Chapter I

EXECUTIVE SUMMARY

Technological superiority continues to be a cornerstone of our national military strategy. Technologies such as radar, jet engines, nuclear weapons, night vision, smart weapons, stealth, the Global Positioning System, unmanned air vehicles, and vastly more capable information technology systems have changed warfare dramatically. Today's technological edge allows us to prevail across the broad spectrum of conflicts decisively and with relatively low casualties. Maintaining this technological edge has become even more important as the size of U.S. forces decreases and as high-technology weapons are now readily available on the world market. In this stressful environment, it is imperative that U.S. forces possess technological superiority to achieve and maintain dominance across the full spectrum of crises and military operations. The technological advantage we enjoy today is a legacy of decades of investment in science and technology (S&T). Likewise, our future warfighting capabilities will be substantially determined by today's investment in S&T.

In peace, technological superiority is a key element of deterrence. In crisis, it provides a wide spectrum of options to the National Command Authorities and combatant commanders (CCs), while providing confidence to our allies. In war, it enhances combat effectiveness, reduces casualties, and minimizes equipment loss. In view of declining defense budgets and manpower reductions, advancing military technology and ensuring that it undergoes rapid transition to the warfighter are national security obligations of ever greater importance.

An assessment of U.S. military forces and capabilities is accomplished every 4 years and becomes the Quadrennial Defense Review (QDR), which makes recommendations for improvements in Department of Defense (DoD) capabilities and operations. The latest QDR Report (Reference 1) was published on September 30, 2001. In the foreword of the 2001 QDR Report, the Secretary of Defense enunciated a paradigm shift in "the basis of defense planning from a 'threat-based' model that dominated thinking in the past, to a 'capabilities-based' model for the future." This capabilities-based model focuses more on how adversaries might fight rather than specifically who the adversary might be or where a war might occur.

In responding to the strategies and plans outlined in the QDR Report and the *Joint Operations Concepts* (JOpsC) (Reference 2), the Director of Defense Research and Engineering (DDR&E) provides management oversight as well as guidance and direction for the DoD Science and Technology program. The Science and Technology Planning Process is depicted in Figure I–1.

To fulfill these obligations for a strong defense S&T program, DDR&E has continued to enhance the strategic planning process for defense S&T. The foundation of this process is the *Defense Science and Technology Strategy* (Reference 3) with its supporting *Basic Research Plan* (BRP) (this document), the *Joint Warfighting Science and Technology Plan* (JWSTP) (Reference 4), and the *Defense Technology Area Plan* (DTAP) (Reference 5). The Defense S&T Strategy, last published in May 2000, is currently being revised. The JWSTP and DTAP documents are also being updated and will be published in February 2005. These documents present the DoD S&T vision, strategy, plan, and objectives for the planners, programmers, and performers of defense S&T.

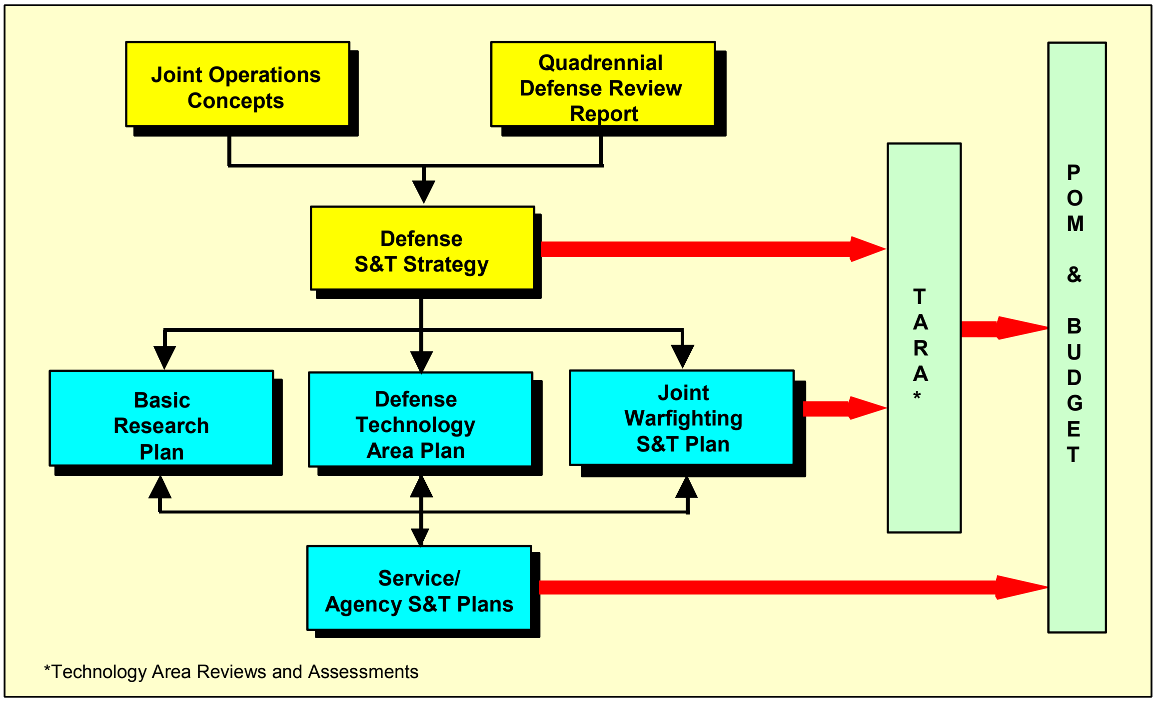

Figure I–1. Science and Technology Planning Process

These documents are a collaborative product of the Office of the Secretary of Defense (OSD), Joint Staff, CCs, military services, and defense agencies. The strategy and plans are fully responsive to the QDR Report and the JOpsC, as shown in Figure I–1. The strategy and plans and supporting individual S&T master plans of the military services and defense agencies guide the annual preparation of the defense program and budget. The strategy and plans are made available to the U.S. Government and defense contractors, and our allies, with the goal of better focusing our collective efforts on superior joint warfare capabilities and improving interoperability between the military services.

The *Basic Research Plan* presents the DoD objectives and investment strategy for DoD-sponsored basic research (6.1) performed by universities, industry, and service laboratories. In addition, the BRP presents the planned investment in each of 12 technical disciplines composing the Basic Research Program.

The coupling of the BRP with the DTAP and the JWSTP is carried out in several ways. First, the planning stage of the 12 technical disciplines has the active participation of both the service laboratories and the warfighters (through the operating commands, such as the Army's Training and Doctrine Command (TRADOC)). This activity takes place by providing requirements and, sometimes, serving on planning committees that focus on or include basic research. Second, representatives of the service laboratories and operating commands also take part in the program evaluation process through attendance and participation in service S&T program reviews and the Technology Area Reviews and Assessments (TARAs) conducted under the auspices of the Office of the Deputy Under Secretary of Defense for Science and Technology (ODUSD(S&T)).

A. DEFENSE BASIC RESEARCH VISION

The Defense Basic Research Program vision is to ensure that fundamental scientific and engineering knowledge and understanding continue to yield both evolutionary and revolutionary technical options required to maintain preeminent warfighting capabilities and a superior national defense capability.

B. DEFENSE BASIC RESEARCH MISSION

The mission of the DoD Basic Research Program is to continue to conduct comprehensive basic research programs that will:

- Provide a strong science and engineering basic research foundation for the discovery and enhancement of new and future technologies required to support the mission of the Department of Defense, by ensuring the availability of a trained scientific workforce in technologies critical for national defense, and the necessary facilities in academia, industrial laboratories, and DoD establishments to perform advanced research.
- Assist in the development of revolutionary military capabilities and systems so that the U.S. military continues to be the best in the world, by providing a stream of basic research results transitioning into applied research and advanced development to ensure that the best available technology reaches the warfighter in the shortest possible time.
- Keep DoD informed of worldwide technological developments and opportunities that might affect U.S. defense—for better or for worse—by focusing on technologies of critical importance to national defense, while maintaining a balanced research program ready to exploit unexpected opportunities or counter unforeseen technological threats.

C. UNDERSTANDING WARFIGHTER NEEDS

The DoD *Defense Science and Technology Strategy* (Reference 3) emphasizes that the Defense Science and Technology Program must "ensure that the warfighters of today and tomorrow have superior and affordable technology to support their missions and provide revolutionary war-winning capabilities. To do this, we must understand the warfighters' needs." DDR&E oversees this strategy for the Secretary of Defense.

In today's global environment, the U.S. military must dominate the full range of military operations—from humanitarian assistance to homeland defense and from counterterrorism to major theater warfare. The key to achieving this full-spectrum dominance is the ability to acquire information superiority and the enabling technologies. In addition, the key to warfighting success is the technologies that make our forces lighter, more mobile, and more lethal. Technological superiority is the principal characteristic of our military advantage.

The *Joint Warfighting Science and Technology Plan* (Reference 4), one of three plans that describe how the DoD S&T strategy will be implemented, describes service/agency investments focused on attaining specific capabilities identified by the Functional Capability Boards (FCBs) associated with each of eight Joint Functional Concepts: (1) Battlespace Awareness, (2) Command and Control, (3) Force Application, (4) Protection, (5) Focused Logistics, (6) Net-Centric, (7) Joint Training, and (8) Force Management. The Defense S&T Program addresses these Joint Functional Concepts in basic research by focusing a significant portion of S&T investment in five areas: (1) information assurance, (2) battlespace awareness, (3) force protection, (4) reduced cost of ownership, and (5) maintaining a balanced basic research portfolio. These five areas are briefly discussed below.

1. Information Assurance

Information assurance remains a core research area for DoD. Research activities related to cyberterrorism, information warfare, and information operations as well as better protection for defense critical information systems are priorities both on the battlefield and for homeland security.

2. Battlespace Awareness

Battlespace awareness (situational awareness and understanding coupled with information assurance) is needed to provide real-time knowledge "from sensor to shooter." In principle, smart sensor webs integrating networks of sensors with cognitive readiness systems will enable U.S. warfighters to exploit battlespace awareness. Basic research is needed to develop the foundations for real-time imagery with automatic target recognition capability. New physical models employing dynamic, intelligent databases are needed to enable real-time intelligence for the warfighter. The extremely large amount of information will require technical tools to help sort, mine, understand, and act in real time.

3. Force Protection

The 21st century warfighter must have the capabilities to survive, fight, and win in a contaminated environment. Investments are needed in research and technology development to provide improved capabilities necessary to protect our forces against chemical and biological threats while minimizing adverse impacts on our warfighting capability.

4. Reduced Cost of Ownership

An increased emphasis is being placed on affordability as a leading investment factor governing the S&T program. Research must be conducted to reduce the cost of operating and maintaining force readiness. One example is the research on improving combustion efficiency of mechanical energy generators and thereby reducing the operating, transportation systems, and associated logistics costs.

5. Maintaining a Balanced Basic Research Portfolio

New military capabilities and operational concepts emerge from basic research. Basic research is a long-term investment with emphasis on opportunities for military applications far into the future. Furthermore, it contributes to our national academic and scientific knowledge base by providing substantial support for all science and engineering. Basic research investments over a long period of time have contributed significantly to new warfighter capabilities—low observables (stealth), lasers, infrared night vision, and microelectronics for precision strike, to name but a few. Many of these major advances were unpredictable. No promising avenue of research should be neglected. Although areas of emphasis may change, it is important to maintain a balanced portfolio in order to be prepared to deal with unforeseen developments anywhere in the world. Investments in defense basic research should help to prevent technological surprises by our adversaries.

Since most research applications require progress across several disciplines, an increased emphasis has been placed on multidisciplinary research activities. The Multidisciplinary University Research Initiative (MURI) program (Chapter VII) is a prime example of the approach to maintain a balanced research portfolio. Another approach is building on current single disciplinary research areas by coordinating them into multidisciplinary efforts. The Strategic Research Areas (Chapter VI) focus attention on a few research areas that offer significant and comprehensive benefits to warfighting capabilities that will foster earlier warfighting applications than might otherwise be possible.

D. OBJECTIVES OF DEFENSE BASIC RESEARCH

Defense basic research is focused in those fields of the physical, environmental, life, and engineering sciences appropriate to meeting long-term national security needs. Although often farsighted and risky, the research can have high payoffs in terms of future military systems. Defense basic research aims to serve as a catalyst to critical technologies that provide the basis for technological progress. As the results of defense basic research are transitioned, they support key military visions and concepts that provide new and improved military functions and capabilities.

Achieving these objectives in the coming decades requires that DoD's S&T programs:

- Maintain technological superiority in warfighting equipment and operations.
- Provide the knowledge basis for technical solutions that ensure opportunities for achieving breakthrough joint warfighting capabilities.
- Balance basic and applied research in pursuing technological advances.
- Incorporate affordability as a design parameter.

The *Quadrennial Defense Review Report* (Reference 1) identifies six critical transformational capabilities:

- Protect bases of operation at home and abroad and defeat the threat of chemical, biological, radiological, nuclear, and explosive (CBRNE) weapons.
- Deny enemies sanctuary by providing persistent surveillance, tracking, and rapid engagement.
- Leverage information technology and innovative concepts to develop interoperable joint command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR) anti-access capability.
- Project and sustain U.S. forces in distant anti-access and area-denial environments.
- Enhance the capability and survivability of space systems.
- Ensure the survival of information systems in the face of attack and conduct effective information operations.

These six QDR capabilities have four transformational attributes:

- Knowledge
- Agility

- Speed
- Lethality.

The *Joint Operations Concepts* (Reference 2) of the Office of the Joint Chiefs of Staff describes how the joint force will operate across the entire range of military operations within the next 15 to 20 years. It was signed by the Secretary of Defense in November 2003 and provides the operational context for the transformation of the U.S. Armed Forces. The JOpsC serves as the unifying framework for developing subordinate Joint Operating Concepts, Joint Functional Concepts, Enabling Concepts, and integrated capabilities. It provides the foundation for the development and acquisition of new capabilities through changes in doctrine, organization, training, materiel, leadership and education, personnel, and facilities, and assists in structuring joint experimentation and assessment activities to validate subordinate concepts and capabilities-based requirements.

The services' visions are contained in the following documents:

- Army—*2004 Army Transformation Roadmap* (Reference 6)
- Air Force—*Global Engagement: A Vision for the 21st Century Air Force* (Reference 7) and the *Air Force Transformational Flight Plan* (Reference 8)
- Navy—*Naval Power 21… A Naval Vision* (Reference 9) and *Navy Long Range Planning Objectives* (Reference 10)
- Marine Corps—*Operational Maneuver From the Sea* (Reference 11).

Taken together, these vision documents describe the concepts of operations and define the capabilities needed to meet the 21st century challenges. They establish the goals for DoD to achieve in the future and define the investment in science and technology. Basic research is a vital part of the S&T program, providing technological opportunities and fundamental understanding of processes and materials on which to base future military technologies.

Basic research is conducted in the context of the five overarching goals adopted by the Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)):

- Achieve credibility and effectiveness in the acquisition and logistics support process.
- Revitalize the quality and morale of the DoD acquisition, technology, and logistics workforce.
- Improve the health of the defense industrial base.
- Rationalize the weapon systems and infrastructure with defense strategy.
- Initiate high-leverage technologies to create the warfighting capabilities, systems, and strategies of the future.

E. TRANSFORMATION INITIATIVES

The Director of Defense Research and Engineering has determined that, in response to the need to develop research programs supporting the critical QDR transformation initiatives, defense science and technology would focus efforts on three transformation enablers:

- *An integrated national framework for aerospace technologies.* This effort seeks to advance aerospace capabilities by emphasizing research and development in three major technology areas: hypersonic flight, access to space, and advanced space technologies. Key developments will include a supersonic/hypersonic missile; high-speed unmanned vehicles; long-range reconnaissance/strike aircraft; and access to lower cost, reusable space vehicles. This initiative will provide support for university and defense laboratory basic research programs that will advance basic understanding of fundamentals along with the support of engineering and science education in fields such as aerospace engineering, advanced materials, advanced energy and power, nanoscience, and other physical sciences.

- *Surveillance and knowledge systems.* This effort will focus on four technical thrust areas: sensors and unmanned vehicles, high-bandwidth communications and information assurance, information/knowledge management systems, and cyberwarfare.
- *Energy and power systems.* This effort will lead to significant reductions in the size and weight of platforms while improving performance. The primary focus will be on four technology areas: power generation, energy storage, power management and control, and directed energy. These areas should provide much greater capabilities to generate, store, and supply electrical and other forms of energy to nearly all air, ground, and sea platforms.

F. THE PAYOFF

Technological breakthroughs and revolutionary military capabilities are difficult to predict from today's investments in basic research. In most cases, the full impact of scientific research does not become apparent until many years after its initiation. It is usually only in hindsight that one discerns the patterns of research that introduced the world to such revolutionary capabilities. However, we know that many of our current military capabilities and systems can be traced back to earlier basic research programs. Many payoffs to the Nation have occurred from timely DoD investments in basic research. Typical of the successes of research transitioned to actual systems in the field are the following:

- Global Positioning System
- Night vision technology
- Airborne Laser
- Internet and World Wide Web
- Satellite technology
- Stealth technology.

A brief description of each of these successes follows.

1. Global Positioning System

Navies have always been concerned with precision navigation on a featureless ocean. The U.S. Navy, working through the Office of Naval Research (ONR), supported basic research that led to an atomic clock (a hydrogen maser) with an accuracy corresponding eventually to a few feet in all three dimensions anywhere on Earth.

The technology underlying the hydrogen maser clock relied on research from atomic spectroscopy studies supported by ONR. Later, advances in satellite technology, coupled with such ultra-precise atomic clocks, helped to provide precision location and navigation. The ONR-funded research, coupled with Air Force–supported research into coded transmission techniques, provided precise ranging and timing data anywhere on Earth from a constellation of Global Positioning System (GPS) satellites. These satellites enabled the development of precision weapon delivery systems that can operate in all weather conditions and engage targets with accuracy on the order of less than 1 meter. Steady investments in basic research over many years have been amply repaid by the superiority of our precision weapon systems. The GPS was a tremendous asset during the Persian Gulf, Kosovo, and recent Iraqi Freedom engagements. The civilian spinoff of GPS is well known.

2. Night Vision Technology

The development of thermal imaging devices—based on long-term basic research in microelectronics, signal processing, and especially advanced materials—has permitted the U.S. Army to "own the night." The original theoretical techniques were proposed in the 1950s. Investigations supported by the Army Research Office (ARO) led to the discovery that the bandgap of mercury cadmium telluride could be engineered with sufficient sensitivity to detect natural thermal emissions. Basic research over a 30-year period into the science of semiconductor materials, metal–semiconductor interfaces and photoemission phenomena, and masers and lasers led to significant military capabilities to image targets at night. The successful use of thermal imaging systems in Desert Storm and the Iraqi Freedom engagements vividly demonstrated the benefit of these systems, giving the U.S. forces a decided military advantage. This successful application provides ample justification for basic research investments made by the Army to advance technology over a period of 35 years; moreover, it has now resulted in commercial and medical applications as well.

3. Airborne Laser

The current Airborne Laser (ABL) program was enabled by basic research (supported by the Air Force Office of Scientific Research (AFOSR)) into laser beam generation techniques and propagation through the atmosphere. Successes in solving the atmospheric turbulence problem have revolutionized the ability to transmit laser beams through the atmosphere and have dramatically improved the ability of *ground-based* telescopes to obtain images of astronomical objects that rival those taken from space by the Hubble Space Telescope. Much of this work was initiated before definitive military requirements were established.

4. Internet and World Wide Web

Another significant breakthrough was the initial development of the Internet by the Defense Advanced Research Projects Agency (DARPA). Many of the investments in basic computer science and technology led to the Advanced Research Projects Agency Network (ARPA-Net), which eventually evolved into the World Wide Web—impacting every aspect of civilian and military life. This modest DoD research investment has spawned an entire multi-billion-dollar information technology industry, which, in turn, has fueled the Nation's economy.

5. Satellite Technology

DoD's early research into satellite technology and space systems has led to today's use of satellites for communications, navigation, and surveillance (including weather observations), thus making the United States more secure through rapid, worldwide communications, precision weapons, and valuable intelligence. Without the DoD investment, the space communications industry would have been slower to develop systems of direct benefit to the Nation's warfighters.

6. Stealth Technology

AFOSR, DARPA, and other government agencies were instrumental in supporting Dr. Joseph B. Keller's initial research on how light and radar are reflected by objects. In an effort to find the key to better radar systems, an AFOSR-supported investigation brought about the development of mathematical formulas that formed the basis for the early research into low-observables technologies, or stealth. The design of the F–117 aircraft not only saves lives but also protects millions of dollars of technology and will continue to do so in future generations of aircraft.