabilities and underlying technologies include:

- Globalization of key industries and increased emphasis on cooperative developments.
- Continued growth of the Internet and free exchange of, and access to, technology.
- Growing reliance and dependence of military forces on commercial off-the-shelf (COTS) technologies, which are likely to be readily available to potential adversaries.

Increased access to the same commercial technologies for military applications will have the effect of leveling the battlefield, particularly in communications, information and, in some cases, precision delivery of weapons.

SECTION 2.1—SMALL- AND MEDIUM-CALIBER WEAPON SYSTEMS

Highlights

- Future military operations are predicated on the premise of "doing more, with less," and this translates directly into requirements for multipurpose-/multimission-capable weapons.
- Small- and medium-caliber weapons are used pervasively and are critical to the mission effectiveness of systems such as the Apache, Comanche, and Blackhawk helicopters; future armored, scout and cavalry, and individual infantry systems; and aircraft armament and naval point defense systems.
- Improvements will come from miniaturization of safing, arming, firing, and fuzing (SAFF) and guidance and control and improved integration of fire control functions in individual, crew-served, and platform-borne weapons.
- Enhanced performance factors envisioned include increased muzzle velocity and rate of fire to enhance lethality and increased standoff range to enhance the safety and survivability of U.S. forces.

OVERVIEW

This section addresses technologies for future systems and ammunition[1] for soldier and platform systems. These systems will include technologies for increasing system lethality (accuracy, firing rate, or projectile/warhead performance), reducing the size and weight to improve portability/transportability of systems, and improving the ammunition handling and logistic support characteristics of such systems and their ammunition.

Despite the increasing emphasis on the development and use of large-caliber systems capable of delivering guided weapons, the direct-fire and small-/medium-caliber guns, rockets, and recoilless rifles and the small grenade and mortar launching systems will remain critical to offensive and defensive military operations.

Individual Soldier Systems

The trend toward individual multipurpose/multimission soldier weapons reflects the overall requirements to increase the soldier's capability so that fewer troops are required to accomplish objectives. High-payoff technology areas include the miniaturization of SAFF devices for air-burst munitions [see Section 2.3, Safing, Arming, Fuzing, and Firing (SAFF)]; miniaturization and integration of fire control systems capable of laser range finding; ballistic computation and automated fuze setting; lightweight weapon materials and structures; and dynamic damping techniques.

Other aspects of individual weapons include the development of nonlethal munitions [see Section 2.13, Non-lethal Weapons (NLWs)] and the design of variable-velocity barrels for variable-lethality weapons.

Crew-Served Systems

Advanced crew-served weapons technologies extend the range effectiveness of lightweight portable weapons systems. Critical performance characteristics identified by the U.S. Army include low system weight and improved firing rates and lethality.

Platform-Borne Systems (Ground, Air, and Naval Gunnery)

Technological advances of interest include the miniaturization of guidance to increase the accuracy of 2.75-in. rocket systems; enhanced warheads for such systems; and advanced ammunition, such as telescoping and caseless ammunitions, to improve the firing rates and handling characteristics of guns.

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1 Having a diameter (or caliber) from a 5- to 12.7-mm round (0.5-in.) for small caliber and up to an 81-mm round for medium caliber.

The new generation of land vehicles needs to be lighter and more reliable, with increased firepower to counter advances in the protective properties of light armor targets. The solution to the armament problem is not a more powerful cannon with a higher caliber munition based on vintage technologies. What is needed is a new integrated gun, ammunition, and ammunition feed system to meet the projected threat. For example, potential applications for the Case Telescoped Weapon System (CTWS) include the U.S. Army's Future Scout and Cavalry System (FSCS), Future Infantry Vehicle (FIV), and Bradley Fighting Vehicle and the Marine Corps' Advanced Amphibious Assault Vehicle (AAAV).

Another U.S. Department of Defense (DoD) initiative for small-caliber ammunition is to leverage to smaller caliber systems the miniaturized guidance and control actuation technology, high-fidelity visual digital simulation, advanced composite motor and structure technology, fire control, insensitive/nondetonable propulsion technology, and enhanced lethality characteristics from the Army line-of-sight antitank (LOSAT) missile program and the hypervelocity missile guidance demonstration. Goals are increased maneuverability against airborne targets at minimum range, with continuous control actuation.

Reduction in weapon size will significantly increase missile platform adaptability to include future main battle tanks (MBTs), helicopters, and multiple lightweight platforms that are strategically deployable. Development of this miniature hypervelocity missile concept will provide capability for a significant increase in lethality, survivability, and mobility of a dual role close combat and short range air defense hypervelocity guided kinetic energy (KE) weapon system. The compact kinetic energy missile (CKEM) technology, which is compatible with the Army LOSAT target acquisition and tracking system, could be compatible with the fire control system, for close combat and short range air defense missions.

Nonconventional weapons technologies will provide the field commander a capability to tailor target effects from less-than-lethal to lethal for small-caliber weapons against lightly armored materiel and personnel [see also Section 2.13, Nonlethal Weapons (NLWs)].

Energetic materials that are 10 percent more powerful, yet less sensitive, will enhance explosively formed penetrator kill capability. Selective-mode warheads that can defeat a heavy armored target (10- to 20-percent increase in performance compared with Javelin) and a lightly armored target (fourfold increase in lethality compared with a standard shaped charge) will be demonstrated.

The Army and the Air Force are exploring the use of layered ceramic materials (functionally gradient materials) to reduce gun-barrel erosion and improve system accuracy and operating life.

Ammunition

Cased, telescoped ammunition contains the projectile inside the cartridge case rather than protruding from the case as with most ammunition. All telescoped ammunition designs have used propellant charges molded or compressed from granular propellant. This molding or compaction process greatly increases the packing density, which enables more energy to be stored. This increased energy provides higher muzzle velocities.

Caseless ammunition offers the advantage of a higher round velocity and a flatter trajectory. In addition, it has the advantage that no spent casings need to be handled. In practice, however, it has proven susceptible to jamming, is more difficult to handle than conventional ammunition, and is potentially more susceptible to cook-off in the gun.

Gun Tube Technology

DoD specifications for improved lethality and greater safety in advanced gun system performance are currently being met by developing, demonstrating, and implementing technologies for the manufacture of medium-caliber gun barrels with high melting point liners. These technologies will enhance barrel life when used with high-impetus munitions under rapid-fire conditions.

The key technical activities are the development and validation of numerical simulation methods to provide a technological basis for integrated (jacket + liner) gun-barrel design optimization and the demonstration of affordable manufacturing technology.

The Advanced Gun Barrel (AGB) project is being monitored by a tri-Service subgroup of the Joint Service Medium-Caliber Automatic Gun Technology Group (JMAT). The AGB project will provide demonstrated methods for optimizing the design and manufacture of advanced performance gun barrels. The technology will be applicable to a wide range of calibers and field requirements.

LIST OF TECHNOLOGY DATA SHEETS
2.1. SMALL- AND MEDIUM-CALIBER WEAPON SYSTEMS

DATA SHEET 2.1. HIGH-FIRING RATE AMMUNITION

Developing Critical Technology Parameter	Telescoping or caseless ammunition for up to ≤ 60 mm and having uniform performance to minimize round dispersion.
Critical Materials	Insensitive high explosives for low-vulnerability ammunition (LOVA).
Unique Test, Production, Inspection Equipment	Equipment for automated production and assembly of ammunition.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Affordability is a key issue because of quantities of rounds manufactured/required.

BACKGROUND

There are two approaches to increasing the firing rate of small-caliber weapons. In the case of telescoping ammunition, the approach is to minimize the length of the round by telescoping the projectiles into the propellant cartridge. In caseless ammunition, the firing rate is improved by the elimination of the requirement for extracting and handling spent cartridges.

These technologies are critical because firing rate is a determining parameter for small-caliber weapon lethality. These technologies also impact logistics and ammunition stowage.

DATA SHEET 2.1. GUN-TUBE TECHNOLOGY

Developing Critical Technology Parameter	Ability to extend barrel life ten-fold for high impetus, small-to-medium caliber weapons, designed for sustained firing rates in excess of 200 rounds/minute.
Critical Materials	Refractory metals, particularly semifabricated forms designed to exhibit specific characteristics (e.g., ductility).
Unique Test, Production, Inspection Equipment	Specially designed equipment for drawing of hollow refractory metal tubes.
Unique Software	The project places heavy emphasis on the development of model and code methodologies. Barrel firing tests are required to provide input data for validation of these codes. Their eventual extension to advanced barrel designs for a range of guns, from 5-in. naval cannon to man-portable automatic weapons, is an important outgrowth of the ongoing project.
Major Commercial Applications	Likely to be employed for industrial tubing, where high-temperature erosion-resistant performance is demanded.
Affordability	Affordability in quantity production is the key issue in the development of this technology. The specific goal is the identification of an optimum manufacturing approach to minimize costs in a 10,000 units-per-year production run.

SECTION 2.2—TACTICAL PROPULSION

Highlights

- Improvements in tactical propulsion will allow U.S. forces to engage increasingly capable adversary threats from outside their effective range, with increased lethality and reduced exposure.
- Critical developments are occurring in energetic materials, in application of materials and structures, and in design, modeling, and simulation of system performance.
- Among the significant advances expected are extremely agile hypersonic (greater than Mach 5) systems capable of engaging mobile/maneuvering targets with high effectiveness.

OVERVIEW

Tactical propulsion encompasses all aspects of on-board propulsion for the delivery of ordnance. These include solid and gel rocket motors and air-breathing propulsion for hypervelocity missiles.

New energetic materials for improved energy and mass fraction of propellants, while reducing sensitivity, improve the strength-to-weight ratio, mechanical response properties, and volume of intercomponents of propulsion systems. This includes, as an important subset, advanced gel and slurry propellants, particularly those that inherently have acceptable logistics handling properties [flammability, viscosity, deflagration-to-detonation transition (DDT) characteristics] or are amenable to handling techniques that will enhance logistics (see Section 2.9, Energetic Materials).

Future military operations are predicated on the premise of "doing more, with less," and this translates directly into requirements for multipurpose-/multimission-capable weapons. Future advances in propulsion performance will involve the development and use of new technologies:

- Advanced structural composite materials to reduce overall rocket motor weight. Included are techniques for incorporating thermal and ballistic protection in essential structures with minimal added weight and volume.
- Materials and structures for sustained hypervelocity operation, specifically for reducing the effects of aerothermodynamic erosion.
- Techniques for design of aerodynamic structures, including modeling and simulation, (M&S) and combustion processes for air-breathing rocket propulsion, including integral rocket ramjet and ducted rockets, and high-performance (> Mach 5, high angle of attack) inlet, combustor, and fuel management subsystems.
- Small- and medium-caliber weapons, which are used pervasively and are critical to the mission effectiveness of systems such as the Apache, Comanche, and Blackhawk helicopters; future armored, scout and cavalry, and individual infantry systems; and aircraft armament and naval point defense systems.

Tactical propulsion technologies address the ability to support several interrelated objectives that underlie significant improvements in operational capabilities:

- Increased payload weight (lethality).
- Increased weapon range (effective envelope).
- Increased velocity and reduced time of flight (decreased exposure and enhanced survivability and increased threat handling).
- Improved agility and maneuverability (greater tactical flexibility and lethality).

This area also includes technologies for reducing the sensitivity of munitions to hazard stimuli, including thermal effects, ballistic impact, and shaped-charge attack.

LIST OF TECHNOLOGY DATA SHEETS
2.2. TACTICAL PROPULSION

Air-breathing Propulsion

DATA SHEET 2.2. CERAMIC GAS-TURBINE ENGINES

Developing Critical Technology Parameters	Higher thrust-to-weight ratios (100-percent increase sought over current state of the art); operating temperatures; nonmetallic and nonmechanical bearings; protective coatings; fuel efficiency (40-percent over current state of the art) for gas-turbine engines having a total diameter of less than 600 mm (23.6 in.).
Critical Materials	High-temperature structural ceramics, specifically aerospace quality rolling element hybrid (ceramic element) bearings; diamond-like carbon (DLC) coatings for bearings and hot section parts.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Experimentally validated computational fluid dynamics (CFD) codes incorporating combined three-dimensional (3–D) aerodynamic and thermodynamic flow properties specific to small-diameter gas-turbine propulsion systems, particularly models characterizing start-up performance, with limited-life design criteria.
Major Commercial Applications	Capability derives from commercial jet aircraft engine technology, particularly engines for general aviation and helicopters, but the end-use operating life requirements are very different and demand different design criteria. One area of interest for commercial activity is that of gas-turbine engines for large-scale model jet aircraft (see ***Background***).
Affordability	Because tactical weapon propulsion systems are expended in numbers, cost is an issue. Ongoing DoD programs have a goal of reducing costs by 60 percent relative to a 1987 baseline for expendable gas-turbine engines.

BACKGROUND

The critical developing aspect of this technology is driven by the inherent loss in performance and efficiency as the size of a gas turbine is reduced. The primary method of counteracting this loss is to increase the operating temperature of the turbine hot section, principally through the use of high-temperature structural ceramics.

The key point is that a growing global interest is evident in the use of very efficient, small gas turbines for a wide range of civil applications, ranging from automotive propulsion to stationary and portable industrial power. Although the specific design will differ from aeroturbines, the underlying technologies may become available. In addition, the life-cycle performance and reliability characteristics of weapons propulsion may facilitate application of the technologies. As an aside, the market in very small gas turbines for model aircraft, which is already a significant application for ceramic bearings, is already well established.

DATA SHEET 2.2. SUPERSONIC COMBUSTION RAMJET (SCRAMJET) PROPULSION (AIR-BREATHING PROPULSION)

Developing Critical Technology Parameters	Hydrocarbon-fueled scramjet capable of specific impulse (I_{sp}) > 850 sec with a specific thrust of 60 lbs(force)/lb(mass) * sec at ≥ Mach 8.
Critical Materials	Carbon-carbon composite structural materials; high-temperature ceramic coatings.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Experimentally validated CFD codes incorporating combined 3-D aerodynamic and thermodynamic flow properties specific to supersonic combustion phenomena, particularly models characterizing performance at high angles of attack.
Major Commercial Applications	Capability may be transferable to or shared with civilian hypersonic transport (HST). In fact, much of the ongoing research in the United States and abroad is directed toward civil aerospace application.
Affordability	Application of the technology to expendable, stand-off weapons systems will undoubtedly necessitate a "design-to-cost" adaptation of the technologies now under development.

BACKGROUND

The concept of supersonic combustion for weapons is relatively old. U.S. Army and Navy researchers filed initial patents in the mid-1970s and early 1980s. However, operational deployment of the technology has been impeded by the need for better materials and designs required to sustain supersonic combustion over the operational flight envelope of the weapons. Most of today's research appears to be directed toward HST.

DATA SHEET 2.2. KINETIC ENERGY MISSILE (KEM) PROPULSION (HYPERSONIC PROPULSION)

Developing Critical Technology Parameter	Aerodynamic stability of KEM at speeds in excess of Mach 5.0; KE in excess of 25 MJ at > 5 km.
Critical Materials	High-strength composite materials; high specific-impulse propellants (I_{sp} ≥ 280 sec).
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Guidance algorithms for guidance of rolling hypervelocity jet frames.
Major Commercial Applications	None identified.
Affordability	Because tactical weapon propulsion systems are expended in numbers, cost is an issue.

SECTION 2.3—SAFING, ARMING, FUZING, AND FIRING (SAFF)

Highlights

- Smart, adaptive fuzing is required to optimize the effectiveness of next-generation multipurpose/ multimission weapons.
- The trend is toward incorporating state-of-the-art electronics for programmable fuzing to allow firing criteria and characteristics to be set at launch.
- Further advances will include a wide range of enabling component technologies designed to increase weapon autonomy. These advances include miniature sensors, advanced signal-processing algorithms, and primary power, power conditioning, and packaging.

OVERVIEW

This section addresses technologies for ensuring the effective employment and optimum lethality of sensor-initiated conventional high explosive (HE) ordnance devices from a variety of expendable delivery mechanisms, including missiles, rockets, artillery projectiles, bombs (free-fall or guided), mines (land and marine), and torpedoes. The technologies addressed are limited to safing, arming, and fuzing (SAF), the design of which will generally be unique to the specific warhead, lethal mechanism, and military objectives.

This section includes component and subsystem technologies for SAF necessary for the proper functioning of a variety of ordnance payloads. These include high-altitude fuzing of canister weapons capable of dispensing submunitions, fuzing for individual submunitions, and fuzing for optimal lethality of single-mission warheads, and techniques for programmable fuzing and firing of aimable and programmable multipurpose/multimission warheads. The data sheets also address key components and enabling technologies, such as primary power sources, power conditioning, and technologies for packaging and integration.

The correct initiation of a warhead to achieve maximum effect depends on the correct functioning of the SAFF of the explosive. The safing and arming mechanism ensures the safety of the warhead throughout its service life up to the time when the weapon needs to be armed or ready to function. Safing and arming are required to ensure that the fuze never sets off the munition before it reaches a chosen burst point relative to a target, even under severe physical stress. The fuze is usually an electronic system capable of sensing or detecting the target and is programmed to set off the munition at the chosen distance from the target.

The intended scenario of use and perceived threat will strongly influence specific weaponization concepts and approaches and the functional capabilities for SAF. Any of these delivery mechanisms weapons require that certain generic SAF functions be performed (see Table 2.3-1).

Depending on the specific operational concept and delivery system, each of these functions requires special technological solutions in terms of primary power and power conditioning, overall weapon integration, and operational control and security.

The following discussion summarizes some of the more important generic aspects of weapons fuzing for different types of delivery systems, damage mechanisms, and intended targets. The discussion emphasizes those that are likely to be driven by developing technologies over the next two decades. The types of warhead damage mechanisms for which critical developing technologies are most likely to affect future capabilities are explosive-driven KE warheads, blast and blast-fragmentation warheads, and directional warheads (including rod and segmented rod as a primitive subset). In addition, SAFF technologies are required for use with fuel-air explosives (FAEs) and with certain types of electronic countermeasures (ECMs) [such as chaff cartridges (e.g., CHAFFROC) and pyrotechnic infrared (IR) decoys].

Table 2.3-1. SAFF Subsystem Generic Functions

Subsystem	Generic Functions
Safing	To ensure that the warhead can be stored, handled, deployed, and employed in a wide spectrum of intended and unintended environmental and threat conditions, with assurance that the round will not prematurely release toxic agents. *Safing HE rounds generally involves multiple mechanical interruptions of power sources and pyrotechnic/explosive firing trains.*
Arming	To ensure that the warhead is placed in a ready operational state so that it can be initiated under specified firing conditions. *Arming HE rounds generally involves mechanical restoration of the safing interrupts in response to conditions that are unique to the operational environment (launch or deployment of the system. An additional feature is that the environment typically provides the energy source to drive the arming action. This requirement would not necessarily be imposed by a proliferant.*
Fuzing	To ensure optimum weapon effectiveness by detecting that the desired conditions for various weapon functions have been met and to provide an appropriate command signal that effects the appropriate actions. *Fuzing generally involves a sensor or target detection device (TDD), signal processing and logic, and an output circuit to initiate firing or other action.*
Firing	To provide reliable initiation of primary explosive train to achieve detonation of the main explosive charge. *Typically consists of a firing circuit capable of withstanding substantial voltages (> 500 V) without functioning, while responding reliably to a low total energy fast rise-time high-voltage pulse.*

The cost of SAFF elements is critical because purchases normally involve such large numbers of devices. A few cents or even fractions of cents per device can significantly affect the affordability or cost effectiveness of designs. The trend toward “smart” munitions and multiple options in the setting and remote setting of fuzes have resulted in fuze developments of high complexity incorporating state-of-the-art communications, sensor, and electronics technology.

Potential critical developing technologies include:

- High-precision fuzing or high spatial resolution fuzing or both to allow the precise control of firing range and firing angle, including guidance-integrated fuzing.
- Applications of smart materials (electroactive ceramics) to super-quick impact or impact delay hard-target, penetration fuzing.
- Conformable antenna arrays for directional fuze sensors.
- High-resolution imaging sensors and algorithms for real-time target analysis and selection of aimpoint for optimum weapons effectiveness.
- Techniques for hardening fuze sensors against ECM or electromagnetic (EM) impulse effects, including optical SAFF devices that are immune to radio frequency (RF) radiation.
- IM technologies, specifically high-reliability, in-line electronic safing and initiation subassemblies (e.g., exploding foil and semiconductor bridge devices) capable of meeting U.S. Ordnance Safety Standards, and specially designed pulsed-power firing circuits for such devices.

LIST OF TECHNOLOGY DATA SHEETS
2.3. SAFING, ARMING, FUZING, AND FIRING (SAFF)

DATA SHEET 2.3. MILLIMETER-WAVE (mmW) AIR TARGET FUZING

Developing Critical Technology Parameter	Monolithic integrated circuits (ICs) comprising complete subassemblies of miniature radar subsystems, particularly those with thermal management techniques designed specifically for limited-life operation at high average powers.
Critical Materials	Specially designed substrate materials, such as gallium nitride compounds, having superior high-temperature performance.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Experimentally validated design models characterizing the RF performance of components over the anticipated range operating temperatures.
Major Commercial Applications	Underlying technologies are common to personal consumer electronics products. However, requirements for thermal management design for limited life in specific military applications are substantially different.
Affordability	Primarily an issue for low-cost expendable ordnance such as future projectile fuzes, low-cost missiles, and wide-area munition.

DATA SHEET 2.3. IMAGING OPTICAL FUZING

Developing Critical Technology Parameter	Passive or active laser profilimetry two-dimensional (2–D) or 3–D pattern recognition and feature extraction for aim/firing-point selection, having an accuracy of 1 m or less.
Critical Materials	High-purity detector materials (HgCdTe, InSb).
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Experimentally validated models and related target databases, particularly those incorporating or correlated to vulnerability and damage-response characteristics.
Major Commercial Applications	Active laser profiling is used in a variety of civil applications, including automated inspection and parts selection.
Affordability	Affordability is a consideration, although increased lethality offers a potential cost performance tradeoff.

DATA SHEET 2.3. IMAGING OPTICAL FUZING—PASSIVE INFRARED (PIR)

Developing Critical Technology Parameter	PIR terminal sensors designed for pattern analysis for target identification and aim/ firing-point selection.
Critical Materials	High-purity detector materials (HgCdTe, InSb).
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Experimentally validated models and related target databases, particularly those incorporating or correlated to vulnerability and damage-response characteristics.
Major Commercial Applications	PIR sensing is used in thermal measurement and monitoring and in remote sensing of earth resources.
Affordability	Affordability is a consideration, although increased lethality offers a potential cost performance tradeoff.

SECTION 2.4—GUNS, ARTILLERY, AND OTHER LAUNCH SYSTEMS

Highlights

- Tube launchers (guns, howitzers, recoilless rocket tubes, and so forth) have been and will continue to be a critical element of effective force projection. Future warfighing concepts of precision strike and maneuver dominance will demand increases in range, accuracy, and rates of fire.
- Improvements are envisioned in lightweight autoloading, higher energy density propellants, IMs [including as an important subarea LOVA propellants and novel techniques for gun propulsion including electrothermal chemical (ETC) and liquid/gel propellant technologies].

OVERVIEW

This section addresses technologies for advanced conventional projectors—specifically guns, howitzers, mortars, and recoilless rocket tube launchers. Critical developing technologies are primarily related to the design and configuration of the launch tube and ancillary support equipment, which are significant factors in determining the accuracy and rate of fire with which the expendable ordnance rounds can be delivered.

Improved performance is dependent on advances in propelling charges, rocket assists, interior and exterior ballistics, and the warhead interfaces. (Missile propulsion systems are addressed Section 2.2, Tactical Propulsion.) Chemical and ETC propulsion systems are of special interest. The emphasis is on improving range and accuracy, increasing KE, increasing mobility, and reducing manpower requirements.

Tube-launched projectiles (guns, howitzers, and recoilless rocket tube launchers) have been and will continue to be an essential element in land, air, or sea warfare. Future warfare concepts for precision strike and maneuver dominance will demand greater range and weapon effectiveness at affordable costs. The objective of controlling the tempo of engagements translates in certain scenarios into requirement for increased rate of fire.

Much of the technology for producing gun tubes—including automated machining involving in-bore sensing on the cutting tools and heavy plating techniques (typically chromium to reduce erosion and wear) remains applicable to a wide range of future armament, including guns for the MBT and advanced major caliber (105 mm and greater) field artillery systems. The antecedents for modern guns and rockets are centuries old. However, despite the long history for this class of weapons, critical technology developments in materials, propellants, and design will be needed to realize next-generation requirements for improved performance and mobility.

Among the advances required beyond those already addressed in *Weapons Systems Technologies* are the following:

- Lightweight autoloading and higher rates of fire.
- Improved propellants to increase range and reduce logistics load.
- LOVA propellant technologies.
- Novel techniques for gun propulsion.
- Techniques for controlling signature and reaction of launcher systems for hypervelocity KE missile systems (e.g., the Army LOSAT system).
- Advanced techniques for operational real-time characterization of internal ballistics and external ballistics to increase system accuracy.

LIST OF TECHNOLOGY DATA SHEETS
2.4. GUNS, ARTILLERY, AND OTHER LAUNCH SYSTEMS

DATA SHEET 2.4. ELECTROTHERMAL CHEMICAL (ETC) PROPULSION

Developing Critical Technology Parameter	ETC to provide muzzle energy in excess of 15 MJ in large-caliber (> 81-mm) configurations.
Critical Materials	High-energy density, low-vulnerability materials in high-energy density formulations; erosion-resistant/long-life composites materials for barrels.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Experimentally validated models interior ballistic response of launcher and projectile.
Major Commercial Applications	Plasma-assisted combustion is an area of general scientific research with application to industrial processes and to energy and transportation sectors. Technologies for application to gun propulsion are specific to the military. Certain underlying scientific principles may be pertinent to high-temperature synthesis, pulsed power, or high energy-rate deformation.
Affordability	Affordability has traditionally been a primary factor in the selection and development of tube-launched weapons. In this case, the ability to enhance lethality within existing platform constraints has the ability to extend the effective operational life of the current generation of MBTs and other systems.

BACKGROUND

The term electrothermal chemical propulsion applies to propulsion techniques (typically applied to gun propulsion, but with some potential applications to space propulsion) wherein the burning characteristics of a chemical propellant are enhanced with an electrically induced plasma. ETC fits into a group of kinetic energy weapons (KEWs) technologies aimed at enhancing lethality by increasing velocity. In order of increasing electrical power requirements, ETC falls between true EM launchers (rail guns and coil guns) and pure chemical propulsion. In the late 1980s, there was also some interest in pure electrothermal (plasma-driven) weapons. However, these weapons have extremely high electrical power requirements. While ETC continues to be an area of interest, the functional goals of the technology have been scaled back substantially in recent years, again because of primary power considerations.

Initially, researchers envisioned ETC as a way to increase muzzle energy by sustaining the design pressure over the full length of the barrel. However, current estimates indicate that this would require on the order of 10 MJ of electrical power.

DATA SHEET 2.4. ELECTROMAGNETIC (EM) LAUNCH TECHNOLOGY

Developing Critical Technology Parameter	EM launch technology for KEWs, capable of delivering > 20 MJ KE on target. This encompasses technology for systems designed for antiarmor and antiair missions.
Critical Materials	Rail materials, specially characterized for low friction, that suppress/retard the formation of undesired plasmas in the wake of the projectile.
Unique Test, Production, Inspection Equipment	Specially designed equipment for measuring internal ballistics of EM launchers.
Unique Software	Computational techniques are expressly identified as areas of active research in annual Institute of Electrical and Electronics Engineers (IEEE) Magnetics Society symposia on EM launchers.
Major Commercial Applications	The primary civilian interest in EM launch technology falls into two primary areas: (1) space launch, where payloads will be substantially larger and (2) high energy-rate physics and materials research. While some of the underlying science and technologies are common, specific operational requirements and technologies per se are likely to be unique for military systems.
Affordability	Significant reductions in component cost would be necessary for high-volume deployment of this technology.

BACKGROUND

Technologies under development for commercial power and transportation (e.g., fuel cells, energy storage systems, and high-power switches) are potentially enabling technologies for EM launch. In addition to the commercial applications cited previously, several countries are pursuing EM launch for fusion fueling and high energy-rate deformation studies and for military applications. The combination of technology availability and research creates a situation for potential exploitation of commercial technologies for antiarmor and air defense missions.

DATA SHEET 2.4. ZONED AMMUNITION FOR AUTOLOADING ARTILLERY

Developing Critical Technology Parameter	Zoned ammunition propellant and handling subsystems for mobile and self-propelled land weapons of 120 mm or larger; capable of operating with high reliability over the following parameters: elevation angles –20 deg to 70 deg; firing rates > 10 rounds per minute; charge accelerations of > 4 m/sec^2, with positive control of position.
Critical Materials	Insensitive high explosives (IHEs); specially formulated binders.
Unique Test, Production, Inspection Equipment	Propellant molding and casting equipment.
Unique Software	None identified.
Major Commercial Applications	None; critical aspects unique to military system.
Affordability	Primarily associated with round and propellant charge because of numbers produced/ required.

BACKGROUND

Full autoloading (of projectile and propellant) poses particular challenges for the gun designer. The loading mechanism must be capable of moving the projectiles and charges rapidly but with positive control to eliminate unnecessary shock caused by impact in the breech and handling mechanisms themselves. Exotic materials are typically not required—aircraft structural aluminum alloys are generally sufficient. The primary design challenge is to obtain consistent handling and control at the extremes of elevation (typically 70 deg to –20 deg) and to ensure proper clearance of all mechanisms over the full azimuth range. While not essential, modern computer-aided design/computer-aided manufacturing (CAD/CAM) systems have been used effectively for virtual prototyping. Among the related supporting technologies under investigation as an adjunct to autoloading is laser ignition.

SECTION 2.5—GUIDANCE AND CONTROL

Highlights

- The ability to exert dominant force with minimum threat exposure and reduced numbers of systems requires weapons with an enhanced single-round capability to detect, locate, engage, and defeat enemy assets autonomously.
- Critical developments are likely to occur because of technological advances in high-resolution sensors, effective integration of multimode guidance sensors, and in novel algorithms incorporating machine intelligence for complex scene analysis, automatic target recognition (ATR), and terminal guidance.
- Increased accuracy will allow for so-called "zero CEP" (circular error probable) delivery of hit-to-kill warheads to achieve assured lethality with minimum collateral damage.

OVERVIEW

This section addresses all types of weapons guidance for precision delivery of conventional munitions. It includes aspects of command communications, midcourse navigation, and sensor technologies associated with delivering surface-to-surface, surface-to-air, air-to-air, and air-to-surface targets and with undersea guidance of mobile mines and torpedoes. It excludes technologies for aim-point selection and direction of conventional weapons effects [e.g., the standoff explosively formed penetrator used in seek and destroy armor (SADARM)], which are addressed in Section 2.3, Safing, Arming, Fuzing, and Firing (SAFF). Also excluded are technologies associated with fire control sensors and direction of unguided rounds and with DEWs.

The following guidance and control technologies comprise a suite of capabilities, the criticality of which will be a function of the launch platform, intended target, and operational scenario (e.g., adverse weather and ECMs).

With the exception of antiship and antisubmarine weapons, where the target size and signal-to-clutter characteristics strongly favor the operational use of active terminal homing, most systems currently deployed use passive homing, semi-active homing, or command guidance. Table 2.5-1 summarizes representative examples of current capabilities.

Table 2.5-1. Summary of Functions and Technologies

Mission Function	Example of Current State of the Art	Critical Developing Technologies
Surface-to-surface	Brilliant Anti-Tank (BAT) passive acoustic/passive IR adjunct IR terminally guided submunition [Army Tactical Missile System (TACMS)] TOW—Wire-guided command line of sight Copperhead—Semi-active laser homing Pershing—Active radar digital scene mapping and correlation Tomahawk Land-Attack Missile	Active laser homing, capable of reliable autonomous acquisition and engagement of armored targets beyond line of sight (BLOS) [e.g., Air Force Low-Cost Antiarmor System (LOCAAS); Army High-Quantities Antimaterial Submunition (HI–QUAMS)] Smart imaging sensors for autonomous precision attack of mobile enemy forces

(continued)

Table 2.5-1. Summary of Functions and Technologies (Continued)

Mission Function	Example of Current State of the Art	Critical Developing Technologies
Surface-to-air	Homing All the Way Killer (HAWK)/Patriot—Command mid-course, semi-active terminal homing Chaparral—Passive IR Aegis Standard Missile	High-accuracy, high-maneuverability "hit-to-kill" terminal sensors for TMD Active terminal homing fire-and-forget air defense weapons
Air-to-surface	Semi-active laser-guided bombs Tomahawk Land-Attack Missile HELLFIRE semi-active terminal homing antitank	Smart Imaging sensors for autonomous precision attack of mobile enemy
Air-to-air	Sidewinder and Sparrow passive IR homing Phoenix missile, semi-active radar guided homing Advanced Medium-Range Air-to-Air Missile (AMRAAM)—active terminal homing	Improved guidance-integrated initiation of warheads for adaptive engagement of high-speed crossing targets Imaging and/or multimode guidance
Torpedoes and propelled mines	Active acoustic terminal homing	None identified

Among the critical developing technology areas identified in the area of guidance and control are:

- Development of active imaging laser terminal homing for BLOS antiarmor weapons. A major focus will be essential improvements needed in algorithms to acquire correct targets reliably in a false target-rich environment. Such algorithms are currently among the critical path items that must be addressed for future systems.
- Design of terminal homing systems with advanced image analysis capability for ATR and warhead aim-point selection and pointing.
- Multimode IR/RF terminal guidance, particularly combined active radar/PIR sensors designed for simultaneous dual-mode operation.
- Guidance and control technologies for so-called "zero CEP" (hit-to-kill) air target interceptors, including high-resolution optical systems (including passive staring arrays and active laser-imaging techniques for false target/decoy discrimination) and active mmW radar sensors.
- High-maneuverability (greater than 60 G) rapid-response guidance systems, including aerodynamic and impulse-reaction motor-steering techniques.
- Guidance and control techniques designed for control of hypervelocity (greater than Mach 5) interceptors.

Key critical developing technologies in these areas will be in:

- Sensors and sensor integration for very precise (more than 1-m CEP) aim-point selection in antiarmor systems and hit-to-kill in air-to-air and surface-to-air systems
- Novel algorithms incorporating machine intelligence and fuzzy logic for effective on-board ATR and complex scene analysis and characterization fro reducing the incidence of false target selection while maintaining a high probability of correct target identification. (Ratios of 10,000:1 favoring correct identification of target in presence of similar objects are needed.)

LIST OF TECHNOLOGY DATA SHEETS
2.5. GUIDANCE AND CONTROL

DATA SHEET 2.5. ACTIVE LASER SEEKER

Developing Critical Technology Parameter	Active laser radar systems providing 3-D pattern recognition and feature extraction for terminal guidance and aim/firing-point selection.
Critical Materials	High-purity detector materials (HgCdTe, InSb).
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Experimentally validated models and related target and environmental databases, particularly those incorporating or correlated to vulnerability and damage response characteristics.
Major Commercial Applications	Active laser profiling is used in a variety of civil applications, including automated inspection and parts selection, remote sensing, and measurement.
Affordability	Affordability is a consideration, although increased lethality offers a potential cost performance tradeoff.

DATA SHEET 2.5. SMALL- AND MEDIUM-CALIBER GUIDANCE AND CONTROL

Developing Critical Technology Parameter	Terminal guidance and aerodynamic control techniques for $\leq$ 60-mm diameter ammunition. (See ***Background*** for discussion of important linkages to other technologies.)
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Automated assembly equipment.
Unique Software	Specialized algorithms for small-body guidance and control.
Major Commercial Applications	None identified.
Affordability	Ultimately affordability will be the driver (see ***Background***).

BACKGROUND

The concept of providing terminal correction for small-caliber projectiles is driven by complex economic tradeoffs between cost and effectiveness. In high-rate-of-fire weapons, cost/round is a critical factor, with the tradeoff becoming one of statistical probability based on numbers of rounds fired and weapon accuracy. As the ability grows to package better sensors and more intelligence in small volume and at lower cost, the tradeoff could swing in favor of terminal guidance. An equally important consideration would be the successful development of economical means of high-volume production of critical developing high-energy density materials (HEDMs) (see Section 2.9, Energetic Materials). Such technologies have the ability to increase lethality of small-caliber rounds to the point where the additional cost is warranted.

DATA SHEET 2.5. AUTOMATIC TARGET RECOGNITION (ATR) FOR AUTONOMOUS GUIDANCE

Developing Critical Technology Parameter	Ability to classify and identify targets reliably from among as many as 100 target classes, in false-target-rich fields within a total search area comprising 1,000× the target acquisition window of the sensor.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Algorithms for multiresolution processing, real-time data fusion, and real-time target discrimination.
Major Commercial Applications	Related image-processing technologies are being developed and used commercially in medicine, law enforcement, transportation, robotics, and in manipulation of multimedia images. These are likely to be the driving force in future developments.
Affordability	Affordability is a consideration, although increased lethality offers a potential cost performance tradeoff.

BACKGROUND

One of the critical limiting factors in wide area fire-and-forget weapons is an inadequate ability to discriminate between real and false targets. The difficulty lies in the fact that the numbers of false-target opportunities in a given search area can be extremely large. This is particularly true for advanced powered rounds, whose search areas may measure 100 km^2 or greater.

DATA SHEET 2.5. ADVANCED COMPONENTS FOR MILLIMETER-WAVE (mmW) SEEKERS

Developing Critical Technology Parameter	Monolithic ICs comprising complete subassemblies of miniature radar subsystems operating at mmW frequencies (730 GHz), particularly those with thermal management techniques designed specifically for limited-life operation minutes at high average operating powers.
Critical Materials	Substrate materials, such as gallium nitride or other wideband gap semiconductor compounds, that exhibit superior high-temperature performance.
Unique Test, Production, Inspection Equipment	Equipment for producing large-area wideband gap wafers with low defect density; equipment specially designed or modified for deposition of high-temperature metallization on compound semiconductor wafers.
Unique Software	Experimentally validated design models characterizing the RF performance of components over the anticipated range operating temperatures.
Major Commercial Applications	Underlying technologies are common to personal consumer electronics products. Most directly applicable dual-use technology identified is collision avoidance/guidance systems for automobiles. Another growing application is short-range communications for a variety of mass-market applications. Civil applications tend to be at V-band frequencies. Further, design requirements for thermal management for limited life in specific military applications are substantially different. However, growing civil interest in the general area of mmW components is promoting the growth and spread of generic technology at the material and component design/fabrication levels.
Affordability	Primarily an issue on low-cost expendable ordnance, such as future projectile fuzes, low-cost missiles, and wide-area munitions (WAMs).

SECTION 2.6—BATTLESPACE ENVIRONMENT

Highlights

- Information superiority will require significant improvements in our ability to characterize the battlespace environment and predict its effects on system performance.
- Making these improvements will demand real-time acquisition and fusion of data for dispersed mobile assets, improved prediction and characterization of sensor and weapon performance under localized effects, and real-time dissemination of results that can be used by operational forces.
- Availability of battlespace environment information will allow commanders to “own the weather,” position forces, and assign weapons for optimum effectiveness under tactical conditions.

OVERVIEW

The battlespace environment provides for the study, characterization, prediction, and M&S of the terrestrial, ocean, lower atmosphere, and space/upper atmosphere environments to understand their impact on personnel, platforms, sensors, and systems; to enable the development of tactics and doctrine to exploit that understanding; and to optimize the design of new systems.

This technology area divides broadly into two major subcategories.

1. Ocean and littoral environments and their effects of sea and amphibious operations, and related sensors and weapons.
2. Land-air environments and their effects on ground vehicle performance and on sensors and weapons performance.

Ocean environments pose particular challenges. Past efforts have been predicated on the construction of databases supplemented by limited on-site information and have been aided by large-scale predictive models driven by large-scale observational programs. Emerging requirements for the rapid deployment of forces capable of operating effectively close to shore or in amphibious operations in the littoral zone create new requirements for the accurate prediction of localized environmental conditions. Among the critical aspects to be addressed are:

- High-resolution current, wave, surf, and tidal forecasting models coupled to atmospheric models for support of operations in shallow water.
- Measurements and models of physical and biological processes that impact acoustic, optical, and EM propagation at surveillance and weapons frequencies.
- Models of fluid-sediment interaction relevant to mine burial, specialized sensing systems for ocean processes in shallow water, and remote sea-floor mapping capabilities.
- Models of the ocean environmental effects on acoustics, optics, and electromagnetics so that environmentally adaptive signal processing can be developed (in cooperation with acoustic and other programs) to improve clutter rejection and target detection.

Information technology (see Section 10, *Information Technology*) plays a crucial role as an enabling technology for running these models and simulations. The increasing power of microprocessors and the speed of interconnection technologies will continue to effect changes in the overall system concepts and implementing architecture of military command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR).

Knowledge of battlespace environmental effects has several operational dimensions:

- Microscale meteorological prediction supports more effective planning for maneuver of ground assets.

- Meso- and microscale measurements coupled to sensor models accurately characterizing basic propagation and clutter phenomenology support accurate prediction of sensor performance and optimal assignment of sensors and weapons designation.

As we move toward the integrated sensor-to-shooter capabilities and the elimination of so-called "stove-piped" command and control (C2), technologies to support the seamless integration of battlespace environment data from diverse sensors operating in different domains will be critical. Finally, these data must be applied with sufficient accuracy to predictive models that characterize sensor and weapon performance to support real-time assignment of sensors and weapons to optimum operational effect. This demands:

- Real-time acquisition and fusion of data from multiple geographically dispersed mobile platforms.
- Development of accurate predictions of localized and battlespace-wide environmental conditions from such data, based on correct physical modeling of the underlying phenomenology.
- Characterization of sensor and weapon performance under localized conditions, again based on physical modeling of the phenomena and sensing mechanisms involved.
- Real-time dissemination of the resulting environmental and battle management information to the operating echelons responsible for engaging the enemy.

The importance of physical modeling derives from the inherently chaotic behavior of nonlinear systems. As science looks at the nature of physical systems with greater accuracy, it observes that very small perturbations in a nonlinear system can later produce extremely large differences in the state of the system. This phenomenon is called the "butterfly effect," after the whimsical notion that an atmospheric disturbance on the order of that created by a butterfly flapping its wings can result in the formation of a hurricane. Conventional Monte Carlo modeling deals with discrete probability functions creating inherent gaps in data through which nonlinear effects may escape undetected. These gaps can be closed, and the accuracy and reliability of modeling can be improved by increasing the spatial resolution and frequency of input data and by relying more heavily on the use of physical rather than statistical performance.

"Physical models" characterize the response of the system in a way that, while still generally dependent upon discrete sensory data inputs and digital processing, more closely approximates a continuum. Future developing capabilities in this area will provide the mathematical underpinnings and analytical tools that improve understanding of complex nonlinear physical phenomena, such as those occurring in advanced materials, fluid flow, acoustic and EM propagation, optoelectronics, and neurophysiological systems. Emphasis is on developing mathematical models—especially nonlinear ordinary and partial differential, difference, and integral equations—and on enhancing the understanding of these models by functional analytical means, often in the context of providing the basis for improving or replacing computational procedures.

Capabilities in battlespace environment are emerging rapidly. Advances in computational capabilities have dramatically increased worldwide capabilities in weather prediction and modeling of complex nonlinear phenomena. These same capabilities support advances in the ability of sensor and weapons designers to characterize the performance of systems as a function of complex environmental conditions.

Much of the underlying phenomenology and technology for environmental sensing has growing civilian uses. A variety of optical measuring techniques are being used to characterize air quality worldwide. In the area of meteorology, the need for more timely, reliable, and higher resolution global weather data has lead to the worldwide dissemination of know-how in this area. Growing sensitivity to the long-term effects of air pollution on health, water quality, and agricultural productivity can be expected to promote the continued spread of technology in this area.

LIST OF TECHNOLOGY DATA SHEETS
2.6. BATTLESPACE ENVIRONMENT

The following developing technologies have been identified, but data sheets are not available at this time:

Battlespace Environment Visualization

DATA SHEET 2.6. BATTLESCALE LOWER ATMOSPHERE METEOROLOGY

Developing Critical Technology Parameter	A 3- to 5-day global ocean-atmosphere coupled model. Ability to derive real-time battlescale data for effective multispectral signature management and deception.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Fully integrated atmospheric prediction and tailored decision-aid software.
Major Commercial Applications	While the civil activity in weather prediction is widespread, the Defense Technology Area Plan (DTAP) asserts that the military requirements covered here are distinct from the broader civil applications and that the industrial base is very small in this area.
Affordability	None identified.

BACKGROUND

One of the most critical aspects of information superiority is a capability to “own the weather.” This means, in effect, the ability to predict weather effects on maneuver and targeting and guidance sensors in real time, with sufficient accuracy to allow commanders to plan missions and assign weapons with optimum effectiveness.

This technology is crucial to the ability of U.S. forces to exploit weather conditions to maximum advantage to evade enemy surveillance and reduce the probability of detection, recognition, or identification. Increased knowledge of the battlespace and better quality and more timely forecasts are needed to maximize operational effectiveness. As a data point, the weather in Desert Storm was the major cause of aborted strike missions. This resulted in over 40 percent of ordnance being unused for targets and greatly compromised battle damage assessments.

The numerical size and physical complexity of data-assimilation problems in the atmospheric and oceanic sciences strain the largest existing computers, as well as the limits of the available theory. Effective mesoscale modeling and prediction will require real-time integration of multisensor data and global weather data.

While macroscale processes govern the weather in a region, microscale and mesoscale processes determine localized conditions affecting weapon and sensor processes. Such phenomena include weather fronts and squall lines, tornadoes, thunderstorms, microbursts, and hail. Conditions may be highly localized (within a few square kilometers) and persist from minutes to hours.

DATA SHEET 2.6. ATMOSPHERIC EFFECTS MODELING AND SIMULATION (M&S)

Developing Critical Technology Parameter	Ability to predict effects of atmospheric attenuation, scattering, distortion, and so forth with sufficient accuracy and within the timeframes necessary for real-time operational deployment, direction targeting, and weapon sensors.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Fully integrated atmospheric prediction and sensor performance models.
Major Commercial Applications	While much of the effort will be military-sensor specific, certain aspects of modeling may be useful in the design and development of commercial communication and remote sensing and atmospheric monitoring.
Affordability	None identified.

BACKGROUND

Accurate knowledge of the effective performance envelopes of sensors (including terminal guidance sensors on board the weapons) enhances the ability of the commander to deploy and direct forces for optimum effect. Battlespace awareness is viewed as key to maintaining information superiority and U.S. dominance on the battlefield. The ability to model atmospheric effects on sensor performance from physical first principals is critical to maintaining accurate knowledge force capabilities under all types of environmental conditions.

SECTION 2.7—WARHEAD TECHNOLOGIES

Highlights

- The emphasis on electronics and smart weapons coming out of the Gulf War has tended to overshadow the significant advances occurring in the effectiveness and lethality of conventional warheads.
- These advances are proliferating, increasing the potential for future technological surprise on the battlefield.
- Warhead technologies encompass a broad spectrum of disciplines, ranging from unfuzed KE penetrating rounds to sophisticated multipurpose/multifunction explosive warheads capable of directional projection of multiple lethal mechanisms. Technological advances are occurring across the entire spectrum.
- Among the more critical developments will be those for reducing the sensitivity of munitions to prevent unintended detonation from a wide range of damage mechanisms.

OVERVIEW

This section covers critical developing technologies for all types of future conventional warhead concepts that employ mechanical blast, shock, thermal pyrotechnic effects, or ballistic penetration to defeat all types of tactical targets, including armored land and marine vehicles, air vehicles, structures, materiel, and personnel. However, the extremely-high-velocity projectiles specially designed for firing from EM launchers (coil guns or rail gun) and certain electrothermal and ETC guns are covered under DEWs and KEWs.

This section also addresses the design and fabrication of future conventional warheads, with emphasis on enabling design technologies and on production methods that offer the potential for order-of-magnitude decreases in quantity production costs for existing devices [such as explosively formed penetrators (EFPs)].

The emphasis on electronics and smart weapons coming out of the Gulf War and reflected in subsequent science and technology (S&T) planning documents has tended to obscure significant advances in effectiveness and lethality of conventional warheads. More powerful computing and hydrodynamic modeling, coupled with improved empirical understanding of materials and their reaction to high energy-rate deformation, has given us much better insights into lethal mechanisms. At the same time, improvements in IHEs and in detonator/initiator technologies are enabling the development of entirely new warhead concepts.

The technology for warheads has not spread at anything like the rate at which technologies for the associated electronics subsystems have proliferated. Nevertheless, proliferation is occurring, and the potential for technological surprise in terms of unanticipated improvements in conventional weapons lethality does exist.

Table 2.7-1 summarizes the wide range of mechanisms, damage effects, and warhead types and the primary tactical targets for each.

KE Penetrators

High-density KE cannon-launched penetrators have been, and will continue to be, a mainstay of U.S. antiarmor capabilities. The most advanced (and most lethal) manifestations of the technology are the modern U.S. depleted-uranium (DU) 120-mm tank-gun armor piercing, fin-stabilized, discard sabot (APFSDS) rounds (see Figure 2.7-1). The areal density of penetrating energy deposited by a round traveling at a given velocity is directly proportional to the material density and length-to-diameter (l/d) of the round. Critical technologies are associated with material alloying and processing technologies to produce rods with greater l/d ratios that will provide acceptable aeroballistic performance and structural integrity on impact, with techniques to reduce parasitic weight of the sabot and errors induced by discarding same, and aeroballistic design of the round flight configuration to reduce dispersion.

Table 2.7-1. Warhead Summary

Lethal Mechanisms	Primary and Secondary Damage Effect	Warhead Types	Weapon Systems	Primary Missions
Inert (nonexplosive) KE penetrator	Armor penetration and internal component kill	KE long rod penetrator Segmented rod warheads	Cannon launched Missile (including hypervelocity)	Antiarmor
Guided, hit-to-kill KE interceptor	Catastrophic structural kill and shock-induced component kill	Aerodynamically guided Impulse-reaction steered	Guided missiles	Theater Ballistic Missile Defense (TBMD)
Explosive-driven KE	Armor penetration and internal component kill	Shaped-charge and explosively-formed penetrators	Cannon launched, direct fire Missile Mortar/artillery launched	Antiarmor Antisubmarine Antiship
Blast and blast fragmentation	Structural kill, component kill or degradation	Conventional single point initiated HE round Dual initiated, focused blast-frag Directional warhead Controlled fragmentation (including preformed fragments)	Cannon launched, direct and indirect fire Rocket propelled Missile Mortar/artillery launched Land mines Sea mines	Antipersonnel Antimissile Air defense Air superiority Land attack
Directional (included rod and segmented rod as a primitive subset)	Structural kill, component kill or degradation	Rod and prescored case warheads Asymmetrically initiated warheads Deformable asymmetrically initiated warheads	Gun launched Missile	Antiair, including, as an important subset, TBMD.

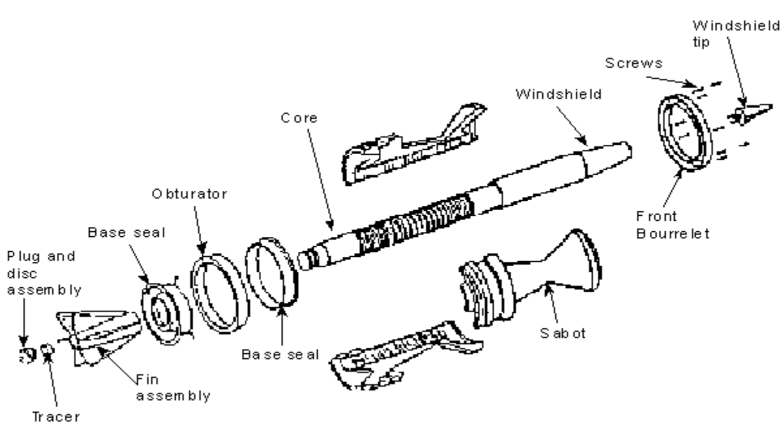


Figure 2.7-1. State-of-the-Art KE Penetrator

While KE penetrator rounds are designed for armor perforation, their effectiveness derives from a multiplicity of complex interrelated effects. These include:

- Interaction of the penetrator itself with internal components (including human operators) of the system.
- Interaction of spallation products and other impact debris with internal components.
- Structural shock and damage to components from shock transmitted through the structure. Damage includes not only catastrophic failure, but also a wider range of degradation effects, such as shock-induced misalignment of optical fire controls.
- Fire damage, whether cause by pyrophoric materials (e.g., DU) or from adiabatic heating and ignition of flammable internal components.
- Explosion/deflagration of stored ammunition and fuels.

The terminal-ballistics and target-interaction aspects of this type of weapon constitute important disciplines in their own right. To reduce duplication of coverage, these topics are addressed in the general discussion of survivability and lethality.

The DU alloy has been the state of the art for large caliber APFSDS rounds since 1970, and improvements in metallurgy and processing have yielded continual advances in l/d and performance of U.S. rounds. Alternative developing technologies include composite rods (typically DU reinforced with higher strength structural elements), and efforts duplicate the performance of DU in tungsten alloys. The primary impetus for looking at tungsten alloy has been to obtain commonality with NATO allies, many of whom will not deploy DU rounds because of environmental concerns. However, since the breakup of the FSU, the United States and its allies have been less focused on planning for a conventional land war against numerically superior Warsaw Pact armored forces, and indications are that other countries have eased their stance on the use of DU.

Segmented rods are a special class of KE penetrator that theoretically could improve overall round impact ballistics and effectiveness. While the concept has been studied for some years, no known programs exist to develop an operational system on this concept.

Hit-to-Kill KE Interceptors

Hit-to-kill (also referred to as “zero or near-zero CEP”) weapons have emerged as one of the concepts of choice for tactical ballistic missile defense. The attraction of the concept lies in the extremely high theoretical energy transfers achieved on impact. For example, the KE of a 20-kg round traveling at Mach 4.0 is approximately 6 MJ. In a TMD intercept, the closing velocities are additive, and the energy transfer associated with the collision correspondingly higher.

In theory, several different ways of delivering the warhead to the target are possible. In practice, however, most future systems envision a terminally guided interceptor, typically reaction motor steered. There are also several conceptual variants on this theme aimed at increasing the lethal radius of the round by extending structural elements (see Figure 2.7-2).

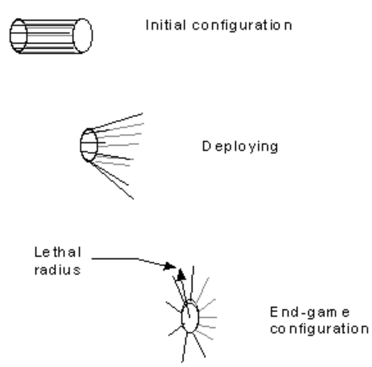


Figure 2.7-2. Hit-to-Kill

The critical developing technologies are primarily associated with the terminal guidance and control, which must be able to sense the relative position of the target relative to the axis and rotation angle of the round so that the firing of the impulse reaction steering motors can be timed precisely to achieve the necessary correction. Section 2.5, Guidance and Control, discusses this concept in greater detail.

Explosively Driven Penetrators

Most conventional penetrating warheads derive their lethal energy from explosives—specifically by imparting KE to a metallic "liner" component. Primarily, the initial shape of the liner (see Figure 2.7-3) governs the exact end configuration and ballistic performance of the penetrator proper.

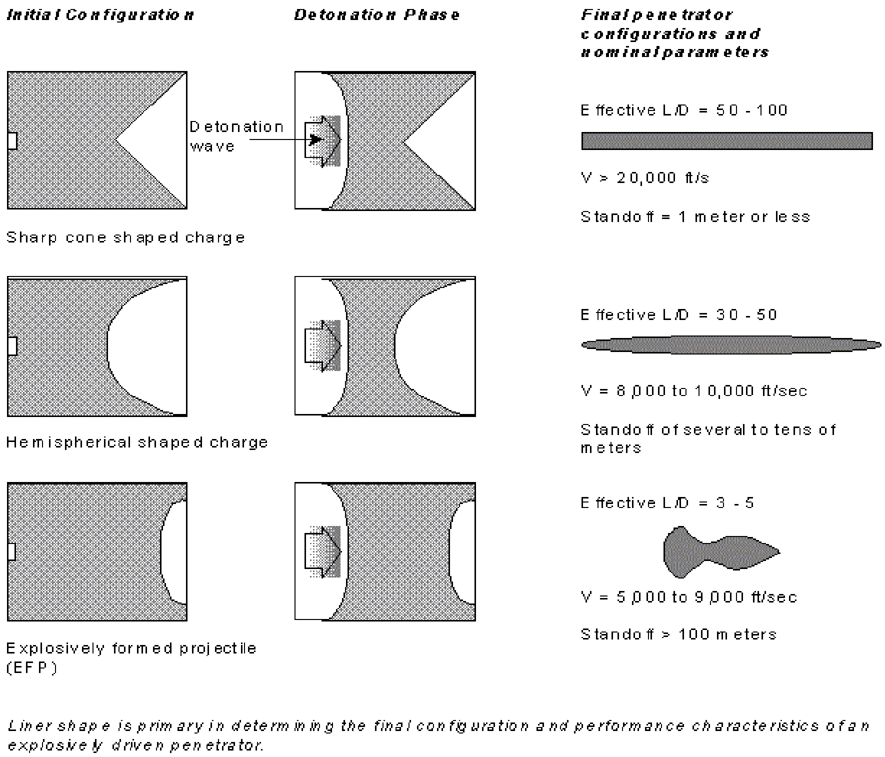


Figure 2.7-3. Explosively Driven Penetrators

Shaped Charges

The oldest and most widely available form of high-explosive antitank (HEAT) round is the conical shaped charge, typically copper. While the basic principles are well known and copper-liner systems have been widely disseminated, certain aspects of fabrication, and particularly for mass-production of required tolerances, remain state of the art. Critical developing technologies are associated with the use of higher density alloys (notably of molybdenum, tantalum, or tungsten) for so-called "deep" conical shaped charge. The primary challenges are the inherently low ductility of these materials and the cost of serial production. Some progress has been made, and molybdenum is being used as a liner material for some of the smaller diameter precursor rounds used in tandem warhead concepts.

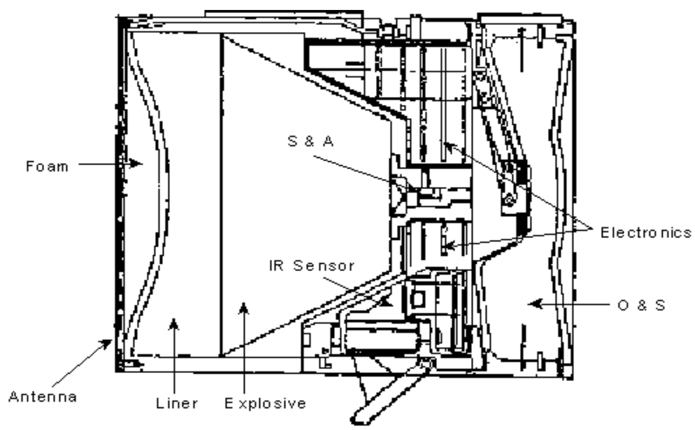
In addition to material selection and processing of the liner, a variety of deep liner configurations have been explored, all with the basic goal of maintaining the integrity of the perforating jet at a given standoff range while maximizing its velocity. Trumpet liners and biconical liners represent techniques to optimize the geometry of the detonation wave-liner interaction by configuring the liner. An alternative technique (more popular with European designers than with designers in the United States) is to tailor the geometry of the detonation wave, typically by inserting an inert element in the charge.

Explosively driven shaped charges have also been incorporated in multiple effects warheads, with only minor reductions in the effectiveness of either the shaped charge or the fragmenting warhead. This basic concept has been applied to large-caliber guided projectiles and small antipersonnel/antimaterial (APAM) submunitions.

While many of the developments in modern shaped charges have been driven by improvements in MBT armor protection, this is by no means the only application of the concept. Shaped charges are used in antisubmarine weapons, where the design of the devices to ensure proper formation of the jet in the undersea environment is a specialized discipline. Shaped charges are also applicable for antitank land mines and for use as cutting charges in a range of civil engineering, mining and oil well development, and demolition applications.

Explosively Formed Penetrators (EFPs)

As illustrated previously, as the liner becomes shallower and thicker, the velocity of the final configuration decreases, but the standoff range becomes substantially greater. EFPs are used in top-side kill weapons, like the U.S. SADARM (see Figure 2.7-4). The net shape of the final penetrator is the result of controlled high energy-rate deformation of the liner. Ductility of the liner material, which tends to decrease nonlinearly as a function of the rate of deformation, is a critical factor in attaining the final shape.



The interior of the SADARM system's submunition is diagrammed. The safe and arming (S&A) device keeps the submunition from exploding should it strike the ground accidentally; the orientation and stabilization (O&S) device rights the submunition after expulsion from the carrier projectile, while a vortex ring parachute keeps it steady as it acquires and homes in on its target.

Figure 2.7-4. SADARM Configuration

Variations in the mechanical tolerances of the liner become sites where concentration of stresses occur, creating localized failure modes that can destroy the liner or degrade its aerodynamic stability (and, thus, accuracy and effectiveness). For this reason, mechanical tolerances in the liner are critical. Critical developing technologies are associated with:

- Mass production of liners, particularly of materials other than copper that have high density, but at the expense of lower ductility.
- Design of penetrators to achieve specific (e.g., finned) final penetrator configurations for enhanced standoff and accuracy.

EFP SAFFing subsystems must be specially designed for target detection and aimpoint selection against a complex clutter background and precision trigger warhead initiation with beginning with standoff ranges of 100 m or greater. There are also look-down/shoot-down concepts (e.g., TOW 2B) employing EFP at short (a few meters or less) standoffs. Critical advancing technologies may also be useful in fuzing shaped-charge weapons in single or tandem look-down/shoot-down configurations.

Multiple Penetrator Warheads

Antiarmor weapons designers have increasingly gone to multiple-device warheads to defeat advanced armor. The basis for the concept is most readily envisioned as it applies to attacking reactive armor (see Figure 2.7-5), where a precursor round is used to initiate the reactive armor appliqué, so that the main charge can form effectively and perforate the exposed main armor. In this application, the timing of the charges relative to the detonation of the reactive armor and to one another is critical to weapon effectiveness. For top-side attack, the timing is also critical to ensure that the jets impinge on the same area.

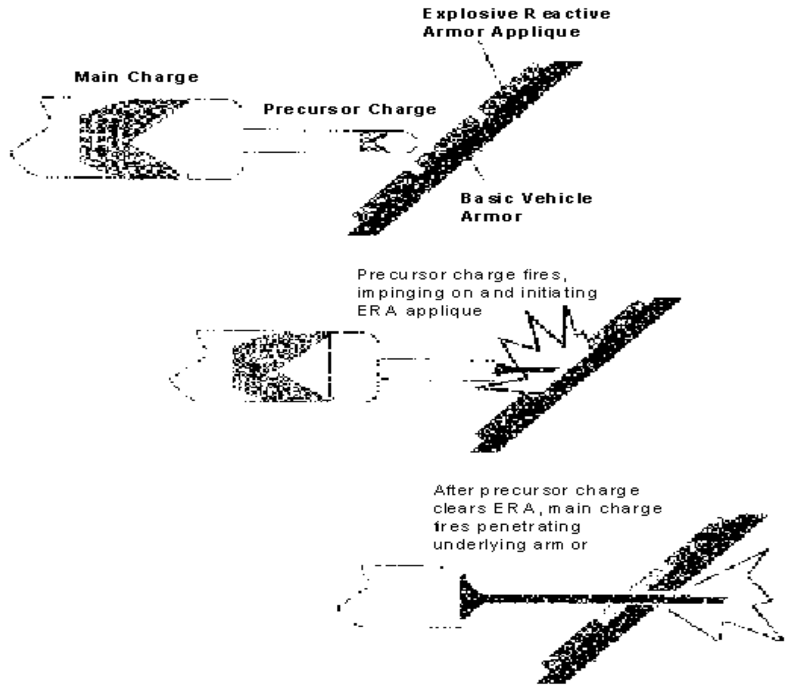


Figure 2.7-5. Multiple Warhead Antiarmor Concept

Blast and Blast Fragmentation Warheads

These warheads represent perhaps the largest single class of weapons. Lethality typically results from a combination of blast overpressure from detonation of a HE and/or ballistic penetration by fragments of the warhead structure, with resulting damage to the target structure or critical components. Table 2.7-2 shows some of the major subcategories of fragmenting warheads and related technologies.

Naturally fragmenting and controlled fragmentation warheads have been state of the art for some time. The know-how to tailor the metallurgy to achieve optimum fragment size and velocity for a given energetic material is addressed in Weapons Systems Technologies. Critical developing technologies are associated with aimable ordnance employing directional warheads and with prefragmented configurations employing special materials for enhanced lethality.

Fuel-Air Explosives (FAEs)

FAEs are a class of weapons that achieves its effect by detonation of a dispersed fuel, using the atmosphere as the oxidizer. The phenomenon is similar to that observed in explosives caused by detonations of suspended dust in grain silos or in natural gas explosions. Unlike these, however, military FAEs are not confined. Thus, detonation is highly dependent upon the density of the dispersed fuel and the precise multipoint detonation of the cloud.

Table 2.7-2. Warhead Technologies

Generic Warhead Type	Description/Technologies
Naturally fragmenting	A naturally fragmenting warhead relies on the inherent brittleness of a homogeneous metal shell under extremely high strain rate deformation to produce an optimum distribution of fragment sizes and velocities. Commonly used in unguided bombs, rockets, and artillery rounds. Know-how associated with selection of materials and metallurgical processes to achieve desired ductility/brittleness characteristics.
Controlled fragmentation	Controlled fragmentation depends upon a variety of techniques to induce fragmentation along particular fracture lines. A variety of techniques have been used, including various metallurgical processes, or mechanical or electron-beam scoring of the warhead case.
Preformed/precast fragmentation	One approach for ensuring optimum effectiveness is to preform fragments of the desired size. The obvious disadvantage is cost; however, this cost is offset if lethality against high value targets can be increased significantly. Preforming the fragments may also allow the use of material that interact more effectively with the target (e.g., high-density metals, materials specially formulated for ballotechnic characteristics) but whose ductility and high strain-rate fracture characteristics would not cause natural fragmentation.
Continuous rod, segmented warheads	Similar in concept to both controlled fragmentation and preformed fragmentation rounds, this class of warhead employs specific design techniques to enhance lethality of the warhead.
Directional warheads	Directional warheads encompass a variety of design techniques used to concentrate the blast and fragmentation pattern in the direction of the target. The earliest and simplest concept was “dual-end” initiation, which has the effect of concentrating the warhead’s energy in a radial disk pattern. Asymmetrical initiation is used in conjunction with directional fuzing to focus energy in a particular angular direction. More complex designs that entail explosive deformation of the warhead to achieve an optimal configuration before detonation have been considered.

Within the explosive cloud, fuel-air explosives are highly lethal—so much so that their compliance with provisions of the Geneva Convention has been defeated. FAEs are also highly effective for defoliation and have been used to initiate detonation of land mines for minefield clearance.

Dual-Use Aspects of the Technology

While shaped charges and EFP devices are predominately military, the underlying related phenomena—high energy-rate deformation and high-temperature synthesis/processing of materials—elicit some commercial interest. This is still an emerging area, however, and has not been widely commercialized. Certain explosive mixes (see discussion of IMs in Section 2.8, Lethality and Vulnerability) are of interest for commercial explosive safety.

LIST OF TECHNOLOGY DATA SHEETS
2.7. WARHEAD TECHNOLOGIES

DATA SHEET 2.7. EXPLOSIVELY DRIVEN PENETRATOR TECHNOLOGY

Developing Critical Technology Parameter	Specific performance parameters will be classified. However, qualitative measures for discriminating the technology include the use of high-Z liners (atomic number > 29) and the development of techniques, including shaping of preformed liner or to allow directional control or formation of improved aerodynamic shapes to improve accuracy at standoff ranges in excess of 100 m.
Critical Materials	Preprocessed liner alloys, specially formulated and/or characterized for EFPs.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated 3–D hydrodynamic codes characterizing high-energy-rate deformation of liners and performance of resulting shaped-charge jets, or EFP rods.
Major Commercial Applications	There is some overlap in the generic technology of shaped charges for mining, demolition, and related applications such as well casing penetration in oil recovery. These, however, are not technology drivers.
Affordability	Affordability has been a major issue in this technology and is a key factor driving much of the work in conventional shaped charges. Specifically, the ultimate performance of the weapon can be extremely sensitive to small variations in how the liner has been processed. Performance achieved with precision-machined prototypes is frequently difficult to duplicate in practice with the liners that are formed by mass-production techniques (e.g., stamping or cold coining).

BACKGROUND

Explosively driven penetrators, as a generic class of devices, encompass a variety of basic design geometries and capabilities, as described Section 2.7, Warhead Technologies. While shaped-charge technology is mature and widely deployed, a considerable exploratory research effort is still aimed toward improving its performance. EFPs offer some advantages in terms of operational flexibility because of their longer standoff capabilities. Changing the initiation can also vary the terminal geometry and shape of an EFP, making them suitable for multipurpose weapons.

DATA SHEET 2.7. KINETIC ENERGY (KE) WARHEAD TECHNOLOGY

Developing Critical Technology Parameter	Inert (i.e., not incorporating explosive charges as part of the expendable ordnance package) for any type of target designed to effect destruction of the target by direct impact, specifically KE penetrators and penetrator mechanisms designed for impact at effective velocities exceeding 1.6 km/sec (see ***Background***).
Critical Materials	High-Z alloys and composites formulated or characterized for specific terminal ballistic (target impact) properties.
Unique Test, Production, Inspection Equipment	Typically requires high-speed flash X-ray photography and, for EM or tube-launched projectiles, specially designed interior ballistics instrumentation.
Unique Software	Empirically validated 3–D hydrodynamic codes characterizing impact performance of KE projectiles, particularly over a range of materials and geometries.
Major Commercial Applications	None identified.
Affordability	Future KE projectiles will be used extensively in direct-fire applications, such as tank armament, where cost per round is a significant consideration.

BACKGROUND

In a strict technical sense, explosively driven projectiles are KE projectiles in the sense that KE is the effective lethal mechanism. In the context of this data sheet, the term KE projectile refers to that specific subset of warheads that, in contrast to EFP and shaped-charge mechanisms, are essentially launched and fly out to the intended targets in their terminal penetrator configuration. Launch mechanisms that have been, or are, under consideration include hypervelocity missile, chemical, ETC, EM launcher (rail gun/coil gun), or combinations of these propulsion mechanisms. Although a distinction has been made between these two classes of KE weapons based on initial configuration, much of the science of inert penetrators, particularly for aerodynamic performance and terminal ballistics, applies equally to long standoff EFPs.

SECTION 2.8—LETHALITY AND VULNERABILITY

Highlights

- Better understanding of weapons effects enable the design of smaller weapons with superior on-target lethality.
- Simply increasing weapons performance alone will not suffice. We must be able to predict confidently the effects of weapons on adversaries' assets and have confidence in the survivability of our own.
- Advances are occurring in materials and in computer modeling of primary and secondary effects of weapons on complex structures.
- Enhanced lethality is fundamental to the development of long-range autonomous submunition weapons that will be lethal and provide tactical flexibility against the full range of air, ground-mobile, and fixed targets they will encounter.

OVERVIEW

This technology area is closely related to warhead design discussed in the Section 2.5, Guidance and Control. It is primarily concerned with understanding the effects of different types of weapons on protected personnel, structures, and systems, and with design techniques for mitigating the effects of same on U.S. systems, materiel, and personnel. The latter area is also closely related to technologies for survivability, armor protection, and warhead defeat, addressed in Section 2.12, Survivability, Armor, and Warhead Defeat Systems. EM vulnerability to countermeasures and to high electromagnetic pulse (HEMP) effects and vulnerability of materiel and personnel to nuclear, chemical, or biological weapons effects are addressed elsewhere.

Through the 1960s, measurements of lethality and vulnerability were based largely on empirical testing of warheads against their intended targets. Empirical data gathered through extensive testing have improved designers' ability to predict weapon effectiveness—based on measured performance against standardized test targets (e.g., rolled homogeneous steel as a standard for armor)—against operational systems.

Modern advances in computing power offer the prospect of further advances. At present, ray-tracing programs allow designers to predict first-order interaction of weapons on complex systems. Models capable of exploiting available computing power for characterizing more complex secondary effects (e.g., transmitted shock, spallation) are still largely critical developing technologies. An area of research with strong potential for furthering critical developing technologies for modeling and simulating the response of materials to high energy-rate deformation is so-called mesoscale technology, which deals with the relationship between atomic/nanoscale properties of materials and their macroscopic structural properties. Research in armor materials and ballistic penetrators indicates that the performance of the finished system can be critically dependent on minute variations in material properties at the atomic/nanoscale level. This growing field will provide the underlying bases for enhanced weapon lethality and for improved ballistic protection.

The Services are examining several classes of revolutionary technologies in an effort to enhance the on-target effectiveness of conventional munitions. The ability to deliver weapons with precision (less than 1.0 m CEP) against specific aim-points on a given target has opened new avenues for technology development and insertion for a variety of weapon classes. Research is focused on optimizing the efficiency and/or the mechanisms with which warheads couple energy to a wide range of target types. This will require continued updates of weapon design and target interaction with computer codes. As noted previously, one of the major thrusts of this work will be to incorporate a realistic understanding of multiple target damage mechanisms, such as the effects of combustion processes that may result from impact.

These effects, also referred to as "behind armor" effects, are complex, multivariable, nonlinear phenomena and are difficult to quantify and model computationally. Ongoing advances in computational speeds provide the tools for more realistic modeling and analysis.

Better understanding of these effects ultimately should lead to smaller weapons with superior on-target lethality (compared with existing munition systems). This will be easier to handle logistically and will increase the weapons loadout of systems that are currently constrained by space or weight. Enhanced lethality technology programs are pivotal in the drive toward long-range, autonomous submunition weapons lethal against the full range of air, ground-mobile, and ground-fixed targets.

One area where significant continued empirical work will be needed is in the development of insensitive munitions (IMs) and in the characterization of the response of munitions (conventional munitions and developing IMs) to a wide range of threat stimuli. For example, the present state of the art will generally allow designers to make qualitative predictions of the relative performance of munitions with insensitive vs. sensitive explosive fills—all things being equal. However, as noted previously, performance and sensitivity are critically dependent on a wide range of processing variables, which weapons designers have only begun to explore systematically. In addition, to meet the requirements for prevention of sympathetic detonation, advances in characterization of complex structural reactions to threats and to unintended detonation or deflagration of stowed ordnance will be needed.

Here, the underlying technologies include development of insensitive energetic compounds and mixtures for use as explosives and propellants, improvements in materials and structures capable of providing protection against thermal and ballistic hazards without compromising basic system performance, development of active (including the necessary sensors) and passive mitigation techniques, and techniques for safing and initiation of primary and secondary explosives.

Dual-Use Considerations

While weapons effects are a uniquely military concern, many of the underlying technologies have civil application. The auto industry, for example, is increasingly relying upon complex modeling to characterize the crash-response characteristics of vehicles and the effects on passengers. The mathematical models are similar, and many of the material and structural design techniques employed to mitigate the effects of shock on passengers may have analogs in military systems.

The civilian market for personal protection is a rapidly growing, worldwide industry. National and international standards for civilian ballistic protection products extend to 12.5-mm armor-piercing projectiles. This threat level is equivalent to that faced by several military systems, including, as an important subset, military helicopters.

LIST OF TECHNOLOGY DATA SHEETS
2.8. LETHALITY AND VULNERABILITY

DATA SHEET 2.8. MESOSCALE MODELING AND SIMULATION (M&S) TECHNOLOGY

Developing Critical Technology Parameter	Models that characterize the performance of materials and structures based on effective integration of analysis that addresses the relationship between the atomic/nano/microscale characteristics of material and its macroscale performance in applications. For lethality modeling, mesoscale M&S of energetic materials, and the reaction/response of metals or ceramics [liner and warhead materials (including preformed fragments) to high energy-rate deformation. For vulnerability modeling, mesoscale M&S of material and structural response, specifically the ability to characterize and predict the macro-structural response of systems based on analysis of the microstructural properties of constituent materials and the specific processes used for fabrication of semifinished or finished structural components and assemblies.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	unique test, production, and inspection equipment and techniques associated with specific materials and manufacturing processes will be essential to validation of models and simulations. Categories of materials where mesoscale modeling will be important include structural ceramics, high-strength superalloys, and composites.
Unique Software	The software will be associated with specific materials and manufacturing processes.
Major Commercial Applications	The types of materials under study have pervasive civil application. Much of the research is driven by automotive and aircraft requirements.
Affordability	Affordability, and specifically the need to develop more efficient and lower cost methods of manufacture, is one of the driving forces behind the rapid growth of this technology.

BACKGROUND

Companies face increasing pressure to produce improved materials and structured fluids, with quicker turnaround and smaller budgets. To solve this problem, research scientists have traditionally pursued one of two options: atomistic or macroscopic modeling. In many cases, however, the intermediate grain structure dictates performance. Recently, there has been a growing awareness of the weaknesses of the capabilities of these analytic methods and an appreciation of the need for better modeling of these characteristics.

Mesoscale modeling is a new technique and is being developed worldwide as an intermediate solution that bridges this gap. Until recently, mesoscale modeling has been largely a topic of research universities and national laboratories. However, industry has begun to pursue it as a reliable way to predict structures, properties, and behavior of materials and fluids without costly experimentation.

Mesoscale modeling is currently being pursued as a means of characterizing a variety of different types of materials, including fluids, energetic materials, and structural materials. In the context of lethality and vulnerability, mesoscale modeling will contribute to the development of better material for KE penetrators and armor.

DATA SHEET 2.8. LETHALITY AND VULNERABILITY MODELING TECHNOLOGY

Developing Critical Technology Parameter	Techniques to combine and extend current M&S capabilities of geometric (ray tracing) analysis of vulnerable component vulnerability, with materials modeling to enable realistic modeling of the secondary effects (e.g., behind-armor effects) of ballistic loads on complex structures.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Specially designed high-speed instrumentation for measurement of component loads and accelerations required to validate M&S software.
Unique Software	Software, including specially designed finite element analysis programs and their related experimentally validated databases, for accurate characterization and prediction of the response and failure of complex structures, subjected to high energy-rate deformation.
Major Commercial Applications	While the military requirements are more stringent and drive the development of this technology, there are civil applications. The underlying high energy-rate deformation phenomena associated with the material science of lethality overlap areas of interest for high energy-rate processing of exotic materials. Vulnerability modeling overlaps with transportation and industrial safety modeling to a significant degree.
Affordability	Only indirectly, to the extent that improvements in lethality may reduce the number of rounds required.

BACKGROUND

The current state of the art typically characterizes lethality and vulnerability in terms of vulnerable component vulnerability and/or the ability of a given lethal mechanism to penetrate specific thicknesses of materials. In practice, however, secondary effects of spallation and transmitted shock can multiply the effect of a given round. The basic ability to characterize the products of spallation is relatively well developed in comparison with M&S capabilities to characterize structural response to high energy-rate loading, such as that which would be experienced under blast shock or ballistic impact conditions.

DATA SHEET 2.8. INSENSITIVE MUNITIONS (IMs) TECHNOLOGY

Developing Critical Technology Parameter	Critical developments beyond the current state of the art will include the ability to tolerate direct impingement of shaped charge and/or shock from high-order detonation of adjacent stores (so-called sympathetic detonation).
Critical Materials	IHEs.
Unique Test, Production, Inspection Equipment	Common to conventional weapons design and evaluation.
Unique Software	Improved modeling of complex structural response to threat stimuli. Distinguishing characteristic is the characterization of phenomena at the boundary between the energetic load and the metal/composite components (including structural components or war components, such as shaped-charge liners or fragmenting warhead casings).
Major Commercial Applications	Limited, if any, for the specific energy-rate regimes of interest.
Affordability	Affordability is a critical issue. One of the technological barriers to deployment of any weapon is the amount of required safety testing. The complexity of the interaction is such that comprehensive live testing is no longer affordable. In addition, as noted in the discussion of energetic materials in Section 2.9, Energetic Materials, the specific constituents of IMs are frequently more costly than their conventional counterparts. The ability to quantify the benefit of adopting such materials is key to a credible cost-benefit analysis and decision on affordability of IMs.

BACKGROUND

IMs contributes to future military effectiveness by reducing personnel and materiel casualties and by reducing the need to stock replenishment rounds to replace loss of ammunition caused by sympathetic detonation.

SECTION 2.9—ENERGETIC MATERIALS

Highlights

- Energetic materials are used ubiquitously: as propellants for guns, rockets, and missiles, in high-explosive warheads for use in virtually all mission areas and in a variety of demolition and construction projects.
- Major advances are being made in decreasing the sensitivity of conventional energetic materials for IMs. At the same time, developing critical technologies, such as cubane and isomer explosives, offer potential for many orders of magnitude greater performance.
- If these technologies are successfully developed, they will allow weapons designers to achieve orders of magnitude greater lethality within very small packaging constraints, enabling the development of entirely new weapons concepts.

OVERVIEW

An energetic material is defined as any explosive, propellant, or pyrotechnic that can sustain a steady-state burning rate greater than 38 mm (1.5 in.) per second under standard temperature and pressure. This encompasses all aspects of energetic materials, including chemical synthesis, formulation, and processing of materials for specific applications. Included are technologies for controlling the reaction of high explosives and the energetic constituents of propellants for use in IMs.

Several different materials have been and continue to be used in military explosives and propellants. The key aspects of critical developing technology in this area include:

- Detonation physics.
- Chemical synthesis of the constituents to requisite purities.
- Formulation and mixing of materials to obtain requisite material performance.
- Mechanical and thermal processing of the material to final configuration.
- Testing (component and full-scale explosives).

Among the parameters of concern are thermal stability and the characteristics of the DDT for a given material, under both normal operating conditions and casualty conditions. Solid-rocket motor propellants (see also Section 2.2, Tactical Propulsion) are produced in a wide variety of forms, using a variety of binders (both inert and energetic) and oxidizers, depending on requirements. Critical developing technologies address issues of performance [specific impulse (I_{sp}) in excess of 250 sec], material sensitivity to shock and ballistic impact, and preventing detonation of propellant grain (characterizing and controlling DDT performance characteristics).

Among the critical developing technologies identified are advanced nitramine compounds, such as NTO, cage compounds, and polycyclic nitramine crystal material (e.g., CL–20)[2] that achieve densities greater than 1.9 gm/cm^3. These materials offer promise for delivering comparable or greater performance relative to older compounds like RDX, cyclotetramethylenetetranitramine (HMX), and ammonium perchlorate (AP), with significantly reduced susceptibility to shock, ballistic impact, and/or high-temperature cook-off.

Such materials are logical extensions of the state of the art in conventional explosives. Beyond this lie two areas of research that hold inherent significance for developing rapidly for critical military applications. The first set of materials is strained molecule cubane compounds [which theoretically have the potential to be 2 to 10 times more energetic than conventional compounds (see Figure 2.9-1)]. Materials based on this structure [e.g., ammonium

[2] CL–20 is a cyclic nitramine with a higher crystal density (over 2.0 g.cm^3), a higher heat of formation, and a better oxidizer-to-fuel ratio than conventional HMX or RDX solids used in propellants.

dinitrimide (ADN) and others] offer several advantages. Specifically, they are less susceptible to accidental explosion and, unlike several existing explosives, are nontoxic and decompose to benign, nontoxic byproducts.

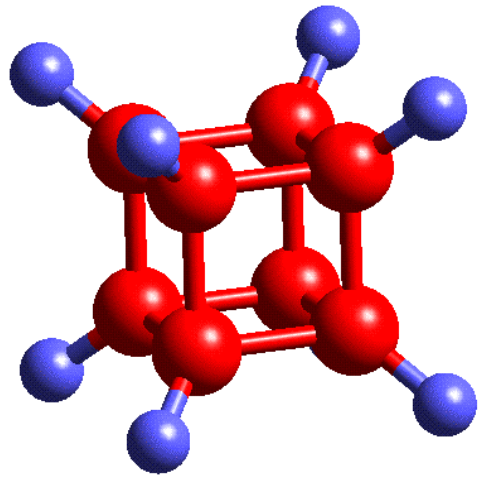


Figure 2.9-1. Cubane Compounds

These cubane compounds have also been discovered to have some surprising civil applications, demand for which may accelerate research significantly. While studying the new material, chemists noticed that its molecular structure was similar to that of an antiviral drug now used to treat the influenza virus. The scientists submitted samples of many new cubane molecules that they synthesized to the National Institutes of Health (NIH), which screened them for medical properties. NIH reported that two molecules possessed moderate anti-HIV [Human Immunodeficiency Virus] and anticancer activity that does not destroy healthy cells.

As unlikely as it seems, this developing explosive technology appears to have significant promise for combating cancer, Acquired Immune Deficiency Syndrome (AIDS), and other viral infections. This technology is being commercially researched and developed through small business and university entities. All report significant promise in using these explosive derivatives in medicine. Unlike current anticancer and anti-HIV drugs, these substances are nontoxic and can be ingested for a very long period without the life-threatening side effects of existing drugs. Also, since additional atoms can be attached to the cubane molecule, its antiviral impact can be greatly increased.

The second set of materials is the so-called nuclear isomer materials, which have the theoretical potential for 100 to 1,000 times the energy density of conventional energetic chemical compounds. These materials are of two varieties: shape isomers and spin isomers. In both types, energy is released in the form of gamma rays when the nuclei of the material transition from a higher energy state to a lower.

State of the Art

Cubane-based explosives, fuels, and oxidizers represent the state of the art in energetic materials. In 1989, while developing an improved route to dinitramines for application on cubanes, a researcher conceived of and first synthesized the dinitramide molecule, the parent of ADN.

More advanced explosives are still in early research phases (see Figure 2.9-2). The basic physical principles have been verified experimentally. However, many practical engineering must be overcome before these phenomena can be exploited in fieldable explosive devices. That said, we should remember that less than 6 years intervened between the first scientific publication (in *British Nature,* January 1939) characterizing the phenomenon of fission and the first operational use of nuclear weapon in August 1945. One can argue that World War II and competition from Japanese or German scientists spurred these developments. At the same time, we must note that this was accomplished using what was, by today's standards, very primitive technology.

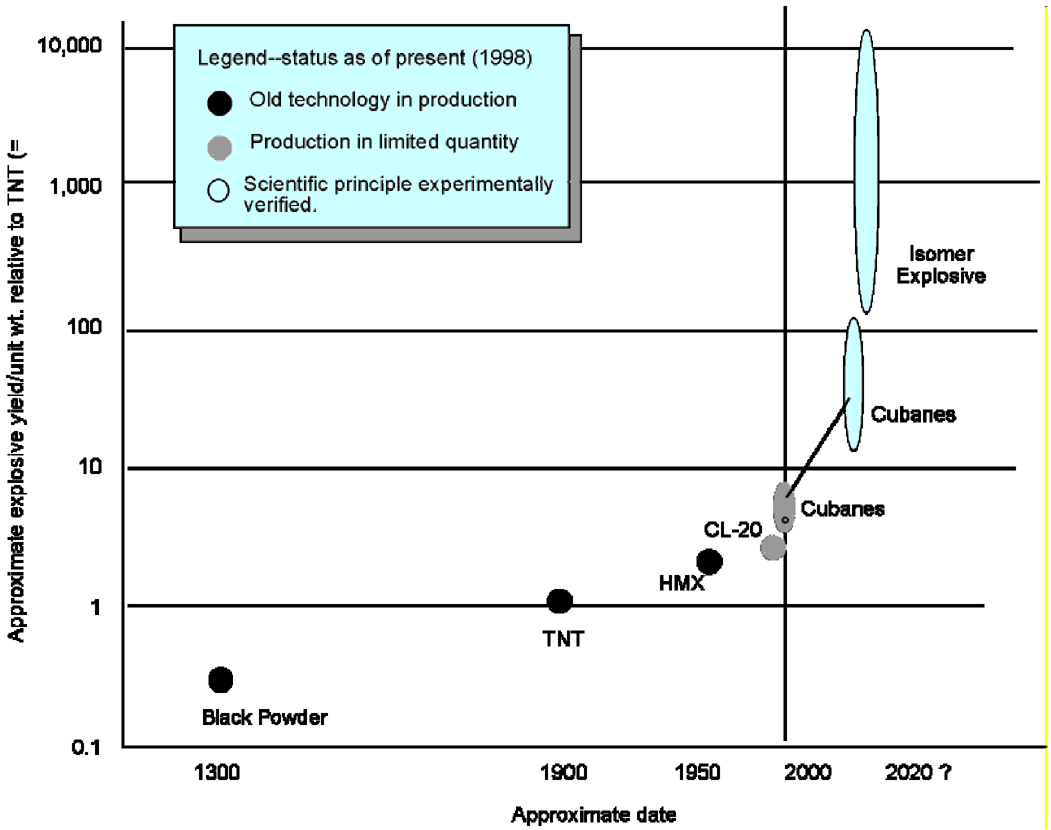


Figure 2.9-2. Trends in Developing Critical Explosives

LIST OF TECHNOLOGY DATA SHEETS
2.9. ENERGETIC MATERIALS

HEDM

DATA SHEET 2.9. POLYNITROCUBANES AND POLYAZACUBANES (HEDM)

Developing Critical Technology Parameter	Synthesis of polynitrocubane and polyazacubane explosive compounds containing five or more nitrogen atoms (see ***Background***).
Critical Materials	Precursors.
Unique Test, Production, Inspection Equipment	Laboratory equipment specially designed for physical processing of explosive polynitro-cubane structures.
Unique Software	Molecular modeling and associated empirical data for validation of same for compound stability analysis and energy yield prediction.
Major Commercial Applications	Potential limited application as commercial explosives for oil, gas, and mineral extraction and demolition. In addition, some evidence suggests that these compounds function as protease inhibitors and may possess antiviral/anticancer properties.
Affordability	A key issue. Note that cost is currently a limiting factor in widespread adoption of several existing potential fills for IMs (see ***Background***).

BACKGROUND

While compounds such as octanitrocubanes hold promise for an order-of-magnitude increase in the performance and yield of HEDM explosives, research is still in the earliest stages. Affordable production will be a critical challenge. Beyond that, such explosives will require extensive research in warhead design. Specifically, new materials may be needed to offset the tendency toward brittleness with increasing rate of deformation.

DATA SHEET 2.9. NUCLEAR ISOMERS

Developing Critical Technology Parameter	Any use of nuclear isomers as an HEDM is considered a critical development.
Critical Materials	Primarily Hf_{178}, but other compounds, such as Os_{187}, Yt_{186}, Ta_{180}, and Zn_{66}, have been discussed as possibilities.
Unique Test, Production, Inspection Equipment	None identified. However, current means of obtaining the isomers of interest are not amenable to economical production.
Unique Software	None identified.
Major Commercial Applications	Energy source.
Affordability	Affordable production of useful quantities of isomers is a critical obstacle to be overcome.

BACKGROUND

In theory, isomer HEDMs have potential energy yields orders of magnitude greater than existing chemical energetics. While the development of useful propellants, explosives, or energy sources based on this phenomenon is probably decades away, such extraordinary energy density has the potential to revolutionize all aspects of warfare. Potential applications range from very high-density energetics for propulsion and warheads to high-energy and power density primary sources to address requirements for EM launchers and all-electric propulsion. (See Section 2.4, Guns, Artillery, and Other Launch Systems.)

DATA SHEET 2.9. INSENSITIVE COMPOUNDS

Developing Critical Technology Parameter	A 50-percent reduction in sensitivity to impact, friction, or heat stimuli, with increased energetic yield.
Critical Materials	A wide variety of energetic compounds, of which those most widely researched at present include cyclical polynitromine compounds (e.g., CL–20), ADN, NTO, and hexanitrostilbene (HNS).
Unique Test, Production, Inspection Equipment	Specially designed mixers and casting equipment for energetic materials.
Unique Software	M&S of compounds to characterize energy stability and yield. Also, see Data Sheet 2.8, Insensitive Munitions (IMs) Technology.
Major Commercial Applications	Commercial explosives.
Affordability	The overriding issue in many cases. The nature of the application—explosive and propulsive fills for high-production quantity expendable ordnance—is such that even marginal costs increases can be prohibitive.

BACKGROUND

The energetic component sensitivity and performance is a critical factor in reducing personnel and materiel casualties and the need to stock replenishment rounds to replace loss of ammunition caused by sympathetic detonation.

Performance and sensitivity of energetic materials are affected by many complex variables. These include—as an important subset—inhomogeneities and faults introduced in large-scale production and loading and fabrication processes. As a result, the overall value of a country’s R&D activities in materials and process technology must be evaluated in the context of their demonstrated abilities to apply new materials technologies rapidly to munitions/ weapons systems.

SECTION 2.10—MINES

Highlights

- Mines are perhaps the most cost-effective and pervasively used means of interdicting large areas and of inflicting significant casualties with minimum risk to friendly forces.
- Global use of low-cost antipersonnel land mines has created a humanitarian threat of gargantuan proportion and spurred demands for a global ban and development of improved mine-clearing technologies.
- To be deployed effectively, future systems must be "smarter," with sophisticated sensors/fuzing and communications, supporting multiple options for dispersing, remote arming, and disarming.
- Key technological advances required for land and sea mines include improved smarts sensing, primary power generation and management, communications, and robotic techniques for both deploying and deactivation/retrieval.
- Such capabilities will allow for precise selective engagement of specific targets, under complete tactical control of the commander, while at the same time limiting or eliminating the threat to noncombatants.

OVERVIEW

Much of the embedded technology for mines (explosives, sensors, SAFF) is common to other types of ordnance. However, the operational scenarios and environments in which mines are used impose unique requirements. This applies to the design, production, and operational use of the mines and of countermeasures required to neutralize or destroy enemy mines. An operationally and geopolitically important element is the growing international sentiment for clean-up and out-right banning of low-cost land mines.

This section addresses critical developing technologies identified as specifically required to meet these unique requirements for land- and sea-based mines. It also addresses sensors and lethal mechanisms associated with land and sea mines and countermine technologies. Critical developing technologies include advanced multisensor surveillance and engagement subsystems, sensor systems for land minefield detection, and advanced robotics and sources for undersea mine clearing.

Mines have traditionally been viewed as a low-cost and effective means to interdict large areas and inflict significant casualties, with limited exposure and minimal risk to own personnel. In its simplest form, a mine consists of an explosive charge and a sensor that, once armed, will initiate the warhead when triggered. Their cost, simplicity, and effectiveness has spurred the global production, sale, and use of literally millions of land mines. These mines function on contact, or when moved or subjected to pressure. They act indiscriminately, and once armed, cannot be readily deactivated.

Land and sea mines are effective weapons for denying or delaying an enemy access to particular areas (e.g., shipping lanes, ports, roads, and runways). Modern technology has allowed these weapons to become even more effective through the use of scatterable, precision, or "smart" devices. As mine technology has advanced, so has countermine technology; however, detecting and neutralizing modern mines is still a very challenging and time-consuming task. In addition, the sheer number of mines needed to deny or delay an advancing force effectively leads to longer term problems. After the fighting has ceased, many unexploded or neutralized mines are left implanted, and these mines then become lethal hazards to the civilian population for many years.

Because of the large numbers involved, cost is a very important issue in developing mines. Making this more difficult is the concomitant need for increasingly smart devices with sophisticated sensor-fuzes and multiple options for dispersing, remotely arming, or disarming. Mine fuzing that can be remotely armed or disarmed is critical to the modern battle plan. Such devices can effectively deny access to the enemy when armed and can be disarmed to allow friendly forces to move freely.

Systems currently in development, like the Army WAM [part of the intelligent command outpost/Raptor program, a follow-on to the intelligent minefield (IMF) Advanced Technology Demonstration (ATD)], incorporate complex target discrimination capabilities to identify specific classes of targets (e.g., armored vehicles). The WAMs are comprised of an autonomous sensor capable of detecting, localizing, and engaging targets within a several kilometer envelope. The individual system can be controlled (activated, deactivated, and assigned specific sectors or targets) from overwatch wide-area sensors or battlefield C2. These systems also incorporate state-of-the-art EFP warhead technologies for effective top-side kill.

Since mines affect such a wide range of social, economic, and political issues, mine clearance has received global attention. The United Nations (UN) estimates that it will cost upwards of $33 billion to clear the approximately 100 million landmines strewn in 64 countries. UN officials admit, however, that new mines are being planted faster than the old ones can be removed. Currently, there are some 5,000 UN de-miners stationed around the globe. Contributors to the UN de-mining fund have included (in addition to the United States' contribution of $6 million) the EU ($4 million), Japan ($2.1 million), Norway ($1.3 million), and approximately $1 million each from Sweden, Denmark, and the United Kingdom.

Many efforts are aimed at advancing mine and countermine technology. Advanced technology efforts are primarily focused on minefield detection and mine localization sensors. The state of the art in clearance today remains at a low level of sophistication, involving physical initiation or destruction of the mines by mechanical or high-explosive means. The former method involves techniques such as large mechanical flails mounted on armored chassis. These flails are essentially derivatives of industrial machines used to shred waste or scrap metal. Explosive devices commonly take the form of a line charge. These are optimized to clear a path for military operations and are not designed achieve the high probability (99.99) level of clearance over a wide area desired for clearing minefields for civilian access. Critical advancing technologies include techniques for wide area dispersal of explosive arrays and high power EMP effects to initiate the explosives.

Inherent in the evolution of mine-clearing technology are requirements for in-stride breaching of mine land and littoral areas. The following points summarize countermine technologies, which are addressed in depth in Section 17, *Sensors*. Key areas of critical developing technology for *land mines* include:

- Developing multisensors and signal processing to track and locate vehicles and vessels accurately. A special subset of interest are techniques for land-based surface-to-air mines capable of interdicting airfields or attacking low-flying helicopters.
- Developing "intelligent" minefield technologies to allow long-range single-point arming, disarming, and control of minefields.
- Developing sensors to differentiate mines from clutter in various soil, foliage, and terrain types.
- Developing sensor fusion techniques and ATR algorithms for autonomous mine localization and identification.
- Developing standoff neutralization technologies using directed energy or area explosives.
- Developing affordable autonomous robotic systems to conduct minefield breaching and obstacle clearance operations.

Undersea mines cover a wide range of operational capabilities and system configurations. These range from shallow-water, anti-invasion bottom mines (similar in design to land mines) to highly sophisticated, self-propelled mobile mines that can be moored at depth and activated remotely or in response to predefined tactical situations. Such systems can exploit one or more sensing mechanisms, including pressure, magnetic, or acoustic signatures for surveillance, targeting, and localization, or fuzing. Key areas of interest for *sea mines* include:

- Developing low-cost, high-performance sensors and data-fusion techniques and extended-life, high-energy density, low-power batteries for surveillance.
- Ensuring the accurate and stable delivery of large distributed minefields at extended standoff ranges. This technology can also be applied to delivery of arrays of explosive charges for minefield clearance.
- Developing processing for high probability of detection and discrimination of underwater mines from environmental clutter in water or buried in the ocean bed.

- Ensuring the reliable targeting and destruction of sea mines in water depths compatible with laser imaging detection and ranging (LIDAR) imaging ranges, including special techniques required to ensure destruction of mines containing IHE fills.
- Developing autonomous or remotely controlled robots for countermine operations. The challenges include the development of sensors, structural materials, and mechanisms capable of extended operations in corrosive saline environments and waters with high turbidity.
- Developing compact, lightweight acoustic and magnetic signal sources for minesweeping from small, shallow-water craft and remotely deployed in-stride obstacle-breaching capabilities in surf and beach zones. The challenge is to detect the mine and generate a target signal capable of initiating the mine at ranges adequate to prevent damage to the countermine system.

Dual-Use Aspects of the Technology

Many of the recent advances in electronics, sensors, optical and optoelectronic devices, coupled with better algorithms, signal-processing techniques, and neural networks, are leading to increasingly sophisticated, sensitive and discriminating acoustic, seismic, multispectral/hyperspectral laser and IR sensors for mine and countermine applications. These developments have been the result of advances in consumer electronics.

The continuing widespread proliferation of microprocessors and digital signal-processing chips will continue to increase the foreign countries' access to the embedded technology needed to build more intelligent mines and minefield systems. However, without access to the empirically validated engineering data needed to optimize target discrimination algorithms, this technology will not be comparable to the state of the art. Such data are likely to be specific to military development and appropriately classified. Similarly, energetic materials for advances in IMs fills will also find application in commercial civil explosives. Again, however, the specific formulations used in, and response characteristics of systems to, particular military threats will not be generally available.

LIST OF TECHNOLOGY DATA SHEETS
2.10. MINES

The following developing technologies have been identified, but data sheets are not available at this time:

Advanced Sea Mine Technologies

DATA SHEET 2.10. INTELLIGENT MINEFIELDS (IMFs)

Developing Critical Technology Parameter	Integration of effective power management, secure communications, and intelligent SAFF techniques.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Signal-processing and control algorithms for overwatch sensors (surveillance and alerting sensors) and target location and identification.
Major Commercial Applications	The technologies associated with IMF per se are directed toward military end use and are not dual use. At the component level, technologies (e.g., microprocessors, microphones, and radio) are quintessentially dual use. Advances are driven by consumer markets, and the resulting products are used pervasively in military systems. However, several overlapping areas of development exist, where commercial technologies may enable future advances: Improvements in the Global Positioning System (GPS) and Geographic Information Systems (GISs) may support complex operations and control. Resolutions of as little as 0.25 m have been demonstrated. The commercial GIS industry, which started in the early 1980s, is now estimated to be worth $3.5B. Commercial applications of acoustic signal-processing technology have emerged and have advanced rapidly, spurred by the growing availability of low-cost, high-power computing. Acoustic analysis, in various forms, has emerged as a key enabling technology for nondestructive evaluation (NDE), fault location, and condition monitoring. Finally, the application of neural networks and fuzzy logic to pattern recognition and decision making may hold potential for enhancing the “intelligence” of future IMF.
Affordability	A major consideration. The affordability issue is associated with the tradeoff in increased cost/unit vs. reduced numbers of units required for improved areal coverage.

BACKGROUND

Generically, an IMF will comprise an electronically controllable munition; command, control, and communications (C3) infrastructure consisting of locating devices and sensors (which may be part of or separated from the individual munitions); and communications links for arming, disarming, and deactivating/cleaning up. Within this generic framework, decisions can be implemented with different degrees of autonomy, ranging from complete operator control to autonomous machine-intelligent operation.

IMF technologies achieve several critical objectives:

- Flexible freedom of action and movement of friendly forces in interdicted areas.
- Real-time information from distributed sensor resources, which provides the commander superior battlespace awareness and allows for more effective and flexible operational control and coordination of attack.
- Decision-support features, which enable the commander to reconfigure and optimize battlefield operations.
- Precise knowledge of mine location, coupled with an ability to self destruct mines electronically, which facilitates cleanup and addresses fundamental humanitarian concerns regarding current wholesale use of land mines.

SECTION 2.11—MISSILE SYSTEMS

Highlights

- Tactical guided missiles have become the primary weapon for most surface-to-surface, surface-to-air, air-to-surface, and air-to-air mission functions.
- Nonlinearities in controls and aerodynamic response create a wide range of anomalous effects, such as mechanical resonances, leading to loss of control and even catastrophic structural breakup of the missile. As the velocity and agility of tactical systems increase, these effects will become more pronounced.
- Future advances will depend upon an ability to model these effects accurately and to manage their impact through the application of new high-strength/high-stiffness materials and smart structures.
- Effective integration of these advances will provide the speed, agility, and accuracy required for effective engagement of higher speed, more maneuverable threat targets they will encounter.

OVERVIEW

Even access to all the component technologies for tactical missile systems does not guarantee the ability of a country to field an effective missile system. This section addresses aspects of critical developing technology for effective system-level design and integration. These include M&S, guidance integration, and end-game analysis, and prediction of weapon effects.

Nonlinearities in controls and aerodynamic response create a wide range of anomalous effects (e.g., mechanical resonances), which can lead to loss of control and even catastrophic structural break up of the missile. As the velocity and agility of tactical systems increase, these effects will become more pronounced. Effective solutions will depend upon an ability to model these effects accurately and to manage their impact through the application of advanced high-strength/high-stiffness materials and smart structures. The latter will include the use of electroactive ceramics for active aerodynamic compensation and electro- or magnetorheological fluids for mechanical damping.

Long-range missiles, particularly high supersonic and hypersonic systems, are subject to aerodynamic heating effects. Structural design and integration, including use of high-temperature ceramics and high-heat-capacity materials (e.g., certain boron compounds) and packaging and thermal management, are critical factors.

The area of sensors and guidance include several critical developing technologies, some of which are also discussed as elements of critical developing technologies in other areas:

- **Adaptive terminal homing for optimizing search/acquisition and terminal homing effects.** This includes intelligent algorithms capable of adapting in-flight to different fields of view, background, and target types based on cues received from onboard midcourse navigation and control.
- **Effective integration of airframe, guidance, and aerodynamic controls with tactical propulsion design.** For example, maneuver limits for terminal guidance control will affect the fluid dynamics of inlets, fuel control, and combustion systems in hypersonic air-breathing interceptors.
- **Guidance and control integration with ordnance package performance.** Terminal guidance (see Section 2.5, Guidance and Control) creates the proper end-game geometry to ensure maximum warhead effect on the intended target. For hit-to-kill, the terminal guidance phase performs this function directly. At the other extreme, missile guidance may simply place the ordnance package in a “window” from which a separate fuzing system detects the firing conditions and initiates the warhead. In between falls a range of options in which varying amounts of information are transferred from guidance to fuzing subsystems.

The warhead must be tailored for optimum effect for intended targets and end-game geometries. These tend to be classified and should be addressed separately. Generic coverage of underlying technologies is provided in Section 2.7, Warhead Technologies.

LIST OF TECHNOLOGY DATA SHEETS
2.11. MISSILE SYSTEMS

DATA SHEET 2.11. TERMINAL GUIDANCE

Developing Critical Technology Parameter	Integration of terminal guidance for autonomous targeting and precision-guided engagement of high-speed maneuvering targets; aimpoint selection on hardened targets/and armor; multimode capabilities, including hyperspectral IR.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	HIL guidance testers.
Unique Software	ATR and pattern recognition/feature extraction algorithms, particularly those incorporating capabilities for variable field of view (FOV).
Major Commercial Applications	None identified at subsystem level. Component technologies will be common to other optical/IR, mmW, and signal-processing applications.
Affordability	An issue, particularly for advanced gun launched.

BACKGROUND

Guidance integration remains among the most challenging design problems for advanced missiles. Current technologies in sensors and guidance techniques (e.g., aerodynamic, reaction motor, thrust vector, or a combination of these) offer a wide spectrum of design options and tradeoffs.

Multimode and hyperspectral guidance provides superior capability for target discrimination. Imaging sensors will allow the warhead lethal effect to be directed against specific aimpoints, significantly increasing the lethality of rounds. The increase in lethality, in turn, will allow campaigns to be prosecuted successfully with fewer rounds, decreasing the logistic requirements.

DATA SHEET 2.11. MISSILE PROPULSION

Developing Critical Technology Parameter	Integration of rocket or air-breathing hypervelocity propulsion for rapid delivery of long-range standoff weapons.
Critical Materials	Lightweight, high-strength composite materials for airframe construction.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	CFD M&S of propulsion systems, particularly performance of air-breathing systems at high angles of attack; characterization of small body rolling airframe reactions at hypervelocity.
Major Commercial Applications	Some of the underlying science may be applicable to civil aerospace planes and launch systems.
Affordability	Significant issue for tactical missiles, particularly smaller diameter systems for antitank and air defense missions.

BACKGROUND

These technologies address the ability to support several interrelated objectives that underlie significant improvements in operational capabilities:

- Increased payload weight (lethality).
- Increased weapon range (effective envelop).
- Increased velocity and reduced time of flight (decreased exposure and enhanced survivability; increased threat handling).
- Improved agility and maneuverability (greater tactical flexibility and lethality).

SECTION 2.12—SURVIVABILITY, ARMOR, AND WARHEAD DEFEAT SYSTEMS

Highlights

- Achieving full-dimensional protection in the face of a rapid spread and proliferation of conventional weapons technology will require significant advances in system protection and survivability.
- This will require the development of critical technologies for system design and analysis and improved armor materials for the implementation of new active protection concepts.
- Effective integration of these technologies provides a hierarchical suite of defenses to reduce the susceptibility of systems to detection and attack by enemy forces, to prevent effective engagement, and to limit damage in the event that U.S. systems are successfully engaged.

OVERVIEW

This section addresses system physical design techniques, subsystems, and devices to degrade or defeat the effectiveness of enemy conventional ordnance directed against U.S. systems and personnel. It does not address signature control, cover and deception, or platform maneuverability to increase survivability by avoiding detection or engagement. Certain of the design technologies addressed may, however, be common to those employed in IMs.

This section also addresses all aspects of on-board protection designed to disrupt or defeat the lethal mechanisms of enemy ordnance. This may include techniques designed to be effective against weapons whose effectiveness has been degraded by a variety of fuze countermeasures but not the countermeasures themselves.

A suite of technology-enabled operational capabilities enhance survivability:

- **Detection avoidance.** This is addressed separately under discussion of LO technology (see Section 18, *Signature Control Technology*).
- **Engagement avoidance.** This encompasses all operational capabilities designed to prevent an enemy from acquiring a fire control solution and engaging detected forces. It results from a combination of design, mobility, countermeasures, and tactics. Of these, only design is addressed in this section. Section 9, *Ground Systems Technology*, will address other aspects of engagement avoidance.
- **Hit avoidance.** The features of design, mobility, countermeasures, and tactics also come into play to induce incoming weapons to miss the target or critical components of the target. Again, only design is addressed in this section. Section 9, *Ground Systems Technology*, will address other aspects of hit avoidance.
- **Physical protection.** These are measures to prevent or mitigate the effects of weapons that hit the target. This includes effects of proximity-fuzed weapons designed to initiate at an appropriate standoff range from the target.
- **Crew protection and damage control.** This includes techniques like automatic fire suppression to limit casualties to personnel and mission-critical equipment, particularly for weapons that successfully breach a system's physical defenses.

System Design

System design can contribute significantly to survivability by reducing the profile and exposure of the system and the critical components. For example, early studies of tank warfare showed that height of the tank's overall profile was significant in determining battlefield survivability. Similarly, critical components can be positioned to increase the degree of screening afforded by nonessential components and terrain. (In this regard, flexibility in packaging and placement of critical propulsion components is viewed as one of the desirable features of electric drive for armored vehicles).

Figure 2.12-1 illustrates some of the advanced design features that have been proposed for future combat vehicles. This figure represents a composite of features that have been prototyped or seriously proposed in concept studies.

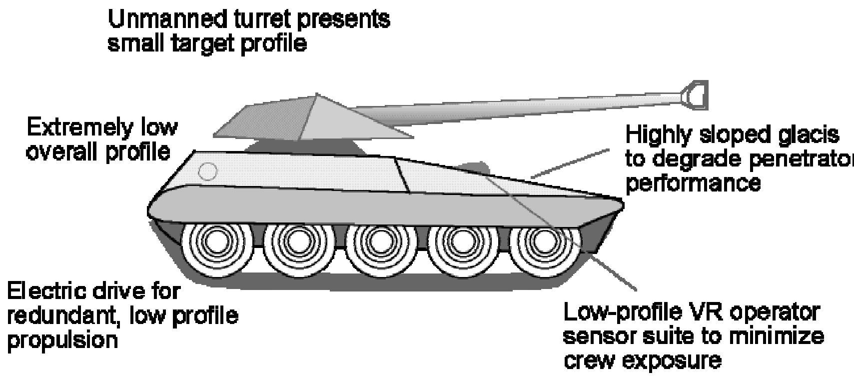


Figure 2.12-1. Advanced Combat Vehicle

Physical Protection

The state of the art in this capability comprises several distinct subtechnologies, including vulnerability analysis, passive protection, and active protection. Specific subitems include:

- **Bulk armor, particularly bulk ceramics.** The challenge is the production of thick sections, free from degrading physical defects.
- **Composite armor, including as a special class lightweight ceramic arrays.** The goal of developing technology is to defeat the 7.62-mm AP round with an areal armor weight of less than 3.5 lb/ft^2. The current state of the art is SiC.
- **High-tensile strength fiber.** This represents a large and rapidly growing international market. The ceramic materials used are being widely investigated for their potential application to high-temperature internal combustion engines.
- **Reactive armor.** Identified critical aspects relate to reducing the sensitivity of the reactive armor elements to sympathetic detonation and other unintended detonations. Ideally, the key is to tailor the response of the subelement of the reactive armor appliqué to the characteristics of an impinging shaped-charge jet.
- **Active armors.** Active armors detect impending penetrator impact and respond to intercept the threat at a standoff distance adequate to degrade and defeat the lethal mechanism. Critical aspects include development and integration of smart sensor suites and algorithms for real-time computation of firing orders for the individual response mechanisms.
- **EM armor.** This is a special category of active armor concept based upon using EM hydrodynamic forces acting on shaped-charge jets to disrupt and degrade the formation of the jet.
- **Transparent armor.** The state of the art is represented by class/polymer composites. The goal of ongoing research in this area is to find transparent ceramics that will equal the ballistic performance of existing glass/polymer (with a 30-percent reduction in weight and thickness) while increasing the in-line transmission in the visible and near-IR regions. Other desired characteristics are superior abrasion resistance, strength, and high-temperature properties. Materials selection and early prototyping efforts are just underway. Once promising materials and configurations have been found, additional efforts may be required to produce the required transparent ceramics in quantity.

  Projects underway are directed at protecting the individual soldier (e.g., law enforcement officers) against small arms at 60 percent the weight of current armor systems. Capabilities sought include transparent armor face shields for protection against small arms artillery and bomb fragments and blast for soldiers, law enforcement officers, and bomb disposal teams and windows for vehicles and shelters at 70 percent the weight of current armor systems. Other projects will provide armor materials and armor systems to protect combat, tactical, law enforcement, and bomb disposal vehicles at 70 percent the weight of current armor systems against medium KE threats, artillery and bomb fragments, and blast. All of these have dual-use applications. Advances in nanotechnology and superplastic ceramics are among those that may be the key to practical processing of transparent ceramics. These underlying technologies will have broad industrial use and commercial application.

LIST OF TECHNOLOGY DATA SHEETS
2.12. SURVIVABILITY, ARMOR, AND WARHEAD DEFEAT SYSTEMS

The following developing technologies have been identified, but data sheets are not available at this time:

Structural Design

Transparent Armor

Active Protection

DATA SHEET 2.12. REAL-TIME, IN-FIELD NONDESTRUCTIVE EVALUATION (NDE) FOR ROTORCRAFT

Developing Critical Technology Parameter	Ability to do real-time (within 15 min) NDE of air worthiness of battle-damaged rotorcraft through active or passive acoustic or vibration analysis, including holographic laser-imaging techniques.
Critical Materials	High-efficiency piezoelectric actuators for acoustic test stimulation.
Unique Test, Production, Inspection Equipment	None identified. However, certain methods of laser holographic measurement and active acoustic sensors may emerge in the future.
Unique Software	Experimentally validated performance prediction algorithms for use in operational systems.
Major Commercial Applications	Widespread applicability to transportation and industrial NDE. Similar techniques are being actively researched for evaluation of degraded/damage infrastructure components (bridges, roads, buildings, and so forth).
Affordability	Primary impact is prevention of unnecessary loss of equipment by enabling operators to fly battle-damaged helicopters to safety within acceptable risk boundaries.

BACKGROUND

With the growing proliferation of armor-piercing small-arms and shoulder-fired antiair missiles, U.S. aircraft will be exposed to increased hazards of battle damage on the ground and during flight. While flight worthiness can be estimated in some cases from visual inspection of damage, operational forces have no direct way of estimating the degree of an aircraft's internal structural damage. Further, the inability to estimate safe operational limits accurately means that aircraft must be operated conservatively, exposing it to further unnecessary risk.

Current research is aimed toward techniques for real-time evaluation of structural reactions to induced stimuli. In the future, as the knowledge base of system response to damage effects becomes more extensive, it may be possible to estimate flight worthiness based on structural response to normal operating vibration.

DATA SHEET 2.12. ADVANCED COMPOSITE ARMOR DESIGN

Developing Critical Technology Parameter	Composite structures designed or characterized for ballistic performance in applications exceeding National Institute of Justice (NIJ) Threat Level IV in armor systems weighing < 3.5 lb/ft^2.
Critical Materials	High toughness ceramics (see Data Sheet 2.12, Ceramics for Ballistic Protection); ballistic fibers capable of sustaining a tenacity of > 30 gm/denier at temperatures > 125 °C.
Unique Test, Production, Inspection Equipment	Ballistic test equipment.
Unique Software	Experimentally validated modeling of ballistic response of composite structures capable of characterizing armor performance across a spectrum of diverse mass/energy regimes and angles of incidence.
Major Commercial Applications	Technology common to protective equipment for law enforcement and for industrial safety applications.
Affordability	Because of quantities associated with the application of this technology to soldier systems, unit cost affordability will be a major consideration.

BACKGROUND

The growing proliferation of higher energy small-caliber weapons and armor-piercing ammunition are driving requirements for lightweight armor, particularly for personnel and aircraft. Materials technologies can also be applied to the design of IMs. Rules of engagement (ROE) and dependence on nonlethal technologies for low-intensity operations increase the potential exposure of U.S. personnel to direct small-arms fire and place a corresponding premium on personnel protection.

DATA SHEET 2-12. HIGH-TENACITY POLYMER FIBERS

Developing Critical Technology Parameter	High-tensile-strength, high-tenacity (> 30 gm/denier) ballistic fibers capable of absorbing high energy-rate deformation and retaining ballistic performance at temperatures > 160 °C.
Critical Materials	Specially characterized precursors for high-performance fibers.
Unique Test, Production, Inspection Equipment	Specially designed spinning equipment, including electrospinning techniques for mass production of high-performance polymer fibers.
Unique Software	Experimentally validated modeling of ballistic response of fibers and fiber-reinforced structures capable of characterizing armor performance across a spectrum of diverse mass/energy regimes and angles of incidence.
Major Commercial Applications	High tensile strength polymer fibers are used in a broad range of commercial applications, including ropes and packaging, tires, sporting equipment, safety equipment, clothing, and so forth. The potential market for affordable fibers is enormous.
Affordability	At the current state of the art, scientists are still trying to understand the basic processes involved in natural production of spider silk. Once these processes are mastered, however, the driving function on further development and use of the material will be affordability and, specifically, the ability to scale up artificial synthesis processes.

BACKGROUND

The growing proliferation of higher energy small-caliber weapons and armor-piercing ammunition are driving requirements for lightweight armor, particularly for personnel and aircraft. Materials technologies can also be applied to the design of IMs. ROE and dependence on nonlethal technologies for low-intensity operations increase the potential exposure of U.S. personnel to direct small-arms fire and place a corresponding premium on personnel protection.

In addition, advances in high ballistic-strength fibers will contribute to the military's capability to meet stringent weight requirements for soldier systems and for other equipment where rugged impact-resistant performance is required. The highest performance polymer fiber known—spider drag-line silk—has the ability to sustain very high deformation rates at tight bend radii. This indicates a potential for substantial improvements in lightweight armor if affordable means of synthetic fiber production can be developed.

No one parameter determines the performance of a fiber in a given lightweight armor application. It is a function of tensile strength, tenacity, elasticity, and other physical properties that govern the mechanical response and toughness of the material when subjected to ballistic impact.

DATA SHEET 2.12. CERAMICS FOR BALLISTIC PROTECTION

Developing Critical Technology Parameter	The performance of a ceramic in a given lightweight armor application is not determined by any one parameter but is a function of hardness and other physical properties that govern the mechanical response and toughness of the material when subjected to ballistic impact.
Critical Materials	Specially characterized precursors (typically high-purity nanopowders) for high-performance ceramics.
Unique Test, Production, Inspection Equipment	Ballistic testing equipment.
Unique Software	Experimentally validated modeling of ballistic response of ceramic elements and fiber-reinforced arrays of ceramic elements capable of characterizing armor performance across a spectrum of diverse mass/energy regimes and angles of incidence.
Major Commercial Applications	Much of the recent advance in ceramic technologies has been driven by commercial requirements and specifically by the search for improved structural materials for high-temperature, high-efficiency, low-emission internal combustion engines.
Affordability	Based on the test results and cost data, the lightest system available to defeat the small-arms threat is a boron carbide/Spectra backing design, and the heaviest system would be an aluminum oxide/Kevlar backing design. Spectra has an areal density approximately one-half that of Kevlar, at approximately three times the cost. The boron carbide/Spectra design would represent a 30-percent decrease in armor areal density weight but would be 70 percent more costly to procure.

BACKGROUND

The growing proliferation of higher energy small-caliber weapons and armor-piercing ammunition are driving requirements for lightweight armor, particularly for personnel and aircraft. Materials technologies can also be applied to design of IMs. ROE and dependence on nonlethal technologies for low-intensity operations increase the potential exposure of U.S. personnel to direct small-arms fire and place a corresponding premium on personnel protection.

SECTION 2.13—NONLETHAL WEAPONS (NLWs)

Highlights

- NLWs are discriminate weapons explicitly designed and employed to incapacitate personnel or material while minimizing fatalities and undesired damage to property and environment.
- A wide range of technology areas are being considered for use in NLWs. These include use of acoustics, chemical materials, electrical and EM energy, optical energy, various types of confinement or immobilizing devices.
- The ability to "tune" the effects of weapons affords commanders significant tactical flexibility, particularly in operations other than war (OOTW), while retaining an element of lethality necessary to ensure full-dimensional protection of U.S. personnel in extreme situations.
- At the same time, NLWs also offer a significant capability in the hands of terrorists or other nonfriendly organizations that might employ them as a precursor to the use of lethal force.

OVERVIEW

This section is limited to NLW technologies designed to physically incapacitate personnel and equipment and degrade or destroy essential materiel, including logistic stores. It does not address other forms of soft system kill, such as offensive information warfare and electronic countermeasures. Nonlethal AP measures include those designed to temporarily incapacitate or restrain individuals or groups of individuals.

DoD [Office of the Assistant Secretary of Defense for Special Operations (OASDSOLIC)[3]] has defined NLWs as follows:

> Nonlethal weapons are discriminate weapons that are explicitly designed and employed so as to incapacitate personnel or material while minimizing fatalities and undesired damage to property and environment. Unlike weapons that permanently destroy targets through blast, fragmentation, or presentation, nonlethal weapons have relatively reversible effects on targets and/or are able to discriminate between targets and nontargets in the weapon's area of impact.

The focus on the distinction between traditional, conventional weapons (which by their nature produce permanent or long-lasting damage) and the reversible effects of NLWs is important. Qualitative differences between NLWs and conventional weapons have profound implications for military operations and strategy. In the context of dominant force, this means that the effects of nonlethal means must be overwhelming, predictable (in terms of degree and duration of incapacitation) and not susceptible to countermeasures, and, ideally, reversible.

The idea of nonlethal force as an element of warfare is old. In fact, Sun Tsu, in *The Art of War*, stresses the desirability of defeating an enemy without killing. However, emphasis on the development of specific nonlethal technologies tailored to military applications is relatively recent. As a result, the state of the art in operational systems is fairly limited. The 40-mm sponge grenade designed to knock down a person hit in the chest or abdomen up to 30 m away is typical of currently deployed capabilities.

The post-Cold War era has evidenced an increasing trend for U.S. military involvement in OOTW. These operations range from simple disaster relief, to peacekeeping, to counter-drug efforts and are not necessarily limited in size or complexity. They may include military intervention that falls short of declared war or major conflict or gradually or suddenly escalate to a larger crisis than originally expected. It is anticipated that OOTW will be the predominant form of future U.S. military operations well into the next century. The nature of such conflict and the domestic and international political implications make it particularly important that casualties (United States and other) be kept to an absolute minimum.

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3 SOLIC (Special Operations and Low Intensity Conflict).

The desire to reduce casualties in future armed conflicts and to support scenarios associated with OOTW has lead to increasing interest in advanced technologies for NLWs. The NLWs are needed in numerous tasks, such as controlling noncombatant crowds, immobilizing approaching or fleeing individuals or vehicles, hostage-rescue situations, seizing equipment and buildings intact, and neutralizing weapons systems. They are designed to temporarily incapacitate a threat, with no long-term debilitating effects. They also include weapons and munitions that focus on "systems" kills and on surgical kills with minimal collateral damage. They may take a variety of forms, including guided weapons, light, sound, gases, or aerosols. The development of these technologies is critical to U.S. success in this type of engagement: to protect the lives of U.S. military personnel and to inflict minimum casualties on noncombatants. In several foreseeable circumstances, expanded options must be available to meet threats for which the use of massive lethal force is counterproductive or inadvisable. Nonlethal concepts can provide additional options for military and political leaders.

A wide range of technology areas is being considered for use in NLWs. These include acoustics, chemical materials, electrical energy, optical energy, various types of confinement or immobilizing devices, and RF DEWs. Specialized expertise in these and other areas is involved in developing practical NLWs.

The scope of nonlethal technology is extremely broad, and it is useful to separate measures directed against personnel from those targeted on equipment and materiel. Major categories of NLWs include:

- **AP technologies to incapacitate, disorient, or immobilize people.** Depending on the technology, weapons may be aimed at one or more specific person or could be area-wide to affect a larger number of people. Critical developing technologies in this area include:
  - Acoustic and infrasonic devices to disorient or incapacitate individuals
  - Laser or stroboscopic light sources to temporarily blind individuals
  - Sticky foam, nets, or other techniques to immobilize individuals and/or constrain their movements
  - Stun guns to incapacitate individuals
  - Chemical agents to calm, immobilize, or incapacitate individuals or crowds
  - Antitraction technologies to immobilize individuals or vehicles.

  As mentioned elsewhere, predictability/reliability of nonlethal measures is critical. Improved M&S of human subjects' range of response to these measures will be critical primary considerations in any design decision regarding lethal weapons because of human subjects' extreme variability to specific stimuli. The measures must be used at levels sufficient to ensure their effect on the most capable and determined members of the threat population. The difficulty arises in that such a level may also prove to be lethal to an unacceptably high portion of less robust individuals. Similarly, measures that are nonlethal under certain conditions may have lethal effects under others. A clear example of this are the rubber bullets and grenades used for mob and riot control, which can be deadly at point-blank range.

- **Antivehicle technologies to immobilize vehicles.** Depending on the technology, weapons may target a single vehicle or the application could be area-wide to immobilize all vehicles in the area. Technologies include:
  - EM energy to disrupt vehicles
  - Airborne chemicals or fluids designed to snuff combustion when aspirated in vehicle propulsion systems
  - Chemicals (e.g., antilubricants and polymer agents) that can be designed to infiltrate operational systems to alter fuels, lubricants, seals, or tires and thereby incapacitate vehicles
  - Antitraction or high-strength adhesive materials to immobilize individuals or vehicles.

- **Antisensor/antimateriel** technologies **to disrupt, destroy, or cause to abort, various weapons, sensors, or other materiel.** Technologies include:
  - Chemicals (e.g., supercaustics, superoxidants) or bioagents that are capable of attacking and damaging key infrastructure (e.g., runways, roads, bridges)
  - Chemicals (e.g., antilubricants and polymer agents) or biological agents that can be designed to infiltrate stores and attack fuels, lubricants, and seals, or attack and degrade other materials.

In addition to these categories, several related nonlethal antisensor countermeasures are addressed in the discussion of EW or DEWs. These include:

- Lasers to neutralize optical and night-vision devices
- EM energy to disrupt computers or other electronics
- High-power microwaves for antimine or antisensor use
- Special-effects warheads to damage, destroy, or cause to abort munitions or fuzes.

The needed technologies and devices for each of these countermeasures are at differing stages of development. Focused programs to develop practical NLWs based on these technologies have begun and are expected to increase.

Despite the emphasis on the humane and, therefore, presumably desirable features of nonlethal technologies, they are not without detractors. Faculty advisors at the United States Air Force Air University offer the following in the abstract to their paper, *Air Power, Nonlethal Weapons and Future National Security Policy*.

> Nonlethal technologies are generating an impressive array of weapons from sticky foam polymers to sophisticated laser, acoustic, and microwave weapons. An investigation of the currently available, emerging, and promising theoretical technologies indicates that the delivery method of choice is likely to be air power. When the traditional mission areas are examined to determine how well NLWs might integrate with air power, it appears that NLWs may represent the next revolution in military affairs. Whether this is true or not is insignificant, however, since NLWs do not constitute a usable military revolution. Despite the unique opportunities NLWs may offer national security decision-makers, the weapons will prove unusable for six reasons: (1) they invite escalation, (2) they increase operational requirements, (3) they will prove to be prohibitively expensive, (4) their use violates the laws of war, (5) they destroy the environment, and (6) they will be difficult if not impossible to regulate. Ultimately, NLWs, like nuclear weapons, come bundled with so many limitations that it becomes difficult to imagine their widespread use in warfare.

Dual-Use Aspects of the Technology

The wide range of scenarios that could arise where NLWs would be needed, coupled with the many possible technologies available for NLWs, makes this a particularly difficult area in which to assess critical developing technologies. Law enforcement and civilian crowd and riot control are the most obvious dual-use applications of this technology, and many of the systems now in use [e.g., Tom A. Swift's Electric Rifles (TASERs), stun grenades, rubber and sponge bullets and grenades, and incapacitating chemicals like Mace and pepper spray] were first developed to meet these requirements.

Some of the technologies, however, will need to be carefully controlled to ensure that they are not available for use against U.S. military or civilian personnel. Because of the dual-use nature of the technologies, establishing and enforcing technology controls will bet difficult. That said, operational military requirements exist for an ability to "tune" the impact of certain weapons over a wide range, from nuisance to lethal effects.

LIST OF TECHNOLOGY DATA SHEETS
2.13. NLWs

The following developing technologies have been identified, but data sheets are not available at this time:

Antipersonnel Technologies

Immobilizing and Restraining Technologies

Antitraction Technologies

Immobilizing Techniques

Antimateriel Technologies

Corrosive Agents

Destructive Enzymes and Chemical Catalysts

DATA SHEET 2.13. INCAPACITATING ACOUSTIC WEAPONS

Developing Critical Technology Parameter	Ability to generate (and, if possible, direct) acoustic energy (typically low frequency (< 10 Hz), with intensities of > 150 dB; identification of precise waveform parameters for optimum coupling and effect.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Models of propagation and human physiological response to acoustic energy.
Major Commercial Applications	Law enforcement; crowd and riot control; counterterrorism.
Affordability	Not explicitly identified as an issue.

BACKGROUND

Interest is driven by requirements for conducting low-intensity operations and MOUT. In these cases, tactical situations and the presence of civilians frequently limit the use of lethal force. Acoustic-beam weapons are still in the conceptual stage, and there are serious technical questions regarding their potential effectiveness, particularly at effective ranges. However, the concepts are still in development, and researchers have only begun to investigate the range of possible options and human physiological responses.

As with other nonlethal technologies, one of the key concerns is the potential for use of nonlethal technologies by terrorists as a precursor to the use of lethal force.

DATA SHEET 2.13. VARIABLE LETHALITY PROJECTILES

Developing Critical Technology Parameter	Development of small-caliber projectiles and projectile launch mechanisms capable of providing a wide spectrum of effects from mild deterrent to lethal force.
Critical Materials	Energetic compounds, specially designed to allow continuous selection of energetic yield and pressure-time characteristics.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Models of human physiological response to impact.
Major Commercial Applications	Law enforcement; crowd and riot control; counterterrorism.
Affordability	Ideally, this technology should meet current requirements for small arms; thus, affordability will be a critical factor for weapons and rounds.

BACKGROUND

As interest in NLWs has evolved, it has become increasingly evident that what is needed, for civil and military forces, is not nonlethality, but the ability to tune the effects of small arms to achieve a specified effect. The goal is to provide law-enforcement officers and peacekeeping forces engaged in low-intensity conflict and MOUT a range of responses that can be tailored precisely to the tactical situation.

DATA SHEET 2.13. COMBUSTION-INHIBITING TECHNOLOGIES

Developing Critical Technology Parameter	Agents that reliably inhibit or degrade combustion of internal combustion or gas-turbine engines, at concentrations commensurate with aerosol delivery over an operating area of several hundred square meters or more.
Critical Materials	Combustion inhibiting compounds.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Models aerosol dispersion, engine intake, and combustion reaction.
Major Commercial Applications	Law enforcement; fire safety/suppression.
Affordability	Not explicitly identified as an issue.

SECTION 2.14—DEMILITARIZATION AND DECONTAMINATION

Highlights

- DoD Air Force Logistics Command Regulation (AFLCR) 136-5 requires that demilitarization and disposal considerations be an integral part of the planning and decision-making processes for all new or modified ammunition items, from conception to final acceptance of the end item.
- The impact of this requirement on life-cycle cost will be a significant consideration in affordability since it affects acquisition decisions.
- Technological advances are needed in detecting, neutralizing, and disassembling unexploded ordnance (UXO); ensuring environmentally safe destruction, decomposition, and/or neutralization of energetic loads; and remediating contaminated soils or water.
- Advances in these areas have the potential to enable the use of higher performance explosives and propellants that currently are not affordable.

OVERVIEW

This section addresses technologies for neutralizing and demilitarizing conventional weapons, including techniques for remote disassembly and for extraction and processing of energetic fills. It also includes techniques for decontaminating and remediating materiel, land, and marine areas contaminated by explosive materials. It does not address chemical and biological decontamination covered in Sections 3 and 5 or technologies for defeating minefields covered in Section 2.10, Mines.

In the past, detonation or combustion of energetic materials was used as a primary means of demilitarization. However, these methods are under sharp governmental scrutiny worldwide for their adverse environmental effects, which include air pollution and, for partial detonation, dispersal of toxic compounds. In addition, chemicals formed by decomposition of explosives are hazardous or toxic.

An assessment of needs and programs cites the following driving environmental considerations for development of innovative demilitarization technologies.

- **The Resource Conservation and Recovery Act (RCRA).** RCRA requires that open burning and open detonation pits be permitted as hazardous waste treatment facilities, and, therefore, these facilities are required to have RCRA Part B permits. Many military facilities have not completed this filing and could be in violation.
- **The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)**. CERCLA is the principal driver for clean-up activities that take place at closed military bases. Clean-up activities could be required for firing ranges or open burn/open detonation pits.
- **The Clean Air Act (CAA)**. CAA places increased requirements on facilities to decrease or limit their emissions of criteria pollutants [e.g., oxides of nitrogen (NOx) and particulates (PM10 and PM2.5), and hazardous air pollutants (HAPs)] from burn pits. Major facilities are required to use the lowest achievable emission reductions (LAER) or best available control technology (BACT) for any modifications that cause an increase in emissions for the pollutant for which they are a major source. This may require facilities to install costly control devices and requires investigations of all technologies that may possibly decrease emissions.
- **DoD AFLCR 136-5**. DoD AFLCR 136-5 expands and implements the joint agreement on demilitarization/ disposal requirements related to the design of new or modified ammunition items issued by the Commanders of AMC, the Naval Sea Systems Command (NAVSEA), the Air Force Logistics Command (AFLC), and the Air Force Systems Command (AFSC). This regulation requires, among other things, that demilitarization and disposal considerations be an integral part of the planning and decision-making

processes for all new or modified ammunition items, from conception to final acceptance of the end item; that safety and environmental quality be primary considerations in the demilitarization and disposal procedures developed; and that maximum attainable recycling and recovery be achieved in accordance with the RCRA.

Affordability is another key consideration. Issues divide into two general categories:

1. Energetic materials, such as TNT, HMX, and RDX, have been produced and stockpiled in weapons in large quantities. Because of the volume of these materials, marginal cost reductions can have significant impact.
2. Expensive high-performance materials, such as TNAZ, CL-20, triaminotrinitrobenzene (TATB), and NTO (some of which are priced at thousands of dollars per pound), are typically used in explosives packages costing $5,000 to $10,000 per unit. For these, recovery of the materials in a form that will permit reuse of the energetic materials and the associated warhead components (cases, shells, and liners) is an important consideration.

The principal subareas of technology where major technological advances are needed have been identified as:

- Detection of unexploded ordnance (UXO), a technology that also plays an important role in counter-proliferation and counterterrorism activities.
- Methods for safe neutralization and disassembly of explosive devices.
- Methods for safe (including as an important subset, environmentally safe) destruction, decomposition, and/or neutralization of energetic explosive and propellant loads, which includes techniques for dissolving and the energetic constituents for future processing.
- Techniques and processes for resource recovery and reuse.
- Techniques for physical, chemical, or biological treatment, including phytoremediation of contaminated soils or water.
- Design for demilitarization.

To expand upon several of these, base hydrolysis produces a nonenergetic, water-soluble waste stream that may require secondary processing. Biodegradation offers a cost-effective and industrially sound method for treating the nonenergetic products from the base hydrolysis process and is applicable to a wide range of bulk explosives or propellants that have been treated via base hydrolysis. The cultures used for denitrification can be obtained from local wastewater treatment plants. In this process, the base hydrolysis solution is neutralized, diluted with water in a 1:1 ratio, and then mixed with an external carbon source (e.g., methanol or dehydrated soluble potato solids). The reaction takes approximately 5 days and produces carbon dioxide and nitrogen as its main byproducts.

The increasing concern for environmental effects and the growing cost of the more sophisticated explosive devices used in modern conventional weapons are providing an incentive for designers to examine more closely the life-cycle cost demilitarization and decontamination. For example, the Navy has proposed the use of ADN as a more environmentally benign alternative to AP. The Services are also seriously investigating the cost-saving implications of recovery and reuse of energetic materials.

Remote disassembly capabilities (some of which are also applicable to mine and countermine applications) require a wide range of diverse supporting technologies. Critical developing areas include virtual reality (VR) telepresence display and precision haptic interfaces with force feedback and control. These subtechnologies have broad commercial application in industrial application and in VR entertainment.

State of the Art

The 1998/1999 level of the state of the art in most countries remains combustion or detonation, with some progressing to use of high-temperature water or other solvent technologies.

Bioremediation of explosives has been demonstrated in batch treatment processes, including continuous flow, reactor processing, and composting treatments. Data on the degradation of HEs using microbes in compost piles and bioreactors provide compelling evidence that in situ microbial degradation may provide a cost- and environmentally effective in situ treatment option. However, few data are available on in situ remediation or in specific techniques for maintaining in situ conditions for the optimum bioactivity. In situ processing eliminates the need for excavation, handling, and off-site treatment and disposal of hazardous and toxic materials and, thus, offers potential cost advantages over existing technologies.

Other notable emerging technologies for the demilitarization of conventional ammunition include supercritical water oxidation (SCWO) of bulk organic waste material (which includes energetic materials); plasma arc thermal treatment of fully assembled small- and medium-caliber pyrotechnic munitions; cyrofracture of explosive-loaded small munitions, such as antipersonnel landmines; and contained detonation chambers to replace open detonation.

With regard to remote disassembly, the underlying VR technologies have been advancing rapidly—so rapidly, in fact, that the technology may be outstripping our knowledge of how to apply it. Much of the ongoing, near-term research will probably focus on the basic phenomenologies of human perception and the derivation of standards for what constitutes "good enough." In this regard, a key factor is that the requirements for total immersion for entertainment purposes may be significantly less demanding than what will be required for effective telepresence for certain military and industrial applications.

Dual-Use Implications

While demilitarization is predominantly a military concern, many of the most advanced techniques of interest, such as in situ bioremediation, have significant potential markets in the civil sector for cleaning up land contaminated by organic and nitrogen compounds.

In the area of tactical demilitarization and explosive ordnance disposal (EOD), a clear civil application for police bomb disposal exists. The underlying technologies also have broad applicability to a wide range of hazardous industrial uses, including maintenance and repair of nuclear power systems and other inaccessible or hazardous infrastructure elements.

LIST OF TECHNOLOGY DATA SHEETS
2.14. DEMILITARIZATION AND DECONTAMINATION

The following developing technologies have been identified, but data sheets are not available at this time:

Demilitarization

Decontamination

DATA SHEET 2.14. ADVANCED ROBOTICS FOR EXPLOSIVE ORDNANCE DISPOSAL (EOD)

Developing Critical Technology Parameter	Robotic EOD equipment incorporating any one or more of the following: • Telepresence • Haptic force feedback manipulation of objects.
Critical Materials	High efficiency shape memory alloys (SMAs) for sensing and feedback.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated models of human response to acoustic weapons under expected range of operational and environmental conditions.
Major Commercial Applications	Technology will be driven by entertainment use and by industrial applications. Haptic device technologies are already being used in biomolecular engineering and remote medical applications.
Affordability	Not an issue.

BACKGROUND

This technology affects the safety of operations and will be an important consideration in EOD in MOUT and OOTW operations. Telepresence is required for remote vehicle operation or for reducing exposure and vulnerability of operators in manned vehicles.

Dual-use aspects include use by civilian police forces in counter-terrorism and for general-purpose industrial use in hazardous environments. Technologies will also find almost immediate use and dissemination in entertainment.