DEPARTMENT OF DEFENSE

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

SECTION 17: SENSORS TECHNOLOGY

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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 17—SENSORS TECHNOLOGY

Scope

Highlights

- In modern warfare, the side with superior sensors has a great advantage over its adversaries.
- Improved sensor performance is required for offsetting or countering the stealthy targets being introduced worldwide.
- Sensor performance can be improved by:
  - Multiple, unique interference-rejection techniques.
  - Automated information management, including using more robust discrimination and correct decisions criteria.
  - Fusion of data from multiple looks and sources, including using network-centric warfare techniques.
- It is envisioned that evolutionary improvements in sensors will continue, but at an accelerated pace.
- Nuclear, chemical residue, and hyperfine interactions technologies [nuclear quadrupole resonance (NQR)] are being used to correctly identify explosives in buried land mines.

OVERVIEW

This section includes the technologies for acoustic and electro-optic sensors and radar, the primary sensors of military interest. Laser sensors are included in the Lasers, Optics, and Supporting Technology section. Gravity and magnetic sensors are included in Positioning, Navigation, and Time section. Inertial, chemical, biological, and nuclear sensors are covered in their respective sections. This section also covers the technologies for the mine detection, minefield detection, and neutralization aspects of countermining.

Acoustic and electro-optic sensors, radar, and countermining are already vital and will become even more so in the future for effective and safe military operations, regardless of whether for open conflict, peacekeeping, training, or humanitarian efforts. Most of the major sensors are also vital for many civilian endeavors as well. It is envisioned that evolutionary improvements in sensors will continue, but at an accelerated pace.

No single sensor approach has been demonstrated to be effective in finding buried mines. The fusion of ground-penetrating radars (GPR), electromagnetic induction (EMI) technologies, and nuclear detection techniques shows great promise for improved target detection with fewer false alarms.

BACKGROUND

The data obtained from these primary sensors is a basic and necessary ingredient for all military planning and operations. In most warfare scenarios, sensors will be used singly or in combinations, with some serving as primary and others used to confirm or verify the results.

SECTION 17.1—ACOUSTIC SENSORS, TERRESTRIAL PLATFORM

Highlights

- Acoustic is the sensor of choice for noise-emitting still and moving targets that are out of the line of sight in a battlefield.
- Acoustic sensors provide effective detection and tracking of noise-emitting targets for battlefield monitoring and targeting.
- Acoustics sensors are typically primary in network of unattended ground sensors (UGS).
- Acoustic sensors provide improved identification and tracking of targets in loud acoustic clutter while rejecting false targets.
- It is envisioned that evolutionary improvements in acoustics will continue, but at an accelerated rate.

OVERVIEW

This subsection covers technologies for the development or production of acoustic systems for terrestrial (land-based) applications. Ground-based, passive acoustic systems for the detection and location of noise-radiating targets, such as intruders, vehicles, and direct-fire weapons are included.

Microphones or geophones are placed for the best reception and maximum received signal-to-noise ratio (SNR). The criterion for decision making and the selection and weighting of discriminating clues is of paramount importance for these systems. For most of these applications, omnidirectional microphone arrays are also required.

Ground vehicles used for the passive reception platform can generate an acoustic environment much louder than the signals to be detected. Self-noise reduction, including but not limited to isolation, is required.

Civilian application includes seismic acoustic systems for locating and identifying petroleum-producing features within Earth’s crust. (The Information Technology section discusses the processing and computational capabilities of seismic land-based processing centers that are considered critical.)

Evolutionary, emerging technology developments are highlighted in the following data sheets. There are no known revolutionary emerging developments underway.

LIST OF TECHNOLOGY DATA SHEETS
17.1. ACOUSTIC SENSORS, TERRESTRIAL PLATFORM

DATA SHEET 17.1. PASSIVE DETECTION OF VEHICLES FROM A LAND-BASED SITE

Developing Critical Technology Parameter	Detecting, identifying, and real-time tracking from a land-based site of noise-emitting, moving target vehicles that are out of the line of sight in a battlefield.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	For air-deployable, all-weather sensors.
Unique Software	Validated set of algorithms that provides the knowledge base for identifying potential targets, discriminating against false targets, and providing real-time tracking of moving targets.
Major Commercial Applications	None identified.
Affordability	Not determined.

DATA SHEET 17.1. PASSIVE DETECTION OF VEHICLES FROM AN AIRBORNE MUNITION

Developing Critical Technology Parameter	From an airborne munition, detecting, identifying, and real-time tracking of noise-emitting stationary and moving target vehicles that are out of the line of sight in a battlefield.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	All-weather, airflow-noise-resistant acoustic sensors.
Unique Software	Validated set of algorithms that provides the knowledge base for identifying potential targets, discriminating against false targets, and real-time tracking of moving targets.
Major Commercial Applications	None identified.
Affordability	The cost of expendable munitions is always a factor.

SECTION 17.2—ACOUSTIC SENSORS, MARINE, ACTIVE SONAR

Highlights

- Active sonar systems provide rapid and accurate target location for developing a quick-response fire-control solution.
- Major improvements in active sonar systems are necessary to counter the more limiting environmental acoustic conditions found in littoral areas.
- A higher ratio of correct decisions to false alarms is to be achieved for littoral areas by improving computer-aided detection, classification, and information management.
- Major operational improvements are to be achieved by increasing reverberation and countermeasure interference-rejection techniques.
- Received signal-to-noise levels are to be enhanced by data fusion from multiple platforms and adaptive processing to better match sonar to the acoustic environment.
- Active sonar for weapons systems is being improved to operate at high speed and resolve, identify, and successfully track small, slow, diesel-electric submarine targets in the adverse shallow-water environment.
- It is envisioned that evolutionary improvements in active sonars will continue, but at an accelerated pace.

OVERVIEW

This subsection covers the technologies for the development and production of active sonars, which employ acoustic signals to echo range and locate underwater objects and to determine features in Earth's crust. Military uses for active sonars include ASW and antiship warfare, weapon homing, torpedo defense, mine warfare, swimmer warfare, deep-sea salvage, and underwater communication and navigation. Commercial uses include locating fish and other objects underwater, seismic exploration at sea, petroleum and mineral exploitation, and academic studies. Dual use includes the detection, classification, and tracking of underwater objects and features for determining bottom depth and mapping and for navigation.

Active sonar performance is highly dependent on the acoustic environment and frequency of the system. The most common propagation paths are direct, bottom bounce, and convergence zone. The major limit is the interference from reverberation, which is created by the backscatter of the transmitted signal as it passes through the ocean medium or is reflected back from the ocean boundaries. Reverberation has near-zero Doppler and thus creates many false alarms and interferes most when tracking slow-speed targets that cannot be separated from the reverberation by doppler processing. Propagation loss in the ocean is frequency dependent, and lower frequencies have been selected to gain longer ranges. Antiship and antisubmarine sonars operate in the 100 Hz–10 kHz frequency band to obtain long ranges out to 30 km. In the shallow water of the littorals, the convergence zone path does not exist and detection ranges are significantly shorter. Mine-detection sonars operate in the 30–100 kHz band to have increased resolution, but as a consequence have shorter ranges of up to 2,000 m. To obtain the resolution required to discriminate and identify small targets or features from background clutter, mine classification, bottom mapping, and deep-sea salvage sonars operate in the 60 kHz to 750 kHz frequency band and have ranges out to a few hundred meters. The active sonar in underwater weapons operates in the 15–60 kHz band and has ranges on the order of 1,000 m to detect, locate, and track the target and provide steering commands. Marine seismic survey systems use a towed 8–200 Hz source and a long, towed hydrophone array to receive the signals bounced off the features deep in Earth's crust. By this process, these systems can locate areas that have potential for producing petroleum products.

Obviously, there is a sizable amount of overlap between the civilian and military applications. Navy sonars operate monostatically or multistatically from a variety of ships, submarines, and aircraft; from moored or bottom-mounted locations; and in all environments. Most active sonar developments have been driven by military use. Civilian sonars are a small but growing part of the active sonar market. Most have dual-use potential for military application.

There are important evolutionary, emerging developments in the following data sheets. There are no known revolutionary, emerging technology developments underway.

LIST OF TECHNOLOGY DATA SHEETS
17.2. ACOUSTIC SENSORS, MARINE, ACTIVE SONAR

DATA SHEET 17.2. ADVANCED DATA PROCESSING FOR ACTIVE SONAR

Developing Critical Technology Parameter	Automated or computer-aided detection, tracking, classification, and identification of undersea-warfare (USW) targets in littoral areas or cluttered acoustic environments using empirically validated clues (discriminates), decision criteria, and decision processes.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) identifying and selecting clues that highlight potential targets and discriminate against false targets, (2) implementing the discrimination process, (3) developing the decision criteria, and (4) for normalizing and thresholding the acoustic signals. These sets of algorithms are for the functions of detection, classification, and identification of targets and target-like false targets.
Major Commercial Applications	Fish, swimmer, and other object-detection sonar systems.
Affordability	The cost of sea tests to obtain realistic target and target-like false target data in a variety of environments is a limiting factor.

DATA SHEET 17.2. ACTIVE SONAR SIGNAL AND DATA PROCESSING FOR MULTIPLATFORMS

Developing Critical Technology Parameter	Real-time processing of acoustic data for fixed, deployed, or mobile arrays operated in the bistatic or multistatic mode to increase target ranges and probability of correct decisions.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Bistatic or multistatic platforms at sea for collection of data.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for synchronizing and normalizing multiple incoming signals, adjusting the dynamic range of multiple incoming signals, and performing data fusion.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests with multiple platforms to obtain realistic target and target-like false-target data in a variety of environments is a limiting factor.

DATA SHEET 17.2. REVERBERATION SUPPRESSION FOR ACTIVE SONAR

Developing Critical Technology Parameter	Real-time tracking of submarine targets with speeds less than 3 knots that are obscured by reverberation or acoustic countermeasures.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for real-time, dynamically (1) identifying and selecting transmit pulse type, coding, length, frequency, and frequency agility that minimize the interference received with the variations being based on the reverberation and countermeasure interference being received; (2) normalizing the incoming signals; and (3) adjusting the receiver dynamic range for very weak incoming signals in the presence of very strong reverberation or countermeasures.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests to obtain realistic target and target-like false target data in a variety of reverberation fields and countermeasures is a limiting factor.

DATA SHEET 17.2. CHANNEL-ADAPTIVE PROCESSING FOR ACTIVE SONAR

Developing Critical Technology Parameter	Channel-adaptive processing using a probe pulse to characterize the medium and optimize the propagation paths being utilized, thereby increasing signal strength and reliable data rate.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for dynamically identifying and selecting transmit and receive parameters in real time, as a means to optimize the propagation path utilized. The parameter selections are based on information extracted from the signals returned from the probe pulse.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests to obtain sufficient data in a variety of environmental acoustic conditions to formulate the dynamic database is a limiting factor.

DATA SHEET 17.2. ENVIRONMENTALLY ADAPTIVE ACTIVE SONAR

Developing Critical Technology Parameter	Dynamically matching transmit parameters to environmental acoustic conditions to minimize multiple arrival of signals that interfere with each other and reduce the signal strength received.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for dynamically selecting and varying, in real time, the transmit parameters pulse length, frequency, and depression angle to minimize the interference from multiple arrivals. The parameter variations are based on historical data and in situ measurements of environmental acoustic conditions such as water depth, water column temperatures, bottom characteristics, and layer depth.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests to obtain sufficient data in a variety of environmental acoustic conditions to formulate the dynamic database is a limiting factor. Cost of expendable, in situ sensors is an affordability issue.

DATA SHEET 17.2. ADVANCED ACTIVE SONAR FOR SUBMERSIBLES

Developing Critical Technology Parameter	Submersible active sonar having feature height finding or beam interpolation, computer-aided detection and track, and fine-angle horizontal and vertical resolution for small object location and recovery and navigation in restricted areas.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Validated set of algorithms for real-time height finding, beam interpolation, and reducing bottom backscatter interference.
Major Commercial Applications	Submersible object location and recovery sonar, obstacle avoidance, feature height finding, and navigation in restricted areas.
Affordability	Not determined.

DATA SHEET 17.2. SUBMARINE AHEAD-LOOKING ACTIVE SONAR

Developing Critical Technology Parameter	Ahead-looking, bathymetric active sonar for submarines using monopulse (interferometric) processing and providing system accuracies better than 0.5 percent of the average water depth (below the platform or above the platform for an ice canopy) across the swath and having the information displayed with 3–D qualities.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Validated set of algorithms for real-time, monopulse interferometric processing.
Major Commercial Applications	Submersible precision navigation and obstacle location.
Affordability	Not determined.

DATA SHEET 17.2. MULTI-ASPECT DATA FUSION PROCESSING FOR ACTIVE SONAR

Developing Critical Technology Parameter	Multi-aspect data fusion processing for submarines and submersibles that provides increased resolution and rapid sensing and visualization of complex shapes.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Validated set of algorithms for real-time data normalization of multiple channels and data fusion processing.
Major Commercial Applications	Submersible small object location and obstacle avoidance.
Affordability	Not determined.

DATA SHEET 17.2. ACTIVE SONAR FOR UNDERWATER WEAPONS

Developing Critical Technology Parameter	For underwater weapons, active sonar having multiple preformed beams with transmit frequency greater than 15 kHz, able to withstand depths greater than 500 m, to transmit sound pressure levels greater than 220 dB (reference to 1 µPa at 1 m), to detect, classify, identify, and resolve targets at ranges greater than 1,000 m, with angular accuracy better than 5 deg and Doppler accuracy better than two knots in clutter.
Critical Materials	Piezoelectric composites and magnetostrictive terfernol D.
Unique Test, Production, Inspection Equipment	Fixed and portable underwater tracking ranges for testing computer-aided processes and obtaining the data base for developing computer-aided processing algorithms.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for real-time target resolution, identification, and tracking.
Major Commercial Applications	None identified.
Affordability	The cost for obtaining the necessary environmental acoustic database and the cost of weapon proofing are major factors for expendable weapons.

DATA SHEET 17.2. ACTIVE SONAR FOR MINE COUNTERMEASURES

Developing Critical Technology Parameter	For mine-hunting sonars, an adaptive beam-forming process that steers nulls toward the bottom and surface interfaces to reduce the reverberation interference that blanks the mine targets in the water column.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for real time, dynamic tracking of the sea surface and bottom interfaces with the water column.
Major Commercial Applications	Detecting fish near the sea bottom.
Affordability	Not determined.

DATA SHEET 17.2. ACTIVE SONAR FOR ANTI-TORPEDO TORPEDOES

Developing Critical Technology Parameter	To detect, resolve, and track incoming torpedoes at ranges greater than 100 m and with an accuracy of within 5 m.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for real-time target detection, resolution, and tracking.
Major Commercial Applications	None identified.
Affordability	Not determined.

SECTION 17.3—ACOUSTIC SENSORS, MARINE, PASSIVE SONAR

Highlights

- Passive sonars are totally covert and are the sensors of choice in several operational scenarios.
- Major improvements in passive sonar systems are required to counter the worldwide submarine-quieting programs.
- Target transients, which are difficult to quiet, are to be exploited by employing unique processing and data management.
- Advanced processes are being developed to extend operational target ranges, thereby expanding the search area coverage.
- Automated target detection, classification, identification, and tracking are being developed for evasive submarine targets.
- Receiving array gain is being increased and self-noise reduced for both hull-borne and towed arrays.
- Advanced processes are being developed for reducing the time required for ranging, tracking, and developing a fire-control solution.
- It is envisioned that evolutionary improvements in passive sonars will continue, but at an accelerated pace.

OVERVIEW

This subsection covers the technology for the development and production of passive sonar systems that are used militarily for the covert location of underwater objects that radiate energy. Passive sonars are used primarily for antisubmarine and anti-surface-ship warfare. Functions performed are detection, classification, identification, location, and tracking of acoustically radiating targets. The radiating energy is created by target vehicle propulsion and maneuvering, flow noise, transmitted acoustic signals, weapons launch, mine and torpedo actuators, and performance of housekeeping functions. Passive sonars are incorporated in submarines, surface ships, mines, torpedoes, and bottom-mounted or deployed sites. They are also incorporated in aircraft by using sonobuoy sensors. Passive sensor arrays are both mounted on the hulls of and towed from submarines, surface ships, and torpedoes.

Passive sonar performance is dependent on the acoustic environment. The major interferences are own-ship noise, radiated noise from nearby friendly ships, noise from shipping at long ranges, and ambient background noise. The ASW passive sonar frequency band has been extended to the lower few hundred hertz as submarines have become quieter. Propagation paths are the same as for active sonar, except the path is only one way.

There are few civilian uses for passive sonar except for academic research. The major concern is with "active" systems—marine seismic towed hydrophones arrays (streamers) and ocean bottom cable systems—that can be used in the passive mode for ASW. Passive sonars have been developed uniquely for naval use. All U.S. Navy passive sonars are U.S. developed and produced.

Evolutionary, emerging technology developments are highlighted in the following data sheets. There are no known revolutionary, emerging technology developments underway.

LIST OF TECHNOLOGY DATA SHEETS
17.3. ACOUSTIC SENSORS, MARINE, PASSIVE SONAR

DATA SHEET 17.3. INTERCEPT RECEIVERS

Developing Critical Technology Parameter	Interception of acoustic transients with 360-deg coverage for the full acoustic spectrum of 10 Hz through 300 kHz and having bearing determination with less than 5-deg error for multiple and overlapping targets.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) selecting the clues that classify and identify transients; (2) implementing the identification process; and (3) developing and implementing the decision criteria. These sets of algorithms are for the functions of classification, identification of transient signals, and determining the bearing of the transient source.
Major Commercial Applications	None identified.
Affordability	The cost of sea tests to obtain a wide variety of realistic platform and weapon transient signals and target-like false-target signals is a limiting factor.

DATA SHEET 17.3. OPEN-OCEAN-DEPLOYED PASSIVE SONAR

Developing Critical Technology Parameter	The detection of multiple electric-propulsion submarines traveling at speeds of less than 6 knots at one convergence zone range (30–60 km) using a deployed array.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) compensating for an irregular array shape, (2) data rate reduction, (3) data fusion, and (4) developing and implementing the decision criteria.
Major Commercial Applications	None identified.
Affordability	The relatively low cost of the expendable array is critical for effective use.

DATA SHEET 17.3. SONOBUOYS

Developing Critical Technology Parameter	The real-time detection, classification, identification, and determination of the bearing of submarine targets using inbuoy, automated processing, and beamforming, including receiving and processing signals from active adjunct transmissions and providing target location.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) selecting the clues that detect, classify, and identify potential targets, (2) implementing the identification process, and (3) developing and implementing the decision criteria. Also, validated sets of algorithms for determining the bearing of targets in the passive mode or the location of targets in the active mode.
Major Commercial Applications	None identified.
Affordability	The achieving of relatively low cost for expendable sonobuoys is critical to acceptance.

DATA SHEET 17.3. UNDERWATER WEAPONS PASSIVE SENSORS

Developing Critical Technology Parameter	The real-time automated target detection, classification, and identification of the flow noise from quiet, electric-propulsion submarines maneuvering at less than 5 knots and at ranges out to 20 km to achieve the following: target track with an error of less than 20 percent and false-alarm rate of less than 10 percent while rejecting countermeasures, all from an autonomous underwater weapon traveling at over 30 knots.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Nose assembly and body machining.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) identifying, selecting, and weighting the clues that detect, classify, and identify potential targets, (2) implementing the automation process, (3) developing and implementing the decision criteria, and (4) tracking the target.
Major Commercial Applications	None identified.
Affordability	The achieving of relatively low cost for expendable torpedoes is critical to acceptance.

DATA SHEET 17.3. PASSIVE SONAR TARGET TRACKING

Developing Critical Technology Parameter	Passive sonar capable of resolving and real-time tracking multiple submarine targets traveling at various speeds and at ranges out to 30 km.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that resolve and track multiple targets identified as submarines with an accuracy sufficient for a fire-control solution.
Major Commercial Applications	None identified.
Affordability	Not an issue.

DATA SHEET 17.3. PASSIVE SONAR RECEPTION

Developing Critical Technology Parameter	Real-time, computer-aided detection, classification, identification, and tracking of quiet submarine targets at ranges out to 30 km with high probability of correct detections and low false-alarm rates.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated sets of algorithms that provide the knowledge base for (1) selecting the clues that detect, classify, and identify potential targets, (2) implementing the identification process, (3) developing and implementing the decision criteria, and (4) developing and implementing the normalization and thresholding of data received from multiple sources. Also, a validated set of algorithms for determining and implementing target track.
Major Commercial Applications	None identified.
Affordability	Not an issue.

DATA SHEET 17.3. PASSIVE SONAR RANGING

Developing Critical Technology Parameter	Determining target range within 1 min after detection of quiet submarine targets at ranges out to 30 km.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Hull-mounted array installation and alignment.
Unique Software	Empirically validated set of algorithms for determining target range using irregular array shapes and for determining the location of array sensors and overall array shape.
Major Commercial Applications	None identified.
Affordability	Not an issue.

DATA SHEET 17.3. PASSIVE SONAR DATA FUSION

Developing Critical Technology Parameter	Real-time fusion of data received from two or more receiving arrays, including those from separate platforms, to increase overall target signal-to-noise ratio (SNR) and thereby increase detection ranges by 50 percent.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated set of algorithms for sorting data by specific target and accurately combining like data to increase target signal strength.
Major Commercial Applications	None identified.
Affordability	Not an issue.

DATA SHEET 17.3. PASSIVE SONAR ARRAY NOISE

Developing Critical Technology Parameter	Electronic processes capable of real-time reduction of flow and acceleration self-noise by 6 dB or greater to increase target SNR and thereby increase detection ranges by 30 percent.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated set of algorithms for isolating target signals from noise.
Major Commercial Applications	None identified.
Affordability	Not an issue.

DATA SHEET 17.3. PASSIVE SONAR ADAPTIVE BEAMFORMING, NULL STEERING, AND SIDELOBE REDUCTION

Developing Critical Technology Parameter	Adaptive beamforming, null steering, and sidelobe-reduction processes capable of reducing interference from acoustic clutter and countermeasures by greater than 20 dB, thereby increasing detection ranges and nullifying countermeasures.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated set of algorithms for adjusting beams and steering nulls to enhance the target SNR.
Major Commercial Applications	None identified.
Affordability	Not an issue.

DATA SHEET 17.3. PASSIVE SONAR HULL-MOUNTED RECEIVING ARRAYS

Developing Critical Technology Parameter	Passive sonar capable of platform speeds greater than 20 knots and depths greater than 300 m without being self-noise limited by using sensor matching, array shading, or pressure-tolerant processing with greater than 10 dB self-noise reduction.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Array installation and alignment equipment.
Unique Software	Validated set of algorithms for pressure-tolerant processing.
Major Commercial Applications	None identified.
Affordability	Not an issue.

DATA SHEET 17.3. ASW VOLUMETRIC TOWED ARRAYS

Developing Critical Technology Parameter	Volumetric towed arrays capable of increased target-detection ranges while maneuvering at tactical speeds by using multiple lines; strength members in hose wall; electronic cancellation of flow or acceleration noise; and vibration isolation and low-noise dynamic leveling with depression force greater than 100 pounds, both at tow speeds greater than 8 knots.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Empirically validated set of algorithms for electronic cancellation of flow- and acceleration-generated self-noise.
Major Commercial Applications	None identified.
Affordability	Not an issue.

SECTION 17.4—ACOUSTIC SENSORS, MARINE PLATFORM

Highlights

- Sonar domes and windows are required to protect sonar transducer and hydrophone elements and are an integral part of the operational platform.
- Acoustic signals are distorted and absorbed by the sonar domes and windows and their supporting structures.
- Platform self-noise must be reduced to counter the quieter submarine targets.
- Domes and windows need to be better isolated from the platform to reduce platform self-noise.
- All noise reduction needs to be effective over the depth excursion of U.S. submarines.
- The amount of self-noise reduction that is needed will require active noise-cancellation systems.
- It is envisioned that evolutionary improvements in platform self-noise reduction will continue, but at an accelerated pace.

OVERVIEW

This subsection covers the technology for the development and production of the interface of acoustic systems with the marine platform. This encompasses all measures taken to reduce the self-noise of ships, submarines, torpedoes, and other sonar platforms. Platform acoustic technologies have a major impact on the sonar systems' capability because they reduce self-noise generated by on-ship machinery or water flow around the platform. Specifically of interest are domes; baffles; the quieting of machinery, including main propulsion, valves, gears, pumps, fans, balancing and mounting of same, measurement techniques, and instrumentation; hull coatings; and active and passive structural noise control. Some of these items are partially covered under signature reduction of radiated noise in Signature Control Technology, Section 18. Radiated noise and ship self-noise that affects sonars often come from the same source, but the process for reduction of these noises can be quite different. There are no known commercial uses for the large acoustic domes and windows that are considered militarily critical. All self-noise reduction for marine platforms has been driven by military application. The U.S. Navy developed most of the acoustic processes covered in this subsection. Evolutionary, emerging technology developments are highlighted in the following data sheets. There are no known revolutionary, emerging technology developments underway.

LIST OF TECHNOLOGY DATA SHEETS
17.4. ACOUSTIC SENSORS, MARINE PLATFORM

DATA SHEET 17.4. MARINE-PLATFORM ACOUSTIC DEVICES AND MATERIALS

Developing Critical Technology Parameter	Devices and materials that are capable of combined noise reduction of greater than 20 dB for frequencies less than 2 kHz or greater than 30 dB for frequencies from 2–5 kHz, with 90-percent effectiveness at speeds over 20 knots and over the depth excursion of U.S. submarines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Underwater anechoic test facility with pressure capability of 1,000 psi.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Not determined.

DATA SHEET 17.4. MARINE-PLATFORM ACTIVE NOISE CANCELLATION

Developing Critical Technology Parameter	Noise reduction of greater than 12 dB by active cancellation techniques.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Not determined.

SECTION 17.5—ELECTRO-OPTICAL SENSORS

Highlights

- This subsection concentrates on the technology for video sensors, image intensifiers, and focal plane arrays (FPAs) as generic technologies applicable to many military and civil applications.
- Uncooled FPAs are very significant because of lower cost and weight. Many opportunities for improvements exist.
- The midwave infrared (MWIR) and short wave infrared (SWIR) region is ripe for further exploitation—especially the 1,000–2,000-nm region.
- The active interest in space applications, both military and civil, has renewed interest in the long-wave IR (LWIR) region.
- Research and development (R&D) is underway to develop imaging solar blind detectors for air vehicle protection. Present systems are non-imaging.

OVERVIEW

The last 40 years of the 20th century brought amazing advances in the ability to create images of scenes at night. DoD, as well as its counterparts in other countries, largely funded the initial development work. The new technology has revolutionized warfare, as demonstrated in Vietnam and the Gulf War. A nation's military forces can now conduct operations at night with efficiency unknown before. A statement of Gen. H. Norman Schwarzkopf, Commander of the Coalition Forces during Desert Storm, best characterizes the new capability: "They couldn't see anything through their sights, and all of a sudden their tank exploded." (27 February 1991.)

"Night vision" is normally considered to embrace two different technologies, image intensification and thermal imaging. Image intensification, which depends on reflected light from objects in the scene, developed earlier than thermal imaging—from an operational standpoint. Thermal imaging depends on blackbody radiation from objects in the scene.

Imaging with Reflected Photons

Image intensification, as it exists in the latest third-generation (vacuum) tubes used in aviation goggles, may be the end of the line for intensified systems development based on the vacuum intensifiers. Little future development is planned. Instead, development is focusing on two different areas of technology:

- Solid state intensifiers
- Exploitation of the 1,000–2,000-nm wavelength region.

Thermal Imaging

Thermal imaging systems for terrestrial applications deployed in the late 20th century operated primarily in two spectral wavelength regions: MWIR (3–5 µm) and LWIR (8–11 µm). These systems originally depended on cooled detector arrays for peak sensitivity, but in the 1990s detectors were developed that required minimal or no cooling. While the uncooled arrays do not achieve the high sensitivity of cooled detector arrays, there are numerous applications that are not possible with the cooled arrays. Without the requirement for cooling engines that consume power, lightweight, affordable systems such as personal viewers and vehicle driving aids are possible. A number of civil applications are appearing in 2000 because of the lower cost.

Space systems operate in several other spectral regions, mainly in the very long wavelength IR (VLWIR) region beyond 11 µm. Ultraviolet (UV) applications also exist. These are expensive, tend to use exotic detector materials, and see limited production.

Early thermal-imaging systems used scanned linear arrays, and much of the operational inventory has these systems. Upgrades to second-generation staring systems are underway, and most planned systems employ staring arrays that require no mechanical scanning.

The key developing technologies in thermal imaging include the following:

- Larger cooled staring arrays
- Multicolor and hyperspectral arrays
- Further improvements in uncooled arrays
- Exploitation of other spectral regions such as short wave IR (SWIR) and UV
- Improved affordability and producibility.

RANGE OF MILITARY APPLICATIONS

A rudimentary form of image intensification existed in the 1940s and 1950s. It was possible to view scenes at night using image converters and IR active illuminators. The early active systems of the 1940s and 1950s used IR blackbody sources, such as filtered searchlights. These still radiated considerable visible energy and were not covert. The filtered IR sources of the early active systems could not be pulsed, as can a laser. The development of cascaded electrostatically[1] focused image intensification and the S-20 photocathode in the 1960s eliminated the need for active illumination, creating a covert or passive viewer. The Starlight Scope, deployed first in Vietnam, was the forerunner of an extensive family of intensified night viewing equipment. The most recent manifestation of this technology is the night vision goggle used by both ground troops and aviators. The original passive intensifier required three cascaded devices, each with a gain of ~40 to achieve enough light gain to be passive. The goggle tube uses a microchannel amplifier that provides the same gain as three older tubes. The latest third-generation tubes use a GaAs photocathode with higher gain and production yield than the S-20/25 multi-alkali photocathodes. New lasers are limited to a narrow bandwidth in the 1,000–2,000-nm wavelength region and are invisible to conventional intensified systems or human eyes.

Thermal imaging systems were deployed experimentally in Vietnam; the best known equipment was the early forward-looking infrared radar (FLIR) equipment deployed on the C–47 and C–130 Gunships. Thermal imaging systems are now (in the late 1990s) widely deployed operationally. These systems range from large, shipboard IR search and track (IRST) systems down to miniature, handheld thermal viewers and include missile night sights and seekers, vehicle driving aids, and airborne FLIR.

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[1] Electromagnetically focused intensifiers existed and were used by astronomers. They were far too large and power hungry for most military applications.

LIST OF TECHNOLOGY DATA SHEETS
17.5. ELECTRO-OPTICAL SENSORS

DATA SHEET 17.5. SOLID-STATE IMAGE-INTENSIFIER TECHNOLOGY

Developing Critical Technology Parameter	1. Low-light level (LLL). 2. 980 × 1,280 pixels with 10 µm pixels, wavelength range: 1,000–2,500 nm. 3. High-temperature operation using thermoelectric (TE) cooling.
Critical Materials	Mercury cadmium telluride (HgCdTe) and indium gallium arsenide (InGaAs).
Unique Test, Production, Inspection Equipment	Modulation transfer function (MTF) testers, night-vision scene simulators.
Unique Software	None identified.
Major Commercial Applications	The same commercial applications as now exist for vacuum intensifiers (e.g., police and industrial surveillance, rescue missions, and sporting activities) can be expected. The commercial applications are not the drivers of this technology.
Affordability	Must be low cost because the sensors will be used at the "soldier level."

BACKGROUND

Current image-intensification night-vision devices operate mainly in the visible spectrum and extend into the near infrared (NIR) by a very small amount. This response is referred to as "photopic" response. They are not operationally sensitive in the SWIR.

DATA SHEET 17.5. TECHNOLOGY FOR THE 1,000–2,000 nm WAVELENGTH REGION

Developing Critical Technology Parameter	1. Solid-state imaging sensors capable of LLL sensitivity; 2. Optimize sensitivity at the wavelength of "eye safe" laser illuminators; and 3. 480 × 640 pixels
Critical Materials	III-V and II-VI semiconductor materials to be identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Not determined.

DATA SHEET 17.5. UNCOOLED IR ARRAY TECHNOLOGY

Developing Critical Technology Parameter	High performance: sensitivity = 0.01 °C; resolution = 1 mil pixels, 1,000 × 1,000 pixels. Micro sensor: 160 × 120 pixels, 2 mil × 2 mil pixel size, no cooling, expendable, 1 oz., 10 mW with power management.
Critical Materials	Microbolometer and thin-film ferroelectric materials.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Vehicle driving aid, perimeter surveillance.
Affordability	Needs to be low cost because it will be used at the "individual soldier" level.

BACKGROUND

Objectives of this technology:

- Smaller pixels and increased sensitivity;
- Larger formats;
- No mechanical chopper (as in pyroelectric detectors);
- No temperature stabilization;
- Lower power requirements;
- Higher frame rates; and
- Use of low-cost optics (see Section 11).

Payoffs:

- Lower cost;
- Longer autonomous life;
- Lighter weight;
- Smaller volume; and
- High performance (comparable to cooled arrays).

DATA SHEET 17.5. COOLED STARING FOCAL PLANE ARRAY TECHNOLOGY

Developing Critical Technology Parameter	Mega pixel arrays (from 1,024 × 1,024 to >2,048 × 2,048); higher operating temperature using thermoelectric (TE) or mechanical cooling (120–180 K) cooling; smaller pixels, 18 × 18 mm multi-color.
Critical Materials	HgCdTe
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	The technology described will result in extremely high performance and civil applications are not yet obvious. Civil applications are not drivers.
Affordability	Not an issue.

DATA SHEET 17.5. LONG- AND DUAL-WAVELENGTH IR FPA TECHNOLOGY

Developing Critical Technology Parameter	• 1,024 × 1,024 LWIR FPAs and 128 × 128 LWIR hardened for space. • Cutoff wavelength in the 14–25-µm range for space surveillance. • MWIR FPAs for threat warning.
Critical Materials	HgCdTe, silicon (Si)/HgCdTe, gallium indium antimony/indium arsenide (GaInSb/InAs) superlattice and gallium arsenide/aluminum gallium arsenide (GaAs/AlGaAs) quantum well materials.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	The technology described will result in extremely high performance, and civil applications, other than astronomy, are not yet obvious.
Affordability	Producibility of low-cost detectors.

DATA SHEET 17.5. SOLAR BLIND ULTRAVIOLET SENSOR TECHNOLOGY

Developing Critical Technology Parameter	Solar blind detector with a noise-equivalent power (NEP) of 10^{-14}.
Critical Materials	Gallium aluminum indium nitride (GaAlN) with a low ($<10^{7}$ cm^{-2}) defect density substrate material.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Not an issue.

BACKGROUND

An objective of this technology is the development of III-V nitride materials and detector technology to demonstrate an imaging ultraviolet FPA. Current operational systems use vacuum, solar-blind photomultiplier tubes (PMTs) and are non-imaging.

DATA SHEET 17.5. SINGLE-PIXEL THREE-COLOR LAYERED DETECTOR

Developing Critical Technology Parameter	Highest spatial resolution detector arrays which have the ability to sense red, green, and blue wavelengths by means of layered detectors on a single-pixel-element basis as required. The device, called the buried triple P-n junction (BTJ) structure can be fabricated using conventional bipolar or bipolar complementary metal oxide semiconductor (BICMOS) processes. Spatial resolution is tripled by this triad-stacking process. This technique eliminates the need for spectral filters. The amount of charge carriers generated depends on both the wavelength of the light and the depth at which it is absorbed. The BTJ exploits this by having three buried (layered) junctions, each producing a photocurrent. Sensitivity has been shown to be comparable or to exceed current visible-array detectors.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Temperature compensation sensitivity algorithms need to be developed. Mapping the device color to the visual range over a wide temperature range is needed.
Major Commercial Applications	If the processes can be developed for mass production capability on current chips, the market is wide open. This technology will eventually replace current triad (side-by-side) color camera detector arrays.
Affordability	This technology should be more affordable than current technology at comparable resolution.

DATA SHEET 17.5 INFRARED ANTENNAS IN FPA FORMAT

Developing Critical Technology Parameter	• Within next 5 years, antenna-coupled, uncooled IR FPAs will provide high-speed, polarization-resolved, wavelength resolved IR imagery using uncooled FPA technology. • Goals are uncooled IR sensors of 10–100 NETD. These sensors will be in FPA format of nominal 512 × 512. These sensors will be tunable in wavelength response over the 3–5 and 8–12 µm bands, with 0.5-µm bandpass. Sensors will be tunable in polarization response for all linear polarization states as well as Left Circular and Right Circular. Tuning shall be in response to a dc voltage of 100 mV.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	• Production—direct-write electron-beam lithography. • Testing—custom apparatus currently under development for assessment of tuning functionality. • Inspection—usual IC inspection techniques.
Unique Software	None identified.
Major Commercial Applications	• Satellite IR remote sensing systems. • Drivers are increased information gathering capability and reduced payload weight.
Affordability	• Sensor costs are a declining portion of overall imaging systems because of cost reductions inherent in uncooled IR FPA technology as compared to HgCdTe cooled FPAs. • Not an issue.

BACKGROUND

Key advantage is the ability to provide wavelength-resolved and polarization-resolved imagery in a no-moving-parts configuration. Reduces sensor system weight and complexity.

Present uncoooled IR FPA development programs are concentrated on realization of sensors operating at the background fluctuation limit of sensitivity, and near-equality with cooled sensor performance. This goal, which represents a fifty times increase in sensitivity relative to current uncooled IR sensors, must be achieved in order to realize the full benefits of polarization-resolved imagery.

SECTION 17.6—RADAR

Highlights

- Improved computational resources and efficient signal-processing algorithms are making it practical to field radars employing space-time adaptive processing (STAP) using large numbers of degrees of freedom for clutter and interference cancellation.
- Low-frequency systems for foliage penetration (FOPEN) and counter-stealth are under development, but radio frequency interference in the VHF/UHF bands and limits on spectrum allocation may limit utility.
- Space-based moving target indication (MTI) and synthetic aperture radar (SAR) systems providing operationally useful revisit rates will become more practical because of lower cost commercial component development for systems such as iridium or its successors.
- Low radar cross-section antennas and radomes, combined with power management and low probability of intercept waveforms, together are decreasing the detectability of stealthy aircraft and cruise missiles.
- Ultrastable solid-state transmitters have increased reliability, produced greater average power, and dramatically increased transmitter stability by replacing conventional tube technology. As a result, radar detection and tracking of sea-skimming and/or land-hugging low-observable missiles and other targets have significantly improved

OVERVIEW

This subsection covers radar systems, the sensors most widely used by all military services. Radars are indispensable for a wide variety of military uses, being installed on the ground and in ships, aircraft, and missiles for search and localization of objects and installations of all types. Radar systems consist of power supplies, transmitters with final amplifiers, antennas, receivers, signal processors, and displays. Emerging radar technology developments include wide bandwidth operation, stability and ultralow noise for coherent operation; advanced software for signal processing; and automatic target recognition (ATR). Development activity includes solid-state transmit and receive modules integrated with antenna radiating elements for active aperture radar, and low radar cross-section antennas. Millimeter-wave radars are now being implemented in missile seeker heads. High-power millimeter wave (94 GHz) radars are being considered for imaging nonmaneuvering aircraft and tactical ballistic missiles (TBMs) with inverse synthetic aperture radar (ISAR) techniques. Low frequency (VHF/UHF) radars are being developed for foliage and ground penetration and to counter stealth vehicle developments.

Critical technologies at the component level that support these advanced sensor developments and continue to be advanced include RF photonics, RF microelectromechanical systems (MEMS), and millimeter-wave integrated circuits (mmICs). GaAs continues to be the major microwave power generation and application material, but advances in InP, SiGe, SiC, and GaN will result in implementation of these materials in selected future applications.

There are a number of evolutionary, emerging technology developments in radar. Airborne moving target indication (AMTI) concepts increasingly depend on STAP advances. FOPEN radar is being explored for SAR and ground moving target indication (GMTI) missions. Bistatic systems continue to be of interest. Space-based AMTI, GMTI, and SAR are under consideration. Advances in target recognition remain key for reduction of fratricide and for effective employment of beyond-visual-range weapons. Ultra-wideband (UWB) radar systems are being employed for foliage/ground penetration and improved target recognition. Ultra-stable solid-state transmitters increasingly are replacing conventional tube technology. Over-the-horizon (OTH) radars, which do not require direct line of sight, have made significant advances. These are highlighted in the following tables. There are no known revolutionary, emerging technology developments underway.

LIST OF TECHNOLOGY DATA SHEETS
17.6. RADAR

DATA SHEET 17.6. STAP FOR AIRBORNE RADARS

Developing Critical Technology Parameter	> 50 dB adaptive nulls in angle/Doppler space; >10 spatial degrees of freedom; real-time operation.
Critical Materials	Optical beamformer/signal distribution
Unique Test, Production, Inspection Equipment	Channel calibration; tracking, and compensation procedures/hardware, particularly those relating to real-time calibration/compensation during operation.
Unique Software	Efficient matrix and spectral signal-processing algorithms.
Major Commercial Applications	STAP for interference reduction in commercial point-to-point/cellular communications systems.
Affordability	High cost due to multichannel antenna/receiver, high-speed computation.

BACKGROUND

STAP samples the environment and adaptively forms filters in angle/Doppler space to optimally cancel both clutter and jammers. Because the system is adaptive, it provides much more flexibility under a wide range of circumstances; however, the flexibility comes at significant cost. The system must have sufficient degrees of freedom to cancel all interfering signals. An estimate of the covariance matrix of the interference must be formed, and that requires sufficient independent samples of the background. The mathematics connected with forming the optimum time and frequency weights is computationally intense and requires very large and very fast computers. Suboptimum techniques are being developed to lessen the computational burden and need for background sample support. As the bandwidth of the system or number of spatial degrees of freedom is increased, hybrid techniques that utilize optical processing combined with digital techniques are being developed.

DATA SHEET 17.6. FOPEN SAR

Developing Critical Technology Parameter	Wideband antennas and coherent transmitters and receivers covering significant portions of the VHF and UHF bands (e.g., 10–90 MHz and 150–550 MHz); coherent transmitter notching, radio frequency interference (RFI) cancellation hardware [pre-analog-to-digital (A/D) cancellation of >10 signals], wideband high dynamic range A/D converters (>500 MHz and >12 bits).
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Wideband and low-frequency antenna ranges (10–500 MHz)
Unique Software	Real-time image formation algorithms running on multiple parallel processors; effective false-alarm reduction algorithms [false-alarm rate (FAR) <0.1/km^2].
Major Commercial Applications	Topographic mapping under heavy vegetation (e.g., single- and double-canopy forest). Forestry surveys. Ground penetration for mine detection
Affordability	Relatively high cost because of tight specifications on multipolarization, wideband transmitters and antennas, and requirement for powerful but compact processors.

DATA SHEET 17.6. FOPEN GMTI RADAR

Developing Critical Technology Parameter	Multi-aperture UHF antennas, STAP algorithms for clutter cancellation, stable coherent oscillators (<–60 dBc/Hz, 5 Hz from the carrier).
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	High-quality (a few meters CEP) positioning equipment (e.g., differential GPS combined with accurate on-board INS) for good target geolocation.
Unique Software	Real time (<1 sec processing time) STAP algorithms; software for registration of GMTI and SAR data, wavelength-diverse waveforms for enhanced target detection.
Major Commercial Applications	Detection of intrusions and illegal activity under jungle canopy by wide-area surveillance systems.
Affordability	Expensive because of large antenna and extensive computing required for STAP.

DATA SHEET 17.6. RADAR-BASED ATR

Developing Critical Technology Parameter	Probability of correct classification levels greater than 90 percent in a multitarget, cluttered environment; ability to operate at detection level SNRs (≈13 dB SNR); and real-time operation (classification within a few seconds of detection). UWB component technology and polarization diverse waveforms and antenna components are being developed to increase resolution.
Critical Materials	Some systems concepts use mmW frequencies to obtain very high resolution (a few inches) with modest percentage bandwidths (a few percent) and take advantage of increased Doppler sensitivity at the higher frequencies for imaging nonmaneuvering aircraft. High-power 94 GHz transmitters (~10 kW average power) must be developed.
Unique Test, Production, Inspection Equipment	RCS ranges capable of generating high-quality HRR and ISAR data (range and cross-range resolutions of a few inches) for use in features databases.
Unique Software	Robust ATR algorithms (> 90 percent probability of correct classification); efficient signature storage and retrieval algorithms.
Major Commercial Applications	None identified.
Affordability	Major additional expense is processing and signature storage. Some algorithms that require particular parameters (e.g., multiple polarizations or a given range resolution) might require radar design/modification.

DATA SHEET 17.6. AIRBORNE "STEALTH" RADARS

Developing Critical Technology Parameter	Low RCS antennas (>20 dB below platform RCS specification); advanced frequency selective surface (FSS) radomes; low probability of intercept waveforms; and conformal antennas. Transmit/Receive module and radiating element designs for low RCS active arrays.
Critical Materials	High-strength, low dielectric constant, low-loss radome and substrate materials.
Unique Test, Production, Inspection Equipment	RCS ranges with sufficient sensitivity to provide both diagnostic and total RCS measurements at component and subsystem levels (noise floor <–80 dBsm); CAD/CAM for accurate, cost-effective manufacture of multilayer radomes. High uniformity T/R Module and radiating element manufacturing.
Unique Software	Antenna and FSS design software combining numerical electromagnetic codes with design optimization software; conformal antenna design and optimization software. Integrated antenna/forebody RCS analysis codes. Adaptive signal processing for waveform intercept reduction.
Major Commercial Applications	None identified.
Affordability	Systems will be significantly more expensive than conventional radars.

DATA SHEET 17.6. BISTATIC SURVEILLANCE RADARS

Developing Critical Technology Parameter	Electronically scanned, multiple-beam antennas for "pulse chasing," high (>100 GOPS) throughput data processors for coherent processing, and high dynamic range receivers (>100 dB).
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Ultra accurate Time, frequency, and navigation instrumentation to determine waveform location and timing to 10's of picoseconds accuracy.
Unique Software	Matched-filter algorithms involving illuminator waveform; target state determination (location, heading, speed) software; antenna control/beam scanning software; and STAP for bistatic clutter mitigation.
Major Commercial Applications	None identified.
Affordability	For a bistatic radar that hosts off of a noncooperative illuminator, transmitter costs are saved and "radar stealth" is inherent. The receiver/processor, however, will be much more complex than for a standard radar, offsetting much of the cost advantage. If a special illuminator, as well as a receiver, must be developed and built, costs will be greater than for a similar monostatic radar.

BACKGROUND

For narrow-beam, scanning illuminators, the receiver antenna must electronically adapt to the transmit beam so that the receiver is looking at potential targets at the correct time. Multi-beam antenna architectures, an attractive alternative to a fast scanning approach, are being pursued as an outgrowth of the STAP research described previously. The receiver system arrays are being partitioned into multiple subarrays to obtain multiple degrees of freedom for the STAP clutter and jamming suppression capabilities. These subarrays produce broad-beam patterns which subtend a large number of transmit pulse positions. The subarray outputs are digitally combined in beamforming algorithms during the STAP operations to form multiple, simultaneous, high-gain, narrow beams across the broad subarray patterns plus the appropriate nulls to cancel clutter and jamming. Although this lessens the severity of the pulse chasing problem, it also combines the technical challenges of STAP and bistatic processing into a common development risk. Systems using omnidirectional illuminators such as radios and TV stations must have very high dynamic range receivers (>100 dB, and in some cases, >125 dB), because the radar may be forced to look near an illuminator direction to detect targets of interest.

The cooperative bistatic SAR spot mode case is much easier than the air surveillance case. The transmit-and-receive beams are aimed at a common spot in GPS coordinates for the SAR image frame time, so pulse-chasing issues are solved by maintaining a common timing reference between the bistatic transmitter and receiver. Atomic clock references and common GPS coordinates and timing references provide a means for maintaining the common timing references. Combining multiple sequential spots creates a SAR area coverage capability. Similar concepts extend to bistatic GMTI applications.

DATA SHEET 17.6. HIGH-PRECISION INTERFEROMETRIC SAR PLUS GLOBAL POSITIONING SYSTEM (GPS) FOR ACCURATE TOPOGRAPHIC MAPPING

Developing Critical Technology Parameter	Multiple-aperture SAR with sufficient separation to give required resolution and differential elevation accuracy [digital terrain elevation data (DTED) level 5, 1-m posts and sub-foot accuracy]; precise aircraft geolocation knowledge; and precise antenna pointing. Combining two frequencies of operation (UHF and C-Band) for bald Earth mapping and terrain feature classification.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Differential GPS and inertial transfer alignment to hold fractional wavelength and microradian accuracy on direction of arrival measurements.
Unique Software	Efficient and accurate phase unwrapping algorithms. Phase center measurement and transfer alignment to enable high accuracy, absolute height measurement.
Major Commercial Applications	Wide potential use for terrain use planning; road route considerations; hydrological analyses.
Affordability	Requires second SAR channel and high phase accuracy hardware, but relatively affordable. FOPEN interferometric synthetic aperture radar (IFSAR) requires second frequency and polarization channels.

DATA SHEET 17.6. ACTIVE RF TAGS

Developing Critical Technology Parameter	Small (<20 mm^3), low-power (<5 mW), personnel-portable identification of friend or foe (IFF) transponders; appropriate encrypted interrogation waveforms commensurate with radar operation/performance.
Critical Materials	High-energy-density batteries (>500 Wh/L in packages <10 mm^3).
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Encryption system (low data rate, <1 kb/s).
Major Commercial Applications	Commercial cellular market. Tracking of rail cars within marshalling yards or trucks within depots.
Affordability	Individual responders should be inexpensive; however, a very large number is required.

DATA SHEET 17.6. SAR/ISAR MISSILE SEEKERS

Developing Critical Technology Parameter	Very small (<1,500 cm^3), lightweight (<5 kg) active radars, missile-electronics compatible SAR/ISAR signal processors, and SAR/ISAR-based ATR algorithms.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	ISAR image-formation algorithms for unknown target motion; appropriate ATR algorithms for desired target classes.
Major Commercial Applications	None identified.
Affordability	At least a factor of two more expensive than conventional active seeker because of signal-processing requirements. Differential will reduce as processing becomes less expensive.

DATA SHEET 17.6. SPACE-BASED GMTI/AMTI

Developing Critical Technology Parameter	Large (>50–500 m^2), lightweight (4 kg/m^2), electronically steered antennas; high-efficiency T/R modules (70 percent at X-band). Photonic signal distribution and beamforming technologies. Reliable microelectromechanical systems (MEMS) components for low-loss, lightweight antenna control.
Critical Materials	Improved batteries (150–175 Wh/kg and 500 Wh/L); improved efficiency solar cells (>25 percent); lightweight power conditioners and support structures; high-efficiency, radiation-tolerant T/R modules, new materials, and device structures for receiver power reduction. Lightweight, high-strength, thin-film materials for deployable antennas.
Unique Test, Production, Inspection Equipment	Commercial assembly-line production techniques to significantly reduce single satellite costs for large constellations; thin-film RF component assembly and test for lightweight deployable arrays; and standardized spacecraft bus designs.
Unique Software	STAP software for real-time clutter cancellation and jammer nulling and on-orbit target detection and classification software to reduce downlink data rates. Integration of SAR/ISAR and GMTI/AMTI waveforms and processing.
Major Commercial Applications	GMTI: traffic monitoring; AMTI: air traffic control over oceans.
Affordability	Constellation costs are projected to be very high.

DATA SHEET 17.6. ULTRA-STABLE SOLID-STATE RADAR TRANSMITTER

Developing Critical Technology Parameter	Four-fold increase in amplifier reliability, highly redundant approach, greater average power than tube version, dramatic increase in transmitter stability.
Critical Materials	Supply of transistors with uniform characteristics.
Unique Test, Production, Inspection Equipment	Taguchi methods and robust development techniques within integrated product team with customer and key suppliers as full-time participants.
Unique Software	Built-in-test equipment to monitor amplifier health.
Major Commercial Applications	Replacement for high-power tube transmitters with improved reliability.
Affordability	Reasonable costs because of unique test and production methods.

BACKGROUND

Solid-state radar transmitters have replaced aging tube technology, leading to improved reliability, maintainability, and availability. In the United States, this has been accomplished by combining the outputs of 160 transistor amplifiers with low-loss microwave combiners. As a result, average power increased, reliability has grown fourfold, and the stability has increased dramatically.

DATA SHEET 17.6. HIGH-POWER 94-GHz RADAR

Developing Critical Technology Parameter	A 10 kW average power 94-GHz radar is under development for ISAR imaging of non-maneuvering aircraft and TBMs.
Critical Materials	Gyroklystron, duplexer, overmoded waveguide, and precise antennas.
Unique Test, Production, Inspection Equipment	High-power test equipment.
Unique Software	Target classification algorithms for aircraft and TBMs.
Major Commercial Applications	None identified.
Affordability	High cost, because of limited availability of components at this frequency.

SECTION 17.7—LAND MINE COUNTERMEASURES

Highlights

- Nuclear and chemical residue technologies that detect the mine main charge explosive will reduce the false-alarm rates.
- Use of hyperfine interactions technology (e.g., NQR) to identify explosive chemicals directly can be used to detect explosive compounds in nonmetallic mines.
- Use of imaging techniques to obtain more reliable information from GPR and EMI techniques will help to reduce false alarms while concomitantly enabling the detection of both metallic and nonmetallic mines.
- Use of ATR to fuse EMI, GPR, IR, and explosive detection signals will facilitate the use of multisensor fusion on vehicle platforms.
- Use of genetically improved bees (or other insects) to identify specific explosive compounds that leak from land mines and unexploded ordnance (UXO).
- Innovative use of dogs and other animals to locate explosives to provide explosive detection at vehicle speeds.
- Miniature shape charge arrays that attack the mine main explosive charge will provide high probabilities of mine kill.
- Directed-energy technologies that either spoof or disrupt mine electronic fuzes will be used to spoof advanced electronic fuzes.

OVERVIEW

This subsection addresses developing technologies for mine and minefield detection and for mine and minefield neutralization. A variety of technologies being developed for both mine detection and mine neutralization are compatible for use in airborne, ground vehicle, and soldier platforms. We therefore address six technology groups: **standoff-minefield detection, vehicle-mounted detection, hand-held detection, standoff neutralization, vehicle-mounted neutralization, and man-portable neutralizers**.

The technologies discussed in this subsection fall into two categories. The first category contains techniques that have been in the development stage for some time and have been used in other applications very successfully, but their support for mine countermeasures has not been justified to date. We expect major improvements in the future either because of a better understanding of the ground environment, a change in the operational procedure, or synergistic effects with other sensors (examples are radar and IR). In the second category are technologies that have been successfully tested in the laboratory and are being modified for field work (an example is NQR) or those technologies that are still in the laboratory testing phase (genetically modified bees and artificial noses).

The mine and minefield detection problems are paced by the large variety in shape, size, and construction of land mines; the variety of environments that they are located in; and also by the amount of clutter in which they are dispersed. EMI techniques have long been used to detect metallic mines, but these techniques detect many forms of metallic clutter found in the ground. New techniques to evaluate the induction decay times peculiar to different targets are being investigated as a means of separating clutter from mine targets. Stepped-frequency GPRs that exhibit high probabilities of detection (higher than 90 percent) of plastic antitank mines and increasingly higher detection rates (70 percent) of the small antipersonnel land mines have been developed. Unfortunately, both active and passive IR techniques have been in the development stage for some time for mine detection. Their appeal has been in the potential to identify minefields from airborne platforms. Unfortunately, the mine signature changes during the diurnal cycle. This variation, coupled with poor performance from current ATR programs, has resulted in investigations into more complex approaches like hyperspectral systems to identify more robust target-recognition techniques. Nuclear detection using thermal neutrons to excite prompt gamma response from nitrogen and nitrogen compounds works well for large antitank mines but is limited in its ability to find the smaller antipersonnel mines. NQR techniques have shown promise in detecting explosives containing RDX such as Comp B. More sensitive techniques are being developed to see the weaker resonances of the most common mine explosive, trinitrotoluene (TNT). Technologies that emulate the biological sensory organs to detect the chemical residue of explosives are being investigated to discern the sensitivities required and the performance in a wide range of backgrounds. Biotechnology approaches are being developed that utilize bioluminescence associated with reaction with explosive compounds. ATR is the major enabling technology for all of these explosive-detection technologies. Progress is being made in fusing the EMI, GPR, IR, and nuclear detection methods on ground-vehicle platforms.

Traditional approaches to mine neutralization utilize mechanical plows, rollers, and flails to clear mines or activate simple pressure plate mines. Modern mines employ advanced electronic sensors and can attack targets and neutralizers from standoff distances. To counter these new mines, two approaches are being developed. Nets that use shaped charge warheads can be propelled over a section of the minefield and then detonated. The shaped-charge warheads detonate the mine main charge, and a path is cleared through the minefield. Successful deployments of these nets have been recently accomplished. A second approach used to deal with electronic fuzed-mines is the use of directed energy to spoof or disrupt the mine fuzes.

BACKGROUND

Mines serve three functional roles on the battlefield: (1) they cause delay leading to a loss of synchronization and loss of surprise; (2) they damage or destroy armored vehicles and dismounted soldiers; and (3) they cause fear and anxiety even with battle-seasoned troops. Mines and minefields are generally placed so that they are covered by direct and indirect fire. The longer the offensive force takes to get through the mines or minefield, the greater the casualties inflicted on the offensive force.

Mines are historically deemed a defensive weapon, but modern warfare also has placed a premium on the use of flank-protection minefields to allow attacking forces to marshal sufficient force ratios (3:1 or higher) necessary to win offensive operations. In the case of the more traditional maneuver type of warfare, the emphasis in countermine operations is speed of detection, neutralization, marking, and breaching.

In recent years, mines have turned from being a military weapon into a weapon that at times is indiscriminately used against civilians. Political turmoil can lead to the use of mines by different political protagonists for specific political or economic gains. U.S. forces are increasingly being deployed in peace-keeping missions to areas of political unrest. In these types of situations, the mine is the weapon of choice for the smaller power or land force. The countermine requirements for these situations require high probabilities of detection and neutralization and low false-alarm rates. These requirements sometimes allow a different set of technologies to be applied for these types of applications.

The fundamental questions addressed in these analyses are the relationship of the speed of detection and neutralization to the probability of detection of neutralization. Second, the technical risks associated with each technological approach must be related to its potential payoff, that is, the transition of a technological approach into a fielded system that meets user requirements. This assessment also must address the relative maturity of various technology approaches, particularly with respect to evolving capabilities in the United States and other nations.

1. The Role of the Speed of Search

For maneuver warfare, the speed of the detector is paramount. The rate at which mines and minefields can be detected and marked has a significant impact on the timelines of the maneuver force. Relatively few technologies are compatible with the requirements for high-speed search of large land areas from airborne vehicles. In fact, many technology approaches can only be effective in the immediate vicinity of each mine.

Figure 17.7-1 shows the probability of mine detection as function of speed of search. In Figure 17.7-1, the speed of search ranges over six orders of magnitude, from basically a stationary examination of an area to an aerial survey. The tail of the arrow represents the current state of the technology, and the arrowheads indicate the direction that new research activity can advance. Physical process limitations, background noise barrier, and clutter barriers are also shown.

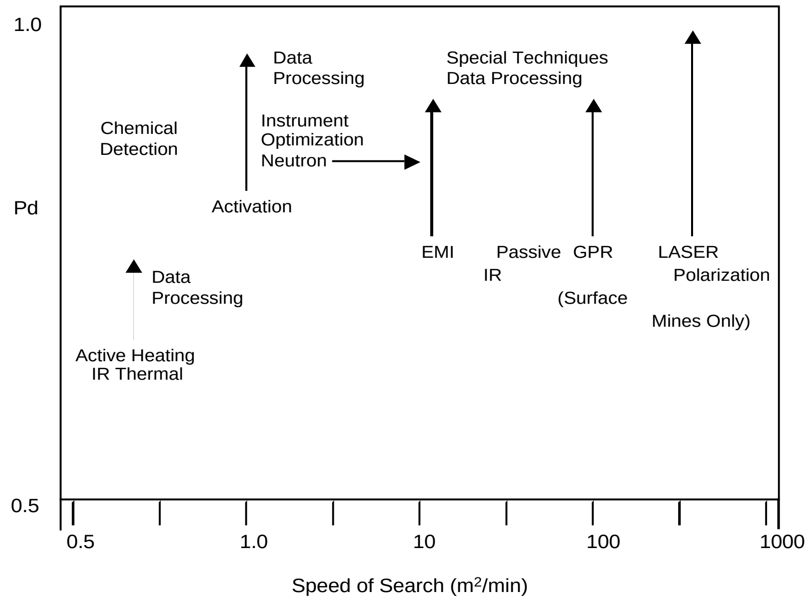

Figure 17.7-1. Mine Detection Technologies and Projections

Clearly, the technologies that cannot sustain a speed of search in the hundreds of square meters per minute would not be compatible with airborne systems used to remotely detect minefields. On the other hand, slower detection technologies such as neutron activation and chemical detection could be used as confirmatory sensors for a near-field interrogation to find buried mines.

We can define the detection quotient, DQ, as the ratio of true detections to the total mines present multipled by the ratio of true detections and the sum of true detections and false detections:

$$DQ = \text{Detection Quotient} = \{T/N\}\{T/[T+F]\},$$

where T = the total number of true detections, N = the total number of mines present; and F = the number of false identifications. In the limit of zero false detections, this definition gives the DQ = true/total. In the limit of high false detections, the DQ decreases to zero even if all the mines are detected. Figure 17.7-2 shows a plot of DQ where the total numbers of mines present is 50. The total number of true detections is plotted on the abscissa and ranges from 0–50. The curves are labeled with the number of false identifications, which range from 0–50.

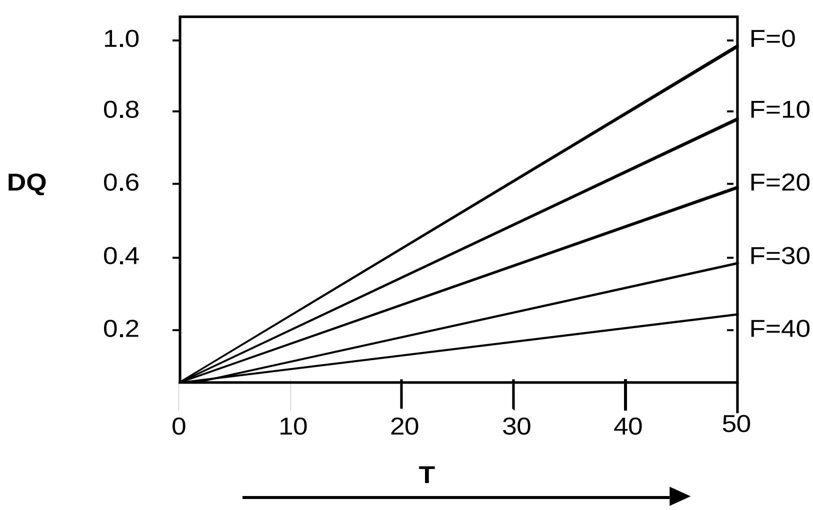

Figure 17.7-2. Detection Quotient as a Function of Mine Detections and False Alarms

The sources of the signals used to detect mines is a method of classifying technology approaches, particularly with respect to selectivity. The most desirable techniques are those that detect specific chemicals or elements that are intrinsic to mines. Since all mines have a main explosive charge, which is generally the largest single component of the mine, detection of main charge explosives should lead to the highest discrimination and lowest false-alarm rates. Nuclear techniques like neutron activation can detect specific atoms contained in the explosive chemical but not the chemical species. However, nuclear techniques can be used in a one-sided geometry and as part of a remote configuration. Techniques that depend on material discontinuities (conductive mine in contact with insulating Earth or vice versa) and detect the casing of the mines are subject to clutter and false-alarm problems. GPR, passive IR, and EMI are examples of these types of detectors. Other techniques that depend on the properties of the bulk mine material (active heating, IR, acoustic) or ground perturbations (radar) become less and less selective and are more prone to false alarms. Table 17.7-1 summarizes the technologies analyzed and places them on a scale of relative selectivity.

Table 17.7-1. Mine Selectivity for Various Technologies

Increase in Selectivity →				
Technology	**Perturbed Soil**	**Bulk Mine Properties**	**Specific Atoms**	**Explosive Chemical**
Neutron activation	No	Yes	Yes	No
Chemical spectroscopy	No	Yes	Yes	Yes
Biochemical	No	Yes	Yes	Yes
Radar	Yes	No	No	No
GPR	Yes	No	No	No
EMI	Yes	Yes	No	No
Passive IR	Yes	No	No	No
Active Heating (IR Thermal)	Yes	No		No
Acoustic	Yes	Yes	No	No

Those techniques that can provide high-resolution images are also very desirable because, on the basis of shape, one may be able to reduce the false-alarm rate. Even if the straight signal is not selective, if it can be used to produce images, then the image may be more revealing and thereby increase the selectivity. Techniques that measure the signal from the casing and give a high S/N may be used to produce images. Figure 17.7-3 is a notional graph that relates the effectiveness of detection to the speed of search.

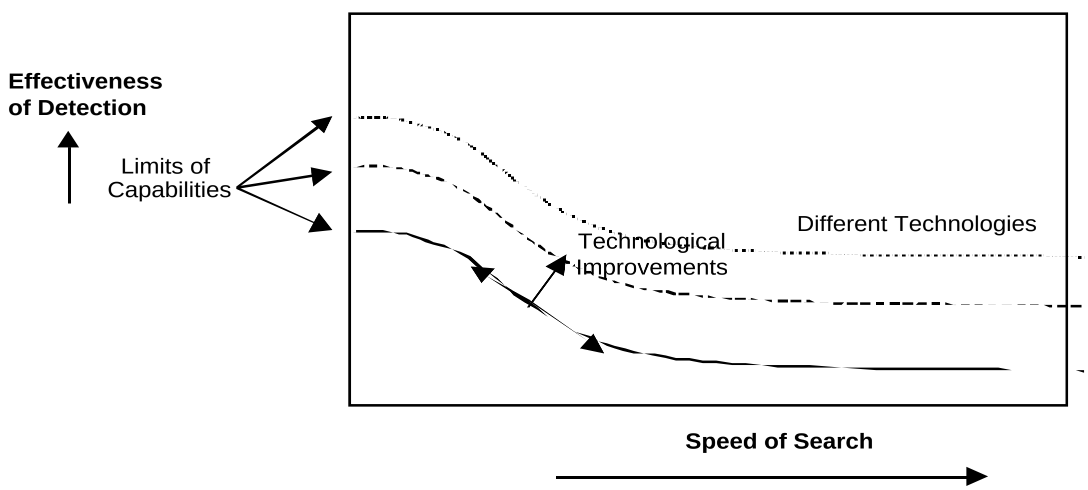

Figure 17.7-3. Effectiveness of Detection at Increasing Speeds

As the speed of search increases, the detection capability decreases, as shown by the solid curve. As the speed of search is decreased, the detection capability increases but eventually reaches a limit of detection capability. Technological improvements could increase the detection as a function of speed of search to produce a higher capability at the low speed limit (see the dashed curve). The dashed curve may actually represent a limit in the improvements that can be achieved with the particular technology because of clutter or inherent instrument limits. To further increase the detection (see the dotted curve) at a particular search rate, a different technique may have to be employed.

Computing effectiveness of technologies and system concepts requires some selection of pertinent parameters:

- Discrimination/selectivity
- Search rate
- False-alarm rate
- Probability of detection
- Sensitivity
- Missed targets.

These parameters could be related through a theory of measurements or through some theoretical model which would involve an assumption about the environment and sources of clutter as well as instrument settings that determine the threshold for signal acceptance. A low threshold would result in missed targets. With a given instrument one could expect an increase in false alarms with an increase in sensitivity. Along with these trends, one would also expect that a requirement of increased discrimination would result in a necessary reduction of the search rate.

In current systems that we have analyzed, there is nothing that can solve all the problems inherent obtaining high probabilities of detection with very low false-alarm rates. The preferred approaches and technologies depend on the kind of targets that are being interrogated, the environment in which they are located, and the rate of search necessary to meet operational requirements. Because there is no “silver bullet,” it is imperative that we turn our attention to using one or more technologies, together with advanced signal processing and ATR. In this realm, it would be ideal to establish as nearly an orthogonal set of technology measurements as possible so that high probabilities of detection can be maintained or improved while concomitantly reducing the false-alarm rate. Therefore, sensor fusion and ATR are a major factor in future increases in capability to be gained in mine detection as well as the proper selection of complementary technology sensors.

Finally, in attempting to determine an optimal set of technology thrust objectives for mine detection, it is also important to consider the inherent risks associated with the development of each technology. Some mine countermeasure techniques have been around for some time and the technologies have been well tested in the field. We may have reached the limits of their capabilities. Special approaches and new instrumental developments provide incentive for further investigation of some mature technologies. Other technologies are less mature, but they offer new possibilities for development. One way to evaluate the benefits of these different systems is by comparing the expected payoff against the anticipated risk. The payoff/risk chart is a method for articulating the joint assessment of risk and payoff. We now look at the different technology groups.

Standoff-Minefield Detection

The ability to detect and mark minefields prior to adverse encounter would be a major enabler for present or future fighting forces. Without an ability to see deeply, there will be no way for the Blue Force commander to avoid or be prepared for enemy obstacles—areas where the enemy wants to fight. Table 17.7-2 shows the relative maturity, research and development prospects, potential speed, general applicability, and mobility for technologies that are candidates for remote or standoff detection of minefields.

Table 17.7-2. Standoff Minefield Detection

Technology	Maturity	R&D Prospects	Potential Speed	General Applicability	Mobility
GPR/SAR	R&D	High	Fast	All Weather	Moderate Size
IR	R&D	High	Fast	Most Weather	Small Size
Active IR	R&D	High	Fast	Most Weather	Moderate Size
Hyperspectral	R&D	High	Fast	Daytime Only	Moderate Size
Biotechnology	R&D	High	Slow	All Weather	Moderate Size

Figure 17.7-4 shows the payoff versus risk associated with passive IR, GPR/SAR, active IR polarization, hyperspectral detection, and the use of biotechnology agents to induce fluorescence in ground absorption of deteriorating mine explosives. All the technologies are rated high payoff because of the high military utility inherent using remote detection. The least mature of these technologies is the biotechnology approach, which is directed at developing enzymes auxotropic for TNT that will bioluminesce when exposed to this explosive. The highest performance to date has been with systems that distinguish the polarization differences between mines and ground reflections. This approach, however, is limited to detecting mines on the surface. Passive IR techniques have been demonstrated to detect buried mines, but the robustness of this approach appears to be limited to particular times during the diurnal cycle. Recent advances in SARs show promise for detecting metallic mines. Some work indicates the utility of using hyperspectral approaches in the 9 µm area to detect the large change in emissivity that occurs when the silicate in top soil is turned under during mine burial.

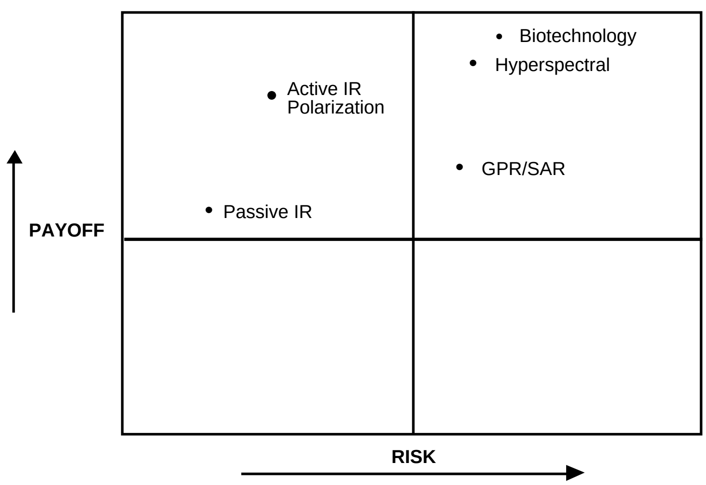

Figure 17.7-4. Standoff Minefield Detection

Vehicle-Mounted Mine Detection

There are also scenarios such as maintaining lines of communication for logistics forces in which close-in or near-field detection would be beneficial. Because road mines are generally used as part of an enemy ambush, a vehicle-mounted detector solves many of the problems of clearing roads. The Army is developing a vehicle-mounted mine detector for such scenarios. Table 17.7-3 shows the maturity, research and development prospects, potential speed, general applicability, and mobility for technologies that could be applied to vehicle-mounted detection.

Table 17.7-3. Vehicle-Mounted Mine Detection

Technology	Maturity	R&D Prospects	Potential Speed	General Applicability	Mobility
Vapor	R&D	Good	Very Slow	Confirm Only	Small Size
Neutron Act.	R&D	Good	Slow	Confirm Only	Large Size
Biotechnology	Research	High	Slow	Primary Sensor	Moderate Size
GPR	R&D	High	Fast	Primary Sensor	Moderate Size
EMI	R&D	High	Fast	Primary Sensor	Small Size
Passive IR	R&D	Good	Fast	Primary Sensor	Small Size
Active IR	R&D	Good	Fast	Primary Sensor	Moderate Size
Acoustic	R&D	Good	Slow	Confirm Only	Large Size
Laser/Acoustic	R&D	High	Slow	Confirm Only	Large Size
Biosensors	R&D	Good	Fast	Primary Sensor	Small Size
Hyperspectral	R&D	Good	Fast	Primary Sensor	Small Size
NQR	R&D	High	Slow	Confirm Only	Moderate Size
Water Jet	R&D	Poor	Fast	Primary Sensor	Moderate Size

Figure 17.7-5 shows the payoff versus risk in development for sensors to be used on vehicle platforms.

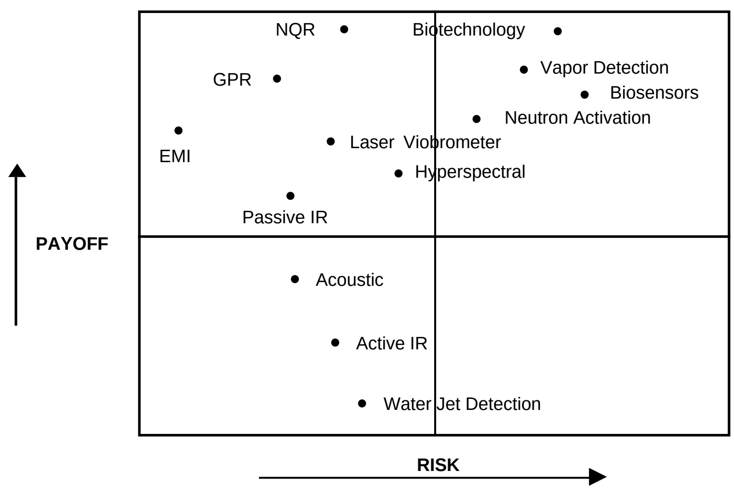

Figure 17.7-5. Vehicle-Mounted Mine Detection

The most familiar of these approaches is the EMI detector used to detect the presence of metallic objects. For vehicle-mounted detection of antitank mines, detection thresholds can be set relatively high, and good discrimination between mines and clutter can be obtained along roads. To detect nonmetallic mines and mines with relatively small amounts of metal, it is necessary to use other detection technologies. Advances in GPRs have recently demonstrated high probabilities of detection with significantly fewer false alarms than earlier systems. Several systems have been developed and tested that incorporate passive IR detection, but in field tests the false alarms inherent in the IR approach limited its relative success. Future technologies that portend greater selectivity include neutron-activation techniques and vapor-particle detection.

Handheld Mine Detection

Handheld detectors are the time-honored approach for finding individual mines. Because most of the original antitank mines had metallic skins, most of the world's mine detectors look for metal, generally through EMI detection. Handheld operations are always slow and cannot be conducted in the presence of enemy fire. Recent peace-keeping roles of the United States place troops in areas after mines and booby traps have been deployed by opposing forces. The Army is developing a handheld standoff mine detection system (HSTAMIDS) to meet these requirements. Table 17.7-4 shows the maturity, research and development prospects, potential speed, general applicability, and mobility for technologies that could be applied to handheld detection.

Table 17.7-4. Handheld Detectors

Technology	Maturity	R&D Prospects	Potential Speed	General Applicability	Mobility
Vapor Detection	R&D	Good	Slow	Confirm Only	Small Size
Biotechnology	R&D	High	Slow	Primary Sensor	Moderate Size
EMI	Fielded	High	Fast	Primary Sensor	Small Size
Passive IR	R&D	Good	Fast	Primary Sensor	Small Size
Biosensors	R&D	High	Fast	Primary Sensor	Small Size
NQR	R&D	High	Slow	Confirm Only	Moderate Size
GPR	R&D	High	Fast	Primary Sensor	Moderate Size
Photon Backscatter	R&D	High	Fast	Primary Sensor	Large Size

Figure 17.7-6 shows the relative payoffs and attendant risks of the different technologies with respect to the development and fielding of improved handheld detectors. EMI techniques are generally used by most the of the world's handheld-detector manufacturers. Recent research in EMI techniques has the potential to reduce false alarms through the use of the time constants associated with the rate of decay of the signal generated in the target material. Also, positive test results with GPR systems show promise for finding plastic and low-metallic mines. Emerging results from NQR experiments suggest that this technology could be used as a confirmation sensor.

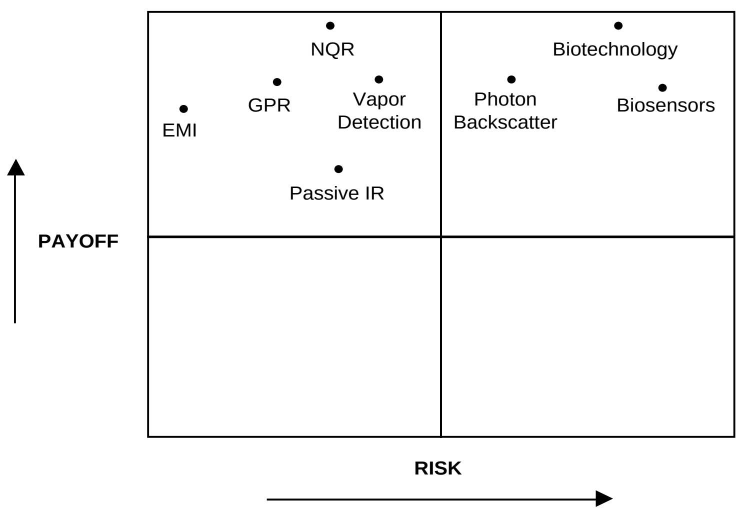

Figure 17.7-6. Handheld Detectors

2. The Role of Speed of Neutralization

The maneuver force is quickly placed at an extreme disadvantage when it has to extract itself from a minefield. The minefield is doctrinally covered by both direct and indirect fire. Waiting for breaching forces is not an option because the attacking force cannot continue the attack without breachers and will sustain unacceptable losses if it maintains its position within range of enemy direct and indirect fire. Ideally, a standoff neutralization system would complement the ability to remotely detect minefields. Standoff breachers can achieve surprise at the point of attack and permit maneuver forces to spend minimal time transiting the breached lane. Minimizing this transit time is important because it reduces maneuver forces' losses to direct and indirect fire while achieving surprise at the point of the breach.

Conceptually, there are several approaches to mine neutralization. For certain scenarios each conceptual approach holds some fundamental value.

Clearance. In its most simplistic sense, the approach would include manual removal of an individual mine from its location or detonation in situ of individual mines by sapper teams. This traditional engineer operation is tactically very slow, but produces safe lanes for following units. This approach is better suited to peacekeeping operations and is certainly not appropriate for maneuver warfare. Mechanized versions of mine clearance include plows and flails mounted on armored vehicles. The purpose of the plow or flail is to move the mines out of the path of the armored vehicle and subsequent vehicles. From a specific energy point of view, the plow and flail are probably the most efficient techniques to rapidly neutralize mines. From an operational point of view, these approaches are time consuming, and the armored vehicles used to propel these clearance devices are very vulnerable to direct and indirect fire.

Signature Duplication. The stimuli that activate mine fuzes can be duplicated to spoof the mines. Rollers mounted in front of armored vehicles produce a pressure signature similar to that of armored vehicles. Vehicle magnetic-signature duplicators (VEMASID) produce oscillating magnetic-flux densities that cause magnetic fuzes to prematurely actuate before the armored vehicle passes over the magnetic mine. These "spoofing" approaches work extremely well only against certain types of mines—those with simple pressure fuzes or single-axis magnetic fuzes. Some modern mines employ double-impulse fuzes (i.e., the fuze looks for the pressure pulse of the second or third roller wheel of an armored vehicle) or multiple-sensor fuzes. For multiple-sensor mine fuzes, it is important that the clearing system contain a spectrum of "spoofing capabilities"—acoustic, seismic, pressure, and magnetic.

Blast Effect Reduction. In this approach, the vehicle and its associated mine-detection and mine-neutralization items are designed to withstand the blast output of the landmines. Several South African vehicles employ a v-shaped chassis designed to deflect the mine blast wave from the vehicle. In addition, these vehicles employ shielding for shrapnel in the form of specially designed seats to dissipate blast loads before they are imparted to the passengers. The approach is successful in areas where the mine threat does not include shape charge or explosively formed fragments as mine warheads.

Directed Energy. There are several directed-energy approaches that can be used for mine neutralization.

Lasers. Successful explosive ordnance disposal lasers have been built and tested on armored vehicles to clear airfield runways. A 5–10-sec laser pulse causes fracture/opening of the ordnance case. Further application of the laser energy can induce low-order deflagrations or burning of the explosive components. Because the laser energy is absorbed in the first micrometer of the explosive material, it is not clear that current lasers can deposit sufficient energy in the secondary explosives to cause detonation. When the mines or ordnance is buried, the narrow energy absorption in the first micrometer of solid requires that the laser spend enough time and energy to vaporize the dirt between the laser and the mine/ordnance casing. Clearly, the extraordinary times and energy required to vaporize soil prohibit the use of laser for neutralization of buried mines and ordnance.

High-Power Microwaves. High-power microwaves (HPM) can be used to attack the electronic/electric components of mine fuzes. The most obvious way is to induce sufficient current in the bridge-wire detonator to cause detonation. Generally, even in open air tests, this approach requires 100 W/cm^2 to induce detonation. Usually, the fuze is protected within the mine structure, making it more difficult to produce this high-energy density at the bridgewire. Other neutralization approaches include component burn-out, spoofing, and mine electronic jamming. To accomplish these objectives, particularly with metallic mines, requires high-power systems to achieve even modest fields within the mine structure. In addition, each metallic mine will produce varying degrees of shielding at different frequencies. The tighter the production standard of the mine, the larger the source required to achieve useful levels within the mine. Attacking buried mines restricts the frequencies that can be used. Soils that contain significant amounts of water also restrict the robustness of the HPM approach. On the other hand, the HPM, unlike lasers, does not have to burn its way to the mine fuze to induce spoofing, jamming, or burnout. In addition, the HPM can produce significant fields over several square meters. This gives the HPM a large footprint that ultimately can provide moderate neutralization speeds for the host vehicle.

Charged Particle Beams. Charged particle beams (CPBs) such as electron beams are strongly scattered in air, particularly at the lower energies. The charged particles are said to have a "range" in air before they lose 1/e of their initial energy. As the accelerating voltage used to produce these beams is increased, the range of the electrons in air increases substantially. Recent advances in bringing million electron-volt pulses into air show promise for propagation distances approaching a kilometer. Just as the charged particle beams have a range in air, they also have a range in soil and a range in various mine components. Electron beams have been shown to induce detonations in both primary and secondary explosives. In theory, it is possible to design a system based on known energy losses in air, soil, and mine components that will detonate the main charge explosive in landmines. The difficulties found in adopting charged particle beams into military systems are numerous: developing an accelerator that would fit any current land vehicle; providing radiation protection during use; and sustainability of a complex accelerator in a dirty battlefield. Like the laser, the charged-particle beam has an extremely narrow footprint. Rastering the beam to provide blind protection across the vehicle front would slow the vehicle to speeds already obtainable with full-width plows. To truly be useful, the charged-particle beam would need to be tied to a forward-looking mine detector. Although advancements are being made in forward-looking detectors (FLIR and UWB), significant progress must be made in raising the probabilities of detection before a hunter/killer concept using a particle beam could be effective.

Explosive Neutralization. Traditionally, explosive line charges and fuel-air explosive devices have been used to clear minefields. This approach is effective against simple, single-impulse mine fuzes; however, there are many single-impulse fuzes that have been fielded that have been modified to require long impulses before fuze actuation occurs. Pressure bladders with different size holes are used to produce impulse-sensitive mines that cannot be actuated by line charges or fuel-air explosives. Other simple pressure systems have been modified so that there is very little surface area that is perpendicular to line charge blast waves. Developments in the United States with explosive powders and in Canada with ladder charges have shown that the main explosive charge in surface land mines can be sympathetically detonated. As the mines are buried deeper and deeper, the efficacy of these approaches degenerates into structural damage to the landmines. But because it can be anticipated that in a mobile war more than 80 percent of the mines would be scattered on the surface, these explosive approaches are attractive. A system approach that incorporated a track-width mine plow, a VEMASID, and an "explosive powder line charge" would be effective against all types of mines.

Shaped-Charge Neutralization. Landmine main charge explosives are susceptible to detonation induced by shaped charges. Even though TNT, a very insensitive explosive, is used by many nations as a landmine main charge explosive, it too is vulnerable to high-velocity shaped charges. The shaped charges are tied together with primacord in a large lattice net that can be rocket propelled over a minefield. The detonation of this explosive net of shaped charges rapidly clears a breach path through a minefield.

Standoff minefield neutralization requires a technology capable of causing mine to actuate at large standoff distances or the development of a system that can be remotely placed into the minefield to clear a breach lane. To be truly effective, the approach must also contain the element of surprise. Approaches that slowly and methodologically clear or neutralize individual mines will be quickly reduced by enemy direct and indirect fire and will also alert the enemy to the planned lane of breach.

Figures 17.7-7 and 17.7-8 show the probability of surface mine neutralization and the probability of buried (4–10 in.) mine neutralization, respectively, as a function of speed of neutralization.

There are major differences in technology capabilities for surface and buried landmines. As discussed previously, lasers have demonstrated utility for neutralizing surface mines and ordnance and have no capability against buried munitions. The HPM approach will work in dry soils and sands to moderate depths against electronic mines. Electron beams will only become attractive when they can be combined with forward-looking detectors that have a high probability of detection.

Advanced explosive systems must be combined with plows for full-spectrum mine clearance because explosive shock pressures dissipate too quickly in air and soil. One approach that does maintain the ability to detonate buried land mines is a shaped charge. The diameter and speed of the shaped charge determine the explosive actuation depths. Explosive net systems that place shaped charges at the lattice intersections of net arrays can achieve rapid neutralization times over large footprints.

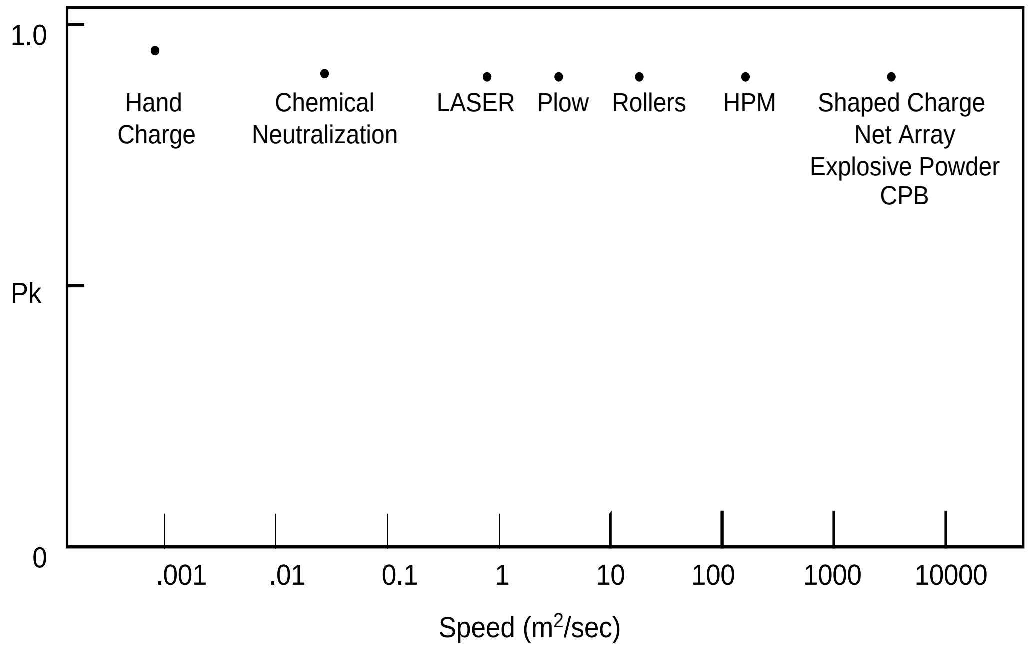

Figure 17.7-7. Area Neutralization Speed for Surface

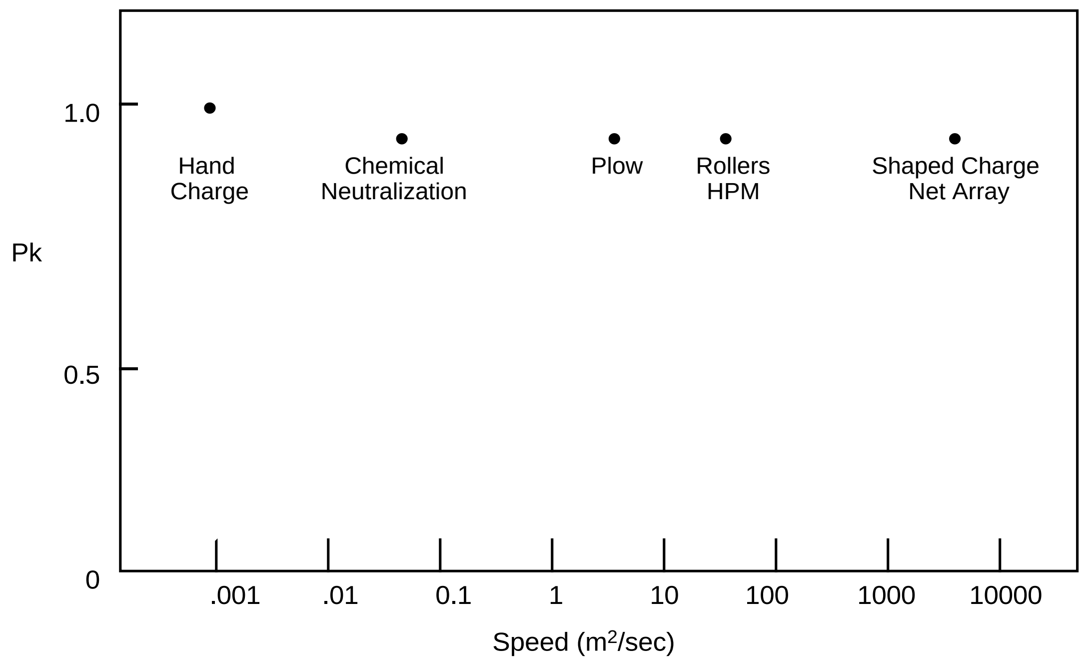

Figure 17.7-8. Area Neutralization Speed for Buried Mines

There are operational scenarios that make good use of most of the preceding technologies. Table 17.7-5 shows the increase in capability for the different technology concepts.

Table 17.7-5. Mine Neutralization Technologies

Technology	Surface Mines	Buried Mines	Attacks Fuzes	Attacks Main Charge	High Tempo Ops
	Increase in Selectivity →				
Hand Clearance	Yes	Yes	No	No	No
Roller	Yes	Yes	Yes	No	Yes
Flail	Yes	Yes	Yes	Yes	No
Plow	Yes	Yes	No	Yes	Yes
VEMASID	Yes	Yes	Yes	No	Yes
Chemical Neutralization	Yes	Yes	No	Yes	No
Laser	Yes	No	No	No	No
HPM	Yes	Sometimes	Yes	No	Yes
CPB	Yes	Yes	Yes	Yes	
Explosive Ladder Charge	Yes	Sometimes	Yes	Yes	Yes
Explosive Powder Line Charge	Yes	No	Yes	Yes	Yes
Shaped Charge Net Array	Yes	Yes	Yes	Yes	Yes

To better understand how these technologies can be used in different mine warfare scenarios, we now investigate the applicability of these technologies to the following technology groups.

Standoff Minefield Neutralization

Table 17.7-6 shows the maturity, R&D prospects, applicability, and mobility associated with different technologies that are appropriate for standoff minefield neutralization.

Table 17.7-6. Standoff Minefield Neutralization

Technology	Maturity	R&D Prospects	Applicability	Mobility
MICLIC	Fielded	Poor	Slow	High
SLUFAE	Type Classified	Poor	Slow	High
Explosive Ladder	Development	Good	Fast	Good
Explosive Powder Line Charge	R&D	Good	Fast	High
Shaped Charge Array	Development	High	Fast	High

The fielded mine-clearing line charge (MICLIC) is towed in a trailer by an armored vehicle. The MICLIC is effective only against simple pressure plate fuzed mines. The surface-launched fuel air explosive (SLUFAE) is likewise limited in its effectiveness to simple pressure plate mines, but this system has its own dedicated vehicle to insure mobility. The explosive ladder is rocket propelled over a minefield and uses large amounts of high explosive to destroy but not necessarily detonate all mines in or under the ladder charge. The explosive powder line charge disperses explosive powders once the line charge strikes the earth. The high pressures and impulses imparted by detonating the explosive charge cause sympathetic detonation of all mine main charges of surface mines. The shaped-charge array is also propelled as an expanding net over the minefield. The net consists of primacord tied to shaped charges placed in a lattice array. The shaped charges induce detonation of all mines under the net. The shaped charge array net is about to enter engineering and manufacturing development.

The payoff versus the risks of development is shown in Figure 17.7-9 for different standoff-minefield-neutralization technologies. The technologies offering the highest payoff are those that attack the mine main explosive charge.

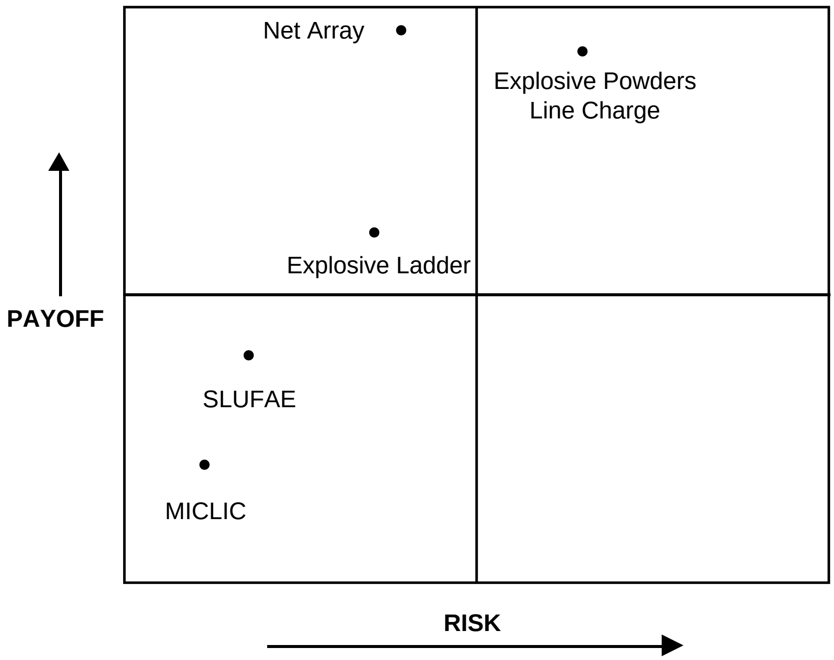

Figure 17.7-9. Standoff Minefield Neutralization

Vehicle-Mounted Mine Neutralization

There are many roles in which vehicle-mounted mine neutralization systems are used. For combat operations, vehicle-mounted neutralization systems are used to provide organic neutralization capability to the lead breaching vehicle, although standoff minefield neutralization systems may have cleared the breach. Additional combat operations include proofing of cleared lanes and mined areas and maintaining open combat roads and trails. After combat operations, vehicle-mounted mine neutralizers are used to clear mined areas and to proof areas where mines have been detected and destroyed or removed. Table 17.7-7 lists the properties of various approaches to mounting neutralization systems on vehicle platforms.

The preferred technology approaches are those that are effective against all types of mines and can be used to create rapid breaches under fire. Rollers are limited to attacking simple pressure-plate mines and some types of magnetic-fuzed mines. Track-width plows can create lanes at the rate of 7–10 kph, but full-width plows travel at significantly lower speeds. Flails are best used in rear areas because of their very slow rate of clearance. Vehicle magnetic signature duplicators (VEMASID) only attack magnetic mine fuzes and can be used together with mine plows or rollers to enable fast breaching. Directed-energy approaches have applications at the present time limited to attacking electronic fuzes or mines on the surface.

Figure 17.7-10 portrays the relative payoffs of different vehicle mounted mine neutralization technologies with increasing risk. The fielded items (i.e., roller, VEMASID, flail, and plow) are the lowest risk systems. The reason for increased payoff of the flail and plow over the VEMASID and roller is the ability of the flail and plow to neutralize all type of mines, irrespective of how they may be fuzed.

Table 17.7-7. Vehicle-Mounted Mine Neutralization

Technology	Maturity	R&D Prospects	Potential Speed	General Applicability	Mobility
Roller	Fielded		< 10 kph	Pressure/Tilt Rod	On/Off road
Plow	Fielded		< 5 kph	All mine types	Off road
Flail	Fielded		< 2 kph	All mine types	No Combat Breach
VEMASID	Type Classified		< 30 kph	Magnetic	On/Off road
Chemical Neutron	R&D	Good	< 2 kph	All mine types	On/Off road
Laser	R&D	Good	< 2 kph	Surface mines	On/Off road
HPM	R&D	High	< 10 kph	Electronic mines	On/Off road
CPB	R&D	Good	< 5 kph	All mine types	On/Off road
Small Shaped Charged	R&D	High	< 30 kph	All mine types	Off road

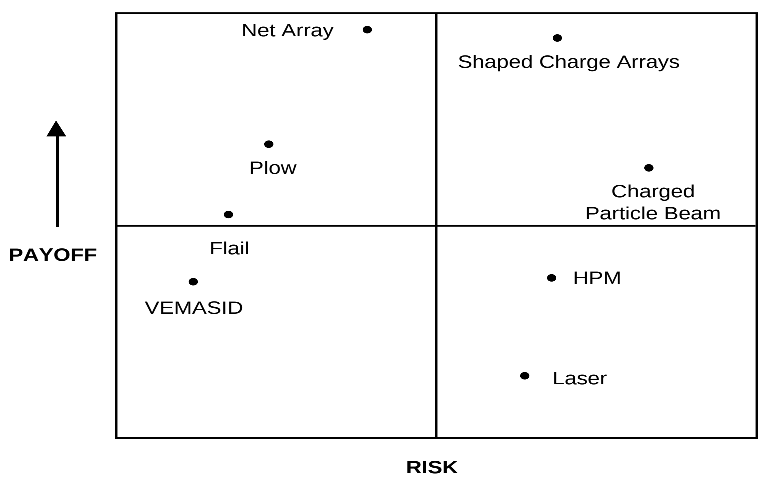

Figure 17.7-10. Vehicle-Mounted Neutralization

The plow has more risk than other fielded systems because the current plows are track-width clearance devices. Additional risk is incurred as full-width plows are being developed. Generally, the directed-energy approaches are riskier than the current mechanical and electrical fielded systems, with little additional payoff anticipated. Explosive net arrays, however, portend large leaps ahead in system capability and mobility.

Man-Portable Neutralizers

When mines are detected or found during road marches or road clearance operations, combat engineers carefully located and mark the mine. A decision is made to blow the mine in place, have an explosive ordnance disposal (EOD) expert remove the device, or to drive around the marked mine. For dismounted infantry assault breach situations, the infantry may face a combination of antipersonnel landmines, antitank mines, barbed wire, and booby traps. For the infantry to breach this complex obstacle, the only technologies currently known that can rapidly create a breached lane through the minefield are explosive line charges and explosive line charges with grenades placed at different intervals. The combination of explosive line charges with grenades helps to clear barbed wire while creating a narrow foot path. For noncombat situations, there are mine suits, special boots, helmets, and visors to protect soldiers performing mine clearance. These operations are dangerous and avoided wherever possible. Dismounted detection and neutralization of mines in rear areas are undertaken only in special circumstances where the mines are an imminent danger to present or anticipated operations.

LIST OF TECHNOLOGY DATA SHEETS
17.7. LAND MINE COUNTERMEASURES

DATA SHEET 17.7. ACOUSTIC DETECTION

Developing Critical Technology Parameter	Synthetic aperture acoustic sensor arrays are used to detect scattering of Raleigh waves by buried objects such as mines. Early results show promise for detecting anti-tank mines to distances of 10 m. Target cross sections were roughly two to three times actual size in first measurements. Raleigh wave transmission through inhomogeneous variously compacted soils leads to ambiguities in target position and target recognition. Smaller sensors placed in larger arrays will improve both detection and recognition of mine targets in the next five years.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Acoustic synthetic aperture arrays can also be used for detection and removal of unexploded ordnance or other environmental contaminants.
Affordability	Development of robust software to manage relatively inexpensive acoustic arrays will be the principal cost driver.

DATA SHEET 17.7. AIR-CHISEL CLEARANCE/NEUTRALIZATION

Developing Critical Technology Parameter	Once a mine detector has indicated the probable location of a mine, dismounted infantry usually approach the indicated spot in a prone position and use a hand probe carefully to try to find the suspected mine. Air chisels are a mechanized method to rapidly uncover soil, leaves, and other debris from the suspected mine location. Air chisels placed on remote-controlled detection platforms could be used to quickly uncover soil and debris from suspected mine locations.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	This approach could also be used for humanitarian demining operations.
Affordability	This approach uses commercial air-compressor technology and would be another tool for quickly finding and identifying buried land mines.

BACKGROUND

Once potential mines have been identified with electronic detectors, air chisels are an inexpensive and effective method to rapidly remove soil down to and around the mine. This approach is applicable only to the ever-increasing role that peacekeeping operations now play in the deployment of U.S. armed forces.

DATA SHEET 17.7. HYPERSPECTRAL DETECTION

Developing Critical Technology Parameter	By looking at very narrow segments of the optical spectrum it is possible to detect natural artifacts commensurate with the placement or burial of a mine. Natural vegetation can exhibit changes in chlorophyll due to the presence of a mine. Other anomalies include the difference in emissivity of silicate in soil at 9 µm. When soil is overturned, there is less silicate at the surface, and the silicate that is at the surface may be obscured by the overturned dirt. The anomaly is detectable sometimes for periods of weeks until the effects of wind and rain return that section to its natural state. The point is that selective absorption or reflection at very narrow frequency bands provide valuable clues as to the presence of man-made objects.
Critical Materials	High-resolution FPAs are needed to obtain high-resolution images of small objects such as mines that may be at the surface or buried. The higher the detection platform is to be flown, the larger the FPA needed to cover meaningful areas on the ground.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Special algorithms must be developed to identify individual mines and minefields.
Major Commercial Applications	Potential use in evaluating environmentally impacted areas or areas where large amounts of UXO exist.
Affordability	Requires expensive airborne optronic systems and software.

DATA SHEET 17.7. BIOTECHNOLOGY DETECTION

Developing Critical Technology Parameter	Development of enzymes that are auxotropic for TNT and luminescent when they react with TNT. These enzymes can be used to find buried mines and UXO that leak trace amounts of explosives into the environment.
Critical Materials	Because there are no known natural enzymes that are auxotropic for TNT and luminescent when exposed to TNT, new enzymes will have to be identified.
Unique Test, Production, Inspection Equipment	Test programs must be developed to insure that the enzymes are compatible and non-incursive on the environment.
Unique Software	None identified.
Major Commercial Applications	This technique could be used for environmental cleanup and UXO remediation of military sites.
Affordability	Potentially an inexpensive means to interrogate large land areas.

DATA SHEET 17.7. DIRECTED-ENERGY NEUTRALIZATION

Developing Critical Technology Parameter	HPMs can be directed at mines employing electronic fuzes to burn out electronic components, ignite the bridgewire fuze, upset electronic functioning, or spoof the fuze into interpreting the microwave signal as a proper firing signal. High-power electron beams can be brought into the atmosphere to attack surface and buried mines. The energy deposit initiates detonation in the mine main charge explosive.
Critical Materials	While laboratory HPM and electron beam sources exist, they are one-of-a-kind items. Special klystron and electron-beam assemblies must be designed for field applications.
Unique Test, Production, Inspection Equipment	Development of radiation-hardened test equipment to test high-power output.
Unique Software	None identified.
Major Commercial Applications	HPM devices can be used to combat terrorists or subversive groups that rely on electronic devices or communication.
Affordability	Directed-energy approaches are large and expensive.

BACKGROUND

Modern mines use electronic fuzing tied to one or more sensors for target acquisition. Many mines also employ electronic self-destruct mechanisms. These electronic circuits are vulnerable to directed-energy weapons such as HPM or charged particle beams.

DATA SHEET 17.7. EMI DETECTOR

Developing Critical Technology Parameter	New fast-response EMI detectors that use both real and quadrature data to determine the time constant rate of decay of mine targets have been developed. These new data provide the opportunity to both detect and classify mine targets. This additional information also provides a basis for rejection of clutter, which will result in fewer false alarms. This new powerful technique may also be able to detect the void produced by plastic mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Special coils must be developed that can both transmit and detect time constants on the order of 1 μsec or less. The time constants associated with different soils and their attendant moisture must also be measured and appropriately archived.
Unique Software	New software must be developed to accurately and quickly evaluate these microsecond interrogations.
Major Commercial Applications	Coin relic hunting detectors or commercial detectors to detect metal pipes in the ground or behind walls.
Affordability	Technology is relatively inexpensive and straightforward.

BACKGROUND

EMI detectors are the most ubiquitous mine- and relic-hunting detectors. High thresholds can be used to distinguish large metallic landmines. Large amounts of metallic clutter on the battlefield lead to extremely high false-alarm rates when EMI detectors are used to find small antipersonnel landmines. New detection capabilities subtend the ability to better distinguish mines from clutter.

DATA SHEET 17.7. EMULATED BIOLOGICAL SENSORS

Developing Critical Technology Parameter	Sensor response to a wide range of explosive compounds with small vapor pressures is difficult to measure in the laboratory. Performing these measurments in nitroaromatic backgrounds that can vary over more than four orders of magnitude adds greater complexity. The design and synthesis of complementary chemoselective coatings for nitroaromatics is coupled with the use surface acoustic wave (SAW) devices to determine explosive vapor sorption and selectivity.
Critical Materials	The construction of carbon bolometers to perform reproducible detection of explosive compounds may be difficult to convert from the laboratory to production status.
Unique Test, Production, Inspection Equipment	The performance of these sensors in areas already contaminated with explosive materials is currently not known.
Unique Software	None identified.
Major Commercial Applications	These devices could be used as explosive detectors for airports and for building security.
Affordability	The technology will be moderately expensive to develop and relatively inexpensive to produce in quantity.

DATA SHEET 17.7. EXPLOSIVE ARRAY NEUTRALIZATION

Developing Critical Technology Parameter	Individual small shaped charges can be used to initiate detonation of buried land mines as they pass through the mine main charge explosive. Matrix arrays of these shaped charges are deployed as a large net with shaped charges at the interstices. The interstices are approximately 15 cm apart so that at least one shaped charge will penetrate any antitank mine covered by the matrix array. The matrix array is deployed after being launched by a rocket over a suspected mined area.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Unique production assembly will be required to produce expandable arrays consisting of shaped charge warheads connected with primacord.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Because the array is consumed in its mine-neutralization mission, the size and cost of the array will determine its ultimate military utility.

DATA SHEET 17.7. GPR DETECTION

Developing Critical Technology Parameter	GPRs operating between 0.3–15 GHz can provide reliable detection of objects to tactical mine burial distances (10–15 cm). Increasing computing performance helps evaluate radar returns from SARs in real time to provide detection for both hand-held and vehicle-mounted mine detection applications.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Each radar array demands separate software be developed to interpret radar return signals.
Major Commercial Applications	Detection of buried pipelines and cables.
Affordability	This is a moderately expensive technology in development and potentially inexpensive for mass production.

DATA SHEET 17.7. PASSIVE IR DETECTION

Developing Critical Technology Parameter	Mines buried in soil near the earth's surface are detectable with passive IR devices for several reasons: the heat capacity of the mine is different from the surrounding soil, so the mine is at a different temperature during most of the diurnal cycle; the amount of moisture above the mine is different from that of the surrounding soil; and the density of the soil put back on top of the mine is different for several weeks after the mine is inserted. As the surrounding soil heats and cools during the diurnal cycle, the mines are differentially heated and cooled so that there are times when the mines are hotter, cooler, or at the same temperature. During the cross-over times, the mines are very difficult to detect. Good results have been achieved in both the mid-wave and long-wave IR bands, with the best results usually occurring 1–2 hours after sunrise or sunset, where the mines are at the largest differential temperatures from the soil.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Because the IR signature of the mine changes during the day, software is being developed that will key on specific temperature differences obtained from selected calibrated targets.
Major Commercial Applications	There are numerous commercial and military uses of passive IR. The uses for the software being developed to find mines could also be used in humanitarian demining applications.
Affordability	Cost of second-generation FLIRs may limit their military utility to being mounted on ground vehicles for road mine detection or on UAVs for remote minefield detection.

BACKGROUND

This technology is important to the future of standoff minefield detection programs both because of its unique capability to detect surface and buried mines from a standoff distance and also because of the relatively small size and weight requirements it imposes on potential platforms.

DATA SHEET 17.7. LASER-INDUCED IR POLARIZATION

Developing Critical Technology Parameter	Man-made objects such as the flat and smooth surfaces on mines polarize light differently than the surrounding soil and vegetation. When a laser source illuminates a specific ground area, the land areas exhibiting substantially unique returns can be examined for the presence of mines. Because the same signal also provides information on the size and placement of the suspected object, the approach can be particularly effective in finding surface mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Unique software is being developed to examine specific polarizations, but also to identify mine fields and mine field patterns.
Major Commercial Applications	Humanitarian demining also has requirements to determine the placement and extent of minefields from standoff distances.
Affordability	This is an expensive technology to develop and produce.

DATA SHEET 17.7. NEUTRON ACTIVATION DETECTION

Developing Critical Technology Parameter	Natural californium sources that emit thermal neutrons are used to produce a prompt gamma from nitrogen in explosive compounds. The approach has been to use neutron activation as a confirmatory sensor to detect the presence of explosive compounds in areas where other mine-detection systems have discovered some form of subsurface anomaly.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Specific software has been developed to process the raw signal counts.
Major Commercial Applications	This approach has been used as an explosive detector at a few airports. Although very expensive, this approach could also be used in some humanitarian demining applications.
Affordability	Number, quality, and calibration of sensors are all major cost drivers in what will be a large expensive system.

BACKGROUND

Thermal neutron activation measures nitrogen directly and through this measurement gives location of the explosive. For buried mine detection, the system must interrogate metric tons of soil. Different environments may require different software to compensate for background clutter.

DATA SHEET 17.7. WATER JET DETECTION

Developing Critical Technology Parameter	The concept is to use the stream of water hitting a hard target to carry the reflected sound back to a detector. Although sensors placed directly on the external surface of UXO and mines can measure the sound velocity in the encased explosive, it has never been experimentally shown that the same types of measurement are possible through the water jet stream. Better detection results have been achieved using hot water to heat the mine so that the thermal signature of the mine is contrasted against the colder soil.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Specific software must be written if the concept can be demonstrated experimentally.
Major Commercial Applications	If the approach can be demonstrated, it could be used to find buried utility lines and sewers.
Affordability	The approach is moderately expensive.

BACKGROUND

Arrays of small, high-pressure water jets can be used to rapidly penetrate several inches of soil cover. The scattering of the water jet by buried objects can be monitored to detect objects with different sound velocities.

DATA SHEET 17.7. CHEMICAL NEUTRALIZATION

Developing Critical Technology Parameter	Many countermine situations require that mines be neutralized in situ with no collateral effects. Although explosive ordnance demolition procedures exist to deal with these types of situations, the reality of the combat situation is that EOD personnel may not be available or too many mines may be involved to make the EOD approach viable. In these cases, mine neutralization could be effected by combat engineers if they had a device that would penetrate the mines and place chemical reagents into the main charge explosive. These techniques have been demonstrated using solvent/reagent solutions to rapidly react the explosive to a nondetonable mass.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	This approach is ideal for humanitarian demining situations, in which it is important that the mines be destroyed quickly and in place.
Affordability	Inexpensive system to procure and field.

BACKGROUND

Methods that chemically change the mine main charge explosive into a nonhazardous residue are needed for future peacekeeping operations. To be effective, the chemical system must quickly chemically react a large variety of secondary explosives. Early systems used both a solvent and a reagent to quickly react the mine main explosive charge. There is currently no ORD or other requirement document for this technology. Attempts have been made to use this approach in humanitarian demining systems.

DATA SHEET 17.7. FLAIL CLEARANCE AND NEUTRALIZATION

Developing Critical Technology Parameter	Flails have been used since World War II to neutralize land mines. The counter-rotating flail acts like an end mill clearing the soil and mines. The clockwise rotating flail can detonate simple pressure fuzed mines and cause catastrophic mechanical damage to the mine body—leaving the primary fuze explosive and booster still in vicinity of main explosive charge material.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	The flail is a large, massive system that can only be used on the front of large tanks or earth movers.

BACKGROUND

Flails mounted on the front of slow-moving vehicles have historically been used to remove mines for off-route applications. The process is generally limited to speeds of 1–2 mph and is best used for clearance in areas not under indirect or direct fire.

DATA SHEET 17.7. HIGH-PRESSURE FLUID JET NEUTRALIZATION

Developing Critical Technology Parameter	Optimization of soil and mine case perforation against a wide variety of metal- and plastic-cased mines can be achieved with fluid jets driven at high pressures. The fluid used by the jet can also contain chemicals/solvents to attack the main explosive charge of land mines. Devices that can be backpack mounted have been demonstrated for use by dismounted troops. Larger devices have been demonstrated from tactical vehicles.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Water jets are already in use commercially for a wide variety of landscaping and gardening applications.
Affordability	This approach is moderately expensive to produce and field.

BACKGROUND

High-pressure fluid jets are currently used in a number of commercial cutting and gardening applications. High-pressure fluids can rapidly penetrate a soil overburden and perforate a mine casing. A variety of chemicals could be used to react the mine main charge explosives.

DATA SHEET 17.7. LASER DOPPLER VIBROMETER DETECTION

Developing Critical Technology Parameter	Laser Doppler vibrometer detection is an emerging technology that requires line-of-sight access to the soil covering the land mine. A laser Doppler vibrometer measures the soil velocity above and around the buried mine that has been stimulated by an acoustic sound source. The approach is consistent with developmental efforts to decrease the false-alarm rates currently exhibited by EMI and radar technology approaches.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	This approach could be used in peacekeeping and humanitarian demining applications.
Affordability	This is a moderately expensive technology to develop and procure.

BACKGROUND

Acoustic sources coupled into the earth produce scattering by buried objects. The soil velocity is measured by the laser vibrometer.

DATA SHEET 17.7. NUCLEAR QUADRUPOLE DETECTION

Developing Critical Technology Parameter	NQR can provide specific information on nitrogen-containing and halogenated compounds. NQR is basically a radio-frequency spectroscopy technique that results from the variation of the nuclear electric field from sphericity.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	NQR technology has been investigated as explosive detectors in airports.
Affordability	This technology is expensive to develop, but could be less expensive to procure.

DATA SHEET 17.7. PLOW CLEARANCE AND NEUTRALIZATION

Developing Critical Technology Parameter	Plows are a traditional method for moving mines from the path of large tracked vehicles such as tanks. For track-width mine plows, speeds of 7–10 mph can be achieved. Full-width plows are being developed, but it is not anticipated that these will function at speeds at or greater than 3 mph. The plow removes all types of mines to depths of 8 in. and has been successfully deployed by many nations in several wars.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	This technique can also be used in humanitarian demining situations.
Affordability	Although the technology is straightforward, its implementation is large, heavy, and costly.

BACKGROUND

Track-width and full-vehicle-width plows mounted on armored vehicles can remove the top soil and buried mines to a depth of approximately 8–12 inches.

DATA SHEET 17.7. MINE ROLLER

Developing Critical Technology Parameter	The use of mine rollers pushed by a tracked vehicle such as a tank is the classic method for defeating simple pressure-pulse mines both on and off road. The simple countermeasure to the mine roller is the use of a double-impulse fuze, in which the first impulse by the roller is ignored and the fuze is actuated by the first bogey wheel of the tank. Mine rollers can also be effective in clearing modern magnetic fuzed mines, particularly under the track of the roller.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Not determined.

BACKGROUND

Large rollers, mounted together in separate roller banks in front of the tracks of armored vehicles, are used to detect road mines and to proof areas against simple, single-impulse mine fuzes. The method combines speed together with a roller survivability generally limited to two mine detonations at the edge of the roller bank.

DATA SHEET 17.7. VAPOR/PARTICLE DETECTION

Developing Critical Technology Parameter	Detection of explosive vapor that has leaked through a mine structure or has been emitted by small amounts of explosive in contact with the outside surface of a mine can play an important role with other detection techniques in explosive verification. The difficulty with this approach is that only small residual amounts of trace vapor remain at the earth's surface above the buried mine. TNT has a very low vapor pressure, and recent measurements indicate that it is difficult to find trace amounts even in the vegetation above the buried mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Explosive sniffers are being used in airports and for building security. This approach is also being exploited for use in humanitarian demining.
Affordability	This is a moderately expensive technology to develop and field.

BACKGROUND

Chemical detectors are an excellent tool to find trace amounts of explosives; however, for the countermine role, the system must detect explosives in a wide range of environments and over clutter differences differing by many orders of magnitude.

SECTION 17.8—SEA AND LITTORAL REGION MINE COUNTERMEASURES

Highlights

- Mine hunting systems capable of stream, tow, and recovery operations from helicopters and that use on-board sonars for mine detection and laser sensors for mine identification are being developed.
- Airborne lidar mine-detection systems are being developed to rapidly detect moored and floating mines.
- New software that uses both archival and in situ environmental data in mine countermeasure equipment is being designed to improve "through the sensor" mine detection and mine identification capabilities.
- Ultrasensitive, optical-fiber, magnetic-field sensors and superconducting quantum interference devices (SQUIDS) are being developed for detection of metal ocean mines.
- Superconducting magnets are being developed to project magnetic flux densities sufficient for shallow water minesweeping of mines that use magnetic fuzes.
- Spectral shaping of plasma discharge acoustic sources is being used to emulate shiplike acoustic signatures for minesweeping applications.
- Electromagnetic and acoustic sensors are being fused for detecting mines in very shallow water environments.
- Low-frequency synthetic aperture sonars are being developed for detecting mines on or in the ocean floor. Mid-frequency synthetic aperture sonars are being developed for long-range detection and classification of bottom mines.
- Toroidal volume search sonars are being developed for high area coverage of mines.
- Streak tube imaging lidar, range gate lasers, and laser line scanners are being developed for mine identification.
- Laser sensors are being developed for fluorescence detection of plastics and other anthropogenic compounds dissolved in seawater.
- Expendable fiber-optic tethered vehicles with sonar and video links and that can be deployed from airborne vehicles to hunt and kill individual mines with shaped charges are being developed.
- Rocket-propelled explosive net arrays and line charges are being developed for the standoff neutralization of mines in the surf zone.
- Supercavitating projectiles fired from airborne platforms are being developed to rapidly neutralize sea mines.
- Precision-guided submunitions are being developed to neutralize beach zone mines and obstacles.

OVERVIEW

The sea offers strategic and tactical mobility to those who control it. During most of the 20th century, however, control of the sea has been focused on the requirements to transition to war on land. The requirements to ferry massive forces ashore and then provide logistic support to those forces has severely limited maneuverability and has restricted choices of landing areas. In the future, the United States will face many different threats to its security and national interests. Most likely, these threats will be in the littorals because more than 75 percent of the world's population and its largest and capital cities are on or near coasts. The requirement to project power ashore means the ability to perform forced entry as well as disaster relief. Both sea mines and mines in the littoral regions limit the ability to maintain pace and sustain operations. It is essential to shape the battlespace in a theater of operations to deal with mines quickly and effectively.

Mines are inexpensive weapons of choice for most third world countries, and can be highly effective when employed in the littoral regions, shipping lanes, and ports. Mine countermeasures includes knowing where the mines and surf/beach zone obstacles are, the ability to clear mines and obstacles, and the ability to obstruct or to destroy mine-laying platforms or mine stockpiles. Mine countermeasure equipment and technology is needed to support four different types of operations: (1) mapping, survey, and intelligence operations; (2) surveillance operations; (3) organic mine countermeasure operations; and (4) dedicated mine-countermeasure operations. Therefore, mine-countermeasure operations—minesweeping and jamming, mine/minefield hunting, and mine/obstacle neutralization—require a spectrum of technology skills ranging from the use of national mapping and intelligence assets to specific mine-countermeasure assets.

Shallow-water influence minesweeping relies on projecting false magnetic and acoustic signatures that "trick" mines employing influence sensors into firing the mine prematurely. Current minesweeping devices use a helicopter to tow a small hydrofoil sled that contains both an electrical generator and a long cable that conducts a large current to project false magnetic-flux densities. MCM ships (Avenger Class) also stream long cables and acoustic devices to project false magnetic and acoustic signals to sweep the mines. New superconducting sources together with plasma discharge acoustic sources are being developed to emulate simultaneously a ship's magnetic and acoustic signatures.

A variety of organic mine countermeasures equipment is being developed to be used in different situations and environments. The AN/AQS–20/X is a helicopter-deployed sensor that uses sonars and laser sensors to detect, classify, and identify bottom and tethered mines. The airborne laser mine detection system uses blue-green laser reflections to rapidly detect moored and floating mines. This system will provide both quick-reaction airborne mine reconnaissance and percursory reconnaissance for dedicated mine countermeasure units. The remote minehunting system (RMS) is an independent platform that will provide surface combatants an organic system capable of detection, classification, identification, and location of moored and bottom mines. RMS uses the AQS-20/X as its sensor payload. The Airborne Mine Neutralization System consists of an expendable neutralization vehicle that can be deployed from a helicopter. The expendable vehicle includes sonar and video links for mine detection and identification and shaped charges for bottom or deep-moored mine neutralization. A new concept for rapidly neutralizing sea surface mines or mines tethered close to the surface is the rapid airborne mine clearance system (RAMICS). The RAMICS uses supercavitating projectiles fired from a helicopter-mounted machine gun and targeted by a blue-green laser. The organic airborne and surface influence sweep system will use magnetic and acoustics signature duplication and projection to sweep influence mines in shallow waters. The Navy is also developing a submarine-launched and recovered unmanned underwater vehicle, called the long-term mine reconnaissance system (LMRS), capable of conducting clandestine mine reconnaissance. The sonar capabilities are similar to those of the AQS–20.

There are also specific ongoing programs to address mine countermeasures in amphibious assault lanes. In the 40–10-ft depth regime, the Navy is developing diver systems, marine mammal systems, and its first small autonomous undersea vehicle. In the surf zone (10–0 ft) and the beach zone, the shallow water assault breaching (SABRE) system and distributed explosive (DET) systems are being developed to explosively neutralize mines. SABRE consists of rocket-launched explosive line charges to rapidly clear lanes in the deeper portions of the surf zone. DET uses a dual rocket-launched distributed explosive net to create safe lanes through the shallowest portion of the surf zone.

The Mine Warfare Environmental Decision Aids Library (MEDAL) provides analytical tools that utilize archival data for mine countermeasure planning and measurements. In the long term, MEDAL will also provide "through the sensor" capability to improve sensor detection and identification performance as well as feeding "through the sensor" data back to the archives. In addition to being a tactical decision aid for mission, MEDAL is also a post-operations analysis tool and provides the connectivity between all mine warfare platforms and the rest of the battle group or the amphibious ready group. Environmental science and technology programs will also be used "through the sensor" to provide information on mine burial, shock-wave propagation, and optimum probabilities of kill.

Emerging technologies that will be incorporated in mine-hunting platforms include toroidal volume search sonar for rapid, full water column mine searches, synthetic aperture sonars to find mines at the bottom or in the soil at the bottom, and advanced signal-processing techniques. Advances in mine identification are being pursued in the development of laser sensor to detect fluorescence of plastics and other anthropogenic compounds and the use of streak tube imaging lidars. The Navy is also experimenting with an advanced underwater surveillance system that will be capable of detecting ongoing mine operations as they occur. Also, networks of autonomous unmanned vehicles are being pursued. These autonomous systems will employ a navigation and control element, have the ability to fuse multisensor information, and provide data transmission and retrieval. To improve remote sensing, the Navy is developing technologies to exploit satellite and theater imagery, together with environmental measurements of surface waves, wind, current, and bathymetry, to more accurately depict the presence and extent of sea and littoral mines. Because ship-to-objective maneuver (STOM) relies on the rapid and accurate elimination of anti-assault mines and obstacles and the rapid movement of forces and materiel ashore, the placement of explosive line charges and distributed explosive arrays deployed from landing crafts, air cushion (LCACs), is not a viable long-term solution. Here, the Navy is exploring novel ways to kill mines and obstacles in the surf zone, on the beach, and in the beach exit zone. Air-launched and gun-fired precision-guided munitions with antimine reactive darts and antiobstacle, continuous-rod warheads are maturing technologies in this area.

LIST OF TECHNOLOGY DATA SHEETS
17.8. SEA AND LITTORAL REGION MINE COUNTERMEASURES

DATA SHEET 17.8. MODULATED PULSE LIDAR

Developing Critical Technology Parameter	Modulated pulse lidar systems are used to enhance the contrast of underwater objects. A multimodulation frequency transmitter and wide-bandwidth, large-area optical detector are being developed [0.5–10 GHz, high optical power (>10 kW), pulsed (10–15 nsec), blue-green (532 nm) optical transmitter]. Field test results conducted at 0.15- and 5-m depth demonstrated improved modulated pulse target returns due to backscatter clutter rejection. The modulated pulse lidar system has the potential to improve lidar system search rates by more than an order of magnitude for mine localization. Critical technologies for development of this technology include large-area, high-speed photo detectors and high-speed optical modulators for high-capacity systems.
Critical Materials	Critical technologies for development of this technology include the need for materials for large-area, high-speed photo detectors and high-speed optical modulators for high-capacity systems.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Optimized sensor performance depends on the development of software that includes ocean optical characteristics.
Major Commercial Applications	This approach is applicable to both biomedical and communications applications.
Affordability	Although most of the parts are commercially available, incorporation of this system into a small number of prototypes will be expensive.

BACKGROUND

Small shallow underwater targets are contrast limited in conventional lidar systems. A multiple frequency system (0.5–10 GHz), high optical power (>10 kW), pulsed (10–15 nsec), blue-green (532 nm) optical transmitter has been developed to measure water and target frequency spectra. Modulated lidar echo returns from 0.15–5-m depths provide significant improvements over that obtainable from conventional lidars.

DATA SHEET 17.8. TOROIDAL VOLUME SEARCH SONAR

Developing Critical Technology Parameter	Toroidal volume search sonars are being developed for full water column, high coverage rate detection and classification of moored and close-tethered mines in deep water. A 360-deg beam pattern provides a 1,500-m diameter path width when mounted on underwater unmanned vehicles.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Advanced signal-processing systems will be required to keep pace with the 6 square nmi/hour coverage rate of this system.
Major Commercial Applications	None identified.
Affordability	No cost issues have been identified.

DATA SHEET 17.8. SYNTHETIC APERTURE SONAR

Developing Critical Technology Parameter	Synthetic aperture sonar technology provides high-resolution detection, classification, and identification of proud and buried mines in water depths to 25 m. Prototypes have been tested using high, mid, and low frequencies. The high-frequency synthetic aperture sonar operates at 180 kHz and is capable of 2.5-cm resolution for mine identification at short ranges. The mid-frequency synthetic aperture sonar is striving to achieve detection/classification ranges of 500 m or more. The low-frequency synthetic aperture sonar operates at 20 kHz and provides 7.5 cm × 7.5 cm resolution for detection and classification of proud and buried mines. At the lower resolution, the system is capable of covering 0.36 square nmi/hr.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Advanced signal processing is required for mine identification and for motion compensation.
Major Commercial Applications	Underwater recovery of artifacts and valuables from sunken ships.
Affordability	No cost issues have been identified.

BACKGROUND

Bottom and buried mines pose a series threat to landing forces. Detection and identification of mines is required in high-clutter, shallow water areas. The synthetic aperture sonars are designed to operate in a fast scan mode, as well as in a high-resolution mine-identification mode.

DATA SHEET 17.8. STREAK TUBE IMAGING LIDAR

Developing Critical Technology Parameter	The streak tube imaging lidar uses a pulsed blue-green laser and a fixed cylindrical lens to project a fan beam beneath a vehicle onto the ocean floor. Conventional optics image the illuminated stripe onto a slit photocathode of the streak tube. Electrons from the photocathode are electrostatically accelerated onto a phosphor anode to form a 2–D range azimuth image for each laser pulse. The pulse rate of the laser is synchronized to the forward speed of the vehicle so that the in-track dimension is sampled in a push broom fashion. The 3–D image is then processed to image both moored and bottom mines.The streak tube imaging lidar will provide a 3–D image at altitudes of 12 m above the ocean floor at speeds to 12 knots.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Only early prototypes exist, so no test or inspection equipment has been identified.
Unique Software	The 3–D images will require special software, particularly for the high sweep rates intended for this sensor.
Major Commercial Applications	The technology is applicable to environmental monitoring.
Affordability	No cost issues have been identified.

BACKGROUND

The objective of streak tube imaging lidar is to develop a mine identification capability to be used after detection and classification of minelike objects to reduce the number of contacts that must be prosecuted. Reducing the number of contacts that must be prosecuted significantly decreases the time it takes to clean an area of mines.

DATA SHEET 17.8. FLUORESCENCE DETECTION OF PLASTICS

Developing Critical Technology Parameter	The objective is to develop a compact laser-induced fluorescence sensor that can detect trace levels of chemical substances on mines in seawater. Fluorescence of natural organic matter will constitute the background signal. Analyses of mine components have shown that marine epoxy resins have fluorescence characteristics that serve as fingerprints of the individual components that make up the epoxy.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	To date, only laboratory instruments have been used to establish technical feasibility.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	No cost issues have been identified.

BACKGROUND

Divers remain a major resource for mine hunting. The use of laser-induced fluorescence sensors to detect mines speeds up a slow and dangerous mission.

DATA SHEET 17.8. EXPLOSIVE NET ARRAYS

Developing Critical Technology Parameter	Because water is an incompressible medium, water transmits shock energy more efficiently than air. Explosive net arrays detonated in water provide sufficient energy to destroy mines and mine casings in water. Explosive net arrays are an efficient method of covering specific water areas to breach a safe landing lane for amphibious vehicles.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Unique production and assembly will be required to produce expandable explosive arrays.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	Because the array is consumed in its breach mission, the size and cost of the array will determine its ultimate military utility.

BACKGROUND

Because breaching minefields plays such a pivotal role in successful amphibious assaults, systems that can quickly and efficiently create breached lanes are critical to mission success.

DATA SHEET 17.8. OPTICAL FIBER MAGNETIC FIELD SENSORS

Developing Critical Technology Parameter	Fiber-optic gradiometers are being developed for shallow water mine detection and classification. An extrinsic Fabry-Perot interferometer (EFPI) configuration with magnetostrictive elements and silicon micromachined substrates is used to create a temperature-insensitive device to detect magnetic field signatures of buried, tethered, and floating ferrous mines. The movements of the magnetostrictive element are monitored using an EFPI configuration. The EFPI is based on the combination of two light waves with a path-induced phase change between them. Current single-axis fiber-optic magnetometers have reached 0.63 mV RMS noise level with resolutions of 35 nT.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Although numerous single-axis fiber-optic magnetometers have been constructed and tested for temperature and magnetic field characterization, production methods have not been defined.
Unique Software	None identified.
Major Commercial Applications	Near-term applications include nondestructive object location and classification for geophysical surveying, environmental remediation, industrial manufacturing, and civil engineering uses.
Affordability	These sensors should be relatively inexpensive to produce and use in naval systems.

BACKGROUND

Fiber-optic gradiometers have advantages over existing gradiometer mine-detection technologies, including wide operating temperature ranges, low power consumption, and small sizes and weights.

DATA SHEET 17.8. MINESWEEPING

Developing Critical Technology Parameter	A conductively cooled, low-temperature, superconducting magnet can be used to project magnetic flux densities sufficient to fire mine magnetic sensors. Because sea mines can use complementary acoustic sensors to detect propeller cavitation noise together with the ship's magnetic signature, spectral shaping of plasma discharge acoustic sources is being developed to emulate ship-like acoustic signatures.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Simulation tools to evaluate projected magnetic and acoustic signatures against mine logic and sensors are required to establish the effectiveness and extent of mine sweeps.
Unique Software	To accurately establish the effectiveness of the sweep approach, software must be developed to accurately portray a wide range of mine magnetic and acoustic responses.
Major Commercial Applications	None identified.
Affordability	Minesweeping is a very efficient method to rapidly clear lanes or specific areas of sea mines.

BACKGROUND

New mines use fuzes employing more than a single sensor for target acquisition. The co-generation of acoustic and magnetic signatures provides rapid clearance of complex fuzed mines. These minesweep systems can be deployed from remotely controlled surface craft or airborne towed vehicles.

DATA SHEET 17.8. EXPENDABLE UNDERWATER MINE HUNTERS

Developing Critical Technology Parameter	An expendable neutralization vehicle to be deployed from airborne mine countermeasure helicopters (MH–53E and SH–60) is being developed. A fiber-optic tethered cable from the expendable vehicle is used for data transfer for sonar and video acquisition of mine-like objects and for the shaped charge detonation sequence for mine neutralization. Future expendable systems that can perform autonomous searches without being fiber optically tethered to a manned platform are required. Precise navigation, communications back to a central point, and battle damage assessments are additional required capabilities.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Special software will have to be developed for mine identification and terminal placement and aiming before initiation of the neutralization sequence.
Major Commercial Applications	None identified.
Affordability	The principal cost issue is the development of a mine identification capability compatible with the expendable vehicle approach.

DATA SHEET 17.8. RAPID AIRBORNE MINE CLEARANCE SYSTEM

Developing Critical Technology Parameter	Airborne lidar systems that detect surface, moored, and tethered mines are used together with high-speed projectiles that can be fired at the detected mines. Super-cavitating projectiles will have on-board reactive material for mine neutralization. The clear advantage of this type of system is the significant reduction in mine clearance time compared with that of surface or submersible vehicles in mine clearance.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	Specific software must be developed for the on-board acquisition, identification, and targeting of mines targeted by the supercavitating projectiles.
Major Commercial Applications	None identified.
Affordability	For the system to be affordable, the system must provide a high probability of mine kill and a low-cost supercavitating bullet.

DATA SHEET 17.8. ENVIRONMENTAL FEEDBACK SYSTEMS

Developing Critical Technology Parameter	Existing and future detection systems can be rapidly updated through software updates provided by environmental feedback systems. Physics-based models are being developed that identify those spatial sediment properties which result in significant changes or errors in mine detection and identification. Electrical properties, combined with seismic and acoustic properties, will be developed to provide a rapid method to predict sediment characteristics that affect mine hunting, minesweeping, and mine neutralization. These properties will then be used to provide "through the sensor" improvements to mine countermeasure systems as they are introduced into new environments and scenarios.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Simulation testing will be required to establish through the sensor adjustments and refinements.
Unique Software	Mine countermeasure equipment software must be compatible with reprogrammed data from the environmental feedback system.
Major Commercial Applications	None identified.
Affordability	No cost issues have been identified.

BACKGROUND

The Navy is required to respond to regional conflicts throughout the world; tactical support of these operations within littoral regions requires accurate and timely environmental information. Because of the range in water optical and sediment properties, the ability of mine hunting, minesweeping, and mine neutralization sensors to rapidly and accurately distinguish mines can vary greatly. Provision of accurate, timely data will ensure that mine countermeasure equipment can perform optimally in a wide range of environments and sea states.

DATA SHEET 17.8. NUCLEAR QUADRUPOLE RESONANCE

Developing Critical Technology Parameter	NQR can provide very specific information on nitrogen-containing and halogenated compounds. NQR is basically a radio-frequency spectroscopy technique that results from the measurement of the effects due to the interaction of the nuclear quadrupole moment (in nonspheric nuclei) with the electric field gradient of the molecular/crystalline environment. Variations of the electric field gradient in different chemicals serve as the source of the fingerprint for identifying explosives. RDX is relatively easy to detect, TNT more difficult. Others are being investigated. The advantage of the technique is that it identifies the chemical directly. Also, the SNR limits detection, not clutter as in EMI techniques. The disadvantage is that chemicals encased in metal are not excited and cannot be detected directly. For metal-cased mines the instrument is used in a metal-detection mode (as a metal detector) NQR detects plastic antipersonnel and antitank mines buried in ground. For antitank mines, the probability of detection is greater than 95 percent at less than 6 in.; for antipersonnel mines it is less than 90 percent at greater than 3 in. Detection of mines in salt water is more difficult but not tested yet.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	NQR technology has been investigated as an explosive detector in airports.
Affordability	The technology is expensive to develop, but could be less expensive to procure in quantities.

DATA SHEET 17.8. ELECTROMAGNETIC INDUCTION DETECTION

Developing Critical Technology Parameter	New fast-response EMI detectors that use both real and quadrature data to determine the time constant rate of decay of mine targets have been developed. These new data provide the opportunity to detect and classify mine targets. This additional information also provides a basis for rejection of clutter, which will result in fewer false alarms. This new technique may also be able to detect the void produced by plastic mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	Special coils must be developed that can both transmit and detect time constants on the order of 1 µsec or less. The time constants associated with different soils and their attendant moisture must also be measured and appropriately archived.
Unique Software	New software must be developed to accurately and quickly evaluate these microsecond interrogations.
Major Commercial Applications	Coin, relic hunting detectors, or commercial detectors to detect metal pipes in the ground or behind walls.
Affordability	Technology is relatively inexpensive and straightforward.

BACKGROUND

EMI detectors are the most ubiquitous mine- and relic-hunting detectors. High thresholds can be used to distinguish large metallic landmines. Large amounts of metallic clutter on the battlefield lead to extremely high false-alarm rates when EMI detectors are used to find small antipersonnel landmines. New detection capabilities improve the ability to better distinguish mines from clutter.

DATA SHEET 17.8. SUPERCONDUCTING QUANTUM INTERFENCE DEVICES

Developing Critical Technology Parameter	SQUIDS are used together with signal-processing techniques to detect sea mines on the seabed or buried in the seabed. The distortion to the earth's magnetic field caused by metallic objects on or in the ocean floor is used to calculate the position of sea mines.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	The high sensitivity of the SQUID devices requires high platform stabilization and stabilization position information to accurately assess the presence of mines and clutter during detection sweeps.
Unique Software	Special software is being written to identify anomalies detected by these extremely sensitive detectors.
Major Commercial Applications	None identified.
Affordability	The development of extremely sensitive superconducting sensors for an ocean environment is expensive. The development risk is offset by the potential payoff for operations to be conducted in the littorals.

DATA SHEET 17.8. REACTIVE MUNITIONS

Developing Critical Technology Parameter	Projectiles either lined with pyrophoric materials or composed of pyrophoric materials can be used to initiate burning as they pass through a target. In the case of both land and sea mines, the burning can lead to total consumption of the explosive charge or to detonation. The critical issues are the projectile velocities needed to effect penetration and the type of pyrophoric material capable of initiating burning in explosives at the chosen velocities.
Critical Materials	At high velocities, a number of materials are known to react pyrophorically with explosives. The use of these materials as liners could make the projectiles less costly and better suited to existing canons, launchers, etc.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	None identified.
Affordability	This approach must be tied to a detection/homing system with a low false-alarm rate. High false-alarm rates will make the system extremely expensive.

DATA SHEET 17.8. HIGH-PRESSURE WATER JETS

Developing Critical Technology Parameter	High-pressure (2,000–100,000 psi) water jets fired at mines can rapidly penetrate the mine case and cause destruction of the mine main explosive charge. Devices that can be backpack-mounted have been demonstrated for use by dismounted troops against antipersonnel land mines. Larger devices that are mounted on tactical and amphibious vehicles for use against antitank and sea mines have also been demonstrated.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	None identified.
Unique Software	None identified.
Major Commercial Applications	Water jets are commercially used in agricultural, mining, and cutting applications.
Affordability	Small backpack systems to neutralize individual mines are relatively inexpensive. Larger water jets need to be mounted on amphibious or remotely controlled underwater vehicles and are moderately expensive.

BACKGROUND

Many operational environments require that individual mines and unexploded ordnance be cleared or neutralized individually. High-pressure water jets are an ideal method for quickly neutralizing these devices without actuating the main explosive charge. Underwater and explosive ordnance disposal applications are ideally suited to this technology approach because they minimize collateral damage during the neutralization process.

DATA SHEET 17.8. PRECISION-GUIDED SUBMUNITIONS

Developing Critical Technology Parameter	Precision-guided submunitions are being investigated as a method for rapidly breaching mine areas in beach areas. The approach requires airborne targeting, homing, and lethal payloads in submunitions.
Critical Materials	None identified.
Unique Test, Production, Inspection Equipment	The complex systems must be matured in simulation before expensive field testing.
Unique Software	New software must be developed for mine targeting.
Major Commercial Applications	None identified.
Affordability	The development cost of this system will be expensive.