Report of the
Defense Science Board
Task Force on

Basic Research

January 2012

Office of the Under Secretary of Defense
for Acquisition, Technology and Logistics
Washington, D.C. 20301-3140

This report is a product of the Defense Science Board (DSB).

The DSB is a Federal Advisory Committee established to provide independent advice to the Secretary of Defense. Statements, opinions, conclusions, and recommendations in this report do not necessarily represent the official position of the Department of Defense (DOD). The DSB Task Force on Basic Research completed its information gathering in April 2011. The report was cleared for open publication by the DOD Office of Security Review on December 7, 2011.

This report is unclassified and cleared for public release.

DEFENSE SCIENCE
BOARD

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301–3140

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY, AND LOGISTICS

SUBJECT: Report of the Defense Science Board Task Force on Basic Research

I am pleased to forward the final report of the Defense Science Board Task Force on Basic Research. The report offers important considerations for the Department of Defense to maintain a world-dominating lead in basic research. Beginning with efforts supporting World War II, the United States built a commanding scientific infrastructure second to none, and reaped considerable military and economic benefits as a result.

The task force took on the task to both validate the quality of the existing DoD basic research program and to provide advice on long-term basic research planning and strategies. Overall, the task force found the current DoD basic research program to be a very good one, comparable to other basic research programs in the government and well-suited to DoD needs. The managers are highly qualified, reviews are plentiful, and coordination is excellent. As is true for most programs in the DoD, however, less bureaucracy and more transparency would be welcome improvements.

In the area of long-term basic research planning and strategies, the task force investigated four topic areas, making recommendations for actions in each of them:

- A more concerted effort is needed to ensure that the U.S. scientific human resources needed by the Department for global military competition will be available, and not assume that it will be so without such determined effort.
- An increasing fraction of the world's basic research is being conducted outside the United States as part of a larger trend toward the globalization of science. In order to avoid technological surprise, it is important for DoD to be involved in the cutting edge of basic research on topics of specific interest to the Department—whether the cutting edge is in the U.S. or overseas.
- A technology strategy is needed that contains objectives expressed with clarity, quantification, priority, and timing. A genuine technology strategy would not only be invaluable in alignment of basic research, but also in alignment of systems, missions, and national security affairs more broadly.

- While basic research was not identified as a barrier to a healthy innovation ecology in DoD, several factors related to the current defense acquisition system were found to limit innovation in major DoD systems.

DoD can dominate the world's military organizations in being able to use basic research results to create new and enhanced military capabilities, by dint of financial resources, infrastructure, and national culture. The task force offers their recommendations that will ensure this continues for decades to come.

For these reasons, I endorse all of the study's recommendations and encourage you to adopt them into the operations of the Office of Acquisition, Technology and Logistics.

Paul G. Kaminski

Dr. Paul Kaminski
Chairman

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DEFENSE SCIENCE BOARD

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: FINAL REPORT OF THE DEFENSE SCIENCE BOARD TASK FORCE ON BASIC RESEARCH

The Department of Defense funds basic research in a wide variety of scientific and engineering fields with a goal of exploiting new knowledge to enhance—and where possible, transform—future capabilities. DoD-funded research is known for high- risk endeavors that have led to paradigm shifts in the nation's technical capabilities.

The task force took on the task to both validate the quality of the existing DoD basic research program and to provide advice on long-term basic research planning and strategies. Overall, the task force found the current DoD basic research program to be a very good one, comparable to other basic research programs in the government and well-suited to DoD needs. The managers are highly qualified, reviews are plentiful, and coordination is excellent. As is true for most programs in the DoD, however, less bureaucracy and more transparency would be welcome improvements.

In the area of long-term basic research planning and strategies, the task force investigated four topic areas, making recommendations for actions in each of them:

- A more concerted effort is needed to ensure that the U.S. scientific human resources needed by the Department for global military competition will be available, and not assume that it will be so without such determined effort.

- An increasing fraction of the world's basic research is being conducted outside the United States as part of a larger trend toward the globalization of science. In order to avoid technological surprise, it is important for DoD to be involved in the cutting edge of basic research on topics of specific interest to the Department—whether the cutting edge is in the U.S. or overseas.

- A technology strategy is needed that contains objectives expressed with clarity, quantification, priority, and timing. A genuine technology strategy would not only be invaluable in alignment of basic research, but also in alignment of systems, missions, and national security affairs more broadly.

- While basic research was not identified as a barrier to a healthy innovation ecology in DoD, several factors related to the current defense acquisition system were found to limit innovation in major DoD systems.

Taken together, the issues addressed in the study point to the important role of basic research in the continuing success of the DoD mission. DoD dominates the world's military organizations in being able to use basic research results to create new and enhanced military capabilities, by dint of financial resources, infrastructure, and national culture. The task force offers their recommendations that will ensure this trend continues for decades to come.

Dr Craig Fields
Co-Chair

Dr Lydia Thomas
Co-Chair

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Executive Summary

The Department of Defense (DOD) funds long-term basic research in a wide variety of scientific and engineering fields with a goal of exploiting new knowledge to enhance—and where possible, transform—future capabilities. DOD-funded research is known for high-risk endeavors that have led to paradigm shifts in the nation's technical capabilities. In many cases, DOD was the first to seed new research performed by many of the world's leading scientists and engineers at universities, federal laboratories, and private industry.

The Defense Science Board (DSB) was charged in August 2010 to validate the quality of the DOD basic research program and to provide advice on long-term basic research planning and strategies for the Department of Defense.

Soon after the task force began its work, the DSB was asked to address additional areas of focus by the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)). The Assistant Secretary asked the task force to advise how the Department should structure its basic research program to incentivize invention, innovation, and the transition of ideas to end-use.

Assessment of the Current DOD Basic Research Program

Overall, the task force found the current DOD basic research program to be a very good one, comparable to other basic research programs in the government and well-suited to DOD needs.

DOD Basic Research Program Manager Qualifications

All of the major decisions relative to DOD-funded basic research—what areas of science to fund, relatively how much to fund each area, how to select the researchers and research projects to fund in each area, how to assess progress of each project—are highly subjective. Because the key decisions are subjective, it is especially important that the individuals making those decisions be highly qualified.

The task force knows of no way to objectively assess the overall qualifications of the DOD basic research program managers, but considered their education as scientists as a reasonable proxy. The task force received information (edited for them to remain anonymous) on the education of the executives in the Services, the Defense Advanced Research Projects Agency (DARPA) and the Office of the Secretary of Defense (OSD) who make decisions regarding basic research (the vast majority of whom have PhDs), and analyzed that information relative to a ranking of the top American research universities. Acknowledging that such ranking is itself subjective, most of DOD's executives making decisions regarding basic research have PhDs from the top tier of American universities—impressive qualifications for doing their jobs.

Project and Program Reviews

The task force finds that there are myriad formal mechanisms in place for assessing the quality of basic research in DOD, and considers those fully adequate. Additional review, inspection, and assessment are not needed and could be harmful.

Assessing the Nature of Funded Research Labeled "Basic"

A study was conducted by the Director for Basic Research in ASD(R&E) to determine if DOD basic research was truly basic in nature, or if it was actually of an applied nature. The study reviewed papers, which appeared in peer-reviewed journals, of research conducted with funding from the DOD basic research program. The large majority of the papers was deemed to be, in fact, basic—not applied—research.

Coordinating Among DOD Basic Research Programs

A number of formal mechanisms are in place for coordination among DOD basic research programs, and the task force finds those fully adequate. Furthermore, basic research program managers do a good job of coordinating their respective portfolios across DOD. The performance of excellent program managers acting on their own volition is most important, and the formal coordination mechanisms are a distant second in importance.

Coordinating Among Federal Basic Research Programs

In parallel, there are a number of formal mechanisms in operation for coordination between DOD basic research activities and rest-of-government basic research programs, and the task force finds them fully adequate. Again, the informal coordination among excellent program managers is much more important than the operation of formal committees.

Efficiency of DOD Funding

The task force examined the flow of basic research funding from congressional appropriation to disbursement, documenting the cost of doing business, using the Air Force as an example. The overall conclusion of the task force is that the efficiency of DOD funding of basic research is consistent with comparable activities.

Burdensome Business Practices Affecting Basic Research

The task force found an alarming level of bureaucratic business practices hindering the conduct of basic research. The challenge is that there are so many sources of bureaucratic burden: legislation; administration requirements imposed from outside DOD; requirements imposed from within DOD; requirements imposed by the Services; and requirements imposed by the basic research-performing organizations themselves, both intramural and extramural. The phrase used within the task force was "death of a thousand cuts."

Unnecessary and unproductive bureaucratic burden on basic researchers funded by DOD equates to reduction of the DOD basic research budget. Reducing that burden is perhaps the most important task to improve the current DOD basic research program. The task force recommends that the Director for Basic Research in ASD(R&E) serve as an ombudsman, seeking to document, eliminate, or waive such unproductive activities.

Overarching Observations

A significant handicap for conducting the study was the difficulty of getting data on the DOD basic research program. What should have been easily retrievable data required huge time-consuming, labor-intensive efforts to collect and assemble due to the lack of a modern management information system that would enable answering questions posed by DOD leadership. It is difficult to have management without management information.

Relative to the organizational structure of the DOD basic research program, over the years a number of alternatives have been considered for the conduct of basic research, in order to improve funding efficiency, coordination, or planning. Combining all basic research from across the Services into one organization is one such variant. The task force concludes that any potential savings, or other supposed benefits, that might accrue from such a restructuring would be far outweighed by distancing basic research from applied research and from the military operators. Furthermore, centralization would eliminate the diversity of views so important for the conduct of basic research.

In sum, the task force found the current DOD basic research program to be a very good one, comparable to others in the federal government and well-suited to DOD's needs. While nothing is ever so good it cannot be improved, the only area found where improvement would make a significant difference would be to reduce the unnecessary bureaucratic burden imposed at all levels of the basic research organization.

Human Resources and Globalization of Science

While the task force has high regard for the current DOD basic research program, there is a long-term concern. An increasing fraction of the world's basic research is being conducted outside the United States. There is a vastly increased rate of growth in the number of non-U.S.-citizens graduating with advanced science degrees, awarded by both U.S. universities and by colleges abroad. More and more scientific publications are based on work done overseas. And there are many other indicators of the trend toward globalization of science.

DOD devotes about 97 percent of its basic research resources to supporting scientific work within the United States. That may have been the right decision in decades past when the United States had a commanding leadership role in almost all areas of science of importance to DOD, but the task force believes a change in strategy is needed for future decades.

In the future, DOD might find itself disadvantaged in the global competition for advanced military capabilities, given the increased rate of growth in the number of non-U.S.-citizens graduating with advanced science degrees, both in the United States and overseas, compared to those granted to U.S. citizens and permanent residents.

To aggravate the situation, most of the scientific work now done in the United States lies outside DOD's purview and, thus, DOD no longer has access to much of the nation's best and brightest science talent as it did during the Cold War.

DOD must address globalization of science both by ensuring U.S. scientific human resources are available to the Department, and by keeping abreast of basic research conducted around the world.

Human Resources

DOD must make a more concerted effort to ensure that the U.S. scientific human resources needed by the Department for global military competition will be available, and not assume that it will be so without such determined effort.

The DOD basic research funding agencies and Services can and should do much better in capitalizing on the talent of the basic researchers that they fund. By systematically exposing these researchers to the "hard" problems that DOD would like to solve, the researchers offer a potential pool of fresh new ideas to help solve DOD problems. In general, the top researchers in the country are very interested in contributing to the solution of hard problems. When effectively exposed to such problems they inevitably respond with enthusiasm to offer thoughtful and creative potential solutions. The task force recommends that the Services and DARPA expand and accentuate efforts to involve basic researchers in solving DOD's challenging problems, in addition to and not instead of conducting basic research. Programs to that end, *e.g.*, the Defense Science Study Group of DARPA, have proven effective, but more is needed.

Turning to the education of scientists, DOD supports a substantial number of undergraduate and graduate students, primarily through research assistantships and DOD's research awards, as well as through a number of science, technology, engineering, and mathematics programs. Nevertheless, the task force recommends that DOD's programs be expanded both with respect to the number of U.S. students supported, and so that the amount of stipends be competitive with career alternatives.

DOD's Service laboratories conduct about a quarter of the Department's basic research, and harmonize basic and applied research informed by the needs of military operations. The task force recommends that laboratory directors strengthen their partnerships with leading universities, ensure that existing authorities are fully used to hire outstanding scientists on a term basis, and work with the military services to create additional billets at DOD laboratories for qualified military officers so as to make science and technology a valued component of a military career path.

While the fundamental qualifications of DOD's basic research program managers are exemplary, continuing attention is needed to refresh those qualifications. The task force recommends that DOD basic research program office directors encourage rotation of active researchers from academia, industry, or federally funded research and development centers (FFRDCs), with tours averaging perhaps four years; that program managers have sufficient sabbatical time, or part-time, to keep their skills sharp by performing personal scientific research and publishing in peer-reviewed journals; and that there be adequate time and funds available for DOD basic research program managers to participate in professional activities.

Globalization of Science

DOD must do an even more effective job in keeping abreast of basic research conducted around the world. In order to avoid technological surprise, it is important for DOD to be involved in the cutting edge of basic research on topics of specific interest to the Department—whether the cutting edge is in the U.S. or overseas.

By far the most effective way to learn what is going on elsewhere is to work and do basic research there, side-by-side with foreign researchers—not just read publications, fund overseas researchers, attend conferences, run small local offices, or make short visits, valuable as those activities may be. U.S. industry has long recognized the trend toward globalization of science. Major corporations have approached the challenge by establishing research entities in strategic locales populated by a mixture of U.S. citizens and local scientists, and have populated research entities in the U.S. with the same mix.

The fraction of the DOD basic research program that is devoted to supporting overseas efforts is not commensurate with the inexorable rise in the fraction of the world's basic research being conducted outside the United States. The task force recommends the establishment of research entities overseas, which might be a satellite of a DOD laboratory, might involve a relationship with a university or other research institution overseas, may involve government-to-government partnership, or other alternatives. Further, the task force recommends that DOD laboratory directors increase the locations at U.S. Service laboratories where foreign researchers can work on basic research, and that DOD basic research office directors should support DOD laboratory and U.S. university researchers to do work overseas.

In short, notwithstanding the favorable assessment of the current DOD basic research program, DOD must give the highest priority to properly addressing globalization of science over the coming decade.

Strategy and Innovation

DOD Needs a Technology Strategy

DOD is moving toward development of a technology strategy, but that task is far from complete. The task force believes that intuition borne of experience will be insufficient to ensure that the areas of basic research supported in-depth by DOD are the ones most important for enabling the technology and systems required for future military capabilities, largely because of the emergence of new adversaries with new tactics and new weapons, with which the U.S. has little experience. Intuition needs to be joined with analysis.

A list of critical technologies does not constitute a technology strategy; nor does a summarizing description of ongoing activities and funding. What's needed are objectives expressed with clarity, quantification, priority, and timing; credible if unproven technical ideas with promise for achieving the objectives; demonstration of the system and mission consequences of achieving—or not achieving—the objectives; and actionable plans for developing the credible ideas in pursuit of the objectives.

A genuine technology strategy would not only be invaluable in alignment of research and engineering, but also in alignment of systems, missions, and national security affairs more broadly.

The task force strongly urges the Department to proceed smartly with the development of a genuine technology strategy that could inform basic research priorities.

Challenges in DOD's Innovation Ecology

On a number of occasions the task force heard concerns that the overall level of innovation within DOD is falling short of what should be possible and what would be desirable. And, furthermore, that the reasons for that shortfall in innovation are somehow related to the research program *per se*, and to the interaction among Service laboratories, universities, companies, and other organizations performing research for DOD.

The task force believes that is not the case, but by a very wide margin the greatest hindrance and handicap of innovation for DOD is the Department's acquisition system and, in particular, the requirements system. The basic research program itself is not a significant inhibitor to DOD innovation nor is it the rate limiter in DOD's innovation process.

It is <u>not</u> the purpose of this task force to pen yet another report on reforming the DOD acquisition system and, in particular, the DOD requirements process. Nevertheless, a few observations are warranted insofar as the potential impact on defense innovation by DOD's basic research program is so compromised by what happens downstream of the scientist's laboratory.

At least five factors related to the current defense acquisition system serve as anchors in limiting the degree of innovation that is found in major DOD systems:

1. the extensive time it takes to bring a system from concept and early exploration to a mature product (years or decades)
2. requirements specifications that focus on a particular implementation approach and solution far too early in the process
3. a risk-adverse climate
4. a disconnect with small, flexible, innovative organizations
5. a failure to require flexibility as a major attribute of new systems

The task force recommendations regarding the acquisition and requirements processes parallel those of over a hundred earlier studies and will not be repeated here. The motive for addressing the matter in a study on DOD basic research is to ensure that the Department's efforts to enhance innovations are properly focused on the acquisition system insofar as improvement of the basic research program would yield consequences marginal at best.

In Sum

DOD can dominate the world's military organizations in being able to use basic research results to create new and enhanced military capabilities, by dint of financial resources, infrastructure and national culture—if DOD can overcome the immense burden of its acquisition system, and if DOD pays sufficient attention to worldwide basic research. In principle, worldwide basic research could benefit DOD disproportionally among global armed forces.

Introduction

The Defense Science Board (DSB) was charged in August 2010 to validate the quality of the basic research program and to provide advice on long-term basic research planning and strategies for the Department of Defense (DOD).

Specific guidance was sought in several areas. A fundamental question was to address the appropriateness of the broad scientific goals of the Defense basic research program. More practically, the task force was asked to determine whether currently funded work within the basic research budget is basic or applied in character, and to evaluate overall program balance between high-risk, high-payoff and lower-risk research.

Additional tasks were to evaluate the intellectual competitiveness of intramural and extramural basic research programs, and to specifically evaluate program balance among single investigators (principal investigators, or PIs), Multi-University Research Initiatives (MURIs), and university affiliated research centers (UARCs).

The task force was further tasked with evaluating the management of the DOD basic research portfolio, including the manner in which the DOD basic research organizations assess the quality of their basic research investments. Specific opportunities were also sought for increased information sharing and cooperation among the DOD basic research organizations and with counterparts in other government agencies. The task force was also asked to identify potential gaps in the department-wide basic research effort.

Soon after the task force began its work, the DSB was asked to address additional areas of focus by the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)). The Assistant Secretary asked the task force to advise how the Department should structure its basic research program to incentivize invention, innovation, and the transition of ideas to end-use.

To address these challenges, the task force sought input from DOD basic research offices, Service laboratories, and basic research project investigators. Task force members also reviewed previous studies on this topic.

Overall, the task force found the current DOD basic research program to be a very good one, comparable to other basic research programs in the government and well-suited to DOD needs. A detailed assessment of DOD basic research is presented in Chapter 2.

However, the task force has a long-term concern. An increasing fraction of the world's basic research is being conducted outside the United States. There is a vastly increased rate of growth in the number of non-U.S.-citizens graduating with advanced science degrees, awarded by both U.S. universities and by colleges abroad. More and more scientific publications are based on work done overseas. And there are many other indicators of the trend toward globalization of science.

The DOD devotes about 97 percent of its basic research resources to supporting scientific work within the United States. That may have been the right decision in decades past when the United States had a commanding leadership role in almost all areas of science of importance to DOD, but the task force believes a change in strategy is needed for future decades.

To aggravate the situation, most of the scientific work now done in the United States lies outside DOD's purview and, thus, DOD no longer has access to much of the nation's best and brightest science talent as it did during the Cold War.

The task force believes that a two-pronged approach is needed for DOD to address globalization of science. First, DOD must make a more concerted effort to ensure that the U.S. scientific human resources needed by the Department for global military competition will be available, and not assume that will be so without such determined effort. This is considered in Chapter 3.

Second, DOD must do an even more effective job than now in keeping abreast of basic research conducted around the world. Ways to do that are considered in Chapter 4.

Overall, the task force found the current DOD basic research program to be a very good one, comparable to other basic research programs in the government and well-suited to DOD needs.

Notwithstanding this favorable assessment of the current DOD basic research program, DOD must give the highest priority to properly addressing globalization of science over the coming decade.

Furthermore, during the conduct of this study on DOD's basic research program, two important related issues arose.

First, DOD is moving toward development of a technology strategy, but that task is far from complete. The task force believes that intuition borne of experience will be insufficient to ensure that the areas of basic research supported in depth by DOD are the ones most important for enabling the technology and systems required for future military capabilities, largely because of the emergence of new adversaries with new tactics and new weapons, with which the U.S. has little experience. The task force strongly urges the Department to proceed smartly with the development of a genuine technology strategy that could inform basic research priorities. This is considered in Chapter 5.

Second, on a number of occasions the task force heard concerns that the overall level of innovation within DOD is falling short of what should be possible and what would be desirable. And, furthermore, that the reasons for that shortfall in innovation are somehow related to the research program *per se*, and to the interaction among Service laboratories, universities, companies, and other organizations performing research for DOD. The task force believes that is not the case, but by a very wide margin the greatest hindrance and handicap of innovation for DOD is the Department's acquisition system, and in particular the requirements system. This matter is considered in Chapter 6.

This study did not do full justice to these substantial issues of globalization of science, technology strategy, and the innovation ecology, largely focused as it is on the current DOD basic research program. Nevertheless, the task force considers addressing those issues of considerably greater import than modest refinement of the already very-good current DOD basic research program.

Notwithstanding this favorable assessment of the current DOD basic research program, DOD must give the highest priority to properly addressing globalization of science over the coming decade.

Part I

The Current DOD Basic Research Program

Chapter 1. Overview of Defense Basic Research

The Department of Defense funds long-term basic research in a wide variety of scientific and engineering fields with a goal of exploiting new knowledge to enhance—and, where possible, transform—future capabilities. DOD funded research is known for high-risk endeavors that have led to paradigm shifts in the nation's technical capabilities. In many cases, DOD was the first to seed new research performed by many of the world's leading scientists and engineers at universities and federal laboratories, as well as in private industry.

Historically, the United States, through both government and industry support, has maintained a world-dominating lead in basic research. Beginning with efforts supporting World War II, the United States built a commanding scientific infrastructure second to none, and reaped considerable economic and military benefits as a result. DOD also can dominate the world's military organizations in being able to use basic research results to create new and enhanced military capabilities, by dint of financial resources, infrastructure, and national culture—if DOD can overcome the immense burden of its acquisition system, and if DOD pays sufficient attention to worldwide basic research. In principle, worldwide basic research could benefit DOD disproportionally among global armed forces.

Today, the U.S. government's investment in basic research has increased roughly at the rate of inflation while private industry's investment has shrunk dramatically. The United States remains a pioneer and leader in many areas, but it is increasingly the case that in today's scientifically competitive world, the United States is only one *among* the world leaders.

DOD can dominate the world's military organizations in being able to use basic research results to create new and enhanced military capabilities, by dint of financial resources, infrastructure, and national culture—if DOD can overcome the immense burden of its acquisition system, and if DOD pays sufficient attention to worldwide basic research. In principle, worldwide basic research could benefit DOD disproportionally among global armed forces.

Rationale for DOD Investment in Basic Research

Basic research provides the Department of Defense with a deep and broad awareness in relevant areas of research. It is defined by the DOD[1] as:

> *The systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long term national security needs. It is farsighted high payoff research that provides the basis for technological progress.*
>
> *Basic research may lead to: (a) subsequent applied research and advanced technology developments in Defense-related technologies, and (b) new and improved military functional capabilities in areas such as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conversion, materials and structures, and personnel support.*

The rationale for DOD to invest strongly in basic research is four-fold:

- Basic research probes the limits of today's technologies and discovers new phenomena and know-how that ultimately lead to future technologies.
- Basic research funding attracts some of the most creative minds to fields of critical DOD interest.
- Basic research funding creates a knowledgeable workforce by training students in fields of critical DOD interest.
- Basic research provides a broad perspective to prevent capability surprise by fostering a community of U.S. experts who are accessible to DOD, and who follow global progress in both relevant areas, as well as those that may not seem relevant—until they are.

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1. Department of Defense, Financial Management Regulation, DoD 7000.14-R, Vol. 2B, Ch. 5, Para 050201, Part B, December 2010. Available at http://goo.gl/vKJjC (accessed November 2011). Note the entire section, with definitions of all sectors of defense science, technology, research, and engineering, is included for reference in Appendix A.

Currently, much more emphasis is placed on the first reason than on the last three reasons, and the task force's recommendations that follow address that imbalance.

Exploration and discovery provide the means for disruptive advances that can improve or radically change military strategy and operations. It is, many times, the only way to solve hard problems, and provides the unique means to enable and prevent capability surprise. Some examples of these are provided in the box on page 10.

Defense basic research establishes and maintains the ready national availability to DOD of experts and expert teams that understand the fundamentals behind today's military technologies, and who can be readily brought in to address time-critical military technology problems. Examples where such expert teams have been critical include the Manhattan Project, radar, stealth technology, satellite reconnaissance, and cyber security.

The DOD basic research program has supported a large fraction of revolutionary research in the physical sciences, as attested, for instance, by the American Academy of Arts and Sciences in its 2008 *ARISE* report.[2] Basic research funding sustains scientific and engineering communities in areas that form the critical technical underpinning of DOD capabilities. (See Figure 1.) These include, for example, mechanical engineering and electrical engineering, where DOD provides 86 and 71 percent of basic research funding, respectively. (See Figure 2.) Other areas that depend on defense funding include ocean acoustics, naval architecture, aerodynamics, and computer science. Without DOD support, these U.S.-based research communities would find it more difficult to expand knowledge, collaborate, publish, and meet. Without adequate U.S. support, these centers of knowledge will drift to other countries.

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2. American Academy of Arts and Sciences, 2008. *Advancing Research In Science and Engineering: Investing in Early-Career Scientists and High-Risk, High-Reward Research.* Available at http://goo.gl/4zMmD (accessed November 2011).

Five examples of how DOD-sponsored basic research has led to broad and powerful game-changing applications in the military and economics arena:

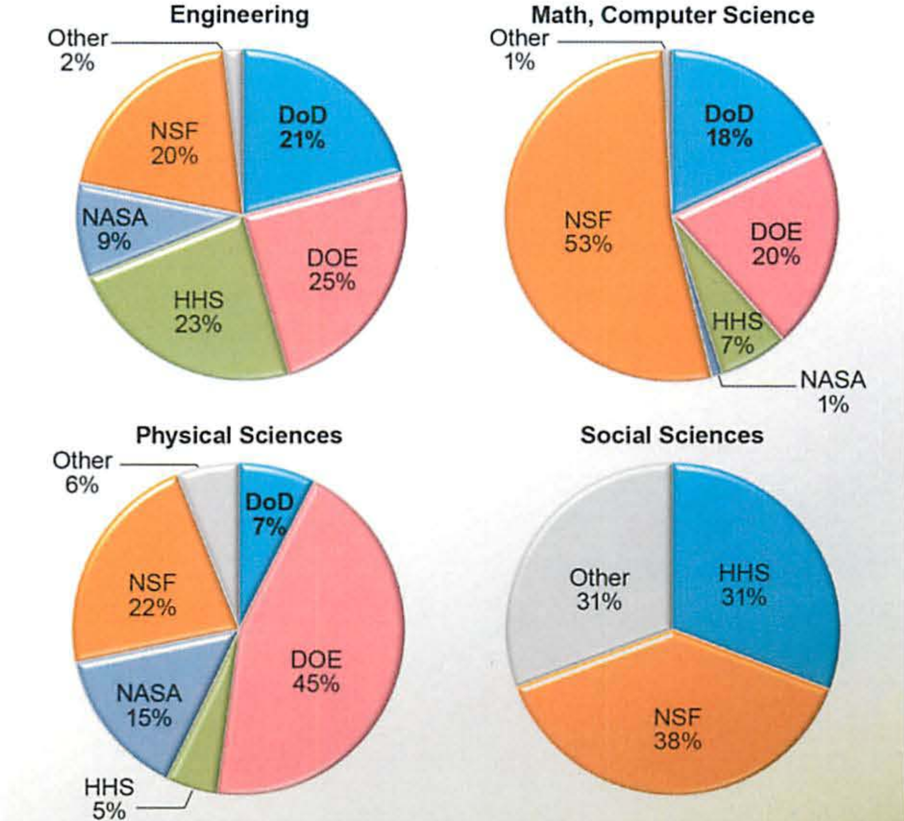
Global Positioning Satellite (GPS) System. The basic science that made this remarkable system possible was started with the magnetic resonance studies of nuclei starting with the work of I.I. Rabi in the 1940s, who realized that nuclear transitions could be the basis for an atomic clock. This was followed by the pioneering work of many others, including his students N. Ramsey, J. Zacharias, C. Townes, and others. Much of the early work was funded by the Navy and was developed and fielded by the Naval Research Laboratory (NRL). The Transit Satellite and the Timation system, which demonstrated the first satellite fix in 1964, eventually evolved into the GPS system, which has become a key military and commercial asset.

Gallium Arsenide (GaAs) Microwave Electronics. In the 1950s, the Navy and the Air Force began funding research on the basic properties of GaAs, which produced the first indication that this compound could improve the performance of high-frequency electronics as compared to silicon by virtue of its very high mobility, and tunable and large band gap. In 1966, Carver Mead demonstrated the first GaAs Field Effect Transistor, and over the next decade the potential of this semiconductor for microwave circuits was evident. By the late 1970s, the Defense Advanced Research Projects Agency (DARPA) began to invest considerable sums into developing the processes for medium- and then large-scale integration of these devices, primarily at Rockwell. In the early 1980s, two companies, Gigabit Logic and Vitesse Semiconductor, were spawned and they pushed GaAs into many defense and commercial applications, spurred on by the DARPA Monolithic Microwave Integrated Circuit (MMIC) project. For example, GaAs chips are in nearly every defense radar system and in many commercial products, such as cell phones.

Magnetic Random Access Memory (MRAM). The fundamental work of R. Meservey and P.M. Tedrow in the early 1970s, supported by the Air Force, proved that ferromagnetic metals had spin-polarized carriers, and for the first time measured the degree of spin polarization using a very novel tunneling technique. However it wasn't until the late 1980s that this spin-polarized transport provided a very novel effect, called Giant Magnetoresistance (GMR), which was demonstrated in a multilayer structure of alternating magnetic and non-magnetic films. The resistance was very different if the magnetic layers had their moment aligned (low resistance) or anti-aligned (high resistance). This work was carried out in Europe independently by two groups, one in France, and one in Germany. By the late 1990s, IBM had incorporated a related structure (spin valve) into a magnetic sensor that became ubiquitous as the read head sensor for magnetic hard drives. In the meantime Moodera, supported by the Navy and working at the Massachusetts Institute of Technology Magnet Laboratory, demonstrated that this GMR-type effect could be significantly enhanced if the normal metal was replaced by a very thin insulating tunnel barrier. This effect, now called Spin Dependent Tunneling, became the basis for a new type of random access, non-volatile memory called MRAM. DARPA started the Spintronics Program to develop this memory in 1996, and this project culminated in 2005 in the introduction of a commercial memory now produced and marketed by Everspin, and a radiation-hard part produced for the DOD by Honeywell, using the Everspin process, in 2010.

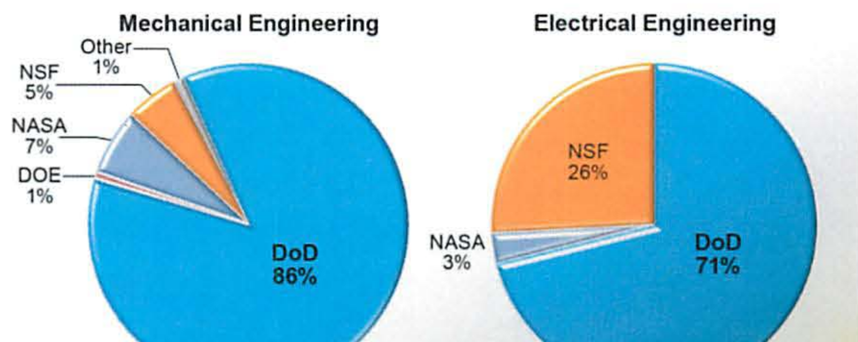
Stealth Technology. While tracking the history of stealth technology is difficult owing to issues of secrecy, there was considerable research beginning in the 1950s on what would now be called metamaterials. These consisted of mixtures of metallic materials, insulating materials, and magnetic materials that had interesting properties at high frequencies. These early experiments were funded by the Navy and the Air Force. The problem of the scattering of electromagnetic waves off arbitrary surfaces was addressed in a fundamental manner in the late 1960s and early 1970s through Air Force funding. These and other basic science efforts were pulled together into several projects to develop the stealth technology as it is known today.

Kalman Filter. A Kalman filter is a set of equations used to minimize the mean square error of measurements in a space and time system that is exposed to random noise and other sources of inaccuracies. The basis for this filter was a paper by R.E. Kalman, published in 1960, supported by the Air Force. The original equations, developed for linear systems, were extended to deal with non-linear systems. Although these equations were not immediately embraced by the mathematics and engineering communities, the extended Kalman filter is now used in many military and commercial systems ranging from image processing to weather forecasting.



Source: National Science Foundation, 2010, Federal Funds for Research and Development: Fiscal Years 2007–09 , NSF 10-305, Table 31.

Figure 1. DOD percentage of federal funding for basic research in selected disciplines, Fiscal Year 2007



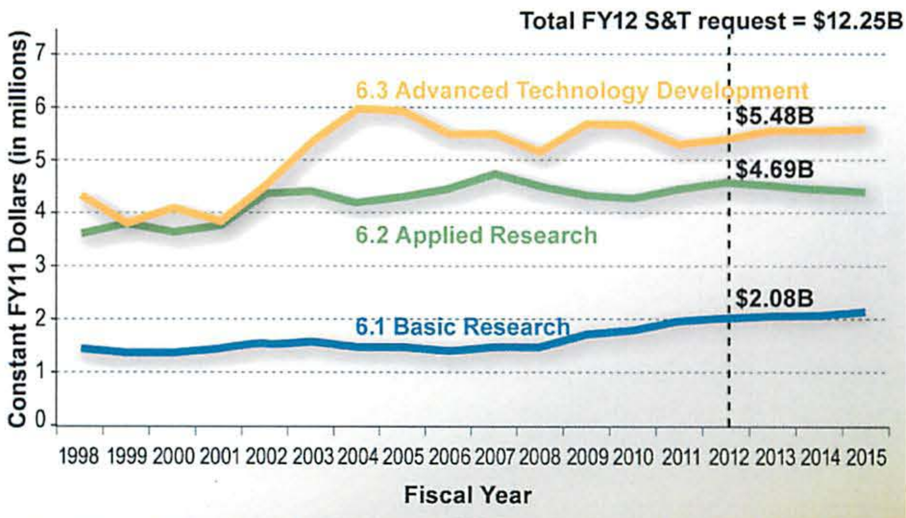
Source: National Science Foundation, 2010, Federal Funds for Research and Development: Fiscal Years 2007–09, NSF 10-305, Table 37.

Figure 2. In certain fields, DOD funds a much larger share of federal basic research, Fiscal Year 2007

Defense Basic Research Funding and Trends

As shown in Figure 3, and broken down in detail in Table 1, the defense basic research budget was approximately $2 billion in Fiscal Year (FY) 2011. While DOD research and development (R&D) investments dominate federal R&D spending, largely because of the substantial DOD investment in development of large military systems, the DOD basic research budget overall is modest compared to other federal agencies, such as medical research in the Department of Health and Human Services and energy and environmental research in the Department of Energy.[3]

Funding for DOD science and technology (S&T) has been relatively flat over the past few years. (See Figure 3.)[4] The DOD basic research budget increased in FY 2011 with a further increase requested in FY 2012. This movement is an indicator of the importance of exploration and discovery to the U.S. defense enterprise.[5]



Source: Z Lemnios, 2011, Shaping the Department's S&T Strategy, presentation at the National Defense Industry Association Meeting, June 21, 2011.

Figure 3. DOD S&T funding by budget activity

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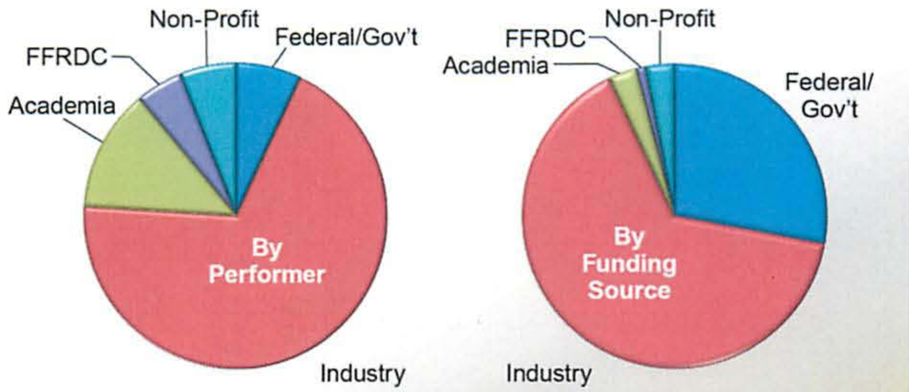
3. National Science Board, 2010. *Science and Engineering Indicators 2010*. National Science Foundation, (NSB 10-01), Figure 4-8.
4. Defense S&T generally includes funding labeled 6.1, 6.2, and 6.3; Defense R&D generally also includes funding labeled 6.4. More extensive definitions are provided in Appendix A.
5. Joanne Padrón Carney, Chapter 5, Department of Defense, in *AAAS Report XXXVI, Research and Development FY 2012*. Available at http://goo.gl/f1OPg (accessed November 2011).

Table 1. Research in the FY 2012 budget (in millions of dollars)

	FY 2010 Actual	FY 2011 Budget	FY 2012 Request
Defense S&T - all	$6,799		$6,875
Defense—Basic Research	*1,815*	*$1,999*	*2,078*
Army	*420*	*449*	*437*
Navy	*544*	*626*	*577*
Air Force	*474*	*514*	*519*
DARPA	*194*	*328*	*329*
Defense Threat Reduction Agency (DTRA)	*40*	*47*	*48*
DTRA Chem-Bio	*64*	*49*	*53*
Health and Human Services – all	31,259		32,173
National Institutes of Health	*30,047*		*31,041*
National Aeronautics and Space Administration	1,488		4,573
Energy – all	7,378		9,030
Energy – Office of Science	*3,908*		*4,142*
National Science Foundation	4,963		5,877
Agriculture	2,235		2,114
Commerce – all	937		1,232
National Oceanic and Atmospheric Admin	*467*		*506*
National Institute of Standards and Tech	*448*		*649*
Interior – all	692		658
U.S. Geological Survey	*587*		*548*
Transportation	727		846
Environmental Protection Agency	502		493
Veterans' Administration	1,082		938
Education	218		242
Homeland Security	361		382
Smithsonian	167		171
All Other	388		483
Total	**$59,196**		**$66,087**

Source: President's 2012 Budget Request

All R&D expenditures in the United States in 2011 totaled approximately $405 billion. As shown in Figure 4, industry substantially leads both in funding and performing R&D, albeit much more development than research.



Note: R&D is primarily funded and performed by industry; DoD basic research (~$2 billion) is less than 0.5% of U.S. R&D funding.

Source: National Science Board. 2010. Science and Engineering Indicators 2010. *National Science Foundation, (NSB 10-01), appendix table 4-3.*

Figure 4. Each circle represents total U.S. R&D expenditures in FY 2007

Finally, the global investment in R&D rose to nearly $1.1 trillion (total) in 2007 in the three major regions where R&D is funded. (See Figure 5.) Since the beginning of the 21st century, global spending on R&D has nearly doubled, publications have grown by a third, and the number of researchers worldwide continues to rise. The rate of growth of these indicators in China, India, and Brazil is much faster than the United States. Funding for R&D in China, for example, has grown by 20 percent per year since 1999, with a goal to spend 2.5 percent of their gross domestic product (GDP) on R&D in 2010.[6] India, Brazil, and South Korea have similar targets; over the same period, U.S. spending is flat or declining.

6. The Royal Society, 2011. *Knowledge, Networks, and Nations: Global scientific collaboration in the 21st century*. RS Policy Document 03/11, pp. 19.

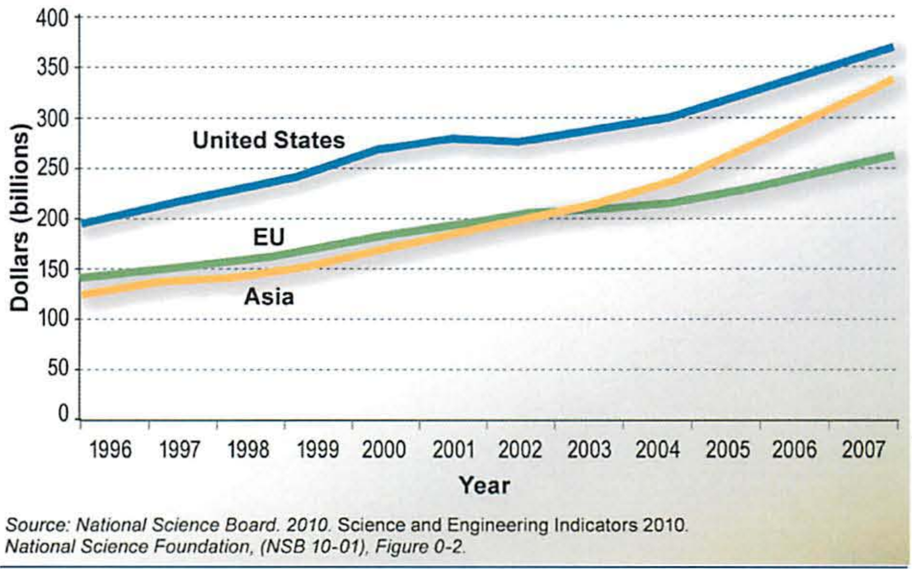


Figure 5. R&D expenditures for the United States, the European Union (EU), and Asia, 1996–2007

Basic Research Organizations

Within the DOD, a number of organizations fund, oversee, and perform basic research. Coordination among the DOD organizations and the external organizations that perform basic research is a constant challenge.

The simplest organizational structure for basic research in DOD is in the Air Force. All Air Force basic research funding is budgeted through the Air Force Office of Scientific Research (AFOSR), and all basic research program management resides in this organization. Intramural research is carried out primarily at the Air Force Research Laboratory (AFRL).

In the Navy, all DOD basic research funding is budgeted through the Office of Naval Research (ONR), and all basic research program management resides in this organization. However, ONR also oversees and manages applied research and advanced development S&T funding for the Navy. Intramural basic research is carried out primarily at the Naval Research Laboratory (NRL).

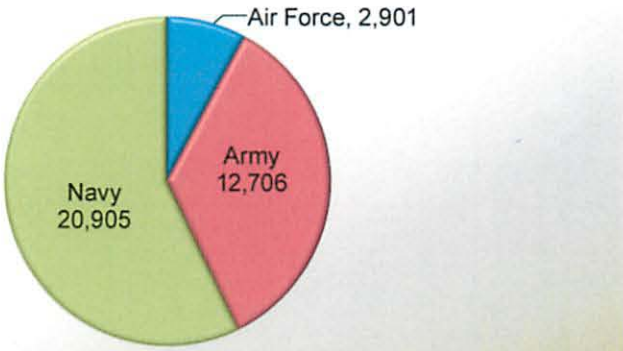
The Army presents perhaps the greatest organizational complexity. All Army basic research funding is budgeted through the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, and policy guidance is provided by the Deputy Assistant Secretary for Research and Technology. However, much of the program management is carried out at other organizations, as follows:

- The Army's research organizations within the Research, Development, and Engineering Command (RDECOM) execute approximately 85 percent of the Army's basic research funding, with about 27 percent intramural (primarily at the Army Research Laboratory, ARL) and about 73 percent extramural (primarily through the Army Research Office, ARO).
- The Medical Research and Materiel Command (MRMC), under the Office of the Surgeon General, is responsible for about 9 percent of the Army's basic research funding, split between intramural and extramural efforts, and including a substantial number of congressional special interest projects.
- The Engineer Research and Development Center (ERDC), under the Army Corps of Engineers, executes an additional 4 percent of the Army's basic research budget, focused on engineering and environmental sciences.
- The Army Research Institute (ARI) for the Behavioral and Social Sciences, within the Army Human Resources Command, executes about 2 percent of the Army's basic research budget, primarily extramurally.
- The Army Space and Missile Defense Technical Center executes less than 1 percent of the Army basic research budget.

At the level of the Office of the Secretary of Defense (OSD), basic research is carried out at DARPA and the Defense Threat Reduction Agency (DTRA). DARPA and DTRA are organized similarly to ONR, overseeing basic and applied research, and advanced development programs. Neither DARPA nor DTRA have a direct relationship with an intramural research laboratory, and their programs fund both extramural researchers and Service laboratories.

The DOD Service Laboratories

Among DOD Service laboratories there are 67 separate facilities.[7] These Service laboratories perform a special role relative to basic research. Basic researchers at the Service laboratories are typically more knowledgeable about military needs, and this knowledge and co-location can facilitate technology transfer to applied research and advanced development. On a broader level, Service laboratories have important missions that involve all levels of research and development, and working in such an environment can provide a unique perspective that enhances basic research. The relative numbers of scientists and engineers at each Service's laboratories are compared in Figure 6.



Source: Diligent Innovations, Department of Defense Laboratory Civilian Science and Engineering Workforce—2011, *May 2011.*

Figure 6. Scientists and engineers employed at Service laboratories

The demographics of the laboratory scientists and engineers may impact their ability to contribute to the DOD mission. The largest population of scientists and engineers within the laboratories is between the ages of 45 and 54, making up 37 percent of the total population of approximately 35,000 individuals. Since 2008, however, the DOD laboratories have seen an increase in the total percentage of scientists and engineers 34 years and under. This group now makes up approximately one-third of the total DOD laboratory population. Scientists and engineers with baccalaureates dominate the current DOD civilian laboratory workforce, with 63 percent holding a bachelor's degree. Individuals with master's level degrees make up 26 percent, and 9 percent hold PhD

7. The Defense Laboratory Enterprise Directory is available at http://goo.gl/eOwU5 (accessed November 2011).

degrees.[8] This demographic profile reflects the fact that the Service laboratories engage in a full gamut of activities, of which basic research is only a part.

While some of these individuals work solely in basic research, many combine basic research with related applied research. In some disciplines, basic and applied research are tightly linked, and the proximity available in a large laboratory environment can facilitate advances. Opportunities for collaboration and an integrated approach can make the Service laboratory a more attractive place for all researchers. Laboratories can also provide access to specialized equipment or information that is difficult for an extramural researcher to purchase or support. However, some basic science techniques are used almost exclusively for military applications, and extramural researchers may not be interested in pursuing them.

University Affiliated Research Centers

A university affiliated research center (UARC) is a strategic DOD research center associated with a university. UARCs were established to ensure that essential engineering and technology capabilities of particular importance to the DOD are maintained. Although UARCs receive sole-source funding under the authority of 10 U.S.C. Section 2304(c)(3)(B), they may also compete for science and technology work unless precluded from doing so by their DOD UARC contracts.

These not-for-profit organizations maintain essential research, development, and engineering core capabilities; maintain long-term strategic relationships with their DOD sponsors; and operate in the public interest. Collaboration with the educational and research resources available at their universities enhances each UARC's ability to meet the needs of their sponsors. A list of DOD sponsored UARCs is provided in Table 2.

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8. Diligent Innovations, 2011. *Department of Defense Laboratory Civilian Science and Engineering Workforce—2011*, May 2011.

Table 2. University affiliated research centers

	Manager	FY10 budget (millions)
University of California at Santa Barbara: *Institute for Collaborative Biotechnologies*	Army	$11.9
University of Southern California: *Institute for Creative Technologies*	Army	$31.3
Georgia Institute of Technology: *Georgia Tech Research Institute*	Army	$13.2
Massachusetts Institute of Technology: *Institute for Soldier Nanotechnologies*	Army	$12.0
University of Texas at Austin: *Institute for Advanced Technology*	Army	$6.1
Utah State University: *Space Dynamics Laboratory*	Missile Defense Agency	$30.5
Johns Hopkins University: *Applied Physics Laboratory*	Navy	$684.3
Pennsylvania State University: *Applied Research Laboratory*	Navy	$97.7
University of Texas at Austin: *Applied Research Laboratories*	Navy	$81.2
University of Washington: *Applied Physics Laboratory*	Navy	$14.0
University of Hawaii at Manoa: *Applied Research Laboratory*	Navy	$2.5
University of Maryland, College Park: *Center for Advanced Study of Language*	National Security Agency (NSA)	$18.7
Stevens Institute of Technology: *Systems Engineering Research Center*	ASD(R&E) and NSA	$7.2

DOD Federally Funded Research and Development Centers

The federally funded research and development centers (FFRDCs) listed in Table 3 were established to perform the mission of providing the Department with unique capabilities in the many areas where the government cannot attract and retain personnel in sufficient depth and numbers. FFRDCs operate in the public interest, free from organizational conflicts of interest, and can therefore assist DOD in ways that industry, non-profit contractors that work for industry, and for-profit contractors cannot. DOD's FFRDCs maintain long-term capability in core competencies in domains that continue to be of great importance to the Department, such as analysis, engineering, acquisition support, and research and development. The three R&D laboratories listed in Table 3 carry out varying amounts of basic research.

Table 3. DOD federally funded research and development centers

	Sponsor
Study and Analysis Centers	
Center for Naval Analyses (CNA)	Navy
Institute for Defense Analyses (IDA)	USD(AT&L)
RAND Arroyo Center	Army
RAND National Defense Research Institute	USD(AT&L)
RAND Project AIR FORCE	Air Force
System Engineering and Integration Centers	
Aerospace Corporation	Air Force
MITRE National Security Engineering Center (NSEC)	USD(AT&L)
Research and Development Laboratories	
IDA Center for Communications and Computing	NSA
MIT Lincoln Laboratory	USD(AT&L)
Software Engineering Institute	USD(AT&L)

FFRDCs that are sponsored by agencies other than DOD also perform substantial and important basic research for DOD. The Department of Energy Lawrence Livermore National Laboratory, the Los Alamos National Laboratory, and the Sandia National Laboratories are examples.

Previous Assessments of Defense Basic Research

A number of previous studies have been conducted to assess basic research in the Department of Defense.

National Academies

In 2005, the National Academies published a report assessing basic research in the DOD.[9] This study was requested by Congress, which noted that in order to maintain the nation's competitive technology base, the DOD continues to fund basic research. However, between 2002 and 2008, it came to the attention of the congressional committees on armed services that basic research funded by the DOD may have changed direction or emphasis. Several organizations, including university research departments and defense laboratories, described areas of concern that included the following:

9. National Research Council, 2005. *Assessment of Department of Defense Basic Research*. National Academies Press.

- Some research conducted using funds designated specifically for basic research might not, under the DOD's definition, be considered basic research.
- Reporting requirements on DOD grants and contracts had become cumbersome and constraining to basic researchers.
- Basic research funds were handled differently among the Services, which made the funds, in some cases, difficult to track and monitor.

These concerns prompted the armed services committees to request that the National Academies perform a study regarding the nature of basic research being funded by the Department of Defense.

The overall conclusion of the study was that no significant quantities of 6.1 funds had been directed toward projects that were typical of research funded under categories 6.2 or 6.3. (See Appendix A.) However, the study members questioned the standard definition of basic research, generally stated as efforts that explore the fundamental nature of science with a goal to discover new phenomena. Such efforts may occur long before a specific use is identified, but, the study noted, it is important to consider the continuing and interconnected need for discovery from basic research through applied research, development, and operations stages.

The study report also expressed concern over trends within DOD for reduced attention to unfettered exploration owed to pressure to meet near-term needs of a nation at war. Finally, the study identified the key to effective management of basic research as experienced, empowered managers. Empowerment factors included flexibility to modify goals and approaches, freedom to pursue unexpected paths and high-risk research questions, minimum requirements for detailed reporting, open communications, freedom to publish, unrestricted involvement of students and postdoctoral fellows, no restrictions on nationality of researchers, and stable funding.

Detailed findings and recommendations from this report are included in Appendix B.

JASON Group

In 2009, the JASON group reported on their 2008 Summer Study on S&T for National Security.[10] This study was chartered by the ASD(R&E) to consider how basic research should be structured within the DOD to best meet the challenges ahead.[11] The study began by recognizing that the context for DOD basic research was changing rapidly owing to changing global circumstances, changing national security missions, the accelerating pace of technology advances, the globalization of technology, the rise and spread of commercial technology that dilutes DOD's influence, and improvements in the global technical talent pool.

The study noted that current and projected future budget requests allocated more money to basic research, but cautioned that such increases alone would not address the aforementioned issues. Rather, systemic and institutionalized changes in process, organization, and personnel would be required.

The JASON group found that a vital DOD basic research program is important to advancing a number of defense-unique fields, to attracting and retaining a high-quality science and engineering workforce, and to maintaining an awareness of (and readiness to exploit) fundamental advances in an increasingly global research enterprise. The common belief that long-term research investments yield low returns and that results can be generated as needed were deemed not correct.

According to the JASON report, the organization of basic research in the Department could be characterized as program management and execution by the Services, with certification, representation, and relatively weak review and coordination provided by the ASD(R&E). While this allowed the Services to "own" their individual programs, it made coordination and synergies less likely, and rendered the basic research program susceptible to a "drift" away from long-term imperatives to short-term needs. Indeed, the extraordinarily productive DOD tradition of knowledgeable and empowered program managers (PMs) supporting the very best researchers working on the most

10. The MITRE Corporation, *S&T for National Security*. JASON JSR-08-146, May, 2009.
11. When this report was published in 2009, the office was termed Director, Defense Research and Engineering (DDR&E). The office of the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) was created in 2011.

fundamental problems seemed to have morphed during the past decade into a more tightly managed effort with a shorter term and more applied character. Evolutionary advances seemed to be the norm, and revolutions were less likely to be fostered.

The study's most fundamental recommendation was to protect basic research funding at the OSD level by strengthening and expanding the role of the ASD(R&E), with a greater visibility in the Department and greater capability to understand and shape the Services' basic research activities.

To address some of the endemic personnel issues in the DOD, the study recommended that a Research Corps be established. A related recommendation was made to the DOD laboratories. While these personnel focus principally on applied R&D activities, the laboratories should also house some researchers engaged in basic research who are well-coupled to the broader research communities.

The study concluded with recommendations to increase DOD participation in the development and maintenance of the S&T educational pipeline. Mechanisms included enhancing existing mechanisms of graduate student and postdoctoral support, exploring training grants and vertically integrated models, and expanding and improving the National Security Science and Engineering Faculty Fellowship (NSSEFF) Program.

Detailed recommendations from this report are included in Appendix B.

Office of Management and Budget Assessment

In 2002, a formal assessment was conducted by the Office of Management and Budget, which published the main conclusion that the DOD basic research program had clear purposes. It helped develop technologies that provide options for new weapons, helped prevent technological surprise by adversaries, and developed new scientists who could contribute to the DOD mission in the future.

Additional conclusions found the program was reviewed regularly by technically capable outside experts, who recommended improvements they believed should be implemented. The expert reviewers indicated that the work is of overall high quality. Finally, research earmarks were found to have increased dramatically in the past 15–20 years. Such projects contribute less than typical projects to meeting the Department's mission, as they don't have to be screened for relevance or quality, and cost more to administer.[12]

12. ExpectMore.com, *Program assessment of Defense Basic Research*. Available at http://goo.gl/9DWjd (accessed November 2011).

Chapter 2. Assessment of the Current DOD Basic Research Program

After an initial survey, the task force identified a number of aspects of the current DOD basic research program warranting assessment.

Ensuring Quality of Basic Research Projects, Programs, and People

Program Manager Qualifications

All of the major decisions relative to DOD funding basic research—what areas of science to fund, relatively how much to fund each area, how to select the researchers and research projects to fund in each area, how to assess progress of each project—are highly subjective. Because the key decisions are subjective, it is especially important that the individuals making those decisions be highly qualified.

The task force knows of no way to objectively assess the overall qualifications of the DOD basic research program managers, but considered their education as scientists as a reasonable proxy.

To assess the demographics and other qualifications of program managers and other senior executives with basic research oversight, the task force asked ONR, ARO, AFOSR, and DARPA to provide information (edited for them to remain anonymous) on the educational and work history of relevant individuals. The response rate was between 80 and 100 percent. ARO and AFOSR personnel were reported to deal almost exclusively with basic research. Many DARPA and ONR managers oversee both basic and applied research, as well some development programs; only those with a primarily basic research focus were accounted. Managers at ASD(R&E) were included, as they influence basic research indirectly.

Education level and institution, work history, time in government, and other factors were reported. Analysis included a comparison of the educational background of the DOD personnel to a standard ranking of the quality of science programs at American research universities. The task force acknowledges that ranking university science programs is hotly debated. Irrespective, this exercise was found to be illuminating. As shown in Figure 7, more than two-thirds of all program managers surveyed have doctorate degrees from Tier 1 schools, with 77 percent from rated schools. Of those from unrated schools, 22 percent were from international institutions that did not appear in the survey.[13]

Additional data was reviewed for program managers and senior executives making or influencing decisions relative to basic research, comparing their time in government and years since receiving a PhD degree.

The task force's overall conclusion from reviewing the data is that these individuals generally have impressive qualifications for doing their jobs.

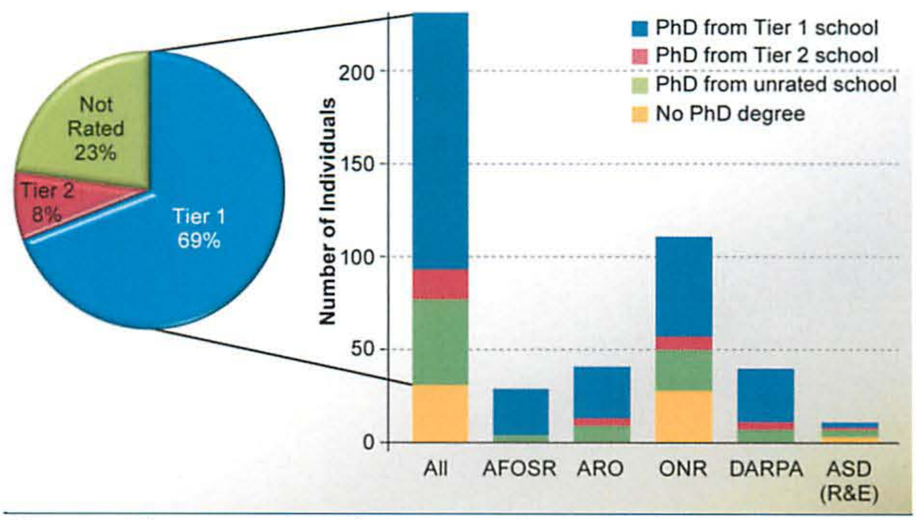

Figure 7. PhDs among DOD basic research PMs

Project and Program Reviews

ASD(R&E) has a statutory responsibility to oversee the DOD basic research program. All of the Services provide for quality reviews of basic research proposals, projects, and programs. Some of these processes are described in Table 4.

The task force finds that the formal mechanisms in place for assessing the quality of basic research in DOD are fully adequate. Additional review, inspection, and assessment are not needed, and could actually be harmful. Such additional bureaucracy may overburden the process, could change project directions unnecessarily, or could impose short-term deliverables that are inappropriate for basic research.

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13. Survey data was compared using *The Top American Research Universities, 2010*. Tier 1 were "Top American Research Universities (1-25)"; Tier 2 were "Top American Research Universities (26–50)", pp 16–19.

Table 4. Methods for reviewing quality of basic research proposals, projects, and programs

	Review	Breadth	Presenters/Reviewers	Frequency	Results
Army	Peer review of grant proposals	All ARO	Combination of internal and external reviewers*	As submitted	Final decision made by PM
Army	Army-wide Basic Research Review (BRR)	All of 6.1 divided into related major topical areas; 2-3 days per area	PIs (or PMs in some cases) present to panels of academic experts and other subject matter experts	Triennial	Written report for official use only (FOUO)
Army	ARO Division Reviews	1.5 days for each Division	PMs present to leading scientists and engineers from Army, DOD, academia, and other government	Biennial	Written report (FOUO)
Army	In-house Laboratory Independent Research (ILIR) review		PMs present to external and internal reviewers*; results briefed to Director of Basic Research	Annual	Programmatic adjustment
Army	ARL Technical Assessment Board (TAB)	Entire S&T and analysis portfolio, by Directorate	National Research Council executed review with independent external reviewers*	Annual	National Academies report (public)
Air Force	Peer review of grant proposals	All proposals	Combination of external (gov and non-gov), AFOSR, and AFRL personnel*	As submitted	Final decision made by PM
Air Force	Program portfolios	Individual programs; length varies with size	PIs present to their peers	Annual	--
Air Force	AFOSR Spring Review	All of 6.1; one week	PMs present to Air Force (AF) leadership, AFRL, AFSTB and AFSAB members, other DOD, senior leaders from academia	Annual	Review is webcast
Air Force	AFSAB Review	All of 6.1; one week	PMs present to AFSAB members	Biennial	Written report
Air Force	AFSAB Technology Directorate Reviews	Entire S&T portfolio, by Directorate; one week	PMs present to AFSAB members	Biennial	Written report
Navy	Peer review of grant proposals	Core Program: at the discretion of the PM; URI program: all	Combination of internal and external reviewers (government and non-government)*	As submitted	Final decision made by PM
Navy	Peer review of basic research	All of 6.1; 1–2 days per program	PIs present to technical reviewers (academia, government, industry)	Triennial	Written report (FOUO)
Navy	ILIR review at Navy Labs	All of 6.1; 2–3 days at each lab	PIs present to review panel (government, PMs)	Annual	Programmatic adjustment
Navy	Program review at NRL by Board of Visitors	All of 6.1; 2–3 days per research area	PIs present to Board of Visitors	Annual	Written report, programmatic adjustment

*External reviewers provide expert input only and do not make decisions on funding.

Assessing the Nature of Funded Research Labeled "Basic"

A study was conducted by Director for Basic Research in ASD(R&E) to determine if DOD basic research was truly basic in nature or if some of the work labeled basic was of an applied nature. This was accomplished by examination and analysis of a sampling of basic research projects conducted by and for the Army, Air Force, and Navy. The study looked at both extramural projects (conducted outside the Services at universities and research institutes) and intramural projects (conducted inside the Services' research organizations or directly supported by the in-house laboratories).

Projects were analyzed by assessing their resultant papers published in scientific journals, with a preference for refereed and peer-reviewed journals. The year chosen for analysis was 2009. The reviewers were qualified scientists and engineers with advanced degrees and experience in DOD R&D programs. Each reviewer scored each paper on a scale of 1 (more basic) to 10 (most applied). Scores were averaged across papers for each project and across reviewers for each paper.

The initial sample of extramural projects was 790 papers from the Army, 1052 papers from the Air Force, and 1819 papers from the Navy. A sample of about 10 percent was selected at random from each Service for examination, numbering 80 from the Army, 100 from the Air Force, and 182 from the Navy. The projects were first screened by analyzing only the titles, and those that appeared to be applied were marked for detailed analysis by the reviewers. Between 15 and 22 percent of projects in the sample sets appeared applied based solely on their titles. Next, the reviewers read the papers associated with an applied-sounding project title (typically one to three papers from each project), as well as a control set of papers from projects that were not initially selected as applied. Each of the resulting 399 papers evaluated was assigned a score of between 1 and 10, as described above.

After the analysis was completed, the percentage of extramural projects identified as clearly basic research ranged from 85 percent at ONR to over 90 percent at ARO. Funded basic research at the Service laboratories was somewhat more applied, ranging from near 70 percent basic at ARL, 75 percent at AFRL, and over 85 percent at NRL.

The results indicated that, on the whole, funds appropriated for conducting basic research are being used for basic research. In addition, a significant percentage of projects with titles that seemed applied were, in fact, true basic research.

A subset of the task force also informally assessed the basic nature of funded basic research at DARPA, and reached similar conclusions as for Army, Air Force, and Navy.

The overall conclusion is that DOD basic research funds appropriated for basic research are principally devoted to basic research. The task force also noted that a small percentage of the funds appropriated for applied research or even advanced development inevitably have the character of basic research. Drawing sharp distinctions is never possible, but no evidence was found to support a material issue.

Coordinating Among DOD Basic Research Programs

Levels of coordination among program managers can take many forms. The easiest form is monitoring, or providing and maintaining awareness of related activities across the DOD. Somewhat more difficult is coordination of efforts, and yet another step up the ladder is collaboration on shared goals. The most difficult form of coordination is reliance, where each program changes direction or emphasis, including moving funding, and relies on a collaborating program manager to provide results. Step one, monitoring and awareness, should be the minimum requirement for all program managers. Step four, reliance, may be desirable in some important areas.

The primary internal coordination for basic research is the Defense Basic Research Advisory Group (DBRAG). This is a joint consultative group comprised of representatives of DOD basic research funding organizations. It is chaired by the Director for Basic Research in ASD(R&E), with principle membership from the Army (Army Director for Basic Research and Director of the Army Research Office), the Navy (Director for Discovery and Innovation, Office of Naval Research), and the Air Force (Director, Air Force Office of Scientific Research). Other members of DBRAG include executives from DTRA and DARPA.

DBRAG meets on topics relevant to the basic research activities of the Department, including reports to the Executive Committee for S&T (EXCOM) and its Deputies' Committee, congressional calls for department-wide briefings and other information, coordinated basic research activities including MURIs, Defense University Research Instrumentation Program (DURIP), Presidential Early Career Award for Scientists and Engineers (PECASE), Minerva Initiative, component research priorities, and policy and business practices. The latter includes departmental grants and contracts policies.

Technical coordination also takes place at the PM level primarily informally through discipline-based coordinating groups. DOD-wide coordination also occurs through participation and attendance at other service program reviews and workshops, such as Reliance 21 and Future Directions. The DOD Techpedia and the Defense Technical Information Center (DTIC) also provide avenues for electronic coordination.

The task force finds that the current mechanisms for coordination among DOD basic research programs are adequate. In general, basic research program managers do a good job of coordinating their respective portfolios across Services. The performance of excellent program managers acting on their own volition is most important, and the formal committee structure is a distant second in importance.

Coordinating Among Federal Basic Research Programs

The primary avenue for S&T coordination across the federal government is the National Science and Technology Council (NSTC). The DOD is a member of all of the committees of the NSTC. Of particular interest to basic research are the Committee on Science, Technology, Engineering, and Math (STEM) Education and the Committee on Science, which encompasses the following areas:

- Aquaculture (Subcommittee, SC)
- Biotechnology (SC)
- Digital Data (Interagency Working Group, IWG)
- Domestic Animal Genomics (IWG)
- Education and Workforce Development (SC)

- Forensic Science (SC)
- Human Subjects Research (SC)
- Large Scale Science (SC)
- Physics of the Universe (IWG)
- Plant Genomes (IWG)
- Prion Science (IWG)
- Research Business Models (SC)
- Science to Support Food and Agricultural Research (Task Force)
- Scientific Collections (IWG)
- Social, Behavioral, Economic Sciences (SC)

Other areas of interest to DOD are covered by the NSTC Committee on Technology; the Committee on Environment, Natural Resources, and Sustainability; and the Committee on Homeland and National Security. A number of government-wide groups operate both independently and as subcommittees of the NSTC. These include such organizations as the Quantum Information Sciences Coordinating Group, the Non-Destructive Evaluation Coordinating Committee, the Networking and Information Technology Research and Development Program, and the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee.

The task force finds that the formal mechanisms for maintaining coordination between DOD basic research activities and the rest-of-government basic research activities are adequate.

Efficiency of DOD Funding

The task force examined the flow of basic research funding from congressional appropriation to disbursement, documenting the cost of doing business for the case of the Air Force. This choice was made for two simplifying reasons: first, approximately 98 percent of Air Force basic research funds are assigned to and managed by a single organization, AFOSR; and second, the Air Force does not mix basic research funds with applied research or technology development funds.

The money flow for FY 2009 is examined in Table 5. The total basic research appropriation was $482 million, and was managed along three separate program elements: (1) core funding, which supports extramural single investigators and basic research activities at AFRL; (2) the University Research Initiative that funds larger grants to multidisciplinary university consortia, graduate and Presidential early career fellowships, and the DURIP instrumentation program awards; and (3) the high-energy laser program.

Table 5. Example funding flow (AFOSR) for FY 2009

	(000s)	**%**
61102F - Core	$328,471	
61103F - University Research Initiatives	141,524	
61108F - High Energy Laser	12,781	
Total Basic Research Funds in the FY10 Budget	***$482,776***	***100%***
Service Withholds (*e.g.*, Congressional, SBIRs, FFRDCs)	27,111	*5.6%*
AFOSR Operational Costs (*e.g.*, salaries, travel)	43,245	*9.0%*
Total DOD Withholds	***$70,356***	***14.6%***
Intramural		
Research at AFRL Laboratories (*e.g.*, LRIR)	55,093	*11.4%*
Research at AFRL Laboratories (Section 219)	7,649	*1.6%*
Extramural		
Research at universities	300,871	*62.3%*
NRC Postdocs and Summer Faculty	7,464	*1.5%*
Educational Fellowships (*e.g.*, NDSEG, ASSURE)	41,305	*8.6%*
Total Research at Laboratories and Universities	***$412,382***	***85.4%***
Institutional Withholds (facilities, etc., estimated)*	127,838	26.5%
Total Funds for Research	***$284,544***	***58.9%***

*Estimated at 31%. Source: CA Goldman, T Williams, DM Adamson, and K Rosenblatt, 2000. *Paying for University Research Facilities and Administration*, RAND MR-1135-1-OSTP, p. 27.

In this case, approximately 9 percent of the appropriated funds for the Air Force basic research program are withheld for the operational costs of the administering office (AFOSR). An additional 5.6 percent are withheld for such purposes as congressional programs, small business innovative research (SBIR) funding, or federally funded research and development centers (FFRDCs). While these uses may include research, the funds, once redirected, are no longer required to fund basic research.

The data also show the split in FY 2009 of Air Force funding for basic research among institutions. More than 85 percent of AFOSR research funding ($349 million) went to universities in FY 2010, primarily through single-investigator grants, URIs, and educational fellowships. Approximately 15 percent ($63 million) was allocated for basic research at the Service laboratories.

The overall conclusion of the task force is that the efficiency of DOD funding of basic research is consistent with comparable activities.

In the course of this task force it became clear that what should have been easily retrievable data required huge time-consuming, labor-intensive efforts on the part of ASD(R&E) to collect and assemble. This is not because the data is not knowable—it is generally known by each responsible program manager—but due to the lack of a modern management information system that would enable answering questions posed by DOD leadership. Addressing that goes well beyond the scope of the task force, but insofar as it is difficult to have management without management information, it would behoove ASD(R&E) to address this matter.

To aggravate the situation relative to financial information like that in Table 5, cost accounting is as much an art as a science; perhaps more so. An essential research expense for one person is bureaucratic overhead for another person.

From time to time, different organizational structures have been considered for the conduct of basic research in order to improve funding efficiency. Combining all basic research from across the Services into one organization is one such variant. The task force concludes that any potential savings that might accrue from such a restructuring would be far outweighed by distancing basic research from applied research and from the military operators. Furthermore, centralization would eliminate the diversity of views so important for the conduct of basic research.

What should have been easily retrievable data required huge time-consuming, labor-intensive efforts to collect and assemble due to the lack of a modern management information system that would enable answering questions posed by DOD leadership. It is difficult to have management without management information.

Burdensome Laboratory Practices

Researchers at DOD laboratories are oftentimes asked to perform tasks or attend training that may be inappropriate in a basic research environment and detract from the time spent on research. A requirement to check all research tools in and out of storage lockers on a daily basis, as is done for maintenance tools, was cited as one such activity at a Service

Unnecessary and unproductive bureaucratic burden on basic researchers funded by DOD in effect equates to reduction of the DOD basic research budget. Reducing that burden is perhaps the most important thing that might be done to improve the current DOD basic research program.

laboratory. A requirement that scientists perform routine repairs to laboratory equipment rather than employ expert technicians was another. These are but two of a number of unproductive or inefficient activities reported to the task force.

The challenge is that there are so many sources of bureaucratic burden: legislation; administration requirements imposed from outside DOD; requirements imposed from within DOD; requirements imposed by the Services; and requirements imposed by the basic research performing organizations themselves, both intramural and extramural. The phrase used within the task force was "death of a thousand cuts." Furthermore, and as usual, "bureaucracy" to one is "good management" to another.

The Federal Demonstration Partnership (FDP) conducted a survey among university researchers and found a similar set of concerns.[14] According to the report, faculty spent approximately 42 percent of their time for federal research projects on research-related administrative tasks. The FDP faculty felt that the administrative burden of federally-funded research is threatening the health of the national research enterprise.

Unnecessary and unproductive bureaucratic burden on basic researchers funded by DOD in effect equates to reduction of the DOD basic research budget. Reducing that burden is perhaps the most important thing that might be done to improve the current DOD basic research program.

RECOMMENDATION

The Director for Basic Research in ASD(R&E) should have responsibility and accountability for working with the DOD laboratory directors to document any activities that are unnecessary or inappropriate in a basic research environment. The rationale to eliminate or waive such activities for basic researchers should be specified and remedial action pursued.

14. RS Decker, L Wimsatt, AG Trice, and JA Konstan. 2007. *A Profile of Federal-grant Administrative Burden Among Federal Demonstration Partnership Faculty*. Available at http://sites.nationalacademies.org/PGA/fdp/ (accessed November 2011).

Such requests should carry the signature of the Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)).

Troublesome Clauses

Troublesome clauses are requirements inserted into basic research agreements that should not apply to basic research. They include publication restrictions, restrictions on participation by foreign nationals ("deemed exports"), and export controls.

On May 24, 2010, USD(AT&L) issued a memo entitled, "Fundamental Research,"[15] with guidance to establishing no restrictions on basic research, consistent with the National Security Decision Directive 189. However, this guidance conflicted with existing policies in the Defense Federal Acquisition Regulation Supplement (DFARS). Contracting officers as a rule opted to prefer the standard DFARS rules rather than the more flexible guidance in the memo. As a result, new DFARS language is out for comment at the time of this writing to resolve this issue, stating an explicit exception for basic research funding:

> *The Contractor shall not release any unclassified DOD information to anyone outside the Contractor's organization ... or any employee inside the Contractor's organization without a need-to-know, regardless of medium (e.g., film, tape, document), pertaining to any part of this contract or any program related to this contract,* ***unless*** *... this information results from or arises during the performance of a project that has been scoped, negotiated, and determined to be* ***fundamental research*** *within the definition of National Security Decision Directive 189 according to the prime contractor and research performer and certified by the contracting component, and that is not subject to restrictions due to classification, except as otherwise required by applicable Federal statutes, regulations, or Executive orders.*[16]

15. The task force equates "fundamental research" with "basic research."
16. Proposed amendment to 252.204-7000(b)(3). *Federal Register* Volume 76, Number 125 (Wednesday, June 29, 2011). Available at http://goo.gl/4mclf (accessed November 2011).

RECOMMENDATION

The Director for Basic Research in ASD(R&E) should be responsible and accountable for additional amended language as needed to address export controls, deemed exports, or other troublesome publication clauses.

Summary

In sum, the task force found the current DOD basic research program to be a very good one, comparable to others in the federal government and well suited to DOD's needs. While nothing is ever so good it cannot be improved, the only area found where improvement would make a significant difference would be to reduce the unnecessary bureaucratic burden imposed at all levels of the basic research organization.

The overarching observation applies to the *current* program, but as noted in the introduction, the task force has four long-term concerns addressed in the chapters of this report that follow.

Part II

Human Resources and Globalization of Science

Chapter 3. Human Resources

There should be more "outputs" of the DOD basic research program than new knowledge, know-how, and ideas. An equally important output is people. In the future, DOD might find itself disadvantaged in the global competition for advanced military capabilities, given the increased rate of growth in the number of non-U.S. citizens graduating with advanced science degrees, both in the United States and overseas, compared to those granted to U.S. citizens and permanent residents.

The primary need is for the performers of research who carry out the day-to-day tasks that produce research results. In addition, people are needed to provide intelligence information to the processes surrounding the research laboratory. They identify the threads that lead to new knowledge and they discuss, debate, and distill possibilities. Further, people provide the advice, management, and oversight that make all basic research projects more effective.

The defense basic research ecosystem is an interdependent organization of people, projects, facilities, and ideas. While research can't be performed without people and facilities, it may not be obvious that people are shaped by the research strategy, or that research directions can be driven by existing facilities. Many other factors affect this system of systems, including discipline shifts, cultural differences, levels of risk, rates of change, interagency complexities, and globalization. It is truly a complex system and presents a challenging problem.

People are Key for Creating and Preventing Surprise

To be successful, the DOD needs to have a long-term relationship with *excellent performers of research*: people with in-depth, world-class, state-of-the-art knowledge in all disciplines that are critical to DOD.

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It is to this group that the DOD can turn if faced with the inkling of technological surprise. So, these excellent performers of research are collectively a set of people who not only can be called upon to *solve urgent problems* in the research realm, but can also provide early warning of possible surprise. For example, if an experiment performed by one researcher, somewhere in the world, has produced surprising results or a breakthrough, other suitably equipped and staffed laboratories must be available to rapidly duplicate or alternatively show the initial results to be false.

A scientist or engineer who is saturated in the technology at hand is best positioned to judge the potential for an experiment to have a particular outcome, or for a breakthrough to occur given the current state of knowledge. Currency is critical; an individual who departs the laboratory loses insight and any deft sense of what might work in a given laboratory experiment over time. New approaches are needed to ensure the DOD basic research program has access to emerging research results.

These key researchers may be found both inside government and outside, both inside the United States and outside. An important source for individuals with needed knowledge, skills, and abilities will be the DOD Service laboratories. Other individuals will be external, many at institutions or universities affiliated with the DOD or other government agencies. To the extent that the defense industry performs basic research, those people can be found in industry. However, breakthroughs are increasingly occurring outside of traditional DOD circles, often internationally. Some highly skilled people, even some with critically and urgently needed skills, may be located in places fully unconnected to DOD. For certain disciplines, the individuals will not be in the United States.

It is not only the skills of the individual researchers that are important; their laboratories, funding infrastructure, and familiarity with DOD are all potential barriers to access. For these reasons, relationships need to be pre-established. For example, when the C-1 cargo plane was undergoing early parachute drop tests, trooper parachutes were colliding, endangering the jumpers. Mathematicians both inside Air Force laboratories and the Courant Institute at New York University mathematically modeled the air flow around the plane and the parachutes and within weeks developed an effective way for the cargo plane to dispense parachutes that eliminated the problem. That was possible only because the mathematicians involved already had computerized mathematical models that could be readily adapted to the challenge.

Excellent performers of research who are familiar with DOD priorities also supply the DOD with *science and technology advisors.* Some serve on various advisory groups such as the Defense Science Board, the three Service science boards, and the JASONs. Others serve as impromptu advisors who participate in workshops, short-lived task forces, or technology focus teams convened by ASD(R&E), DARPA, or the Services.

These groups also provide a pipeline of individuals who come into the DOD S&T program for several years as *program managers.* This infusion of new people rotating through the DOD S&T organizations (*e.g.*, the basic research offices, DARPA, and the Service laboratories) brings new ideas and approaches. They enhance the quality and the vitality of the S&T organization, and substantially increase the organization's ability to maintain relations with the broader research communities in all critical disciplines.

Finally, all of this rests on the ability to recruit excellent *students* into defense basic research areas. A critical step is to provide both inspiration and adequate compensation that result in a healthy basis for recruiting among the U.S. population.

To keep this ecosystem healthy, several approaches are needed. First is an understanding of what areas of knowledge are critical for future defense systems, as discussed in Chapter 5 on a technology strategy and, hence, the human resources skill mix required. Next, outreach is important to inspire the best people at all levels to work on solving these defense challenges. This begins with establishing two-way communication with the warfighter, and needs to reach out to K-12 students; undergraduate and graduate students; and active researchers in academia, government, and industry. Innovative compensation strategies are needed to make defense basic research competitive among the many options the best minds will have. Finally, strategies are needed to ensure that defense basic research programs can access the knowledge, skills, and abilities necessary to manage this dynamic system.

Inspiring Excellent Researchers to Address DOD Problems

A major objective of DOD's basic research activities is to engage the nation's best and brightest scientific and technical talent in national defense issues. This has long been important in order to harness emerging and still undiscovered S&T opportunities to national security needs. It is becoming even more important now in order to avoid technological surprise. Much of emerging science and technology not only lacks DOD priority but is unfamiliar to DOD. This leads to the increasing likelihood that DOD will be unable to anticipate the exploitation of new technology opportunities by potential adversaries.

The task force commends the various programs that draw excellent researchers to DOD problems. Primary examples are the highly-competitive postdoctoral research opportunities offered by the Services. Participants in these programs quite frequently become actively involved in DOD activities.

Other programs identify excellent and recently-tenured researchers in science and engineering. The Young Investigator Programs offered by the Services, and the Young Faculty Awards offered by DARPA provide three-year research grants and an introduction to the DOD research structure, and the PECASE program offers support for up to five years. Two more focused efforts are the DARPA-funded Defense Systems Study Group (DSSG) and the more recently created Computer Science Study Group (CSSG). (See box on page 44.) In these programs, a number of visits and meetings introduce the participants to a wider range of DOD problems, organizations, and people.

High-performing faculty members are identified by the NSSEFF program that selects recipients to conduct revolutionary research in conjunction with DOD. The NSSEFF program provides for the direct engagement of fellows and their teams of undergraduate, graduate, and postdoctoral scholars with DOD scientists and engineers. These talented technical teams are also often included in DOD research-focused workshops. The task force notes that the Department has not recruited a new NSSEFF class for over a year. This program is potentially very beneficial for DOD and could be more fully exploited. The task force encourages ASD(R&E) to explore ways to connect these distinguished scientists with important DOD scientific and technical challenges.

The DOD basic research funding agencies and Services can and should do much better in capitalizing on the talent of the basic researchers that they fund. By systematically exposing these researchers to the "hard" problems that DOD would like to solve, the researchers offer a potential pool of fresh new ideas to help solve DOD problems. In general, the top researchers in the country are very interested in contributing to the solution of hard problems. When effectively exposed to such problems they inevitably respond with enthusiasm to offer thoughtful and creative potential solutions. A critical issue is establishing a forum where they can be efficiently and effectively exposed to these problems and have some time to brainstorm potential solutions with their peers. Inevitably these sessions end up with follow-on work by these researchers that support national objectives.

The converse situation also exists; the Services can and should do better at capitalizing on their military troops who have an interest in science and technology. Former Secretary of Defense Robert Gates recently offered this advice to new Army officers: "In addition to the essential troop command and staff assignments, you should look for opportunities that in the past were off the beaten path, if not a career dead end—and the institutional Army should not only tolerate, but encourage you in the effort. Such opportunities might include further study at grad school, teaching at this or another-first rate university, spending time at a think tank, being a congressional fellow, working in a different government agency, or becoming a foreign area specialist."[17] The task force respectfully adds opportunities to work at a Service laboratory or in an S&T program office as additions to this list.

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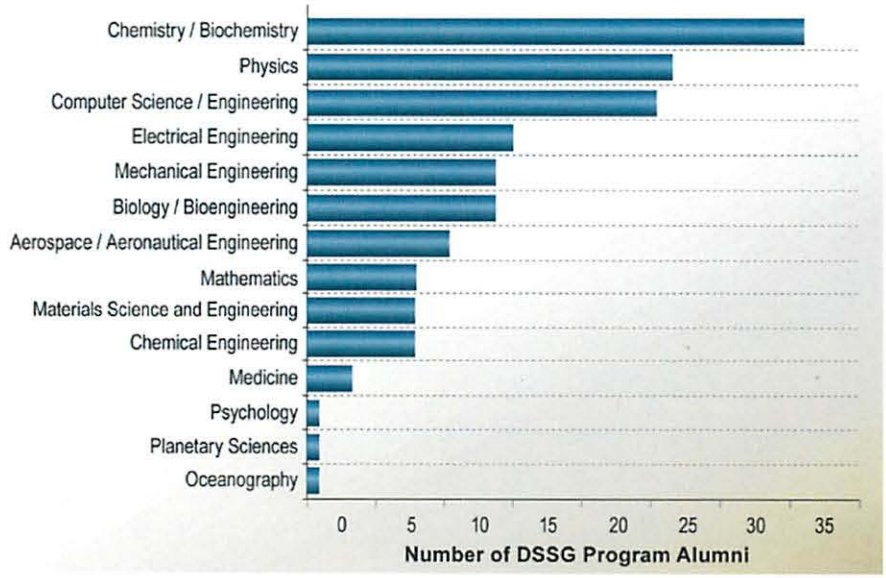
17. Secretary of Defense Robert M. Gates. Speech at West Point on February 25, 2011.

Building Bridges: The Defense Science Study Group

Attracting the participation of the nation's top scientists in national security issues presents a formidable challenge. Many universities that house the nation's top scientific talent are culturally and organizationally removed from DOD. A DOD program meeting this challenge is the Defense Science Study Group (DSSG).

The objectives of this 25-year-old program are to identify emerging leaders of S&T and introduce them to the national security community. The program is intended to instill an appreciation for the technical and operational challenges facing the national security community and the dedication of the troops, and to foster in them a long-term interest in national security. Finally, the program also seeks to create a network of informed and involved alumni, and to provide opportunities for those alumni to address national security challenges.

The program selects about 15 recently tenured faculty members as "fellows" from a diverse set of fields every two years. (See figure below for a breakdown of 149 participants over the past 10 years by discipline.) Most have had no previous experience or contact with the DOD. The program consists of eight sessions over eighteen months for a total of about 40 days. These sessions include visiting facilities and installations, interacting with department personnel from senior civilians and flag officers to junior enlisted soldiers, and performing studies, or "think pieces." Annual program costs have risen with inflation from less than $500,000 per year in 1990 to just over $900,000 per year today.



The fellows, having been exposed to troops in the field and all types of military equipment, landed on a carrier, flown on a tanker refueling operation, and so on, bring first hand experiences to their students and other faculty members. They return with a broad understanding of national security needs and areas where science, engineering, and university graduates can contribute.

After the program ends, DOD support continues by maintaining the participants' clearances, providing contacts in DOD, and promoting their membership on DOD boards and panels. The program has succeeded; over half the DSSG alumni have served on science advisory panels (over 200 separate participations) and 11 have served in government in S&T leadership positions. DARPA expands alumni engagement by conducting workshops to address important national security challenges and providing awards for outstanding think pieces.

Although DSSG is a success, it reaches only a small fraction of the nation's top S&T talent. The program is oversubscribed; in the latest application period, about 150 faculty members were nominated.

RECOMMENDATIONS

The task force offers the following recommendations to build stronger relationships between basic researchers and the ultimate users of the outcomes of their research:

- The Director of DARPA expand the DSSG program by doubling the number of participants. This could be done by selecting a group of participants every year rather than every other year and running two overlapping programs each with about 15 participants. The overlap would provide opportunities to bring the two groups together for workshops and other relationship-building activities. This expansion should include an appropriate number of behavioral and social scientists, and medical researchers, insofar as those areas are among those chronically getting short shrift by DOD.
- ASD(R&E) initiate DSSG-like pilot programs in the Services with a goal to expand the network of informed and engaged scientists and engineers exposed to the national defense community and its challenges. The pilot programs need not precisely replicate the DSSG template. Indeed, experimentation is desired to explore other schema to foster a long-term interest in national defense in emerging S&T leaders. Some may require a shorter commitment of time, as compared to the 40 days over two years for DSSG. The eventual goal would be to increase the number of participants by a factor of five to ten over today's approximately 15 every other year.
- ASD(R&E) direct all DOD basic research funding agencies to initiate summer activities to expose their basic research performers to military operations and critical technical problems relative to their mission. The goal is to ensure each researcher understands the ultimate challenge their research may address without unduly focusing the research or limiting its potential.
- USD(AT&L) initiate pilot programs for cadets, midshipmen, and junior officers to participate in research tours at DOD laboratories, FFRDCs, or other institutions that carry out basic research in support of national defense.[18] Once the pilot program is complete,

18. An example outside DOD is the National Nuclear Security Administration (NNSA). "NNSA Places 56 Participants Throughout Enterprise as Part of Military Academic Collaborations Program," Press Release, May 26, 2011.

evaluate the potential to provide similar experiences for officers as a tour of duty.

Strengthening the Technical Talent of U.S. Citizens

For decades, politicians and leading educators have expressed concern over the number of U.S. citizens who obtain higher degrees in critical scientific fields. It is important to reach these students at a critical point in their decision-making so as to encourage them to pursue a doctorate degree in engineering or the sciences.

The drop in the proportion of U.S. citizens seeking advanced degrees in science and technology is well documented. As shown in Table 6, the growth in temporary visa holders receiving doctoral degrees in certain fields has significantly outpaced U.S. citizens and permanent residents.

While the citizenship status of students is important to DOD, it may not be important to all research sponsors or to all employers. This reduces the need for university departments to undertake the difficult task of recruiting U.S. citizens, and encourages them to recruit foreign national individuals to maintain their size and obtain research funding. Today, more than 50 percent of all students in engineering doctorate programs

Table 6. Doctorate degree recipients

PhD Recipients	1979	1989	1999	2009	% Change
Physical Sciences					
U.S. citizens and permanent residents	3,501	3,455	3,835	4,414	26.1
Temporary visa holders	673	1,534	2,121	3,531	424.7
Engineering					
U.S. citizens and permanent residents	1,616	2,231	2,893	3,148	94.8
Temporary visa holders	819	1,948	2,191	4,211	414.2
Life Sciences					
U.S. citizens and permanent residents	4,458	4,866	5,810	7,783	74.6
Temporary visa holders	695	1,169	2,137	3,096	345.5
Social Sciences					
U.S. citizens and permanent residents	5,379	4,654	5,853	5,605	4.2
Temporary visa holders	546	888	1,054	1,709	213.0

Source: National Science Foundation, Division of Science Resources Statistics. 2010. *Doctorate Recipients from U.S. Universities: 2009.* NSF 11-306, Table 16.

are temporary visa holders.[19] It is not surprising that, as a result, many of the professionals currently filling academic positions at universities and scientific positions in research laboratories are foreign-born.[20] The task force believes this indicates the United States is losing the technology race for the minds of talented citizens who increasingly have chosen law or finance over science and engineering. In the 1960s, a combination of inspiration and compensation resulted in a large number of U.S. students entering the fields of engineering and science. When the President declared that the United States would put a man on the moon and return him safely, he inspired tremendous excitement about science and technology. The government quickly sponsored well-paid traineeships through the National Science Foundation (NSF), the Atomic Energy Commission, and the National Aeronautics and Space Administration to encourage students to pursue doctorate degrees.

The proportion of U.S. citizens in science and engineering graduate programs continues to decline. While approximately 90 percent of graduate students in engineering and physical sciences receive stipends today,[21] this financial support is typically not focused on recruiting U.S. citizens to graduate school as it was in the past. As a result, current programs are not achieving the national objective to provide an adequate cadre of U.S. citizens in science and engineering areas of interest to DOD.

DOD Fellowship and Scholarship Programs

In the 1960s, student stipend take-home pay was equivalent to the take-home pay for a new B.S. graduate. Today, as shown in Table 7, the typical starting salary of a B.S. engineer is about $50,000 per year and the graduate student stipend for the a DOD fellow is as low as $25,000. Such stipends for outstanding U.S. citizen candidates cannot compete and attract the students wanted and needed by DOD's basic research programs.

19. National Science Foundation, Division of Science Resources Statistics. 2010. *Doctorate Recipients from U.S. Universities: 2009.* NSF 11-306, Table 16.
20. CM Matthews. 2010. *Foreign Science and Engineering Presence in U. S. Institutions and the Labor Force,* Congressional Research Service, October 28.
21. National Science Foundation. 2010. *Doctorate Recipients from U. S. Universities.* NSF 11-06, Figure 4C.

Table 7. 2011 Average annual starting salary

	Bachelor's	Master's	PhD
Engineering	$49,351	$59,993	$76,117
Post Doc			*45,000*
Academic			*75,000*
Industry			*85,000*
Electrical Engineering	53,719	--	77,388
Mechanical Engineering	52,776	--	70,769
Sciences			
Physical Sciences (Math, Chemistry, Physics)	41,272	49,113	66,760
Post Doc			*45,000*
Academic			*55,000*
Industry			*95,000*
Computer Sciences	45,893	58,609	--
Biology	38,012		
Professional degrees			
Law			56,927
Medicine			104,618
Liberal Arts			
Business	38,330	56,473	55,556
Communications	34,947		
Social Sciences	35,214	42,587	53,276

Sources: Collegiate Employment Research Institute, *Recruiting Trends 2010-2011*, Special Report 5-11: Starting Salary Offers; National Science Foundation, *Doctorate Recipients from U.S. Universities: 2009*. NSF 11-306, Table 16.

It is critical to replenish the cadre of technical experts across all disciplines important to DOD. Newly graduated students at all levels are needed by both DOD and by the industry supporting DOD.

ASD(R&E) reports that DOD funds about 11 percent of all full-time science and engineering graduate students supported by the federal government, and does so in all 50 states.

The DOD supports over 5,000 undergraduate and graduate students primarily through research assistantships and DOD's research awards, with additional support through programs such as the Science, Mathematics and Research for Transformation (SMART) scholarship-for-service program, and the National Defense Science and Engineering Graduate (NDSEG) fellowship program. (See box on page 49.) Additional programs target students in specific areas such as information assurance or undersea weapons technology, or in specific geographic areas. Many other students attend dedicated institutions, such as the Naval Postgraduate School and the Air Force Institute of Technology. Through all these programs, ASD(R&E) reports that DOD funds about 11 percent of all full-time science and engineering graduate students supported by the federal government, and does so in all 50 states.

A Quick Profile of DOD-Sponsored Student Compensation

NDSEG Fellowships

- Selection based on academic records, personal statements, recommendations, and GRE scores (no minimum GPA)
- Acceptance rates average under 10 percent
- Lasts for three years
- Pays for full tuition and all mandatory fees
- Pays up to $1,000 a year in medical insurance
- Annual stipends average $31,000/year
- Annual budget of $43.9 million (FY2010) targets approximately 200 new awards each year

SMART Scholarship-for-Service Program

- Requires a minimum cumulative GPA of 3.0 on a 4.0 scale, and then competes among applicants
- Lasts up to five years
- Pays for full tuition and all mandatory fees (no cap)
- Pays for summer internships at DOD laboratories
- Pays up to $1,200 per year in medical insurance
- Pays a $1,000 book allowance
- Includes mentoring and employment placement after graduation
- Annual stipends range from $25,000 to $41,000 depending on prior educational experience (and may be prorated depending on award length)
- Annual budget of $31.6 million (FY 2010) targets approximately 600 new awards each year

RECOMMENDATIONS

The following recommendations are offered as innovative compensation strategies to help DOD basic research compete for the best minds:

- The ASD(R&E) Science, Technology, Engineering, and Mathematics (STEM) Development Office should expand summer internship programs to place promising young men and women with U.S. citizenship in defense-related S&T activities between their junior and senior year in high school, between high school and college, and for their first few summers during college. These programs should be available for students to work in government R&D laboratories, FFRDCs, and defense contractors.
- The ASD(R&E) STEM Development Office should double the existing doctoral fellowship programs in the National Defense Education

Program and the NDSEG, track outcomes, and consider even higher investment in future years.

- The ASD(R&E) STEM Development Office should ensure that fellowship programs for doctoral students:
  - Award a stipend with an amount at least 80 percent of the median annual salary for graduating seniors with B.S. degrees
  - Expand locations for summer internships to include FFRDCs, UARCs, and defense contractors in addition to government R&D laboratories
  - Give the school the recipient attends an additional benefit per year of approximately $10,000

The task force expects that DOD will set an example for other government agencies to follow in executing these recommendations. Estimated costs for DOD are shown in Table 8.

Table 8. Proposed additional DOD science and engineering education program costs, annually

	Number of people	Annual stipend	Cost of stipends	Admin costs	Total
Increase number of summer internships	3,000	$8,000–$18,000	$45 M	$5 M	$50 M
Double the number of SMART and NDSEG awards	800+800	50,000	80 M	5 M	85 M
Create additional fellowship positions	600	50,000	30 M	5 M	35 M

DOD Laboratory Personnel

Maintaining a constant influx of new ideas and fresh perspectives is important to the vitality of the DOD laboratories. Term employees, visiting researchers, or military officer rotations can help accomplish this. Additionally, term employees build relationships and gain an understanding of DOD laboratories that can last a lifetime. On-site contractors, while valuable to the DOD laboratories, do not fill these roles effectively, because they tend to become *de facto* permanent employees. Further, the rotation of military officers between operations and research can bring a fresh understanding of operations to the laboratories and a higher level of technical literacy to the operational military.

Recommendations

The following recommendations are made to DOD Service laboratory directors to maintain a vital workforce:

- DOD laboratory directors should establish long-term partnerships with leading universities and other research organizations that accommodate meaningful personnel exchanges that may last a few months to a few years.
- DOD laboratory directors should fully utilize existing authorities to hire outstanding scientists and engineers on a term basis, such as the Intergovernmental Personnel Act Mobility Program (IPA)[22] and the Highly Qualified Experts (HQE)[23] authorities.
- DOD laboratory directors should work with the military services to create additional billets at DOD laboratories for qualified military officers, with the eventual goal to make S&T a valued military career path, on a par with pilots or intelligence experts.
- DOD laboratory directors should use the funds authorized by Congress (according to Section 219 in the National Defense Authorization Act) to support sabbaticals for experienced laboratory basic researchers at outstanding research universities.[24]

Additional recommendations are made concerning recruiting and hiring new graduates:

- DOD laboratory directors should greatly increase the number of DOD laboratory postdoctoral scientists and engineers at the Service laboratories.

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22. The Intergovernmental Personnel Act Mobility Program provides for the temporary assignment of personnel between the federal government and state and local governments, colleges and universities, Indian tribal governments, federally funded research and development centers, and other eligible organizations. Program information is available at http://goo.gl/Gi96H (accessed November 2011).
23. The Highly Qualified Experts program provides for the temporary assignment of personnel from U.S. industry to the federal government. Authorities and limitations are available at title 5, U.S. Code § 9903. *Attracting highly qualified experts.* http://goo.gl/pxich (accessed November 2011).
24. See Appendix C for more information on Section 219.

- DOD laboratory directors should offer summer internships to NDSEG and other DOD support recipients and develop relationships with them in order to more effectively recruit the best upon graduation.
- DOD laboratory directors should expand their use of the SMART, NDSEG, and other DOD scholarship programs to identify promising recruits to include all students who receive DOD grant funding.

Some personnel practices will require action at the OSD level. For example, DOD laboratories currently have two categories of senior civilian personnel, members of the Senior Executive Service (SES) and Senior scientists and technologists (ST). According to the DOD interpretation of personnel regulations, SESs perform only high-level management duties, and STs perform only high-level R&D. Neither category is appropriate for high-level scientists and engineers who perform a mixture of management and R&D. Under the authority of the Science and Technology Reinvention Laboratory (STRL) program, DOD has the authority to establish a Professional Scientific and Technical Corps (PSTC) that would bridge this gap. A few laboratories have established such positions, but most have not.

Congress has also authorized direct hire authority at STRLs for certain candidates under Section 1108 of the National Defense Authorization Act (NDAA) of 2009. This authority may be exercised for scientific and engineering positions at STRLs for an additional 2 percent of the total number of such positions. This authority currently expires on December 31, 2013.

- The Under Secretary of Defense for Personnel and Readiness (USD(P&R)), in coordination with ASD(R&E), should publish an implementation policy for a Professional Scientific and Technical Corps and authorize all laboratories to hire or promote under this policy.
- DOD laboratory directors should fully utilize the "direct hire authority at personnel demonstration laboratories for certain candidates" found in Section 1108 in the 2009 National Defense

Authorization Act to hire outstanding scientists and engineers as basic researchers.[25]

- ASD(R&E) should seek legislation to extend the 2009 NDAA Section 1108 direct hiring authority beyond 31 December 2013.

Managing the Basic Research Portfolio

As stated in Chapter 2, all of the major decisions relative to DOD funding basic research—what areas of science to fund, relatively how much to fund each area, how to select the researchers and research projects to fund in each area, how to assess progress of each project—are highly subjective. Because the key decisions are subjective, it is especially important that the individuals making those decisions be highly qualified.

DOD basic research program managers responsible for the management of basic research efforts reside in ASD(R&E), the military secretariats, and the Services' basic research offices. They have primary responsibilities to identify the best researchers and exciting research opportunities in their fields nationally and around the globe, keep abreast of pertinent scientific literature, review white papers and proposals, participate in grants selection and administration processes, and respond to senior Pentagon and congressional inquiries—all the while maintaining contact with their many grantees without over-management of the performers. Balancing these responsibilities will strongly depend on their technical competence and management experience.

That leads to considerations of selection of program managers. Many are, as is proper, drawn from the ranks of the performers. Many also work in temporary appointments; that is, they come from a performer role, work in a management role for two to five years, and rotate back to resume work as a performer or performer's manager. Both the individual and the program gain from this process; the individual broadens his or her horizons and gains a useful understanding of the system and people while the program gains with technically competent management.

In order to make rotations work, it is important to provide mechanisms that support what otherwise might disrupt one's career. Presently,

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25. Duncan Hunter National Defense Authorization Act for Fiscal Year 2009, Public Law 110-417. October 14, 2008. Available at http://goo.gl/JBliN (accessed November 2011).

temporary details are the best means of providing reasonable rotation rates while minimizing career disruption. Existing authorities to accomplish this are the IPA or the HQE authorities.

Another issue that deserves attention is the tendency for program managers to remain near their home base, a situation seriously exacerbated by limitations on travel funds. When the manager can travel—versus requiring the performer to travel—performers spend less unproductive time and program managers gain a better and deeper understanding of the research. Moreover, requiring performer teams to travel substantially increases the net government expense.

Communication among performers working in similar areas is also very important for progress in basic research. Finding the appropriate level for periodic performer meetings should be determined for each area. At the top level, two models may be the Defense Sciences Research Council (DSRC) and the Information Science and Technology (ISAT) Study Group.

Recommendations

The task force offers the following recommendations to ensure effective and exemplary program management of defense basic research:

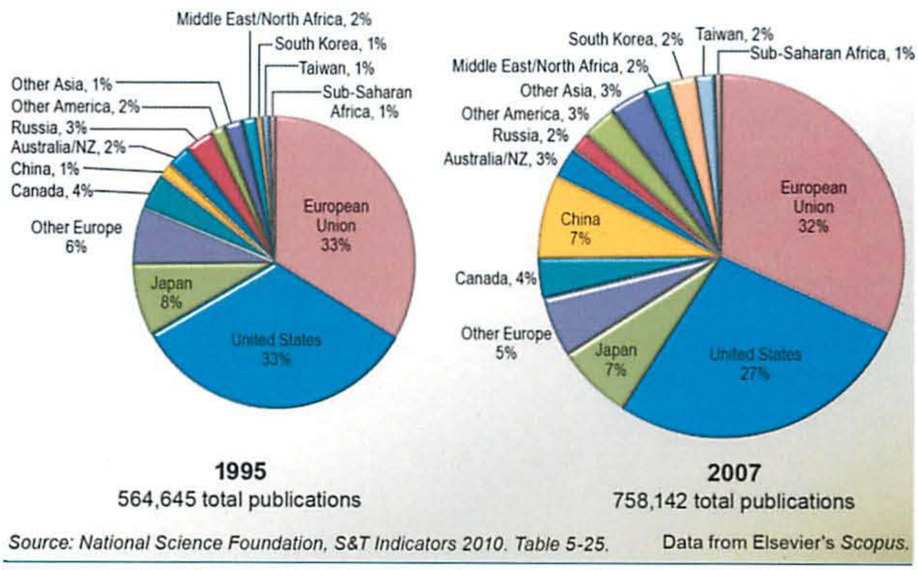
- DOD basic research program office directors should rotate active researchers from academia, industry, and FFRDCs using the IPA or HQE programs as appropriate. A useful goal may be to use these tools to keep the average time away from the laboratory low; less than five years for program managers if possible. Tours should be for nominally four years to best match up with the typical rotation of three-year grants.
- DOD basic research program office directors should facilitate personnel rotations between program management and hands-on laboratory basic research. Useful rotations can occur one day a week, can call a researcher to government service for a few years, or can include periodic sabbatical time. DOD basic research program managers can keep their skills sharp by performing personal scientific research up to 20 percent of their official work schedule and by publishing their personal research findings in peer-reviewed journals.

- DOD basic research program office directors should provide funds and time for basic research program managers to attend relevant professional society meetings, both in the United States and overseas. These conferences provide excellent opportunities for performer meetings. In addition, program managers should fully participate in professional society activities, including publishing review articles and serving as editorial board members of professional journals. These and other activities enhance the skills and professional reputation of both the program and the program manager and should be given great weight in the annual evaluation process and in promotion consideration.
- DOD basic research program office directors should provide an adequate number of S&T program assistants to help execute the administrative activities associated with proposal review, grant administration, workshop organization, and other program management duties. Assistance with administrative tasks is needed to allow each program manager to perform at their best and to reserve adequate time for higher level activities. Program assistants should have degrees in science, technology, engineering, or mathematics.
- DOD basic research program office directors should place special emphasis on gleaning useful advice from DSSG, the Computer Science Study Group (CSSG), NSSEFF, and PECASE alumni. Avenues to accomplish this may include meetings to discuss new results or general topics (in person or virtual), or it may include study groups or red teams that meet for weeks or months to tackle a timely problem. DOD should fully utilize those advisors who have shown special enthusiasm and aptitude for addressing national security challenges for basic research.

Chapter 4. Globalization of Basic Research

While the United States has been the preeminent research-producing nation for the past 50 years, basic research today is becoming increasingly global. For example, the growth in research publications (see Figure 8) and patents (see Table 9) has occurred primarily in the developing world. In the past, many of the best students and researchers chose to study and work in the United States. This situation is changing. Many countries are making new and significant investments in basic research, and a larger number of nations are participating at the leading edge of scientific discovery (see Figure 9). Further, some foreign-born scientists are leaving the U.S. to return to their native countries to find better opportunities, spurred by strict U.S. immigration laws and the poor U.S. economy. [26]

It is important for the DOD to be involved in the cutting edge of basic research on topics of specific interest to the DOD—whether the cutting edge is in the United States or overseas.



Source: National Science Foundation, S&T Indicators 2010. Table 5-25. Data from Elsevier's *Scopus.*

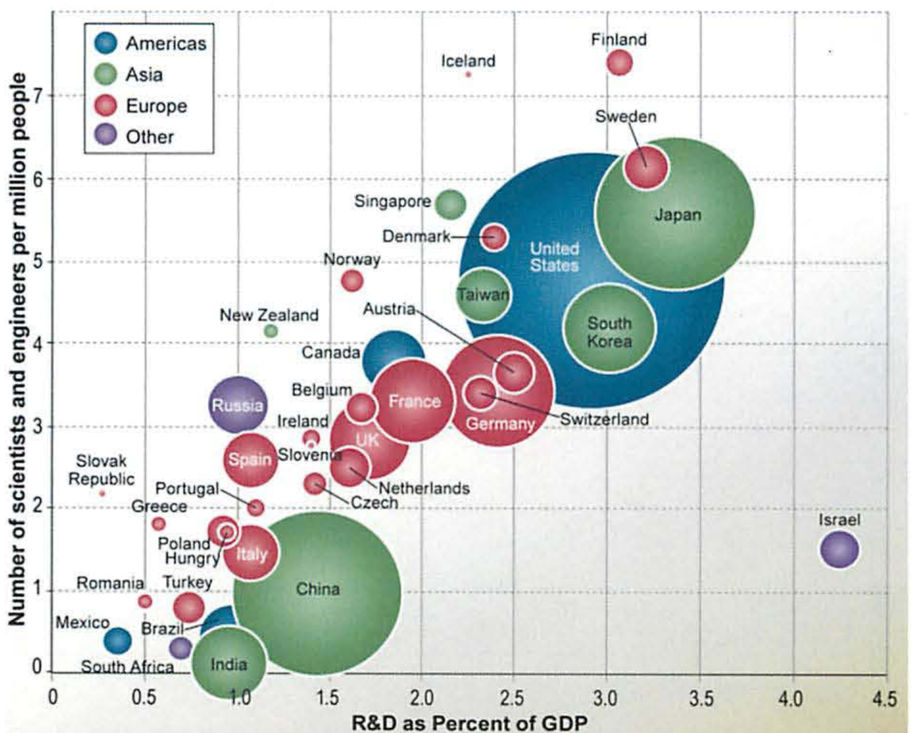
Figure 8. Comparative proportion of global publications by country

26. V Wadhwa, A Saxenian, R Freeman, G Gereffi, and A Salkever. *America's Loss is the World's Gain*. March, 2009. Available at http://goo.gl/uderz (accessed November 2011.)

Table 9. Top overseas patent registrations at the U.S. Patent Office

1989		1999		2009	
Japan	20,169	Japan	31,104	Japan	35,501
Germany	8,352	Germany	9,337	Germany	9,000
France	3,140	France	3,820	South Korea	8,762
UK	3,100	Taiwan	3,693	Taiwan	6,642
Canada	1,960	UK	3,576	Spain	6,472
Switzerland	1,362	South Korea	3,562	Canada	3,655
Italy	1,297	Canada	3,226	UK	3,175
Netherlands	1,061	Italy	1,492	France	3,140
Sweden	837	Sweden	1,401	China	1,655
Taiwan	591	Switzerland	1,279	Israel	1,404
Australia	501	Netherlands	1,247	Italy	1,346
USA	50,184	USA	83,905	USA	82,382
Global total	**95,537**	**Global total**	**153,485**	**Global total**	**167,349**

Source: U.S. Trademark and Patent Office

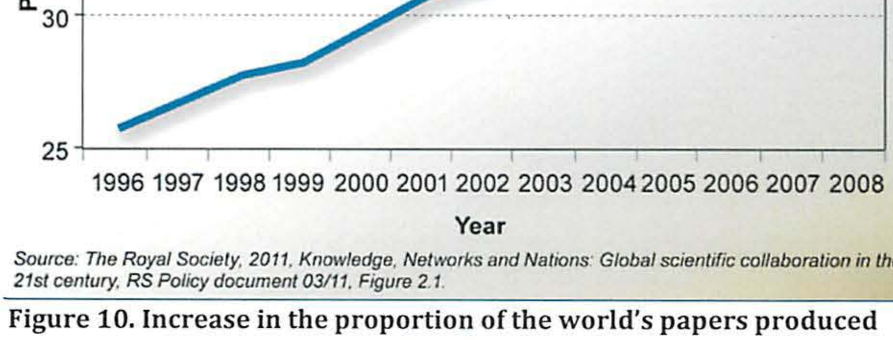


Source: Stability Returns to R&D Funding, *R&D Magazine, December 2010, p. 4.*

Figure 9. Global R&D in 2010 (The size of each circle reflects the relative amount of annual R&D spending in each country.)

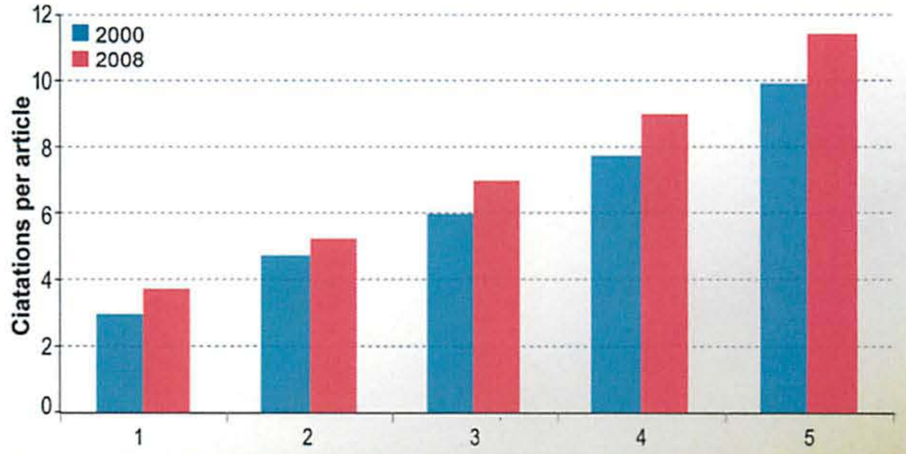
As the world continues the globalization of technology, manufacturing, and commerce, the United States will be more dependent than ever on technology and innovation for its defense and national security strategy from outside its sphere of influence. In order to avoid technological surprise, it is important for the DOD to be involved in the cutting edge of basic research on topics of specific interest to the DOD—whether the cutting edge is in the United States or overseas.

More than at any time in the past, science is an activity that is conducted collaboratively and internationally. International collaboration is an integral part of the modern scientific culture. While not a new development, several factors have been responsible for its continued growth: the ease of worldwide travel, high-bandwidth communication, and the recognized benefits of sharing ideas and approaches among the world's leading researchers. In addition, with the high costs of constructing and operating experimental facilities with specialized instrumentation and the unique skills required to operate, most large scientific facilities are run as international operations. This is reflected in scientific publications, where international collaboration has increased dramatically (Figures 10 and 11). Funding across borders is also on the rise (Figure 12).



Source: The Royal Society, 2011, Knowledge, Networks and Nations: Global scientific collaboration in the 21st century, RS Policy document 03/11, Figure 2.1.

Figure 10. Increase in the proportion of the world's papers produced with more than one international author



Source: The Royal Society. 2011. Knowledge, Networks, and National: Global scientific collaboration in the 21st century. RS Policy document 03/11, Figure 2.7.

Figure 11. Citations per article versus number of collaboration countries, where "1" means all authors were from one country.

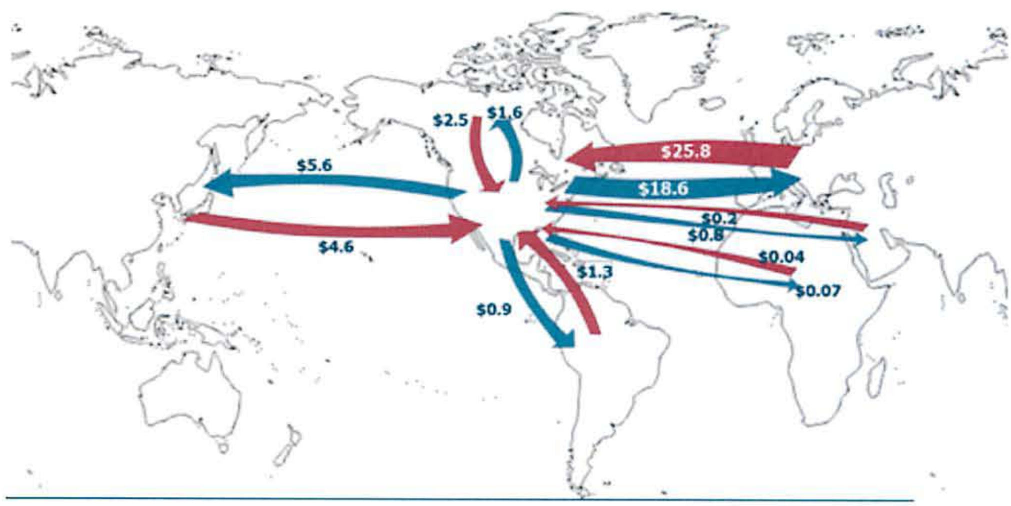


Figure 12. Overseas R&D funded by multinational companies creates complex exchanges. (Arrows show R&D performed by U.S. affiliates of foreign companies in the United Stated, by investing region, and R&D performed by foreign affiliates of U.S. multinational companies, by host region, 2006 (in billions of current U.S. dollars))

Implications for the Department of Defense

Leading-edge basic research results in new fundamental understanding and new know-how (the detailed knowledge of process and testing techniques). Advances in fundamental understanding are published and presented in open forums. Know-how is frequently not discussed openly but can be vital to the exploitation of the fundamental understanding. Basic researchers frequently spend time in other laboratories in order to become familiar with the particulars of the research being done in different environments. This enables them to gain an understanding of the know-how that they can then apply in their own laboratory. It is important to maintain a current knowledge of the evolution of the technical details that underpin the advances in fundamental understanding; doing so will require a persistent presence in the leading laboratories.

By far the most effective way to learn what is going on elsewhere is to work there, not to read publications, attend conferences, or make short visits, valuable as those latter activities may be.

In sum, by far the most effective way to learn what is going on elsewhere is to work there, not to read publications, attend conferences, or make short visits, valuable as those latter activities may be.

The next generation of scientists and engineers—both in the United States and overseas—are responding to these trends. The number of U.S. students studying abroad is climbing every year, from less than 50,000 in 1985 to more than 200,000 in 2005. Students are increasingly going to study in non-traditional destinations, and increasingly to non-English-speaking countries. U.S. students studying in China leapt 34 percent between 2003 and 2005, and the numbers going to Argentina and India both were up more than 50 percent.[27]

Scientific research has always been a global endeavor, with a great number of collaborations, conversations, and conferences involving international thought leaders. Transitioning the fruits of basic research to the reality of manufacturing has been far more local, and in this area, the United States has excelled. The United States has, for many years, relied on

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27. Institute of International Education. 2007. *Meeting America's Global Education Challenge: Current trends in U.S. study abroad and the impact of strategic diversity initiatives.* Available at http://goo.gl/R5w5P (accessed November 2011).

a university system that attracted outstanding scientists and engineers from the rest of the world. Today, the United States remains conclusively the global leader in science, according to metrics such as the size of the research community and the number of Nobel prizes. Global science funding, however, is growing and the United States can no longer attract all the best and brightest from the rest of the world.

For the United States to maintain its lead, trained scientists from around the world must be able to come to the United States and participate in the research carried out here. As well, students from around the world must be allowed not only to attend U.S. graduate schools but even more important to remain in the United States for postdoctoral work and careers in science.

And the converse: U.S. scientists have to work abroad, side-by-side with foreign researchers in their laboratories, and U.S. students have to study abroad.

How DOD has Responded to Globalization

In the area of scientific development and innovation, international boundaries are fading, making DOD's relationship with the global network of researchers even more critical for scientific and technological advancement and success.

How the Department assesses, funds, and tracks leading edge research must incorporate this globalization, and must assess research trends worldwide. Research performers and managers do this through the normal course of their activities—reading publications, attending international conferences, and collaborating with the others in their fields. The task force fully supports these efforts.

A critical component of this worldwide science assessment comes from DOD's global offices. At these offices, Service program managers keep abreast of leading science in their regions by attending conferences and visits to research institutions, with an eye to funding leading regional scientists of interest to the United States and supporting collaboration with U.S. scientists. The major activities of these offices are to have a visiting scientist program, to provide conference support, and to provide research funding. Specific programs are listed in Table 10.

Table 10. Global program elements in each military service

Navy

A key organization for all defense S&T is ONR Global, organized to provide worldwide S&T-based solutions for current and future naval challenges. Leveraging the expertise of more than 50 scientists, technologists, and engineers, ONR Global maintains offices in London, United Kingdom; Tokyo, Japan; Singapore; Prague, the Czech Republic; and Santiago, Chile. ONR Science Advisors are also located in Naples, Italy; Yokosuka, Japan; Okinawa, Japan; and (at one point) Bahrain.

It is the mission of ONR Global to build relationships between the international scientific community and the naval research enterprise, and to identify new technologies to support the Naval Science and Technology Strategic Plan. ONR Global pursues these goals through the following programs:

- The Visiting Scientist Program supports travel of international scientists to the U.S. and to international conferences
- The Conference Support Program supports international conferences and workshops
- The Naval International Cooperative Opportunities in S&T Program supports joint research projects

Army

The Army has International Technology Centers in Canada, England, Germany, France, Japan, Singapore, Australia, Argentina, and Brazil; however these are not generally affiliated with basic research efforts.

The Army Research Laboratory has launched an International Enterprise in 2011, with the goal to foster communication and build relationships with research partners overseas. Currently, the Army highlights international cooperation through the "Five Eyes" Tripartite Technical Cooperation Program (TTCP), as do the other two Services. TTCP membership comprises Australia, Canada, New Zealand, the United Kingdom, and the United States. Similar coordination occurs through the NATO Research & Technology Organization, as well as through bilateral agreements with countries including the United Kingdom, Canada, Israel, France, Germany, and others. While the stated goals of these programs may be focused on technology, cooperation in the area of basic research is many times an easier opportunity for all parties.

Air Force

AFOSR has offices in London, United Kingdom; Tokyo, Japan; and Santiago, Chile. It is the mission of the International Office in the Air Force Office of Scientific Research to integrate and support Air Force fundamental research with discoveries of emerging foreign science. Some programs aimed at these goals include:

- Window on Europe, Window on Asia, and Window on the Americas provide opportunities for AFRL scientists to conduct research in foreign non-government laboratories for up to six months; Window on Science provides opportunities for foreign researchers to visit DOD laboratories and other U.S. research institutions for up to two weeks.
- USAF/National Research Council Resident Research Associateships provide research opportunities to post-doctoral and senior scientists (including senior foreign nationals) to work in AFRL, the U.S. Air Force Academy, and Air Force Institute of Technology research laboratories for one to three years.
- The Engineer and Scientist Exchange Program provides an opportunity for military and civilian scientists in DOD to conduct research in foreign government laboratories and for foreign government (military and civilian) scientists to work in DOD laboratories; international agreements are established for Australia, Canada, Chile, Egypt, France, Germany, Greece, Israel, Italy, Japan, Korea, Netherlands, Norway, Poland, Portugal, Singapore, Spain, Sweden, and the United Kingdom.

On an interagency level, DOD personnel also communicate with NSF offices in Paris, Beijing, and Tokyo. All of these offices and programs provide direct interchange with members of the scientific and engineering community and encourage the establishment of beneficial relationships between DOD scientists and engineers and their foreign counterparts within their geographical areas. In all of these efforts, however, the emphasis is primarily on making research connections rather than toward global assessments. Reporting in support of the global watch mission is relatively infrequent and somewhat informal. In addition to maintaining international offices, the Services invest some of their basic research funds in foreign institutions. In FY2011, the Navy reports a 3 percent, the Air Force, 2.5 percent, and the Army, 2 percent, of 6.1 funds allocated internationally [28] In addition, DARPA devotes a percentage of their resources to funding research overseas.

The ASD(R&E) is required to carry out a global research watch effort, mandated by 10 U.S.C., Section 2365. This requirement is fulfilled in a number of ways, and no single and pervasive system exists for international scientific assessment and awareness for DOD. Programs supporting this goal include the Army's Global S&T Watch and Technology Information Papers online, and the Navy's monthly Global Technology Awareness briefs and the Knowledge Management System website.

A focal point for basic research is the Scientific Situational Awareness workshops sponsored by ASD(R&E) designed to facilitate discussion in scientific communities and to help define global centers of excellence for given disciplines. In addition, DOD maintains the Developing Science and Technologies List (DSTL) in an effort to assess technologies that could improve U.S. military capabilities once mature. The objectives of the list are to characterize these developing technologies and to assess worldwide technology capabilities. The DSTL identifies scientific research efforts that have the potential to significantly enhance or degrade U.S. military capabilities starting five years into the future. The DSTL is intended as a reference document, as well as a guide for international cooperation programs.

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28. Department of Defense, Financial Management Regulation, DoD 7000.14-R, Vol. 2B, Ch. 5, Para 050201, Part B, December 2010. Available at http://goo.gl/vKJjC (accessed November 2011).

In addition to DOD's formal mechanisms for responding to globalization, DOD-funded researchers view themselves as competing in not just the U.S. research community, but the global research community as well, and find a competitive edge by partnering and closely monitoring their international peers. DOD should encourage such collaboration and monitoring, specifically by funding foreign travel and attendance at international conferences, and by funding the infrastructure necessary for virtual collaboration. DOD-funded researchers can serve as monitors of research advancement, in addition to the Service international offices and other formal DOD mechanisms.

How Industry Has Responded to Globalization

U.S. industry has long recognized the trend toward globalization of science and technology. Major corporations have approached the challenge to access the best ideas by going well beyond attending international meetings and reading publications. They have located research entities in strategic locales populated by a mixture of U.S. citizens and local scientists, and have populated research entities in the U.S. with the same mix:

- GE went aggressively global in the 1990s, and now has research laboratories in Bangalore, India; Shanghai, China; Munich, Germany; and Rio de Janeiro, Brazil.
- Microsoft, according to their Microsoft Research India website, is "seeking great researchers and post docs wherever we can find them" and has more than 850 researchers working in locations around the world—including Cairo, Cambridge, Aachen, Beijing, and Bangalore.
- IBM established a research presence in Switzerland in 1956, Israel in 1972, and Japan in 1982, and now has additional labs in Delhi and Bangalore, India; Sao Paolo and Rio de Janeiro, Brazil; and Beijing, China.
- Yahoo! expanded their Silicon Valley research labs to facilities in New York City, Bangalore, Barcelona, Santiago, Haifa, and Beijing. The reasons for this expansion are varied, and include exploiting personal contacts or university partnerships, accessing talent that is difficult to move to California, keeping talent that would rather go "home," and instilling a sense of competition among research

groups. Challenges include communication in the virtual workplace, effective tech transfer to products, and the cost/benefit ratio.

The success of IBM's laboratory in Zurich makes it a model for other overseas laboratories within IBM. The laboratory has two missions: perform basic research in fields related to information technology and work on applied research in areas that have an identified path to commercialization. Over time, the laboratory has established very close connections with the European research community and has been able to attract both leading researchers and strategic partnerships.

For many companies, location matters less to their increasingly virtual—and global—workforce. This is equally true for small startups without the time or money to pursue work permits, but that do have access to shared virtual workspaces and overnight shipping. Virtual tools improve communication among researchers both across the campus and around the world. Many companies have found they can maintain around-the-clock progress on critical discoveries by handing off results across time zones as one shift leaves the lab and another arrives for work.

Looking to Industry as a Model for Success

The best practices in the industrial world are to establish foreign laboratories that perform best-of-breed research in selected fields and are fully integrated into the local scientific community. Researchers participate with state-of-the-art research in regional university and government laboratories. Working closely with the local research community results in a fuller understanding of the state of the art.

The best practices in industry allow visiting scientists to access specific laboratory locations or, preferably, laboratories at partner universities, so as to minimize their access to confidential information.

All industrial efforts have begun small, with one foreign laboratory and two or three specific research areas to gain an understanding of the success strategy. For example, locating a robotics research laboratory in Japan would directly connect U.S. research with the leading edge research in Japan. A typical time for a new laboratory to establish a close connection to the local community and begin delivering significant results is five years.

The percentage of DOD basic research funding that is devoted to supporting overseas efforts is not commensurate with the inexorable rise in the percentage of the world's basic research being conducted outside the United States.

A laboratory must have facilities to conduct research. The location should be in close proximity with local centers of excellence in the research to be conducted, and, ideally, should be located so as to minimize the moving and living expenses of the researchers.

A laboratory needs to have a staff of at least five researchers in each area of interest with a mix of short-term (1 year or less) and long-term researchers (more than a 3-year residence). Two or more long-term researchers in each area would overlap their tenures in order to provide the best connection to the local research community. Shorter-term employees should have specific research topic areas chosen before the assignment begins, and have the responsibility to transfer technology back to U.S. laboratories.

The task force found that the percentage of DOD basic research funding that is devoted to supporting overseas efforts is not commensurate with the inexorable rise in the percentage of the world's basic research being conducted outside the United States.

Recommendations

The task force offers the following recommendations to the department to more effectively address globalization of the basic research enterprise. The task force strongly supports these activities for coordinating with, reaching out to, and harvesting the results of basic research around the world:

- USD(AT&L) should establish locations where U.S. researchers can work side-by-side with leading foreign scientists, following the best practices of U.S. industry and academia. Such a location may be structured as an international satellite campus of an existing DOD Service laboratory, involve a relationship with a university or other research institution overseas, involve a government-to-government partnership, or other alternatives.
- DOD laboratory directors should increase the locations at U.S. Service laboratories where foreign researchers can work on basic

research topics during a visit, term, or sabbatical without the need for security clearance, and should increase their invitational support of foreign scientists.

- DOD basic research office directors should establish programs for DOD laboratory and U.S. university researchers to spend a visit, term, or sabbatical at a foreign laboratory to interface with leading basic researchers in areas of interest to the DOD.
- ASD(R&E) should increase the percentage of basic research funding that is invested internationally from 2.5 to 3 percent to 5 percent over the next two years. As shown in Table 11, such an increase will provide a tremendous boost for international collaboration, while leaving a substantial increase for the domestic base.

Table 11. DOD International Research Funding

	FY 2010 Actual	FY 2012 Request	% Change
Total 6.1 funding	$1,815 M	$2,078 M	+14%
Proposed for international programs	2.5% = $45 M	5.0% = $104 M	+129%
Remaining for domestic programs	$1,730	$1,972	+12%

Part III

Strategy and Innovation

Chapter 5. The Need for a DOD Technology Strategy

The Role of Strategic Planning

The task force acknowledges the centrality of intuition borne of experience for deciding what areas of basic research should receive DOD support. However, DOD is faced with new adversaries, new tactics of said adversaries, and new weapons available to and used by said adversaries. In that light, DOD has not accumulated the experiential base to engender the greatest confidence in intuition alone. An analytic framework would add to that confidence. Such an analytic framework is oftentimes called a "technology strategy."

By this definition of a technology strategy, a definition largely shaped by the best industry practice, the task force cannot find such a plan within DOD. The ASD(R&E) thoroughly understands this and is making progress toward the construct of a technology strategy for the Department. The task force applauds and encourages these efforts and direction.

The value of having, and using, a departmental technology strategy to inform basic research investment, and also to guide both applied research and advanced development, is clear. In addition, systems and technology seem to play such a central role in the conduct of U.S. military affairs in general that such a technology strategy would not only be invaluable in alignment of research and engineering, but in alignment of systems, missions, and national security affairs more broadly.

In times past, the regret to DOD for not having such a plan could be small. That is not the case now. DOD no longer has purview or even cognizance of all emerging science and technology. As discussed elsewhere in this report the DOD must find ways to engage more of the nation's top S&T talent in national security challenges. Thus, in the absence of a plan that incorporates specific steps to understand and exploit the extensive globally created S&T, it is possible and likely that DOD will miss important opportunities to craft new capabilities enabled by new S&T. More worrisome yet is that DOD will not be able to anticipate and counter novel capabilities produced by potential adversaries.

A technology strategy would not only be invaluable in alignment of research and engineering, but in alignment of systems, missions, and national security affairs more broadly.

What is a Technology Strategy?

A list of critical technologies does not constitute a technology strategy; nor does a summarizing description of ongoing activities and funding, although such a list and descriptions have sometimes been offered as evidence of strategic planning. An effective technology strategy should have at least five elements:

1. A vision of what DOD's S&T enterprise consists of, why it exists, and the rationale for science and technology endeavors.
2. An assessment of emerging areas of science and technology, particularly areas of rapid change and substantial promise.
3. Realistic objectives, prioritized and quantified as much as possible. Objectives need to be expressed with sufficient clarity that, later, a disinterested observer could tell if they were actually accomplished. For most areas of S&T that means quantitative expression. And, insofar as DOD is perpetually engaged in an ever-changing competition, that means aspiring to at least an approximate timescale as part of a technical objective: advancement 5 years out might be valuable, advancement 50 years out, less so. Objectives must also be desirable. Presumably a good DOD technology strategy would explain why the advancement sought would actually enhance national security if achieved, and would hinder national security if the S&T falls short.
4. An approach to achieve the vision and objectives. It should include discussion of uncertainties, challenges, and obstacles. Including objectives that are not achievable is not helpful. Accomplished engineers are facile in doing highly approximate, order-of-magnitude back-of-the-envelope calculations to assess whether an idea could get us into the ballpark, or not, of what's desired to meet an objective. Objectives without ideas, albeit half-baked and unproven, are not convincing.
5. Finally, detailed plans are needed on how to achieve the objectives, acknowledging that such plans always undergo change.

Table 12. Issues Surrounding a DOD Technology Strategy

Challenge	Response
There is too much uncertainty in the nature of S&T. Much of S&T is experimental and exploratory attributes that don't easily lend themselves to strategic planning approaches predicated on accurate forecasting.	Strategic planning is most needed when there is great uncertainty. A set of rules would be sufficient when accurate forecasting is possible.
A strategic plan is counterproductive and will stifle creativity.	Much greater threats to creativity are some of the administrative practices covered elsewhere in this report. Planning and creativity need not be incompatible.
It is too hard.	Yes, effective strategic planning in the face of uncertainty is not a trivial task, but that shouldn't be an excuse for not doing it.
Lists of critical technologies and descriptions of current activities are the S&T strategic plan.	Not true.

The S&T Strategic Plan for the DOD Research and Engineering Enterprise meets a few of these criteria, but by no means all. Strategic planning that captures all five of these elements has proven elusive in DOD S&T. Over the years DSB task forces have heard a number of reasons for the lack of a DOD S&T strategic plan.

Current S&T Priorities

In the absence of a genuine technology strategy, the ASD(R&E) has put forth seven technology priority areas and six basic science priority areas. These are included here for reference. However, there is no way to have sufficient confidence that these lists are both necessary and sufficient, nor is there any robust relationship postulated between the two lists.

The seven current defense technology priority areas for S&T investment[29] are:

1. **Data to decisions:** Science and applications to reduce the cycle time and manpower requirements for analysis and use of large data sets

29. Department of Defense. Memorandum on *Science and Technology (S&T) Priorities for Fiscal Years 2013-17 Planning*. Available at http://goo.gl/ba6Ys (accessed November 2011.)

2. **Engineered resilient systems:** Engineering concepts, science, and design tools to protect against malicious compromise of weapon systems and to develop agile manufacturing for trusted and assured defense systems
3. **Cyber science and technology:** Science and technology for efficient, effective cyber capabilities across the spectrum of joint operations
4. **Electronic warfare/electronic protection:** New concepts and technology to protect systems and extend capabilities across the electro-magnetic spectrum
5. **Counter weapons of mass destruction (WMD):** Advances in DOD's ability to locate, secure, monitor, tag, track, interdict, eliminate, and attribute WMD weapons and materials
6. **Autonomy:** Science and technology to achieve autonomous systems that reliably and safely accomplish complex tasks, in all environments
7. **Human systems:** Science and technology to enhance human-machine interfaces to increase productivity and effectiveness across a broad range of missions

The six current DOD priority areas for basic research are:

1. **Synthetic biology:** Convergence of life sciences and the physical sciences
2. **Engineered materials:** Metamaterials, plasmonics, spintronics, optoelectronics, atomtronics
3. **Quantum information and control:** Taking Heisenberg to the next level: entangled states and new capabilities in communication, sensing, imaging, simulation, and computing
4. **Human motivations and behavior:** Understanding individual decision-making processes and social networks
5. **Cognitive neuroscience:** Neuro-cognitive performance, plasticity, brain-electronics interfaces
6. **Nano-science and engineering:** New structures, devices, manufacturing, and finding the nano-basis for assembly and manufacturing

Without a technology strategic plan, lists of priority science or technology areas cannot be specified with sufficient clarity relative to quantitative performance, to timing, or to feasibility and desirability.

Managing the Portfolio of Basic Research Investment

A two-part portfolio strategy for basic research investments makes a great deal of sense. Broad investment in essentially all areas of science is needed to sensibly yield knowledge and know-how important for military capabilities. In addition to the creation of knowledge and know-how, such investment provides a much-needed window on the expanse of basic research performed on a global basis. Some basic research is obviously evolutionary, providing small steps of improved capabilities on a relatively slow time scale. With similar research by likely adversaries, the expectation is that the United States will neither achieve large military advantages nor fall significantly behind. Most of the science in that category will be published across the globe at a similar pace. Investment in these areas maintains DOD's expertise and depth of understanding.

For a few areas of science, significant in-depth investments make possible the potential for major advances that could provide DOD with competitive advantage, or could ensure that DOD is not at a competitive disadvantage. Determining the selection criteria for such investments is a key challenge, as indicated through the following questions:

- Is there a major, revolutionary discontinuity in the field?
- Would significant DOD funding be a meaningful part of the whole, on a global basis?
- Is DOD poised to make use of advancement vis-à-vis applied research and advanced development?
- Would advancement, if swiftly and energetically exploited, make a significant difference in the nation's national security capability?

A DOD technology strategy is not critical for guiding broad investment among most fields of science, but it is critical for informing selection of a few fields of science where in-depth funding to potentially provide competitive investment is both advisable and feasible.

Exploiting Knowledge to Gain Military Advantage

Knowledge gained through basic research must be exploited to be of military value. Today, the U.S. military is in a position to exploit the scientific results of basic research when military adversaries cannot—even when they have access to the very same knowledge—by dint of financial resources, culture, and U.S. infrastructure.

That competitive opportunity—transitory, as are all competitive differentiators—makes it all the more frustrating when innovation is hindered "downstream" from basic research, as discussed in Chapter 6.

RECOMMENDATIONS

The task force offers the following recommendations to the department

- ASD(R&E) should craft a genuine technology strategy.[30]
- ASD(R&E) should articulate a two-part portfolio strategy for basic research investments. One part should include broad investment in essentially all areas of science that could sensibly yield knowledge and know-how important for military capabilities. A second part should include selected, in-depth investments to provide the potential for major advances that could lead to a competitive advantage.
- ASD(R&E) should ensure the tenets of a technology strategy are implemented in the basic research enterprise. These tenets should not only be directed toward basic research projects or programs; rather, they should also affect such activities as outreach to students and to young faculty; recruitment and training of government researchers and managers; and identification of S&T advisors.

30. In 2005, the DSB conducted a comprehensive study of ASD(R&E)'s (then termed DDR&E) roles, missions, authorities, and resources, and, as part of that study, drafted a memorandum that could be the starting point for an updated directive from the Secretary that would facilitate the construct of a technology strategy. See Appendix D for the memo text.

Chapter 6. DOD Innovation Challenges

One fundamental motivation for DOD funding of basic research is expectation that scientific insight will translate into military innovation to enhance national security.

What, if anything, limits DOD's innovation ecology? Most observers of DOD would argue that the products that ultimately reach the troops do not exhibit the same degree of innovation typically found in the commercial sector. While commercial industry differs in many respects from the DOD's defense industry, and while the size of the DOD enterprise tends to limit agility and innovation, nevertheless, it is useful to probe the question of what limits innovation in the DOD ecology.

Two questions related to the above were examined:

1. Can improvements to DOD's basic research program or to the interaction, communication, cooperation, and/or coordination among the research performers materially enhance DOD's level and rate of innovation?
2. What effect does DOD's acquisition system have on DOD's level and rate of innovation?

The task force found no evidence that a lack of product innovation in the hands of end-users stems from a lack of relevant or potentially useful technology emerging from the DOD research program or from non-DOD research. Rather, the apparent sluggishness in innovation is more a function of the manner and time required for technology maturation beyond the realm of research, and requirements and acquisition processes and procedures that impede adoption of technology and new concepts of operations.

The task force finds that the basic research program itself is not a significant inhibitor to DOD innovation, nor is it the rate limiter in DOD's innovation process.

It is NOT the purpose of this task force to pen yet another report on reforming the DOD acquisition system, and, in particular, the DOD requirements process. Nevertheless, a few observations are warranted insofar as the potential impact on defense innovation by DOD's basic

> The basic research program itself is not a significant inhibitor to DOD innovation, nor is it the rate limiter in DOD's innovation process.

research program is so compromised by what happens downstream of the scientist's laboratory.

Maturing Technology within DOD

Within the DOD S&T program, many programs and projects have aimed at maturing technology using a number of different approaches, shown in the innovation cycle in Figure 13:

- Mature the process of using a novel material; or mature the manufacturing process to increase yield, reduce cost, and scale up.
- Create prototypes that incorporate user concepts of operations to provide experience with a new technology and encourage advocacy.
- Make it possible for university students, small companies, government laboratories, and industry to design devices and deliver prototypes by acting as a brokering service to facilitate cost-effective and timely fabrication, assembly, or manufacture.
- Define innovation challenges using organized competitions or prizes as the incentive for teams to form and compete.

All of these approaches, and more, have been routinely applied for decades. Such activities are typically and appropriately funded outside the

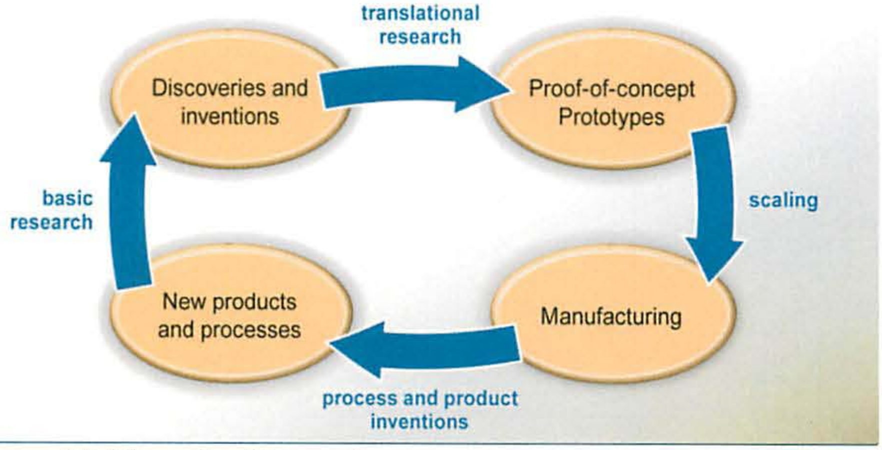

Figure 13. The cycle of innovation

basic research funding line, and the responsibility for their execution lies with the DOD sponsor (usually one of the Services, DARPA, or DTRA). The Office of the ASD(R&E) can help this process by identifying synergies among R&D projects and by facilitating interactions with excellent researchers from academia and industry.

Impacting Innovation through the DOD Acquisition System

Five factors related to the current defense acquisition system serve as an anchor in limiting the degree of innovation that is found in major weapons systems:

1. The extensive time it takes to bring a system from concept or early exploration to a mature, fieldable product
2. Requirements specifications that focus on a particular implementation far too early in the development process
3. A risk-averse climate reflected in requests for proposals and their competitive evaluation
4. A disconnect between smaller, flexible, innovative organizations and larger organizations that have the capacity to develop, produce, and support major weapons systems
5. A failure to require "flexibility" as a major attribute of new weapon system procurements

Reducing Time from Concept to Fielding

DOD's acquisition processes, particularly the requirements process and the extensive length of time it takes to move from concept to fielding, are an anchor on innovation. If it takes 20 years to conceive, develop, and produce a first generation system, there is little chance that it will contain cutting edge technologies. It is clearly recognized that the military must have the ability to acquire new capabilities based on technology more rapidly. In a 2009 study, *Fulfillment of Urgent Operational Needs*, the Defense Science Board found that not all of DOD's needs can be met by the same acquisition process and that a rapid process to meet urgent needs can function in parallel and concurrently with the more deliberate and more comprehensive acquisition process that would serve the majority of acquisition needs. That report recommends that the Secretary of Defense establish parallel acquisition processes. Similarly, the 2008 DSB Summer Study on *Capability Surprise* and the 2010 Summer Study on *Enhancing Adaptability of U.S. Military Forces* both came to similar conclusions and recommendations.

This report will not repeat the process recommendations contained in these past studies, nor deal with the broad issue of rapid acquisition. Rather, the intended emphasis in this report is to consider how such processes relate to the science and technology activities, *i.e.*, when such a process is being used to achieve a genuinely new capability, in contrast to an acquisition where the capability already exists and the need is for rapid fulfillment.

When a genuinely new capability is desired, it is critical that the rapid acquisition process:

- Emphasize needs, rather than requirements
- Make real tradeoffs between cost, capability, risk, and time to field
- Evaluate the base technologies for readiness
- Evaluate the production processes (manufacturing or software development) to assure robustness
- Evaluate the systems architecture in which the new capability will be operated to ensure successful insertion

The science and technology programs (primarily at levels 6.2 and above) field many technology and capability demonstration programs. These are better matched to a rapid acquisition process that is striving to balance urgent needs against technology maturity, rather than a deliberate acquisition process constrained to fully meet requirements at minimum risk with little ability to trade off cost, risk, and capabilities.

Time between discovery and the effective application of an innovation varies widely. For example, when a technology or product is unlike what has been available in the past, it typically requires a decade or more to mature and to be adopted even when programs are executed well. In contrast, if an innovation is incremental in nature, adoption can occur in weeks and months. One way of implementing new technology within major system acquisitions is to make greater use of block upgrades.

One common argument against block upgrades is that repeated sweeps of existing systems are needed to reliably perform maintenance, logistics, or operational training. However, innovations in information technology now enable inventory systems that uniquely track each individual system in such a way that the technology base for each component is known and supported. Similarly, built-in fault diagnostics and automated spares tracking and management ease the maintenance and logistics issues, and system-imbedded training can minimize the impact of new subsystems and/or componentry. As a result, variety in a collection of similar but not identical weapon systems can be managed today far more expeditiously than in the past.

The task force offers no specific recommendations for basic research, but suggests the recommendations on rapid acquisition and block upgrades contained in recent DSB studies (2008, 2009, and 2010) should be reviewed by USD(AT&L) and the implementation of a dual track acquisition process be initiated.

Focusing Requirements Too Early on a Specific Implementation

Requirements often express "how" something should be done rather than "what problem" needs to be solved. This creates two issues, both of which tend to discourage innovation. The first is that such a "how" specification is inherently restrictive and limits the breadth of approaches that might be pursued, including, perhaps, those built on either technological or operational innovation. The second issue has to do with how an industrial supplier will view deviating very far from the specified solution, even within the narrow framework it represents. For example, a sensor could be specified as requiring a 180 degrees field of view. In the evaluation criteria for this requirement, suppose that there are no points for greater fields of view, even though providing this added capability might decrease the number of sensors required and represent lower total system cost. Under such a set of requirements and evaluation rules, very few, if any, contractors will propose an innovative approach, fearing that either they will be considered non-compliant or that they will be evaluated solely on their higher unit cost without any regard to the lower overall system cost. Similarly, deviating very far from the specified technology, (*e.g.*, replacing an optical sensor with an acoustic sensor) might satisfy the objective of the procurement, but would be viewed as a major risk by any competitive bidder.

While it may be appropriate to limit the potential range of solutions when specifying a competitive procurement for later phases of development, this kind of restrictive requirement often creeps into the earlier concept definition phases of development even though the very purpose of these early phases is to explore alternative solutions to a problem and their associations within the performance, risk/opportunity, schedule, and cost space. Yet too often, this space remains largely unexplored, either because of preconceived ideas within the service acquisition community, and particularly their laboratories, or effective technical marketing by industry. In either case, an opportunity to assess the pros (performance, cost, broader application) and cons (risk and schedule) of using advanced, but, by definition, less mature technology is lost.

Shifting a Climate of Risk-Averse Acquisition

The issue of acquisition risk highlights another barrier to industry willingness to embrace the latest technology in favor of more traditional and fully mature technology. When specifying a competition for the early phases of a major system procurement, the requirements may leave open what is to be procured by properly specifying only the broad capabilities required. However, a request for proposals will often specify a technology or manufacturing readiness level that needs to be achieved by a time certain in the future, and ask the potential bidder to outline the design and development program required to achieve that level at that time. While the intention of such a requirement is to ensure that a capability can be fielded at a given time with a reasonable probability of success, it has an unintended consequence of chilling a bidder's willingness to embrace advanced technology. Such adoption carries with it many different competitive risks and/or penalties, as perceived in the competitive thought process of any major contractor:

- If there is some new whiz bang technology that might make a big difference, can I make a convincing case that I can mature the technology sufficiently to meet the specified time requirement?
- If so, my development phase needs to be very aggressive—will I price myself out of the competition?

- What if I get selected and can't mature the technology sufficiently? Will this come back to haunt me on other procurements in my past performance?
- If I am willing to take these risks, what is there in the evaluation criteria that gives me offsetting credit for the extra performance or other benefits that accrue to my use of advanced technology?

In general, the current culture fosters meeting minimum requirements in the allotted time at low risk and at the lowest, or at most, within striking distance of the lowest cost. Almost inevitably, the downside of proposing, and trying, an innovation solution with some risk is much greater than the upside for its successful implementation. This is not a climate favorable to the adoption of advanced technology.

Comparing Small, Agile, Innovative Companies and Large, Major, Industrial Companies—and the Government Itself

So why doesn't the smart, far-seeing, large industrial contractor either develop the advanced technology that will put him in a favorable position on some future procurement or team up with some smaller, more agile, outside developer of advanced technology? This does happen, but more often there is a serious gulf between the fruits of basic research and reaching the maturity level necessary to be adopted for inclusion in later, more competitive, critical decisions by major defense contractors. Universities and small research companies tend not to build strong relationships with industry owing to cultural differences, data right issues, the fear of being milked and dropped, and so on. The reverse relationship does not happen as much as perhaps it should because there is no convenient vehicle for industry to understand what enabling or differentiating opportunities may exist within academia or small research institutions.

It is interesting to note that even within a single large company this is often the case. Most major defense contractors acknowledge the difficulty they have in general with fostering innovation within the constraints of a culture that by necessity has to protect against the severe penalties of mistakes occurring within major back-end developments or high rate production. The typical way this protection is provided is by establishing a variety of step processes that have to be followed—in pursuits, in development, in production, and in support. Recognizing that these processes tend to stifle innovation and discourage out-of-the-box thinking, these companies set up small groups, relatively isolated from these processes, with more relaxed profit-and-loss requirements, fewer process constraints, and more autonomy. But having done so, and often with these special groups doing very good work at the front end in fostering some new capability, even here the bridge between front end and back end is weak and often non-existent. Typically managers of big DOD programs, both in industry and the government, resist scheduling innovation into their programs. Thus, if innovation hasn't been factored in the formative stages of major programs, it is unlikely ever to find a way in.

The most difficult players to involve in innovation maturation activities are small companies. They often are not knowledgeable of how to expeditiously contract with the government. They often do not have, and do not want to add, the staff to perform the support functions that government contracting requires. Further, when intellectual property that will determine the success or failure of the company is involved, there can be difficulties in negotiating contract terms. In particular, the most recent legislative change to industry intellectual property rights in contracting with the DOD, in which any government funding, including reimbursable private funding, gives the government complete rights to the contractor's intellectual property, will aggravate this reticence still further and may limit cutting edge independent development even in the large defense companies.[31]

In order to bridge this gap between a nascent product and its adoption for specific government use, the intelligence community has developed a new model. The Central Intelligence Agency (CIA) initiated and funded a 501(c)3 company called In-Q-Tel—a private not-for-profit firm—as a matchmaker to find technology to meet potential needs. In-Q-Tel contracts with small companies using private industry contractual terms, acting to bridge the gap between small firms and the government.

31. The legislation involved is a provision of the National Defense Authorization Act for Fiscal Year 2011, signed into law on January 7, 2011. In particular, Section 824 of the Act provides "Guidance Relating to Rights in Technical Data" and amends Section 2320(a) of Title 10 of the United States Code, the provision that defines the allocation of rights in intellectual property under government contracts.

Over the past 11 years, In-Q-Tel has developed programs with more than 160 startups. These are In-Q-Tel-funded engineering and development efforts aimed at customizing the startup company's technology for consumption by the intelligence community. To date, these have yielded 297 pilots, in which end-users in the intelligence community experiment with the newly developed solutions in real world operating environments. This has resulted in the intelligence community adopting and funding over 100 technologies within their programs.

One important attribute of the In-Q-Tel model is that within the largest customers, the CIA and the Defense Intelligence Agency (DIA), there is a small integration center that seeks out needs and customers within the intelligence agency that might be served by In-Q-Tel's companies. Experience shows that this internal integration center greatly increases the potential for actual technology transfer. Although In-Q-Tel was created by the CIA, other intelligence agencies, Homeland Security, and law enforcement agencies have begun using it as a source of technology.

Imposing Flexibility as a Fundamental Attribute of New Weapons Systems

In many ways, the DOD now requires contractors to more easily enable the incorporation of new hardware technologies and improved software processes and algorithms. These include requirements for modular architectures, open designs, fully published interfaces, and so on. All of these are aimed at enabling the replacement of major components and subsystems, when a newer, better, cheaper, or higher performance option is available from any provider. Flexibility may, in some cases, be sufficient to change out major subsystems when an opportunity to implement something better arises. This begs the question of how to specify new systems to make them inherently more flexible—not only to incorporate new technologies more rapidly, but to be able to change methods of operation overnight based on lessons learned the previous day. The fact that today most major weapons systems are software driven, that systems routinely contain data recorders that capture operational data, that data connectivity exists between forward operations and rearward analysts, and that modified software builds can be delivered to systems in the field from development centers far away at the speed of light—all contribute to being able to achieve far more operational flexibility in our new weapons systems than has been the case in the past. But in order to achieve that flexibility it must be specified as a specific requirement.

The problem of insufficient innovation getting into major procurements is real, even though measuring or proving this remains a challenge. No one thing is the cause. The problem is not a lack of good basic research, nor is it a lack of excellent people and organizations to perform it. It is also not a lack of good engineering in later stages of development.

The biggest problems are identified as:

- Restrictive requirements and no mechanism for balancing risk with opportunity in front end definitions
- Disconnects between front end and back end engineering
- Time from concept definition to fielding
- Disincentives for small innovators to work with major suppliers and with DOD
- Disincentives to any risks
- No current method to establish near-real time operational flexibility as a requirement in today's acquisitions

Recommendations

- USD(AT&L) establish a requirement in all system concept formulations for full exploration of the dimensions of risk, technology readiness, development time, cost (full lifecycle costs as well as development), performance, and operational flexibility within relatively loose boundaries established in the government's requirement statement. That requirement should focus more on the problem to be solved or the operational need to be addressed than on a specific materiel solution.
- USD(AT&L) should require all acquisitions evaluation criteria to state how attributes will be evaluated and the government's value structure for those attributes (*i.e.*, near-term risk vice longer-term cost). The government should also state how the results of those tradeoffs will be incorporated into further development phase requirements and competitive evaluation.

- USD(AT&L) should give credit to proposals that include outreach to non-traditional, non-DOD sources of innovation or advanced technology.
- ASD(R&E) should consider whether the lessons learned from In-Q-Tel can be applied selectively in DOD, for areas of technology that are advancing rapidly, and where a rich set of small companies exist.

Chapter 7. Summary of Recommendations

The DSB was tasked to:

- Assess the quality of the basic research program
- Provide advice on the long-term basic research planning and strategies
- Render guidance on the appropriateness of the broad scientific goals of the basic research program
- Determine whether the basic research budget was used to fund only basic research
- Evaluate the balance between high-risk, high-payoff and lower-risk research
- Evaluate the intellectual competitiveness of intramural and extramural basic research programs, specifically with regard to the balance between single investigators, Multi-University Research Initiatives and university-based centers
- Evaluate the management of the basic research portfolio
- Identify potential gaps in the Department's basic research effort

Shortly after the task force began its work, the ASD (R&E) asked DSB to also advise on how the Department should structure its basic research program in order to incentivize invention, innovation, and the transition of ideas to end-use.

The task force addressed these requests through input from Defense Department basic research offices, Service laboratories, and basic research project investigators, and by reviewing previous studies of the basic research program.

The consensus of opinion, following the information presented by the above sources, as well as an independent analysis of the research funded through the basic research budget, is that the basic research program is a very good one. However, the task force is concerned that a designation of "very good" will not apply in the long term unless more attention is paid to human resources, the globalization of science, development of a technology strategy and mitigation of the major impediment to innovation, namely the DOD acquisition system.

A few smaller but important problems with the current basic research program were encountered that also warrant attention. For instance, what should have been easily retrievable data required huge time-consuming, labor-intensive efforts to collect and assemble due to the lack of a modern management information system that would enable answering questions posed by DOD leadership. It is difficult to have management without management information.

Further, the unnecessary and unproductive bureaucratic burden on basic researchers funded by DOD in effect equates to reduction of the DOD basic research budget. Reducing that burden, whether from legislation, administrative requirements imposed from outside or within DOD, and the Services, is perhaps the most important thing that might be done to improve the current DOD basic research program.

The following two recommendations are offered to help reduce bureaucracy and improve efficiency and effectiveness of the basic research enterprise.

1. The Director for Basic Research in ASD(R&E) should have responsibility and accountability for working with the DOD laboratory directors to document any activities that are unnecessary or inappropriate in a basic research environment. The rationale to eliminate or waive such activities for basic researchers should be specified, and remedial action pursued. Such requests should carry the signature of the Under Secretary of Defense for Acquisition, Technology and Logistics (ASD (AT&L)).
2. The Director for Basic Research in ASD(R&E) should be responsible and accountable for additional amended DFARS language as needed to address export controls, deemed exports, or other troublesome publication clauses.

Human Resources and Globalization of Science

DOD must make a more concerted effort to ensure that the U.S. scientific human resources needed by the Department for global military competition will be available.

The task force offers the following recommendations to build stronger relationships between basic researchers and the ultimate users of the outcomes of their research.

- The Director of DARPA should expand the DSSG program by doubling the number of participants. This could be done by selecting a group of participants every year rather than every other year and running two overlapping programs, each with about 15 participants. The overlap would provide opportunities to bring the two groups together for workshops and other relationship-building activities. This expansion should include an appropriate number of behavioral and social scientists, and medical researchers, insofar as those areas are among those chronically getting short shrift by DOD.
- ASD(R&E) initiate DSSG-like pilot programs in the Services with a goal to expand the network of informed and engaged scientists and engineers exposed to the national defense community and its challenges. The pilot programs need not precisely replicate the DSSG template. Indeed, experimentation is desired to explore other schema to foster a long-term interest in national defense in emerging S&T leaders. Some may require a shorter commitment of time, as compared to the 40 days over two years for DSSG. The eventual goal would be to increase the number of participants by a factor of five to ten over today's approximately 15 every other year.
- USD(AT&L) direct all DOD basic research funding agencies to initiate summer activities to expose their basic research performers to military operations and critical technical problems relative to their mission. The goal is to ensure each researcher understands the ultimate challenge their research may address without unduly focusing the research or limiting its potential.
- ASD(AT&L) initiate pilot programs for cadets, midshipmen, and junior officers to participate in research tours at DOD laboratories, FFRDCs, or other institutions that carry out basic research in support of national defense. Once the pilot program is complete, evaluate the potential to provide similar experiences for officers as a tour of duty.

The following recommendations are offered as strategies to help DOD basic research develop scientific human resources.

- The ASD(R&E) STEM Development Office should expand summer internship programs to place promising young men and women with U.S. citizenship in defense-related S&T activities between their junior and senior year in high school, between high school and college, and for their first few summers during college. These programs should be available for students to work in government R&D laboratories, FFRDCs, and defense contractors.
- The ASD(R&E) STEM Development Office should double the existing doctoral fellowship programs in the National Defense Education Program and the NDSEG, track outcomes, and consider even higher investment in future years.
- The ASD(R&E) STEM Development Office should ensure that fellowship programs for doctoral students should:
  - Award a stipend with an amount at least 80 percent of the median annual salary for graduating seniors with B.S. degrees
  - Expand locations for summer internships to include FFRDCs, UARCs, and defense contractors in addition to government R&D laboratories
  - Give the school the recipient attends an additional benefit per year of approximately $10,000

DOD's Service laboratories conduct about a quarter of the Department's basic research. These recommendations are made to DOD Service laboratory directors in order to maintain a vital workforce:

- DOD laboratory directors should establish long-term partnerships with leading universities and other research organizations that accommodate meaningful personnel exchanges that may last a few months to a few years.
- DOD laboratory directors should fully utilize existing authorities to hire outstanding scientists and engineers on a term basis, such as the IPA and HQE authorities.
- DOD laboratory directors should work with the military services to create additional billets at DOD laboratories for qualified military officers, with the eventual goal to make S&T a valued military career path, on a par with pilots or intelligence experts.
- DOD laboratory directors should use the funds authorized by Congress (according to Section 219 in the National Defense

Authorization Act) to support sabbaticals for experienced laboratory basic researchers at outstanding research universities.

Additional recommendations are made concerning recruiting and hiring new graduates:

- DOD laboratory directors should greatly increase the number of DOD laboratory postdoctoral scientists and engineers at the Service laboratories:
  - DOD laboratory directors should offer summer internships to NDSEG and other DOD support recipients and develop relationships with them in order to more effectively recruit the best upon graduation.
  - DOD laboratory directors should expand their use of the SMART, NDSEG, and other DOD scholarship programs to identify promising recruits to include all students who receive DOD grant funding.
  - USD(P&R), in coordination with ASD(R&E), should publish an implementation policy for a Professional Scientific and Technical Corps and authorize all laboratories to hire or promote under this policy.
  - DOD laboratory directors should fully utilize the "direct hire authority at personnel demonstration laboratories for certain candidates" found in Section 1108 in the 2009 National Defense Authorization Act to hire outstanding scientists and engineers as basic researchers.

- ASD(R&E) should seek legislation to extend the 2009 NDAA Section 1108 direct hiring authority beyond 31 December 2013.

The task force offers these recommendations to ensure effective and exemplary program management of defense basic research:

- DOD basic research program office directors should rotate active researchers from academia, industry, and FFRDCs using the IPA or HQE programs as appropriate. A useful goal may be to use these tools to keep the average time away from the laboratory low; less than five years for program managers if possible. Tours should be for nominally four years to best match up with the typical rotation of three-year grants.

- DOD basic research program office directors should facilitate personnel rotations between program management and hands-on laboratory basic research. Useful rotations can occur one day a week, can call a researcher to government service for a few years, or can include periodic sabbatical time. DOD basic research program managers can keep their skills sharp by performing personal scientific research up to 20 percent of their official work schedule and by publishing their personal research findings in peer-reviewed journals.
- DOD basic research program office directors should provide funds and time for basic research program managers to attend relevant professional society meetings, both in the United States and overseas. These conferences provide excellent opportunities for performer meetings. In addition, program managers should fully participate in professional society activities, including publishing review articles and serving as editorial board members of professional journals. These and other activities enhance the skills and professional reputation of both the program and the program manager, and should be given great weight in the annual evaluation process and in promotion consideration.
- DOD basic research program office directors should provide an adequate number of S&T program assistants to help execute the administrative activities associated with proposal review, grant administration, workshop organization, and other program management duties. Assistance with administrative tasks is needed to allow each program manager to perform at their best and to reserve adequate time for higher level activities. Program assistants should have degrees in science, technology, engineering, or mathematics.
- DOD basic research program office directors should place special emphasis on gleaning useful advice from DSSG, CSSG, NSSEFF, and PECASE alumni. Avenues to accomplish this may include meetings to discuss new results or general topics (in person or virtual), or it may include study groups or red teams that meet for weeks or months to tackle a timely problem. DOD should fully utilize those advisors who have shown special enthusiasm and aptitude for addressing national security challenges for basic research.

Globalization of Basic Research

The task force offers the following recommendations to the Department to more effectively address globalization of basic research. The task force strongly supports these activities for coordinating with, reaching out to, and harvesting the results of basic research around the world.

- USD(AT&L) should establish locations where U.S. researchers can work side-by-side with leading foreign scientists, following the best practices of U.S. industry and academia. Such a location may be structured as an international satellite campus of an existing DOD Service laboratory, involve a relationship with a university or other research institution overseas, involve a government-to-government partnership, or other alternatives.
- DOD laboratory directors should increase the locations at U.S. Service laboratories where foreign researchers can work on basic research topics during a visit, term, or sabbatical without the need for security clearance, and should increase their invitational support of foreign scientists.
- DOD basic research office directors should establish programs for DOD laboratory and U.S. university researchers to spend a visit, term, or sabbatical at a foreign laboratory to interface with leading basic researchers in areas of interest to the DOD.
- ASD(R&E) should increase the percentage of basic research funding that is invested internationally from 2.5 to 3 percent to 5 percent over the next two years. As shown in Table 11, such an increase will provide a tremendous boost for international collaboration while leaving a substantial increase for the domestic base.

Strategy and Innovation

The task force believes that intuition borne of experience will be insufficient to ensure that the areas of basic research supported in depth by DOD are the ones most important for enabling the technology and systems required for future military capabilities. Analysis is needed in addition to intuition. Even though DOD is moving toward development of a technology strategy, the task is far from complete. Therefore the task force respectfully recommends the following.

- ASD(R&E) should craft a genuine technology strategy.
- ASD(R&E) should articulate a two-part portfolio strategy for basic research investments. One part should include broad investment in essentially all areas of science that could sensibly yield knowledge and know-how important for military capabilities. A second part should include selected, in-depth investments to provide the potential for major advances that could lead to a competitive advantage.
- ASD(R&E) should ensure the tenets of a technology strategy are implemented in the basic research enterprise. These tenets should not only be directed toward basic research projects or programs, rather, they should also affect such activities as outreach to students and to young faculty, recruitment and training of government researchers and managers, and identification of S&T advisors.

The task force found the greatest hindrance to the innovation ecology of the Department to be the acquisition system, particularly the requirements system. The recommendations below would lessen the acquisition system's negative impact on innovation, but these recommendations are not meant to fully address reform of the DOD acquisition and requirements system.

- USD(AT&L) establish a requirement in all system concept formulations for full exploration of the dimensions of risk, technology readiness, development time, cost (full lifecycle costs as well as development), performance, and operational flexibility within relatively loose boundaries established in the government's requirement statement. That requirement should focus more on the problem to be solved or the operational need to be addressed than on a specific materiel solution.
- USD(AT&L) should require all acquisitions evaluation criteria to state how attributes will be evaluated and the government's value structure for those attributes (*i.e.*, near-term risk vice longer-term cost). The government should also state how the results of those tradeoffs will be incorporated into further development phase requirements and competitive evaluation.

- USD(AT&L) should give credit to proposals that include outreach to non-traditional, non-DOD sources of innovation or advanced technology. ASD(R&E) should consider whether the lessons learned from In-Q-Tel can be applied selectively in DOD, for areas of technology that are advancing rapidly, and where a rich set of small companies exist.

In Sum

DOD can dominate the world's military organizations in being able to use basic research results to create new and enhanced military capabilities, by dint of financial resources, infrastructure and national culture—if DOD can overcome the immense burden of its acquisition system, and if DOD pays sufficient attention to worldwide basic research. In principle, worldwide basic research could benefit DOD disproportionally among global armed forces.

Appendix A. DOD Definitions of Research, Development, Test, and Evaluation Activities

The research, development, test, and evaluation (RDT&E) budget activities are broad categories reflecting different types of RDT&E efforts. "Defense S&T" activities generally include budget activities 6.1, 6.2, and 6.3, as defined here. "Defense R&D" generally includes Defense S&T and also includes budget activity 6.4.

Budget Activity 6.1, Basic Research. Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high payoff research that provides the basis for technological progress. Basic research may lead to: (a) subsequent applied research and advanced technology developments in Defense-related technologies, and (b) new and improved military functional capabilities in areas such as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conversion, materials and structures, and personnel support. Program elements in this category involve pre-Milestone A efforts.

Budget Activity 6.2, Applied Research. Applied research is systematic study to understand the means to meet a recognized and specific need. It is a systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods. It may be oriented, ultimately, toward the design, development, and improvement of prototypes and new processes to meet general mission area requirements. Applied research may translate promising basic research into solutions for broadly defined military needs, short of system development. This type of effort may vary from systematic mission-directed research beyond that in Budget Activity 1 to sophisticated breadboard hardware, study, programming, and planning efforts that establish the initial feasibility and practicality of proposed solutions to technological challenges. It includes studies, investigations, and non-system specific technology efforts. The dominant characteristic is that applied research is directed toward general military needs with a view toward developing and evaluating the feasibility and practicality of proposed solutions and determining their parameters. Applied research precedes system specific technology investigations or development. Program control of the applied research program element is normally exercised by general level of effort. Program elements in this category involve pre-Milestone B efforts, also known as Concept and Technology Development phase tasks, such as concept exploration efforts and paper studies of alternative concepts for meeting a mission need.

Budget Activity 6.3, Advanced Technology Development (ATD). This budget activity includes development of subsystems and components and efforts to integrate subsystems and components into system prototypes for field experiments and/or tests in a simulated environment. ATD includes concept and technology demonstrations of components and subsystems or system models. The models may be form, fit, and function prototypes or scaled models that serve the same demonstration purpose. The results of this type of effort are proof of technological feasibility and assessment of subsystem and component operability and producibility, rather than the development of hardware for service use. Projects in this category have a direct relevance to identified military needs. ATD demonstrates the general military utility or cost reduction potential of technology when applied to different types of military equipment or techniques. Program elements in this category involve pre-Milestone B efforts, such as system concept demonstration, joint and Service-specific experiments, or technology demonstrations, and generally have Technology Readiness Levels of 4, 5, or 6. Projects in this category do not necessarily lead to subsequent development or procurement phases, but should have the goal of moving out of S&T and into the acquisition process within the future years defense program (FYDP). Upon successful completion of projects that have military utility, the technology should be available for transition.

Budget Activity 6.4, Advanced Component Development and Prototypes (ACD&P). Efforts necessary to evaluate integrated technologies, representative modes, or prototype systems in a high fidelity and realistic operating environment are funded in this budget activity. The ACD&P phase includes system-specific efforts that help expedite technology transition from the laboratory to operational use. Emphasis is on proving component and subsystem maturity prior to integration in major and complex systems, and may involve risk reduction initiatives. Program elements in this category involve efforts prior to Milestone B, are referred to as advanced component development activities, and include technology demonstrations. Completion of Technology Readiness Levels 6 and 7 should be achieved for major programs. Program control is exercised at the program and project level. A logical progression of program phases and development and/or production funding must be evident in the FYDP.

Budget Activity 6.5, System Development and Demonstration (SDD). SDD programs have passed Milestone B approval and are conducting engineering and manufacturing development tasks aimed at meeting validated requirements prior to full-rate production. This budget activity is characterized by major line item projects, and program control is exercised by review of individual programs and projects. Prototype performance is near or at planned operational system levels. Characteristics of this budget activity involve mature system development, integration, and demonstration to support Milestone C decisions, and conducting live fire test and evaluation, and initial operational test and evaluation of production representative articles. A logical progression of program phases and development and production funding must be evident in the FYDP consistent with the Department's full funding policy.

Budget Activity 6.6, RDT&E Management Support. This budget activity includes research, development, test and evaluation efforts and funds to sustain and/or modernize the installations or operations required for general RDT&E. Test ranges, military construction, maintenance support of laboratories, operation and maintenance of test aircraft and ships, and studies and analyses in support of the RDT&E program are funded in this budget activity. Costs of laboratory personnel, either in-house or contractor operated, would be assigned to appropriate projects or as a line item in the basic research, applied research, or ATD program areas, as appropriate. Military construction costs directly related to major development programs are included.

Budget Activity 6.7, Operational System Development. This budget activity includes development efforts to upgrade systems that have been fielded or have received approval for full rate production and anticipate production funding in the current or subsequent fiscal year. All items are major line item projects that appear as RDT&E Costs of Weapon System Elements in other programs. Program control is exercised by review of individual projects. Programs in this category involve systems that have received Milestone C approval. A logical progression of program phases and development and production funding must be evident in the FYDP, consistent with the Department's full funding policy.

Appendix B. Findings and Recommendations Made in Previous Studies

Assessment of Department of Defense Basic Research (National Academies, 2005)

Finding 1. Department of Defense basic research funds under 6.1 have not been directed in significant amounts to support projects typical of 6.2 or 6.3 funding.

Finding 2. Research managers are well-motivated and generally successful in focusing 6.1 funding on the discovery of fundamental knowledge in support of the range of Department of Defense needs.

Finding 3. Having specific applications in mind is not a useful criterion for discriminating between basic and applied research.

Finding 4. The set of attributes and desirable characteristics of basic research widely shared among experienced basic research managers can be beneficial in distinguishing between basic and applied research.

Finding 5. The basic research needs of the Department of Defense are complex and do not end when specific applications are identified.

Finding 6. The need for ongoing discovery from basic research can, and usually does, continue through the applied research, system development, and system operation phases.

Finding 7. Included in the range of values expected from basic research in the Department of Defense are (1) discovery arising from unfettered exploration, (2) focused research in response to identified DOD technology needs, and (3) assessment of technical feasibility.

Finding 8. A recent trend in basic research emphasis within the Department of Defense has led to a reduced effort in unfettered exploration, which historically has been a critical enabler of the most important breakthroughs in military capabilities.

Finding 9. Generated by important near-term Department of Defense needs and by limitations in available resources, there is significant pressure to focus DOD basic research more narrowly in support of more specific needs.

Finding 10. Universities, government laboratories, and industry have overlapping roles in basic research: universities primarily address the creation of broad new knowledge and human competencies, and Department of Defense laboratories and industry are more sharply focused on discovery tied more directly to identified DOD needs.

Finding 11. A clear understanding of the value expected from basic research across its full range provides the most reliable assurance of long-term Department of Defense leadership support for the basic research.

Finding 12. A variety of management approaches in the Department of Defense is appropriate to the widely diverse missions and motivations for basic research.

Finding 13. The key to effective management of basic research lies in having experienced and empowered program managers. Current assignment policies and priorities (such as leaving substantial numbers of program manager positions unfilled) are not always consistent with this need, which might result in negative consequences for the effectiveness of basic research management in the long term.

Finding 14. The breadth and depth of the sciences and technologies essential to the Department of Defense mission have greatly expanded over the past decade.

Finding 15. In real terms the resources provided for Department of Defense basic research have declined substantially over the past decade.

Finding 16. The demand for new discovery argues for significantly increased involvement of university researchers. Yet some younger university researchers in the expanded fields of interest to the Department of Defense are often discouraged by the difficulty in acquiring research support from the department.

Finding 17. Recent pressures to apply restrictions on participation and publication through export controls on Department of Defense-sponsored research funded in 6.1 both disqualify it from being considered basic research as defined by National Security Decision Directive 189 and threaten to change fundamentally the open and public character of basic university research. This finding does not apply to research funded in 6.2.

Recommendation 1. The Department of Defense should change its definition of basic research to the following:

> *Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and has the potential for broad, rather than specific, application. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, social, and life sciences related to long term national security needs. It is farsighted high-payoff research that provides the bases for technological progress. Basic research may lead to (a) subsequent applied research and advance technology developments in Defense-related technologies, (b) new and improved military functional capabilities, or (c) the discovery of new knowledge that may later lead to more focused advances in areas relevant to the Department of Defense.*

Recommendation 2. The Department of Defense should include the following attributes in its guidance to basic research managers and direct that these attributes be used to characterize 6.1-funded research:

- a spirit that seeks first and foremost to discover new fundamental understanding,
- flexibility to modify goals or approaches in the near term based on discovery,
- freedom to pursue unexpected paths opened by new insights,
- high-risk research questions with the potential for high payoff in future developments,
- minimum requirements for detailed reporting,
- open communications with other researchers and external peers,
- freedom to publish in journals and present at meetings without restriction and permission,
- unrestricted involvement of students and postdoctoral candidates,
- no restrictions on the nationality of researchers, and
- stable funding for an agreed timetable to carry out the research.

Recommendation 3. The Department of Defense should abandon its view of basic research as being part of a sequential or linear process of research and development (in this view, the results of basic research are handed off to applied research, the results of applied research are handed off to advanced technology development, and so forth). Instead, the DOD should view basic research, applied research, and the other phases of research and development as continuing activities that occur in parallel, with numerous supporting connections among them.

Recommendation 4. The Department of Defense should set the balance of support within 6.1 basic research more in favor of unfettered exploration than of research related to short-term needs.

Recommendation 5. Senior Department of Defense leadership should clearly communicate to research managers its understanding of the need for long-term exploration and discovery.

Recommendation 6. Personnel policies should provide for the needed continuity of research management in order to ensure a cadre of experienced managers capable of exercising the level of authority needed to effectively direct research resources. Further, in light of the reductions in positions reported to the Committee on Department of Defense Basic Research, the Department of Defense should carefully examine the adequacy of the number of basic research management positions.

Recommendation 7. The Department of Defense should redress the imbalance between its current basic research allocation, which has declined critically over the past decade, and its need to better support the expanded areas of technology, the need for increased unfettered basic research, and the support of new researchers.

Recommendation 8. The Department of Defense should, through its funding and policies for university research, encourage increased participation by younger researchers as principal investigators.

Recommendation 9. To avoid weakening the long and fruitful partnership between universities and Department of Defense agencies, DOD agreements and subagreements with universities for basic research should recognize National Security Decision Directive 189, the fundamental research exclusion providing for the open and unrestricted character of basic research. DOD program managers should also explicitly retain the authority to negotiate export compliance clauses out of basic research grants to universities, on the basis of both the program's specific technologies and its objectives.

S&T for National Security (JASON, 2009)

Program Recommendations

Recommendation 1. *Focus on funding people before projects.* The "payoff" to DOD is a cadre of people in the internal and external communities who are cognizant of both DOD needs and the forefronts of science, as well as the research itself.

Recommendation 2. *Ensure that 6.1 activities conform to the 6.1 definition.* There are several steps that can be taken to achieve this goal. For example, accounting can be structured to make the use of 6.1 funds transparent. Further, the DDR&E [now ASD(R&E)] could certify annually to the SecDef that 6.1-funded activities are basic research as defined by the DOD. Finally, non-conforming activities should be moved to other budget lines in subsequent years.

Recommendation 3. *Eliminate large fluctuations in 6.1 funding and schedules.* Long-term research efforts cannot be turned on and off with yearly budget cycles and service rotations. Indeed, for a researcher, stable funding is more productive than more variable funding. Pressures to shape the basic research program around the "War of the Month" should be avoided.

Personnel Recommendations

Recommendation 4. *Establish a Research Corps within each service* to address the chronic S&T personnel issues within the services. DOD should develop an S&T Corps to bring in military people outside of the normal line promotion process. Routine rotations across service boundaries should become normal career progress. Civilians should also be assigned to the S&T corps and allowed to compete for opportunities across service lines.

Recommendation 5. *The DOD labs should house some researchers that are well-coupled to the broader S&T communities.*

University Recommendations

Recommendation 6. The Department should consider outreach and summer internships rather than scholarships for undergraduates (*e.g.*, Research Experience for Undergraduates).

Recommendation 7. *The DOD should consider other models in addition to PI-driven graduate student and postdoctoral support.* In particular, DOD should consider graduate training grants in other agencies such as NSF, NIH, or HHMI.

Recommendation 8. *Improve the coupling between DOD supported faculty and DOD S&T needs.* In particular, it is most important to build a community and educate them about issues before a crisis that could benefit from their participation.

Recommendation 9. *Expand (with improvements) the new National Security Science and Engineering Faculty Fellowship (NSSEFF) Program.*

Organization Recommendations

Recommendation 10. *Protect 6.1 funding at the OSD level by strengthening and expanding the role of the DDR&E.* At a minimum, the office should substantively review and comment on the Services 6.1 budget requests before these requests are sent to Congress and to review and reprogram basic research funds appropriated by Congress before these funds are distributed to the Services.

Recommendation 11. *Line acquisition and operational leaders should have input to, but not decision authority over, the 6.1 budget.*

Recommendation 12. *Redefine and elevate the DDR&E position to that of an Undersecretary for S&T*, effectively separating the research and acquisition functions.

Recommendation 13. *Create a basic research advisory committee reporting to the USD(AT&L).* The membership of this committee should include the *DDR&E* and appropriate Service personnel, together with an equal number of external members with high scientific and technical credentials from academia and industry. The committee would review and advise annually on the health of DOD basic research.

Appendix C. Section 219 Funding

Public Law 110–417, title II, § 219, October 14, 2008, 122 Statute 4389, as amended by Public Law 111–84, title XXVIII, § 2801(c), October 28, 2009, 123 Statute 2660, provided that:

(a) Mechanisms to Provide Funds.—

(1) In general.—The Secretary of Defense, in consultation with the Secretaries of the military departments, shall establish mechanisms under which the director of a defense laboratory may use an amount of funds equal to not more than three percent of all funds available to the defense laboratory for the following purposes:

(A) To fund innovative basic and applied research that is conducted at the defense laboratory and supports military missions.

(B) To fund development programs that support the transition of technologies developed by the defense laboratory into operational use.

(C) To fund workforce development activities that improve the capacity of the defense laboratory to recruit and retain personnel with needed scientific and engineering expertise.

(D) To fund the revitalization and recapitalization of the laboratory pursuant to section 2805 (d) of title 10, United States Code.

(2) Consultation required.—The mechanisms established under paragraph (1) shall provide that funding shall be used under paragraph (1) at the discretion of the director of a defense laboratory in consultation with the science and technology executive of the military department concerned.

(b) Annual Report on Use of Authority.—Not later than March 1 of each year, the Secretary of Defense shall submit to the congressional defense committees [Committees on Armed Services and Appropriations of the Senate and the House of Representatives] a report on the use of the authority under subsection (a) during the preceding year.

(c) Sunset.—The authority under subsection (a) shall expire on October 1, 2013.

The Army laboratory directors executed the implementation plan for Section 219 with 7 laboratories participating in FY 2010 and have additional laboratories anticipated to participate in FY 2011. The Army laboratories invested $31.6 million funds from a total of $2,026 million in FY 2010 funding as described by Section 219. These activities included $10.8 million for infrastructure improvements, $10.2 million for innovative in-house basic and applied research, $9.7 million for workforce retention and development, and $0.9 million for transition of technology development. Funding sources included 6.1 through 6.7, direct OSD, reimbursable RDT&E and military reimbursable RDT&E. Depending on the laboratory, the burdened rates ranged from 0.11 to 3 percent of the core mission funds.

The Office of the Assistant Secretary of the Navy (Research, Development, and Acquisition) established the Naval Innovative Science and Engineering program to implement Section 219. In FY 2010, this program had $48.9 million from Research, Development, Test, and Evaluation, Navy programs (6.1 through 6.7) and was executed by 15 Department of Navy laboratories as a mechanism to revitalize their laboratories and re-build their world class capabilities.

The Air Force FY 2010 219 program had a budget of $39.4 million. Of this budget, $23.3 million supported 24 basic and applied research programs. The transition of technologies from the defense laboratory to operational use had 7 programs for a total of $7 million. Workforce development activities accounted for 21 programs at a cost of $4.3 million. Three recapitalization and revitalization projects were supported at a cost of $4.9 million.

Appendix D. Draft Memorandum from 2005 DSB Report on the Roles and Authorities of the Director of Defense Research and Engineering

Draft memo text from the 2005 DSB Study on the Roles and Authorities of the Director of Defense Research and Engineering.[32]

The Department's preeminent ability to understand, nurture and exploit science and technology (S&T) was a major contributor to victory in the Cold War. This ability has remained a critical enabler of the powerful new capabilities demonstrated since then.

However, our ability to continue to do so faces new challenges, not the least of which is the commercialization and globalization of technology. Resourceful adversaries now have a much richer menu of technologies to exploit for their own use against U.S. interests. At the same time our ability to use all available technology is hampered by research and development practices still influenced by Cold War requirements.

Civilian technologies undergoing revolutionary progress can have profound and unforeseen influence on future military affairs. We have not seen the last of such impacts from information technology. We will surely see more from biotechnology and nanotechnology. We must ensure that we are the first to understand these effects and the first to exploit or counter them as appropriate.

Furthermore, while critical, technology is only an enabler of new capabilities. The capabilities we need to counter new threats depend perhaps even more so than during the Cold War, on our human resources. Therefore, we must foster closer collaboration between our warriors and technologists so that the introduction of new technology is tied to development of concepts, doctrine, tactics and training.

In the face of these challenges I have asked the USD(AT&L) and the DDR&E, in accord with Department of Defense Directive 5134.3, to take

32. Defense Science Board. *The Roles and Authorities of the Director of Defense Research and Engineering*. October, 2005. Available at http://goo.gl/zTBxb (accessed November 2011).

steps to ensure that we will exploit technology to the fullest and avoid technological surprise. One of these steps is to develop a strategic technology plan. The plan is intended to help ensure on the one hand, that our S&T activities support national defense goals, and on the other, that our strategies are informed by a deep understanding of technology. The strategic plan should be developed within 90 days of receiving this memorandum and be updated annually.

The plan will provide a rationale and roadmap for a robust long-term science and technology effort. It will tie technology objectives closer to the operational capabilities spelled out in the National Defense Strategy. It will identify:

- Critical investment areas
- How to make much more effective use of technology developed in the commercial sector, academia, and other government agencies
- Ways to be more successful in anticipating how adversaries will exploit technology. This will involve the intelligence community and require red teaming and net assessment
- Means for more timely collaboration between warriors and technologists to permit rapid insertion of new capabilities into ongoing operations.
- Steps to increase the technical depth and breadth of the OUSD(AT&L) staff

The Deputy Secretary and I are committed to spend the time needed to achieve these objectives. Please provide the necessary support to this important effort.

Terms of Reference

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

AUG - 2 2010

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference – Defense Science Board (DSB) Task Force on Basic Research

You are requested to form a DSB Task Force on Basic Research to assess matters relating to departmental planning and managing the defense basic research program.

It is the responsibility of the Department of Defense (DoD) Science & Technology community to be the innovators and motivators of new technologies for the Nation's future defense. Creating next-generation military capabilities and avoiding technological surprise requires a strong foundation of basic scientific research that is appropriately broad and forward-looking, of the highest quality, and with the potential to seed high-payoff transformative scientific breakthroughs.

The Task Force on Basic Research will serve as a mechanism for external validation of the quality of the basic research program and for advice on long term research plans and strategies for the corporate-wide defense basic research portfolio. Organizational efficiency and the effective utilization of quality program personnel are equally essential. The Task Force should give additional strategic guidance on DoD basic research efforts by assessing:

- The appropriateness of broad scientific goals as a basic research program, specifically whether the 6.1 funded work is basic or applied research in character,
- The manner in which the components assess the quality of their basic research investments,
- Basic research portfolio management across DoD, and opportunities for increased information sharing and cooperation among the components and with other federal research agencies,
- Potential gaps in the current Department-wide basic research program,
- Overall program balance, including a balance between single-principal investigators (PI's), Multi-University Research Initiatives (MURI's), university-based centers (e.g. UARC's) and high-risk high-payoff vs. lower risk research,

- Intellectual competitiveness of intramural and extramural basic research programs.

The Task Force will be sponsored by the Under Secretary of Defense for Acquisition, Technology and Logistics. The Director, Defense Research & Engineering is authorized to act upon the advice and recommendations of the Board. Dr. Lydia Thomas and Dr. Craig Fields will serve as the Chairpersons of the Task Force. Dr. Robin Staffin, Office of the Director, Defense Research and Engineering, will serve as the Executive Secretary and Major Michael Warner, United States Air Force, will serve as the DSB Secretariat Representative.

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

Ashton B. Carter

Task Force Members

Chairs

Craig Fields	Private Consultant
Lydia Thomas	Private Consultant

Executive Secretary

Robin Staffin	ASD(R&E)

Members

John Foster	Private Consultant
Theodore Gold	Private Consultant
Anita Jones	University of Virginia
George Heilmeier	Private Consultant
Ronald Kerber	Private Consultant
Larry Lynn	Private Consultant
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December 15, 2010

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Abbreviations and Acronyms

ACD&P	Advanced Component Development & Prototypes
AFOSR	Air Force Office of Scientific Research
AFRL	Air Force Research Laboratory
AFSAB	Air Force Science Advisory Board
AFSTB	Air Force Science and Technology Board
ARI	Army Research Institute
ARL	Army Research Laboratory
ARO	Army Research Office
ASD(R&E)	Assistant Secretary of Defense (Research and Engineering)
ATD	Advanced Technology Development
CIA	Central Intelligence Agency
CNA	Center for Naval Analysis
CSSG	Computer Science Study Group
DARPA	Defense Advanced Research Projects Agency
DBRAG	Defense Basic Research Advisory Group
DDR&E	Director, Defense Research and Engineering
DFARS	Defense Federal Acquisition Regulation Supplement
DIA	Defense Intelligence Agency
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DSB	Defense Science Board
DSRC	Defense Sciences Research Council
DSSG	Defense Science Study Group
DSTL	Developing Science and Technologies List
DTIC	Defense Technical Information Center
DTRA	Defense Threat Reduction Agency
DURIP	Defense University Research Instrumentation Program
ERDC	Engineer Research and Development Center
EXCOM	executive committee
FDP	Federal Demonstration Partnership
FFRDC	federally funded research and development centers
FOUO	for official use only
FY	fiscal year

FYDP	future years defense program
GaAs	Gallium Arsenide
GDP	gross domestic product
GMR	Giant magnetoresistance
GPS	Global Positioning Satellite
HHMI	Howard Hughes Medical Institute
HHS	Department of Health and Human Services
HQE	highly qualified experts
IDA	Institute for Defense Analyses
ILIR	in-house laboratory independent research
IWA	Interagency Working Group
IPA	Intergovernmental Personnel Act
ISAT	Information Science and Technology
MMIC	Monolithic Microwave Integrated Circuit
MRAM	Magnetic Random Access Memory
MRMC	Medical Research and Materiel Command
MURI	Multi-University Research Initiative
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
NDSEG	National Defense Science and Engineering Graduate
NIH	National Institutes of Health
NNSA	National Nuclear Security Administration
NRC	National Research Council
NRL	Naval Research Laboratory
NSA	National Security Agency
NSET	Nanoscale Science, Engineering, and Technology
NSF	National Science Foundation
NSSEFF	National Security Science and Engineering Faculty Fellowship
NSTC	National Science and Technology Council
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
PECASE	Presidential Early Career Award for Scientists and Engineers
PI	principal investigator
PM	program manager
PTSC	Professional Scientific and Technical Corps
R&D	research and development

RDECOM	Research, Development, and Engineering Command
RDT&E	research, development, test and evaluation
S&T	science and technology
SBIR	small business innovative research
SC	subcommittee
SDD	Systems Development & Demonstration
SecDef	Secretary of Defense
SES	Senior Executive Service
SMART	Science, Mathematics and Research for Transformation
ST	scientists and technologists
STEM	science, technology, engineering, mathematics
STRL	Science and Technology Reinvention Laboratory
TTCP	Tripartite Technical Cooperation Program
UARC	university affiliated research centers
USAF	United States Air Force
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology and Logistics
USD(P&R)	Under Secretary of Defense for Personnel and Readiness
WMD	weapons of mass destruction