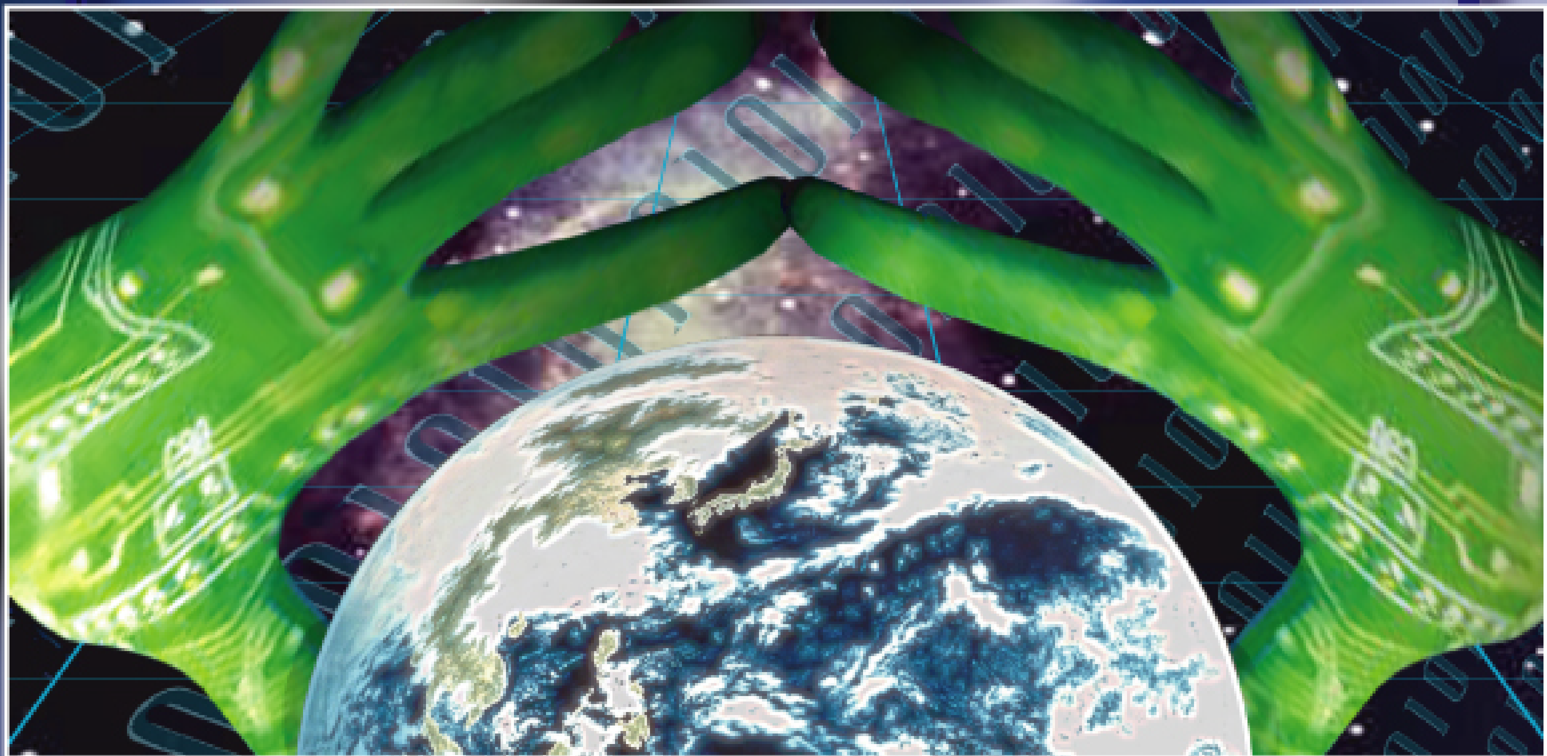

DoD SCIENCE & TECHNOLOGY INVIGORATION

A MONOGRAPH BY
HUGH MONTGOMERY

Potomac Institute for Policy Studies

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Department of Defense Science And Technology Invigoration

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A REPORT FOR THE OFFICE OF NAVAL RESEARCH
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FEBRUARY 2002

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The Potomac Institute for Policy Studies is an independent, 501(c)(3), not-for-profit public policy research institute. The Institute identifies and aggressively shepherds discussion on key science and technology issues facing our society, providing in particular, an academic forum for the study of related policy issues. From these discussions and forums, we develop meaningful science and technology policy options and ensure their implementation at the intersection of business and government. The Institute's current endeavors have required the formation of special efforts in: terrorism and asymmetry; emerging threats and opportunities; national health policies; science and technology forecasting; and national security

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The conclusions of this monograph are the authors, and do not necessarily represent the views of the sponsors or the Institute.

PREFACE

On the staff of the Potomac Institute for Policy Studies (the "Institute") are many employees who have come to us after long and successful careers, often in the public sector. It has been an Institute tradition to ask these employees to spend some time recording their thoughts on matters of particular interest to them. The choice of subject is guided by the employee's depth of experience as well as his or her concern about associated issues. In many cases, the subject is also of great interest to a sponsor, who agrees to fund the resulting monograph.

In response to an unsolicited proposal submitted in early 2001, the Office of Naval Research (ONR) awarded a grant to the Institute that funded research for this monograph on the need for invigorating the Department of Defense's (DOD) science and technology (S&T) management and investment. Drawing from many years of experience the author, Mr. Hugh Montgomery, provides the results of extensive reading, with an emphasis on numerous Defense Science Board studies on the subject, and traces the history of the Department of the Navy (DON) Warfare Center System to illustrate his points. He concludes with a plea to develop a better understanding of the strengths and weaknesses of DOD's S&T system and to begin a series of examinations that will bring beneficial changes to a crucial aspect of our defense strategy – developing and exploiting the best technology for the defense of our country. Although the opinions contained are the authors and do not necessarily represent the views of the sponsor, we hope this thoughtful treatment of the subject will contribute to the understanding of this important issue area.

Mr. Montgomery served the U.S. Navy for over thirty years, principally in conducting and managing research and development (R&D). His last assignment was Deputy Director, Test and Evaluation and Technology Requirements, Office of the Chief of Naval Operations (N091B). With impressive expertise in science and technology, public and private sector research, development and acquisition, and in building programs and management systems, Mr. Montgomery was instrumental in creating the Advanced Technology Demonstration (ATD) and Future Naval Capabilities (FNC) Processes. In his last assignment he served as the senior Department of Navy (DON) career civilian for requirements, assessment, planning, budgeting and program justification to Congress. He provided oversight of a $1.7 billion annual S&T and supporting R&D investment.

During his career, Mr. Montgomery developed an in-depth understanding of the industry R&D base. He served as the first Navy Independent Research and Development (IR&D) Program Manager, with oversight and assessment responsibilities for $5B annual private industry R&D investment. He built DON interface with major corporations in the private sector. He also developed the first Planning, Programming and Budgeting System (PPBS) process for DON technology programs and he became the first DON principal official for S&T PPBS/budget development.

His many awards include the Navy Distinguished Civilian Service Award (highest DON award), which he received in 1992 and 2000—the first time it's been presented twice to the same person. He was also awarded the Presidential Meritorious Executive Award, the Navy Superior Civilian Service Award (Second Highest DON Award), and the Secretary of Defense's Commendation / Superior Performance Award. He holds six patent awards.

James J. Richardson, Ph.D.
Vice President for Research
Potomac Institute for Policy Studies

DEPARTMENT OF DEFENSE
SCIENCE AND TECHNOLOGY INVIGORATION

ABSTRACT

Numerous expert studies suggest that the Department of Defense (DOD) and the national science and technology (S&T) base have been in a slow decline since the Viet Nam War. Reasons given include decreased funding, disestablishment of executive level sponsors, and growing competition for top-level personnel. This report examines the evidence of decline and offers a set of metrics that may be used to conduct an objective assessment of DOD S&T capabilities and of the best use of those capabilities. In addition, the potential for invigorating the DOD Research, Development, Testing and Evaluation (RDT&E) base, and the S&T base in particular, is discussed in the context of the same metrics. The insights and thought processes necessary to develop, define, and most importantly, come to agreement on metrics and options will be invaluable in directly pursuing and addressing the immense problems associated with optimizing the DOD's S&T operations for today's and tomorrow's world, an undertaking beyond the scope of this study.

A history of the national S&T base shows profound changes over the past 30 years or more. Many critics of today's S&T system believe these changes result from a series of arbitrary reactions to trends in the public and private sectors. Whether this is true or whether these changes simply reflect inevitable and proper adjustments to different times, it is clear that the S&T system needs attention. The first step is to develop a means to analyze the complex and multifaceted issues associated with the national enterprise supporting science and technology.

This paper proposes an approach to such an analysis, one that incorporates metrics tailored to the issues at hand. Some of those issues are examined, using the history of the Naval laboratory and warfare center system as a case in point. Then, a structured approach is built for use in understanding the pressures on the S&T system and how that system should react. Most notably, the analysis must identify those factors that have had the greatest effect on the technology base and which of these factors can be affected by government. Once this is done, subsequent studies can perform the necessary analyses, formulate solutions, and finally, work out an implementation strategy.

Given that invigoration of the DOD S&T base is necessary at some level, a great difficulty is identification of which aspects of the system require invigoration and the direction that such an invigoration should take. Unknown, for example, is the appropriate mix of technical skills to meet the challenges of the new century. What must be developed ultimately is a strategy that considers the national S&T enterprise and the contributions of both public and private sector activities. This paper recommends a baseline assessment from which development of such a holistic strategy can begin.

In preparation for this task, a survey of past studies of the DOD and Naval S&T system has been performed, offering a summary of common conclusions and recommendations.

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EXECUTIVE SUMMARY

In the early days of the Reagan defense buildup, Secretary of Defense Caspar Weinberger wrote,

> We face the danger of losing our edge because we have not adequately replenished the reservoir of scientific concepts and knowledge to nourish future technologies during subsequent years of fiscal neglect of defense research and development. Given these circumstances, we must systematically replenish that scientific reservoir, using the unique and diverse strengths of the United States scientific community ... Given the relatively long lead time between fundamental discovery and applying such knowledge to defense systems, the true measure of our success ... may not be apparent for several decades. When the 'moment of truth' arrives, we cannot afford to be found wanting. Thus we must revitalize the productive partnership between the university community, industry, and the DOD in-house laboratories.[1]

President John Kennedy's announcement in 1962 of the national goal to land an American on the moon and return him safely to earth before the end of the decade launched a science and technology (S&T) golden age for the United States. For science and engineering graduates, there was the promise of an exciting time of discovery and an opportunity to serve their nation at the same time. The level of S&T investment was at an all-time high. Specific incentives for defense-related employment included the promise of occupational draft deferments for scientists in defense laboratories, accompanied by a sharp downturn in non-Department of Defense (DOD) hiring of scientists and engineers as NASA neared its moon goal. In the late 1960s, this enabled the DOD to recruit and retain an exceptionally talented group of young professionals. However, after the Viet Nam War, the situation changed radically. DOD laboratories began a period of two decades of minimal new hiring, with low attrition. Although total DOD S&T funding remained relatively constant, Service S&T spending began a decline that continued to the end of the century; their S&T focus decreased as Defense Agency S&T budgets increased.

The law supporting industry Independent Research and Development (IR&D) changed in 1990, and IR&D investment shrank to less than half of its previous level. The Navy's Independent Exploratory Development (IED) Program, designed to support the best ideas of the best scientists and engineers, was cancelled. Near the century's end, the rate of hiring of DOD scientists and engineers increased, but with intense private sector competition for the best and brightest added to the historically cumbersome and inflexible regulations for Civil Service hiring and noncompetitive pay rates. Added also was a growing public disinterest in pursuing S&T curricula and an attitude prevalent among many leaders that in-house DOD S&T investment was not required, i.e., that the private sector could and would provide the technology as necessary.

At the beginning of the twenty-first century, an entire generation of defense science and engineering talent is preparing for retirement. An important issue for immediate study is the impact of the departure of this generation without capable, trained relief to maintain the technical corporate memory, i.e. the potential for loss or significant degradation within the next decade of U.S. technological leadership in areas of critical national interests. It can be argued reasonably that new blood in the system may introduce an era of fresh thinking, but it is difficult to escape the conclusion that the potential exists for serious loss of capability, particularly in the "art of science"—things that are learned from experience and not from formal education. Should this loss occur without a strategy to compensate, the DOD S&T engines could stumble, and perhaps grind to a halt. Indeed, there is evidence that this is happening.

There is no shortage of studies of the DOD Research, Development, Testing, and Evaluation (RDT&E) infrastructure over the past two decades. In fact, it is difficult to filter and distill the information overload into what are highly consistent conclusions. This report highlights studies of greater prominence or depth, focusing in particular on the reports of the Defense Science Board (DSB) of the past decade. Although only a small sample of the available information is highlighted, the degree of consistency among the studies is exceptionally high, including even those studies conducted prior to the Reagan defense buildup of the 1980s. Many began with a basic assumption that DOD laboratories are essential, and did not attempt to investigate or justify their existence within the DOD and national system.

Of the studies that addressed the need for an independent in-house RDT&E capability, points of agreement on their value to DOD include:

- To help DOD and the Services to be smart buyers;
- To ensure the ability to respond rapidly in times of crisis;
- To support facilities and capabilities not practical in the private sector;
- To execute S&T programs and maintain the long term view;
- To provide direct technical support to the warfighter; and
- To maintain technical corporate memory.

Virtually all of the studies recognized that the laboratory hiring reductions of the 1970s-1980s, after several years of significant "staffing up," created a predictable future loss of technical competence and technological leadership. The dominant points of concern include:

- The DOD laboratory system has declined in numbers by approximately 35 percent since 1990.
- The DOD laboratory system is likely to lose by retirement within five years a generation of experienced and talented staff, with no trained backup to carry forward.
- Civil Service hiring practices and policies severely limit recruitment of the best personnel, either in career or appointee status.
- The current S&T funding level inhibits funding incentives for recruitment of the "best and brightest," increases risk for the future and raises acquisition costs.

The dominant recommendations include:

- DOD must augment its senior staff through contract staff and the Intergovernmental Personnel Act (IPA) Mobility Program from industry, academia and non-profits.
- DOD must utilize and exploit commercial technology wherever and whenever possible.
- DOD must act quickly.

This report addresses the specific case of the need for invigoration of the S&T base within the major components of the DOD S&T enterprise. A primary objective is to investigate methodologies to ensure the "highest and best" use of the technical capabilities of the DOD laboratories in today's changing environment, including optimizing the necessary public-private sector relationships. The second objective is to ensure that the technical capabilities of the enterprise remain sufficiently robust to meet the needs of the DOD today and in the future. A longer-term objective is to determine what is required of the enterprise to satisfy the needs of the DOD-after-next. Finally, the most important challenge is to determine how best to attract the talent to ensure technical excellence in the future. (Note: These objectives are likely to apply equally to government agencies, defense contractors, and other elements of the private sector. If so, only a top-down, holistic strategy will succeed.)

The recent economic downturn, hiring cutbacks in the commercial technology sector and especially the events of September 11, 2001, have provided a DOD employment environment similar to that of thirty-five years ago. A number of other independent factors have aligned to create the right timing and to provide an opportunity for DOD S&T invigoration. First, and most important of these, is the time urgency for loss of irreplaceable senior staff. Well-documented from multiple studies is the fact that the highly talented generation hired in the Viet Nam era will retire from the system within five years, in many cases without trained relief to preserve the corporate memory. At least three DSB Task Force reports published in the year 2000 express concern for the loss of capability within the DOD laboratory system and propose significant remedial actions.[2,3,4] These reports echo concerns expressed over the past two decades. Second, a new forcing function to address the issue is contained in Section 913 of the Conference Report accompanying the National Defense Authorization Act (NDAA) for Fiscal Year 2000 (Appendix A). This legislation provides for the DOD an opportunity (1) to determine the state of S&T capability within the S&T enterprise and (2) to develop a long-range plan (including both public and private sectors) to ensure the maintenance of essential capabilities. A third factor is the change in national administration, which invariably leads to evaluation of the infrastructure and changes to policies of the past administration. Finally, there is growing recognition in the military and across the public and private sectors of the vital importance of modernization, scientific discovery and innovation to the U.S. national defense and economic interests.

This study developed metrics for near-term assessment of the state of S&T in the DOD laboratory system and related Federally Funded Research and Development Centers (FFRDCs). Past studies of assessment metrics agree that objective evaluation of Research and Development is very difficult at best, that one set of metrics does not apply universally, and that the number of metrics for an evaluation should be small, preferably no more than a half-dozen. The following assessment metrics are proposed:

1. Quality and military impact of the products of the organization;
2. Organizational core competencies;
3. Value-added of the organization;
4. Quality of the technical staff;
5. State of physical resources; and
6. State of fiscal resources.

The following actions are recommended:

1. Conduct an assessment of the DOD S&T enterprise, and the DOD laboratory and warfare center system in particular. The assessment should be consistent with the requirements of the Section 913 legislation and with requirements input of the Service Chiefs, Systems Commands, and Commanders-in-Chiefs (CINCs). Recommended metrics for assessment are the six listed above.

2. Develop a strategy to ensure maintenance of the DOD S&T corporate memory as the current generation of senior scientists and engineers retires. Examine the potential new window of opportunity to recruit the "best and brightest" into the DOD laboratory system and defense-related industry.

3. Develop a strategic plan for the DOD S&T infrastructure of the future, defining the complementary roles of the Laboratory/center system, academia, FFRDCs and University Affiliated Research Centers (UARCs), and private industry. The system of the future should be flexible, innovative, willing to promote bypassing the next generation of technology, and able to support the military forces in effective utilization of the systems and technologies of U.S. and international military and commercial activities.

4. Establish and monitor closely a 6.2 base program within the DOD laboratory system to encourage discovery and innovation.

5. The Director Defense Research and Engineering (DDR&E) should take the lead to carry out the above recommendations.

I. INTRODUCTION

In 1973, a joint review of Independent Exploratory Development (IED) was conducted between the Naval Research Laboratory (NRL) and the Naval Weapons Laboratory (now Naval Surface Warfare Center Dahlgren Division). IED funding, representing the Laboratory Directors' only internally managed Applied Research (6.2) dollars, disappeared in S&T funding reductions of the last decade. IED dollars were few and very precious, allocated only to the best people and the best ideas (Note: There has always been and there will always be more worthy ideas than funds.). A project considered for funding during that review was a radically new concept called Global Positioning System (GPS), for which the briefer requested one or two work-years of funding to examine feasibility. GPS in 1973 represented exceptionally high technical and budget risk, but the panel, with absolutely no idea of any unclassified or non-military applications, decided the technology might be worthy of a few "sorcery and alchemy" dollars. Almost thirty years later, GPS is a household word in commercial and military applications, and the impact of this breakthrough technology finally may be understood and appreciated.

In the new millennium, Naval IED funding no longer exists, the Navy's 6.2 Applied Research account is half the size of 1973 and the focus of Naval and other Service warfare centers has become shorter-term, farther from science and technology (S&T). In this climate it is reasonable to question (1) whether today's breakthrough ideas with levels of risk comparable to GPS in1973 would be seriously considered for S&T funding, and (2) whether the current capability of DOD's in-house research and development (R&D) infrastructure is sufficient to create and to develop such "out-of-the-box" concepts. These are vital questions from both a DOD and national perspective.

President John Kennedy's announcement in 1962 of the national goal to land an American on the moon and return him safely to earth before the end of the decade launched what was to become a S&T golden age for the United States government. The President's timing was outstanding. Although he did not live to see the maturation of his lofty vision, the cause captured not only the imagination of the American people as a whole, but also the imagination of a young and talented baby-boom generation in particular. This was a generation born after World War II (WWII) and raised in the Eisenhower years, with vague recollections of Korea but vivid memories of Sputnik, Berlin, and the Cuban Missile Crisis. For this generation, a career in science offered the ability to participate in a great and exciting adventure and serve the nation at the same time. This was made possible by a sufficient level of national S&T investment to support this adventure. In the specific case of the Department of Navy (DON), its growing 1962 Applied Research (6.2) budget was three times larger than the draft FY 2002 President's Budget request for the same account.

Far less noble but of significance in the latter half of the decade was the fact that male scientists graduating with B.S. degree or advanced degrees, as the oldest in the draft pool, were highly vulnerable to be drafted and sent to combat in the nation's most unpopular war. The attractiveness of occupational deferments for scientists in defense laboratories and a downturn in non-DOD hiring of scientists and engineers (S&Es) as the National Aeronautics and Space

Administration (NASA) neared its moon goal combined with grand causes and patriotism and created a 1965-1971 buyer's market for the DOD, an opportunity to select the best of an exceptionally talented pool of young professionals.

By the end of the Viet Nam War, the climate had changed radically. Federal employment, and defense employment in particular, was not viewed with respect, and morale of workers sagged. Most occupational deferments ended with the draft lottery system, and employees who worked for DOD only to avoid the draft (a small number) moved on. DOD laboratories began a period of two decades of minimal new hiring, low to moderate attrition and a talented work force entering middle age. Service S&T spending began a slow, steady decline that continued through the end of the century. Although DOD S&T investment remained relatively constant through the 1980s and 1990s, creation of the Strategic Defense Initiative initiated a significant funding migration from the Services to Defense Agencies (Figure 1.).

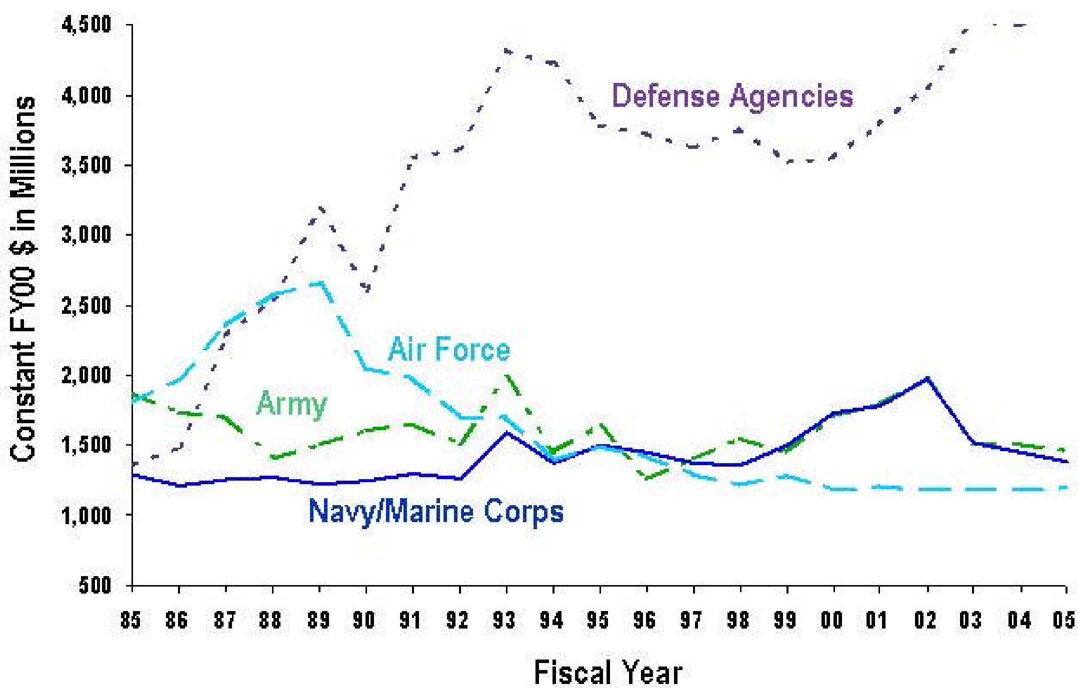

FIGURE 1. COMPARISON OF DOD S&T ACCOUNTS

Note: The Services and Agencies execute significantly different S&T investment strategies. The Services tend to invest their share (half) of S&T - the high-risk portion of the DOD investment portfolio - in numerous smaller projects. The Agencies tend to concentrate S&T investment into a smaller number of projects at higher funding levels.

In the early Clinton years of federal downsizing, introduction of new scientists and engineers into the DOD S&T community slowed to a crawl as work force reductions and privatization goals were achieved primarily by means of hiring freezes, attrition, and outsourcing. In the latter years of the Clinton Administration, some hiring of scientists and engineers resumed, but with new and intense private sector competition for the best and brightest added to the historically cumbersome and inflexible regulations for federal hiring and noncompetitive pay rates.

Figure 2, using data developed in 1995 by the Navy, graphically illustrates the existence of manpower generation gaps. Similar trends are known to exist in the other Service RDT&E activities, but there is not a comparable historical database for the enterprise as a whole. Thus potentially serious issues of manpower and capability losses are not readily apparent.

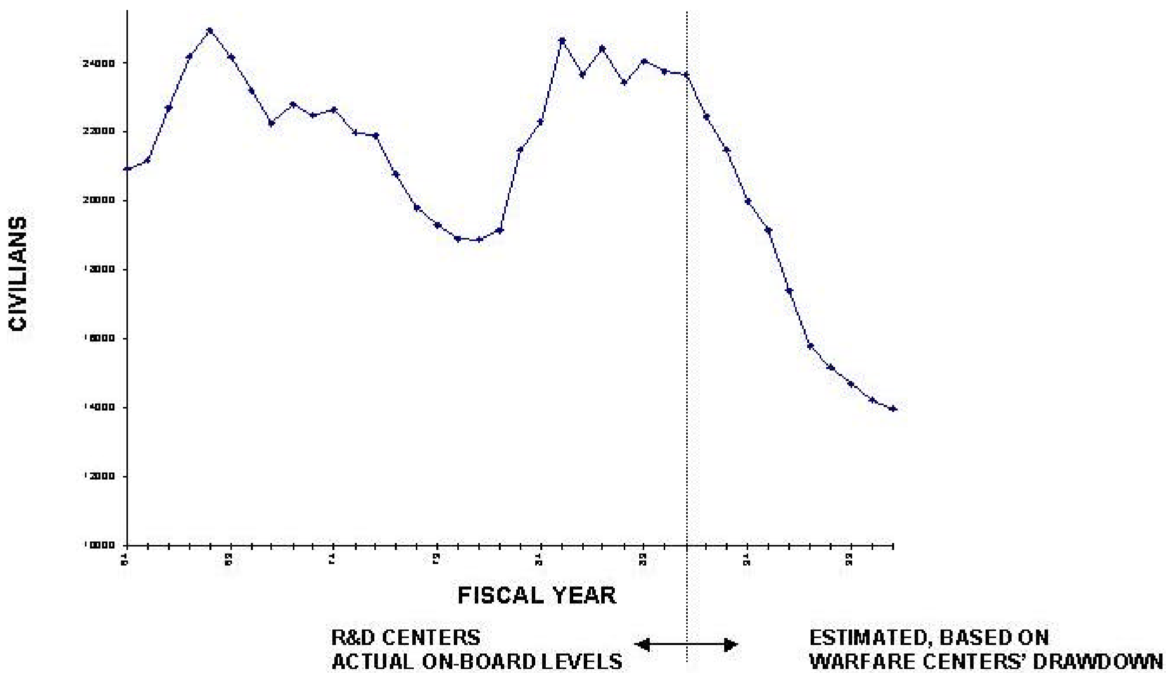

FIGURE 2. NAVAL WARFARE CENTER CIVILIAN MANPOWER LEVELS

At the beginning of the twenty-first century, an entire generation of defense science and engineering talent is preparing for retirement. An important issue for immediate study is the impact of the departure of this generation without capable, trained relief to maintain the technical corporate memory, i.e. the potential for loss or significant degradation within the next decade of U.S. technological leadership in areas of critical national interests. It can be argued reasonably that new blood in the system may introduce an era of fresh thinking, but it is difficult to escape the conclusion that the potential exists for serious loss of capability, particularly in the "art of science" - things that are learned from experience and not from formal education. Should this loss occur without a strategy to compensate, the DOD S&T engines could stumble, and perhaps grind to a halt. Indeed, there is evidence that this is happening.

This study proposes an examination of the need for invigoration of the S&T base within the components of the DOD S&T enterprise and the direction that invigoration should take. A primary objective is to investigate methodologies that ensure the "highest and best" use of the technical capabilities of the Service laboratories and warfare centers, and how to optimize them for today and tomorrow's world. This implies in no way the intent to maintain status quo, but rather the intent to establish the most appropriate and complementary relationships among the public and private sector components of the enterprise. The second objective is to ensure that the technical capabilities of the enterprise remain sufficiently robust to meet the needs of the DOD today and in the future. A third, longer-term challenge is to determine what is required of the enterprise to satisfy the needs of the DOD-after-next, i.e., what must the system become and what has to be done to get there? Assuming that reliance on the private sector is at least a part of the solution, the potential for private sector substitution for a portion of DOD's S&T force must be examined closely and a methodology to accomplish the required leveraging must be developed. This leads to hard questions such as the DOD personnel, infrastructure, and skills required as well as how to address military-specific technologies and products that may have no private sector interest.

The final and most important challenge: how to ensure technical excellence in the DOD and nation-after-next outside the climate of noble causes, excitement, and adventure that existed in the late 1960s and which naturally attracted the best and brightest into federal service. The recent economic downturn, hiring cutbacks in commercial technology employment and especially the events of September 11, 2001 may provide a forcing function similar to the scientific employment environment of thirty-five years ago. If so, there may be a recruitment window of opportunity for DOD and the defense-related private sector.

This report will examine how such questions can be addressed. It will review the history of the Naval warfare center system as a case study, highlight findings and recommendations from past R&D infrastructure studies, and propose an approach for assessment and potential invigoration of the S&T capabilities of the DOD S&T enterprise.

II. HISTORY OF THE DEPARTMENT OF NAVY WARFARE CENTER SYSTEM.

This section documents the history of the Naval warfare centers as a case study of the decline in in-house DOD S&T capability. Although the specific details vary somewhat, the concerns identified for the Naval activities apply equally to the other Service components of the DOD S&T enterprise. Thus it is logical to assume that many, if not all of the potential solutions for Department of Navy problems apply to all Services.

The evolution of the shore establishment and acquisition processes of the Department of the Navy (DON) is characterized by 124 years of relative stability, followed by 35 years of multiple, significant changes. The Naval Bureaus were established in 1842 as a replacement for the Board of Naval Commissioners, which provided management over Naval material affairs. After 124 years of survival through multiple wars and political administrations, the Bureaus were replaced in 1966 by six Systems Commands (SYSCOMS), which reported to the four-star Naval Material Command (NAVMAT).[5]

Under this new structure the SYSCOMS were charged with conceiving, developing, acquiring and logistically supporting Naval platforms and their weapons. This was accomplished through program offices, a field structure and industry, with technical support from Naval R&D activities (commanded by military officers but staffed predominantly by Civil Service employees) and university laboratories. The Director of Navy Laboratories (DNL) was established to provide representation, oversight and (loose) coordination of the Navy Laboratory and Warfare Center System. The university laboratories were placed administratively under the SYSCOM for which they did the majority of work. The Naval R&D activities, however, although they received the majority of their funding from the SYSCOMs, reported administratively to NAVMAT and DNL, who was double-hatted also to the Assistant Secretary of the Navy for Research, Engineering and Systems.[6]

At the same time as NAVMAT was organizing, the Director, Defense Research and Engineering (DDR&E, Dr. John Foster) asked Dr. Leonard Sheingold, vice president of Sylvania Electronic Systems, to chair the Defense Science Board (DSB) Task Force on Department of Defense In-House Laboratories. The Sheingold study proposed that individual laboratories be reorganized into technical centers, each possessing a “critical mass” of one thousand specialists performing R&D as well as demonstrating the workability of prototypes. About 70 percent of the effort would be devoted to in-house activities rather than contract monitoring, and each center director would control the resources necessary to accomplish the mission. Within days of the formal release of the Sheingold Report, DDR&E directed the Navy to initiate plans to establish weapon systems development centers.[7]

Timing was excellent for staffing of the Navy’s new R&D centers. Science and technology funding was at its all-time high, partially a result of the race into space and the national goal established by President Kennedy to put an American on the moon by the end of the decade. Added to those lofty and noble goals of national interests, space exploration, scientific discovery, and contributing to the interests of one's country, employment by a military laboratory held the promise also of occupational draft deferments for a growing population of baby-boom male scientists and engineers (S&Es), many of whom did not relish the thought of being drafted into ground combat in the nation's most unpopular war. In addition, scientific employment opportunities took a drastic downturn at the end of the decade, and new M.S. and Ph.D. degree scientists offered to accept Civil Service employment at entry levels as low as GS-5 instead of the usual GS-9/11/12. Thus the DOD and Naval R&D establishment were able to increase their staff easily, picking and choosing from the most talented of young scientists and engineers. The centers also enhanced the education levels and kept morale high through formal professional training programs and graduate education, frequently provided on site.

The Naval Material Command proved to be a good steward of the Naval R&D centers for the nearly two decades of its existence. Even though S&T funding dropped sharply during the latter years of the Viet Nam War and declined at a pace of about two percent per year for the rest of the decade (and since), the Naval Laboratory and warfare center community and associated university labs developed and transitioned the requisite technologies for such advanced systems as the Aegis Combat System, towed arrays, GPS, laser-guided projectiles, reactive weapons, and directed energy technology, to name only a few.

However, life in the "DNL Labs," as the community was known, changed dramatically in April 1985 when Navy Secretary John Lehman announced the disestablishment of the Naval Material Command, beginning a period of instability in the Naval technical community that arguably continues to this day. The R&D centers and the university laboratory responsibilities were placed initially under the Office of Naval Research (ONR), but ONR was not prepared to manage such a large component (over 20,000 people) of the shore establishment. Less than a year later they were moved to the Space and Naval Warfare Systems Command (SPAWAR), newly created to oversee systems architecture. Unfortunately for the warfare centers, laboratory management was not a vital interest of a command facing the difficult task of creating the Naval System for Warfare Systems Architecture and Engineering. Furthermore, SPAWAR was placed in the unenviable position of coordinating the activities of warfare centers that received most of their funding from other (peer, but larger) Systems Commands.[8]

The SPAWAR laboratory management era ended in January 1992, when the office of the Director of Navy Laboratories was formally abolished. Four new "megacenters" were established [Air, Control, Command (C2) and Ocean Surveillance, Surface, and Undersea], with each center reporting to the SYSCOM representing its major source of income.[9] The movement of the warfare centers under the Naval Systems Commands was the most visible of three major events in the early 1990s that fundamentally changed the character of DON S&T execution. This move occurred despite deep concerns within the R&D community that the near-term focus necessary for the SYSCOMs to accomplish their primary missions would lead to a slow degradation of the long-term (S&T) capabilities of the warfare centers.

After the disestablishment of DNL, it was intended that two new committees would perform the Laboratory/Center oversight function. The Navy Laboratory and Center Oversight

Committee (NLCOC), chaired by the Assistant Secretary of the Navy for Research, Development and Acquisition [ASN (RDA)] and including the Vice Chief of Naval Operations and Assistant Commandant of the Marine Corps as principal members, and the Systems Commanders as associate members, were to provide policy level oversight. The last meeting of the NLCOC was in 1992. The Navy Laboratory/Center Coordinating Group (NLCCG), which includes the commanders and technical directors of the warfare centers and the Commanding Officer and Director of Research of NRL (with a rotating chair), is still active. This forum is effective as a vehicle for communication among the members of the community, but is designed to focus inward rather than on Naval policy and external representation issues.

A second event occurred almost unnoticed in 1991, but which had a significant effect on the national and Naval technology base. Public Law (PL)-914-41, Section 203, of the 1971 Military Personnel Authorization, provided for private industry recovery of IR&D expenses as general and administrative overhead, for building the future business and technology base. Companies with IR&D programs in excess of $4 million were required: (1) to submit a technical plan describing each technical project, which the DOD would evaluate for "potential military relevance;" (2) to negotiate an agreement with the DOD which established an IR&D ceiling for cost recovery (Note: Most companies exceeded the cost recovery ceiling each year, with company dollars paying as much as one-third of the total IR&D.); and (3) to present an on-site review of its IR&D program to the DOD at least once every three years.[10] In December 1991, responding to pressure from industry to simplify the process and to allow full recovery of IR&D expenses, Congress passed PL-102-190, which stated "that independent research and development and bid and proposal costs of DOD contractors shall be allowable as indirect costs on covered contracts to the extent that such costs are allocable, reasonable, and not otherwise unallowable by law or under the Federal Acquisition (FAR)." The legislation allowed full recovery of IR&D expenses and negated the requirement for IR&D ceiling negotiations with DOD (industry's primary goal in pursuing the legislation) but also negated the requirement for industry reporting and DOD review and oversight of IR&D.[11]

From a national technology base perspective, PL-102-90 produced two unintended negative consequences. First, it allowed (thus effectively encouraged) industry to reduce overhead rates by reducing IR&D investment. IR&D budgets shrank to less than half their levels before the law change, and the character of IR&D work became nearer-term (more like bid and proposal funding) as the Reagan defense budget dropped to the early Clinton administration levels. Second, the DOD and industry lost overnight a forcing function to encourage and assure access by individual performers to each other's R&D, ending a period of many years of mutually advantageous technical communication and leverage between the public and private sectors. Ironically, although demands for leverage of private sector technology increased steadily throughout the decade following passage of PL-102-90, private sector technology development became, with few exceptions, far less visible to the DOD.

The third event was the loss of the 6.2 Laboratory Independent Exploratory Development (IED) Program in 1993, cancelled because of DON S&T reductions and a historically difficult

Congressional budget defense (a casualty of Congressional staff concerns over after-the-fact program review and oversight). IED was a relatively small account (nominally $25 million/year), with funding allocated to NRL and the warfare centers to complement the 6.1 Laboratory Independent Research Program of similar size, which still exists today. These programs represented together an exceptionally effective DON investment in new, generally high-risk/high-payoff technologies – "disruptive technologies," in the terminology of Bower and Christenson,[12] that has become a current term of choice. IED funding at a specific Division site was modest [e.g. an activity the size of Naval Surface Warfare Center's (NSWC) Carderock Division might receive $2 million each of Independent Research and IED funds], and frequently was divided into increments of less than one work-year each. Selection of projects for In-house Laboratory Independent Research (ILIR) or IED funding gave NRL and the warfare centers an excellent way to reward innovation and to encourage the best and brightest. Technologies such as GPS, reactive weapons, and submarine bow planes were supported in their infancy with IED funds. The loss of IED represented a major blow to the S&T communities within the centers, forcing many scientists and engineers into non-S&T career paths.

After the cancellation of IED, ONR created and maintained a similar Applied Research "Base Program" at the Naval Research Laboratory. The concept proved to be an important resource for the NRL Director of Research to assure future excellence in research and to reward innovation. Base Program funding has been Congressionally defensible (unlike IED, for which defense was difficult), but S&T base programs were not established at the four major warfare centers.

In 1995, the Naval Air Warfare Center (NAWC) headquarters staff was disestablished, and the R&D and S&T activities remaining from what was known in 1985 as the Naval Weapons Center and the Naval Air Development Center were integrated into the NAVAIR structure. Three years later the components of the DON Command, Control, Communications, Computer, and Intelligence (C4I) R&D infrastructure were integrated into SPAWAR. Although NAVSEA attempted to integrate the NSWC components into its structure in 1999 (but maintained the warfare center identity and the Technical Director position), at the time of this writing both NSWC and the Naval Undersea Warfare Center (NUWC) retain their status as independent entities within the Command.

The Marine Corps became a new player within the DOD laboratory system in 1995 when the Commandant established the Marine Corps Warfighting Laboratory (MCWL) at Quantico, Virginia. Through a series of major exercises and warfighting experiments, MCWL introduced the first "Battle Lab" of the Department of the Navy. In 2001, MCWL established its first civilian Technical Director position, to make the organization more compatible with the Naval RDT&E infrastructure and to ensure corporate memory.

Thus the Department of the Navy entered the new millennium with a SYSCOM-centric warfare center infrastructure and a new and growing Marine Corps R&D presence. The current organizational structure is arguably better coupled to the acquisition and budget processes than in the old "DNL Lab" days. There are potentially serious near-term issues, however, which include:

1. An aging DON senior work force, with an entire generation eligible to retire within five years and potentially without trained replacements in the pipeline to carry forward;
2. A Naval S&T budget that has declined steadily since the 1960s, specifically in Applied Research;
3. Declining industry IR&D investment, now focused primarily on the short-term (a complement, but not an alternative to DOD S&T); and
4. The requirement for a strategic vision for the DON RDT&E infrastructure and resources to focus technology investment and assure technological superiority for the Navy-After-Next.

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III. DOD LABORATORY AND WARFARE CENTER STUDIES

There has been no shortage of studies of the DOD laboratory infrastructure over the past two decades. Indeed, the greatest difficulty in examining the health of the system is in filtering and distilling the information overload into useful and objective conclusions. The following discussion highlights some studies of more prominence or greater depth, focusing in particular on the reports of the DSB of the past decade. Although only a small sample of the available information is highlighted, the degree of consistency across all the studies is exceptionally high, including even those studies conducted long before the Reagan defense buildup of the 1980s. Unfortunately, few studies were conducted using formal metrics or a scientific approach. Many began with the basic assumption that DOD laboratories were essential, and neither investigated nor attempted to justify their appropriate role within the DOD and the national system. Reports that provide significant justification for the existence of the laboratory system are specifically highlighted below. The comments included below are not intended to represent all the findings of the various studies, but to provide a sampling of significant comments as related to the laboratory and warfare center infrastructure. Greater detail is included for the most recent studies. For the sake of brevity, common findings (which are legion) may not be repeated. Significant studies include:

"Report of the Defense Science Board Task Force on Efficient Utilization of Defense Laboratories," October 2000.[13] This report responds to Congressional reporting requirements contained in Section 913 of the FY-2000 National Defense Authorization Act (See Appendix A).

Findings:

1. The military laboratories represent an important source of innovation.
2. The current Civil Service salary, regulations make recruiting and maintaining quality professional staff extremely difficult.
3. The process and regulations for approval of Senior Executive Service appointees make it extremely difficult to recruit the leading technical and administrative professionals.
4. DOD lab personnel decreased 36 percent in last ten years; many of the younger staff members with training in current technology are no longer employed.
5. About 30 percent of the professional staff are within five years of retirement
6. Many of the DOD laboratories are physically separated from the development centers that are the natural recipients of their innovations, impeding transfer of technology.
7. Based on private sector experience, competition between defense laboratories could enhance productivity.

Recommendations:

1. The Secretary of Defense (SECDEF) should instruct the Services to bring in private sector S&Es under contracts and IPA agreements from universities, industry and non-profits for a majority of the laboratory professional staffs.
2. SECDEF should seek relief from procedures inhibiting Executive Service appointments
3. If consolidations are undertaken, locate laboratory operations physically close to Service development and procurement centers.

4. The Under Secretary of Defense for Acquisition, Technology and Logistics [USD (AT&L)] should maintain competition between defense laboratories, especially for 6.1 Basic Research.
5. DDR&E should utilize university technology historians to develop understanding of past relevance of defense laboratories.
6. DDR&E should utilize the National Academies of Science (NAS) to examine periodically (e.g. every three years) the quality of the defense laboratories.

"The Defense Science Board Letter Report on DOD Science and Technology Program," August 2000[14] **and "Report of the Defense Science Board Task Force on Defense Science and Technology Base for the 21st Century," June 1998.**[15] This letter report responds to the request of Section 212 of the FY 2000 Defense Appropriation Report that the DSB provide an assessment regarding the appropriate funding level for the DOD Science and Technology Program.

Findings:

1. "DOD should be requesting higher levels of funding for the S&T Program."
2. "Much of current industrial research has a very short time horizon and, in addition, tends to be focused on incremental improvements of current civilian products."
3. The current Civil Service Personnel System has a very negative impact on the capabilities and morale of the DOD and Service Laboratory and Center technical personnel."
4. The focus of the current DOD S&T Program is primarily on incremental improvements in current capabilities."
5. DOD and Service research facilities are physically disconnected from weapon development and procurement organizations, and many are old and poorly equipped.

Recommendations:

1. The DOD S&T budget should be increased by $1 billion/year.
2. "DOD should not depend on civil sector research for all its needs."
3. DOD should depend less on the Civil Service System and more on universities and industry to provide professional personnel for DOD and Service laboratories.
4. DOD should emphasize innovative technology initiatives leading to new military capabilities.
5. DOD and the Services should consolidate and modernize their R&D facilities.

"Report of the Defense Science Board Task Force on the Technology Capabilities of Non-DOD Providers," June 2000.[16] This Task Force was asked to support the Department's in-house study by examining the capabilities of non-DOD providers to provide warfighting technology, engineering and test capabilities for future U.S. military forces.

Findings:

1. Commercial industry is generally disinterested in developing products for DOD, as the opportunity costs are too great, cost of doing business is too high, etc.
2. The U.S. and worldwide research base has increased significantly since WWII, but the DOD contribution has remained essentially constant.
3. DOD/Service S&T and acquisition infrastructure has decreased 25 percent since 1990; funding has decreased 35 percent.

4. "DOD should concentrate the efforts of its limited laboratory and center resources on those unique military technologies and systems which are of crucial importance to maintaining U.S. military preeminence."
5. "...Commercial firms today have greatly reduced their funding of long-term, generic technology development, meaning technology that may not find applications until ten years and beyond."

Recommendations:

1. Establish the Office of Global Technology Acquisition, funded at $100 million/year and focusing on militarily important technologies, "disruptive technologies," novel approaches to acquire technology, and commercial contracting/licensing practices.
2. Increase to 50 percent the Service S&T management and laboratory staff contracted from the private sector.
3. Increase funding of DOD-relevant university research by 30 percent.
4. Initiate a high-level "Packard-like" Commission to develop an integrated requirements/acquisition process.

Defense Science Board. "Human Resources Strategy," February 2000.[17]

Findings:

1. Service laboratories downsized 35 percent during the the1990s.
2. Thirty percent of the DOD laboratory staff is within five years of retirement, with no replacement staff in training to provide continuity of technical expertise and corporate memory.
3. The staff and capability losses have potentially serious negative impacts on future military capabilities, i.e. can the U.S. achieve a Revolution in Military Affairs before an adversary?
4. The report agrees strongly with past DSB studies that the inflexible Civil Service system is to blame for many of the problems.

Recommendations:

1. DOD should acquire a high-quality staff from universities, non-profits and industry.
2. Reinstate PL-80-313 to enhance outside recruiting.
3. Civil Service post-employment and pension restrictions should be relaxed.

Defense Science Board. "FFRDCs and UARCs Independent Advisory Task Force," January 1997[18] and "Task Force on the Role of FFRDCs in the Mission of the DOD," April 1995.[19]

Findings and Recommendations:

1. In-house laboratories and private industry have gained some of the unique competence that initially characterized FFRDCs.
2. Reliance of DOD on FFRDCs and UARCs was reaffirmed for well-defined functions.
3. DOD should accurately define FFRDC/UARC tasking.
4. DOD Should use open competition when appropriate.

"Navy Laboratory and Center Coordinating Group (NLCCG) Ad Hoc Study of the Value of Naval Warfare Centers," November 1996.[20]

Addressed need for in-house laboratory system.

Findings and Recommendations:

Naval in-house technical organizations exist to ensure that:

1. Technical program risk is recognized and minimized.
2. DON receives maximum benefit from technology and other modernization investments.
3. Warfighters are provided rapid, direct technical support.
4. DON maintains a technical corporate memory.
5. A long-term view is available for decision-making.
6. Special facilities are maintained.
7. A technical honest broker is available to DON.
8. Stewardship is maintained across the life cycle.

Naval Research Advisory Committee. "Naval Research and Development," October 1994.[21]

Findings and Recommendations:

1. There are significant organizational weaknesses in Naval R&D structure, personnel policies, financial execution and planning.
2. Process weaknesses include weak integration between Naval doctrine and R&D, a requirements process that does not address prioritization or assess cost, risk and affordability (Note: The current Future Naval Capabilities (FNC) process was established to address precisely these concerns; applied only to the Naval S&T Program.).
3. Navy must protect and retain critical DON-unique resources (products, capabilities, facilities, personnel) before the ability is lost.
4. Navy should create a single Warfare Systems Command as the focal point for the Navy's R&D and material needs.

White House Report 94: "OSD Interagency Review of Federal Labs" of 12 September 1994.[22]

Addressed need for in-house laboratory system.

Findings and Recommendations:

DOD in-house laboratory system is needed:

1. To ensure lowest cost to the sponsor;
2. To avoid technological surprise;
3. To provide rapid, flexible responses to military needs;
4. To conduct inherently governmental tasks;
5. To maintain technical corporate memory;
6. To provide technology and system integration;
7. To provide continuity across system life cycles; and
8. To ensure long-term military R&D.

Defense Science Board. "Task Force of Defense Laboratory Management'" April 1994.[23]
Findings and Recommendations:
1. "Resize and restructure the Defense Laboratories to enable them to respond to external changes and better use their resources."
2. "Pursue a vigorous program of outsourcing defense laboratory activities."
3. Establish long-term managerial oversight by DDR&E.

Defense Science Board. "Defense Technology Strategies," January 1992.[24]
Findings and Recommendations:
1. The military benefited greatly in the Gulf War from DOD laboratory technology prototypes deployed rapidly into the field.
2. DOD should make maximum use of Advanced Technology Demonstrations (ATDs) and Advanced Concept Technology Demonstrations (ACTDs) for rapid transition of technology into military use.

Adolph Commission: Federal Advisory Commission Report on "Consolidation and Conversion of Defense R&D Labs," 30 September 1991.[25]
Addressed need for in-house laboratory system.
Findings and Recommendations:
The DOD laboratory system is needed:
1. To allow the Services to be smart buyers of new and improved systems;
2. To act as principal agents for maintaining the technology base;
3. To ensure technological innovation and avoid technological surprise;
4. To support acquisition programs;
5. To provide special facilities not practical in the private sector;
6. To provide rapid response in times of crisis;
7. To provide constructive technical advice;
8. To support the user in application of new technology;
9. To translate user needs into technology requirements for industry; and
10. To serve as an S&T training ground for civilian and military acquisition personnel.

Defense Science Board. "R&D Strategy for the 1990s," October 1990.[26]
Findings and Recommendations:
1. DSB expressed serious concerns with deteriorating quality of personnel. "We must begin now to develop a set of activities that will represent our best efforts ... [to develop] inducements for attracting, training and retaining the best people to serve our country."
2. Increase centralization of R&D management within DOD. (Note: This recommendation was perceived by the Services as a potential threat to their laboratory systems and was a factor in the Services' consolidation of their RDT&E infrastructure into "megacenters.")
3. DOD should exploit private sector R&D.
4. DOD must maintain the ability to generate breakthrough technology.

Defense Science Board. "Report on Technology Transition in the DOD," December 1988.[27]

Findings and Recommendations:

1. Navy ATD Program embodied intent of Packard Commission recommendations on prototyping of defense technologies.
2. ATDs encourage technology transition.
3. All Services should apply at least 50 percent of their 6.3 budget to ATDs.

CNO Executive Board Study, published in *U.S. Naval Institute Proceedings,* "Eating Our Seed Corn," by Karl M. Duff, July 1984.[28]

Findings and Recommendations:

1. The DOD's "fly before buy" policy produced severe adverse impact on RDT&E accounts, as no fiscal adjustments made to accommodate greatly increased costs.
2. Result is dramatic S&T decline as percentage of budget, inadequate 6.3 prototype funding, and acquisition program stretch-out.
3. Chronic 6.3 program instability must be rectified to stabilize acquisition program costs.
4. "A policy of structured RDT&E growth for competitive experimental prototyping is necessary and is the most feasible means of introducing corrective resource allocation to the Navy's long-term operational capabilities and acquisition process."

"Naval Material Command Mission Review Panel Report," 13 December 1982. Addressed need for in-house laboratory system.[29]

Findings and Recommendations:

Naval laboratories are needed:

1. To help the Navy be a smart buyer;
2. To ensure technical leadership and expertise;
3. To provide warfare and system analyses;
4. To interact with and support the operating forces;
5. To plan and conduct the DON S&T program;
6. To provide an independent source of prototyping, concept evaluation, systems engineering and concept validation;
7. To ensure technology transition;
8. To provide quick response to crises; and
9. To provide special RDT&E facilities.

Under Secretary of Defense for Research and Engineering. "An Independent Review of DOD Laboratories," March 1982.[30]

Findings and Recommendations:

1. There is a significant "loss of work force competence" in the DOD laboratory system.
2. There is "extensive erosion in the competence, morale, and effectiveness of this work force [which] if continued, would lead to the decline of the laboratory system."

Under Secretary of Defense for Research and Engineering Report, "Required In-House Capabilities for DOD RDT&E," 1 October 1980.[31]
Addressed need for DOD in-house laboratory system.
Findings and Recommendations:
The DOD laboratories are needed:
1. To help the DOD be a smart buyer;
2. To manage RDT&E programs;
3. To provide technical intelligence assessments;
4. To provide options for future systems;
5. To exploit new technological opportunities;
6. To interact with and understand the military user; and
7. To evaluate contractor proposals and products.

White House Report 79: Federal Coordinating Council for Science, Engineering and Technology. "Application of OMB Circular A-76 to R&D: an R&D Management Approach," 31 October 1979.[32]
Addressed need for DOD in-house laboratory system.
Findings and Recommendations:
The DOD laboratories are needed:
1. To help the DOD be a smart buyer;
2. To conduct mission-oriented studies, technical analyses and evaluation;
3. To provide R&D for the long term;
4. To provide independent Test and Evaluation (T&E);
5. To ensure R&D corporate memory;
6. To provide rapid response capability; and
7. To support unique R&D facilities not feasible in the private sector.

There is a remarkable degree of consistency in the reports listed above and in the many dozens more that could have been referenced. This is true whether the studies focused on the value of the laboratory system or focused on the problem areas.

Points of universal agreement with respect to the need for an independent in-house RDT&E capability in DOD include:
- To help DOD and the Services to be smart buyers;
- To ensure the ability to respond rapidly in times of crisis;
- To support facilities and capabilities not practical in the private sector;
- To execute S&T programs and maintain the long term view;
- To provide direct technical support to the warfighter; and
- To maintain technical corporate memory.

Almost all of the reports recognized that the laboratory hiring slowdowns/freezes of the 1970s and 1980s after several years of significant "staffing up" created an entirely predictable future loss of technical competence and technological leadership. Such an outcome was forecast as early as the 1982 articles referenced above. Taken as a whole, the dominant points of concern include:

- The DOD laboratory system has declined in numbers by approximately 35 percent since 1990.
- The DOD laboratory system is likely to lose by retirement within five years a generation of experienced and talented staff, with no trained backup to carry forward.
- Civil Service hiring practices and policies severely limit hiring of the best personnel, either in career or appointee status.
- S&T funding decline compounds the problem by inhibiting incentives for recruitment of the "best and brightest," raising acquisition costs and increasing risk for the future.

The dominant recommendations include:

- DOD must augment its senior staff through contract staff and IPAs from industry, academia and non-profits.
- DOD must utilize and exploit commercial technology wherever and whenever possible.
- DOD must act quickly.

IV. Metrics for Evaluation of Research and Development – Sampling of Previous Studies

Just as there is no shortage of studies on the DOD RDT&E infrastructure, there is no shortage of articles on study metrics. While there is less unanimity in the collective recommendations than for the laboratory studies, certain specific patterns emerge, particularly with respect for metrics to evaluate R&D. A sampling is listed below:

Army Research Laboratory Technical Assessment Board, 1999. [33]

Conclusions: The outcome of R&D activity often cannot be quantified in advance. In fact, it may lag the initial R&D by several decades.
Recommendations: Recommended a combination of peer review, customer evaluation, and performance measures (papers, patents, backlog, diversity, cycle time, etc.).

Brown and Svenson, "Measuring R&D Productivity," Industrial Research Institute, 1998.[34]

Conclusions: Far too much emphasis on in-process measurement and feedback, behavior, R&D outputs (papers, presentations, patents, awards, etc.)
Recommendations:

1. Focus on external, not internal measures.
2. Focus on outcomes (quality, quantity, cost), not behavior.
3. Measure only valuable accomplishments.
4. Make the system simple - no more than six to eight key indices.
5. Make the system more objective than subjective (difficult for R&D).

GAO Report, "Measuring Performance - Strengths and Limitations of Research Indicators," March 1997.[35]

Conclusions: "… many of the R&D output measures tracked by the private sector do not apply directly to the federal government."
Recommendations: Recommends combination of return on investment (ROI) evaluations, patents, bibliometrics, and peer review.

Adolph Commission, Federal Advisory Commission Report on "Consolidation and Conversion of Defense R&D Labs," 30 September 1991.[36]

Conclusions: A single set of measures of effectiveness (MOEs) will not apply across the board to every laboratory.
Recommendations: Recommended set of input and output MOEs for DOD laboratory reviews.

Input MOEs:

1. Mission – clear, substantive, unique
2. Types and percentages of funding and applied work-years
3. Specific tasking/responsibilities
4. Workload – demonstrated need for products
5. Quality of facilities
6. Employee credentials – degrees, GPA, training

Output MOEs (applied as appropriate):

1. Transitions to warfare systems
2. Reports/presentations - internal/external
3. New system concepts – proposed/successful
4. Proposals of all kinds – proposed/successful
5. Systems specifications developed
6. Systems analysis
7. Invention disclosures, patents
8. Peer review – qualitative
9. External awards
10. Reputation among users – commendations, surveys
11. Audits – types of problems, resolved vs. unresolved

National Research Council (Lawrence) Study of Feasibility of Assessing the Quality of S&Es in DOD Laboratories, March, 1985.[37]

Conclusions: "Identical quality measures cannot reasonably be applied to all DOD laboratory S&Es." For example, a famous scientist who publishes regularly in respected journals and a relatively unknown scientist who develops technology to lower the cost of a major weapons system may be judged very differently by peer and customer communities.

Recommendations: Measures may include a subset of: (1) bibliometry; (2) technical reports; (3) awards; (4) invitations to scientific meetings; (5) peer review; and (6) supervisory ratings.

Army Science Board Summer Study, 1982.[38]

Conclusions: "There is no objective basis for concluding that the quality [of S&Es] is adequate to meet requirements…"

Recommendations: Focus on quality, not quantity; discontinue practice of forcing S&Es into management before promotion to senior ranks.

V. METRICS FOR EVALUATION OF RESEARCH AND DEVELOPMENT – RECOMMENDATIONS

The common themes in the above references are clear, that objective evaluation of R&D is difficult at best, and that one size does not fit all in terms of R&D metrics. Another consistent theme, which meets the criterion of common sense, is that the number of metrics for an evaluation should be small, under ten and preferably no more than a half-dozen. With these facts and assumptions in mind, and after considerable discussion with experts in the DOD R&D community, the following metrics are suggested for a relatively objective evaluation of the health of science and technology in the DOD laboratory and warfare center system. Because "one size does not fit all" for R&D assessment, other metrics may be applicable on an activity-specific basis.

1. Quality and military impact of the product. While most would agree that quality and excellence in the final product is the ultimate standard against which any activity should be judged, it is a very difficult metric to utilize, especially for S&T output. Customer satisfaction is a subjective but essential factor in the evaluation, and quality can be frequently an "eye of the beholder" characteristic.

Recommended evaluation criteria include:

1. Transitions to acquisition programs and to the fleet (for 6.2/6.3);
2. Problems solved (or avoided) by the organization;
3. Rapid response capability in crisis;
4. Smart buyer functions, savings generated and costs avoided; and
5. Perceived responsiveness and support to the military user.

Data frequently would be subjective (although existence of a product in a fielded system is clearly a success), and would be gathered from on-site assessments of the current warfare center programs, customer interviews/surveys, Service databases, and from the activities themselves. Quality of the data available immediately is poor-to-fair, with insufficient granularity for simple analysis.

2. Core Competencies. This metric is very important in a time of potential funding reductions, future downsizing and/or Base Closure and Realignment Commission (BRAC) actions. While the first metric addresses the quality of the product of the organization for DOD application, the core competency metric focuses more on the internal capabilities that make the organization uniquely valuable to the DOD. Assessments would be conducted in a manner consistent with the seminal articles on the subject by G. Hamel (U. of Michigan) and C. K. Prahalad (London Business School) and published in the Harvard Business Review in the 1989-91 time frame. Hamel and Prahalad introduced the twin concepts of strategic intent (aggressively stretching resources rather than fitting resources) and core competence (collective learning in an organization, especially with respect to integration diverse skills and multiple streams of technologies). By their model, the core competence list of an activity would be very short, fully understood and fully supported by all levels of the organization (e.g. Honda - best automotive engines and engineering).[39,40]

Recommended evaluation criteria include:

1. Essential competencies existing only at the specific activity – must maintain.
2. Essential competencies existing also at other DOD or private sector activities – maintain, share or hand off to other activity.
3. Identify competencies/functions that may not be essential, potential to discontinue.

In addition to site visits, data would be gathered from the Services, data calls, IR&D database, and industry associations. With few exceptions, relevant high quality data is available.

3. Value-added of the organization. The intent of this metric is to determine whether organization performs vital and unique - and/or uniquely governmental - functions, functions that cannot or should not be performed elsewhere. Also, is the activity an integral part of the decision-making process or simply a gatherer/compiler of information for the decision-maker.

Recommended evaluation criteria include:

1. Level of S&T conducted in-house, contracted.
2. Level of development conducted in-house, contracted.
3. Level of other hands-on work vs. contract monitoring?
4. Does activity determine the cause of problems (regardless of who works on problem)? Validate correctness of solutions? Conduct final certification of systems?
5. How does the activity help DOD to be a smart buyer?
6. Other inherently governmental functions.

In addition to on-site visits, data generally would be available from the Services, augmented by a data call to the centers to address the questions. Quality of the data available immediately is fair to good.

4. Quality of the technical staff. This metric is especially important with respect to concerns that a generation of expertise may retire soon, leaving behind a generation gap of capability. The issues are not simply demographics and hiring trends, but also in terms of the character of the work and training for the new hires, i.e. are they conducting S&T, managing contracts, developing budgets, etc.?

Recommended evaluation criteria include:

1. Demographics of technical personnel, generation gaps of expertise.
2. Maintenance of the technical corporate memory.
   - Current/projected technical capabilities
   - Current/projected technical deficiencies.
3. Hiring trends.
   - Age of new hires
   - Education level
   - Education mix
4. Character of work/training for new hires.
   - S&T

- Hands-on R&D
- Project/program management
- Contract management
- In-service engineering
- FYDP/budget development

5. Intangible benefits for technical staff.
   - Rewards and recognition for excellence
   - Technical support, facilities
   - Professional development, training

In addition to site visits, data would be gathered from the Services, data calls, and one-on-one interviews. Data quality available immediately is good.

5. State of Physical Resources. This metric is intended to address the physical infrastructure in terms of physical condition, uniqueness, and potential intangible benefits for the S&Es.

Recommended evaluation criteria include:

1. Support of unique facilities not feasible in the private sector
2. Private sector facilities
3. Opportunities for connectivity, virtual centers
4. Potential facilities duplication, opportunities for consolidation, leverage
5. Facilities as intangible benefits for staff

In addition to site visits, data would be gathered from the Services and data calls. In most cases, data quality available immediately is good.

6. State of Fiscal Resources. This metric is intended to address the adequacy of the current budget to support a healthy DOD S&T and R&D program into the future.

Recommended evaluation criteria include:

1. S&T funding trends - total and as percent of total obligation authority (TOA)
2. RDT&E funding trends
3. TOA trends, mix of non-RDT&E
4. Related private sector funding trends

In addition to site visits, data would be gathered from the Services, data calls, IR&D database, and industry association data. With few exceptions, the relevant high quality data is available.

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VI. TIMING FOR S&T INVIGORATION

In the early days of the Reagan defense buildup, Secretary of Defense Caspar Weinberger wrote,

> We must recognize that our current advantages come principally from the momentum in basic technologies we developed during the 1950s and 1960s, the 'golden period' of United States scientific exploration. We face the danger of losing our edge because we have not adequately replenished the reservoir of scientific concepts and knowledge to nourish future technologies during subsequent years of fiscal neglect of defense research and development. Given these circumstances, we must systematically replenish that scientific reservoir, using the unique and diverse strengths of the United States scientific community ... Given the relatively long lead time between fundamental discovery and applying such knowledge to defense systems, the true measure of our success ... may not be apparent for several decades. When the 'moment of truth' arrives, we cannot afford to be found wanting. Thus we must revitalize the productive partnership between the university community, industry, and the DOD in-house laboratories.[41]

Although the events of September 11, 2001 have made permanent changes to the American attitudes toward defense, a number of other independent factors have aligned to create the right timing and an opportunity to consider DOD S&T invigoration. First and most important is the immediacy of loss of irreplaceable senior staff. Well-documented from multiple sources is the fact that a highly talented generation hired in the Viet Nam era will retire from the system within five years, without trained relief to preserve the corporate memory. Today's situation was created through 1960s rapid expansion, 1970s-80s hiring freezes, 1990s downsizing via buyouts and other retirement incentives, and an R&D shift to industry. As is true in most fields of endeavor, scientists quickly become aware that the "art of science and technology" is much more a function of personal hands-on experience and tutelage of veterans than of formal education. Time is short to compensate for today's generation gap and to prevent permanent loss of capability in DOD-unique technology areas (energetic materials, hydrodynamics, etc.). In a March 14, 2001, white paper on the Naval warfare centers, Dr. Charles Schoman states "The Navy is in danger of losing a capability which it has taken years and billions of dollars and millions of man-hours to develop – this is its in-house technical capability. This selected capability was developed because it was determined the Navy needed it. Once it is lost it probably cannot be rebuilt. The danger is great, but can be partially and quickly corrected by internal Navy decision and actions. However, time is running out. Both people and facilities don't last forever."[42]

A positive factor is the opportunity afforded by the DOD reporting requirement contained in Section 913 of the Conference Report accompanying the National Defense Authorization Act (NDAA) for Fiscal Year 2000, which states: "...the Secretary of Defense shall develop an appropriate performance review process for rating the quality and relevance of work performed by the Department of Defense laboratories. The process shall include customer evaluation and peer review by Department of Defense personnel and appropriate experts from outside the Department of Defense. The process shall provide for rating all laboratories of the Army, Navy, and Air Force on a consistent basis."[43] The Congressional requirement provides both an excellent opportunity and a forcing function (1) to determine the state of S&T capability within the DOD S&T enterprise, and (2) to develop a long-range plan (including both public and private sectors) to ensure the maintenance of essential capabilities.

An additional factor is the change in administration, which normally leads to an evaluation of the infrastructure and policies of the past administration. Three Defense Science Board Task Force reports published in the year 2000 each express concern for the loss of capability within the DOD laboratory system and propose significant remedial actions.[44,45,46] These reports echo concerns expressed two decades ago on the same issues and restate that the time for action is now.

Finally, there is growing recognition in the military and across the public and private sectors of the vital importance of modernization, scientific discovery and innovation to the U.S. national defense and economic interests. Then Secretary of the Navy Richard Danzig stated in the 1999 Annual DOD Report to Congress that "...today's readiness is being preserved at the expense of tomorrow's requirements."[47]

Vice Admiral Dennis McGinn discussed the importance of S&T investments to encourage the rapid, low-cost examination of emerging "disruptive technologies," in a March 9, 2001 *Defense Daily* interview. In that interview, Admiral McGinn stated, "Innovation and new ideas are in fact what is required in this dynamic time." [48]

On the same day, Dr. D. Allan Bromley (Yale physics professor and S&T advisor to the President from 1989-1993) expressed a similar sentiment from a different perspective in a *New York Times* editorial. Dr. Bromley stated,

> The 21st century economy will continue to depend on scientific innovation. Economists estimate that innovation and the application of new technology have generated at least half of the phenomenal growth in America's gross domestic product since World War II ... Technological innovation depends upon the steady flow of discoveries and trained workers generated by federal science investments in universities and national laboratories. These discoveries feed directly into the industries that drive the economy. It's a straightforward relationship; industry is attentive to immediate market pressures, and the federal government makes the investments that ensure long-term competitiveness.[49]

VII. An Approach for Science and Technology Invigoration Within the DOD S&T Enterprise

As discussed in the introductory section of this report, there are four primary issues to be addressed:

1. Determination of the fundamental value of the DOD laboratories and warfare centers and of their "highest and best" uses, as they exist today.
2. Ensuring the technical capabilities of the DOD S&T enterprise are sufficiently robust to meet the Department's needs of today and in the foreseeable future.
3. Determination of what is required of the DOD S&T enterprise to satisfy the needs of the DOD-after-next.
4. Creation of the environment to draw the best and brightest into the DOD and federal S&T enterprise of the future.

To address fully the fundamental value of the DOD laboratories and centers and their "highest and best" uses in today's environment and in the future requires a comprehensive top-down strategy for RDT&E that exists only in part. An excellent Office of Net Assessment Summer Study of 1992 conducted for the Under Secretary of Defense (Policy) and led by Andrew W. Marshall and James G. Roche provides useful insights for evaluation criteria. Four core competencies were identified (based on the Prahalad and Hamel model[50]) that characterized the Department of Defense, including the:

1. Ability to manage across the broad organization of the DOD that consists of many diverse and sometimes competing sub-units (command and control and logistics);
2. Ability to link separate streams of advanced technologies;
3. Ability to manage diverse constituencies and needs (training, morale, human relations);
4. Capability to establish a professional armed force, provide leadership for it, develop operational art and implement joint and combined operations ("self awareness" within the forces that encourages and rewards integrity, innovation and professionalism).[51]

The second identified competency, the ability to link separate streams of advanced technologies, "is manifest in systems engineering and architecture, in communications, in intelligence, in global surveillance, in modeling and simulation, and in high performance technologies." Following the Prahalad and Hamel model, the physical embodiment of one or more core competencies is a core product, which for DOD includes products such as avionics, fire control systems, positioning systems, acoustic and other sensing, propulsion technologies, guidance systems, display systems, and tactical training.[52] This competency is linked especially closely with effective in-house RDT&E activities.

A logical approach in assuring the relevance of the Service warfare centers for today's environment would couple an objective core competency assessment with requirements input from the Service Chiefs, Systems Commands, and CINCs. This approach could address also the second major issue, ensuring sufficient technical capability within the warfare center system, through the addition of a management and technical quality assessment, including customer input and peer review from within and outside the DOD.

The third issue, i.e. to determine the requirements of the enterprise for the future, while difficult, is addressed also in the Marshall and Roche study. This study introduced the term "military after next" as an analogue to the "factory after next" concept of Professor Joseph Bower of the Harvard Business School. The report states "the 'next factory' will provide a marginal increase in technology to produce marginal increases in operating efficiency and cost-effectiveness over that which already exists. A better strategy is to bypass that next generation of plant and to build 'the factory after next,' the one that represents a generational step in terms of technologies, operational effectiveness and operational concepts. Therefore, the 'factory after next' will realize increases in effectiveness and productivities that 'the next factory' could never match and can never achieve." The report then recommends that, "What we have to do now is to begin our planning for the 'military after next' that will be able to cope with the adversaries of any class. Once we have spent ten years doing business as usual, making marginal improvements in the capabilities of our forces, it is going to be too late to try and reorient our thinking and catch up to the strategic problem that we may face in 2012." Three new competencies are suggested for the future: (1) "the ability to lead, plan and manage the process of using a wide range of political, economic and military instruments for shaping the future security environment;" (2) "the in-depth understanding of relevant regions and cultures;" and (3) the ability to better utilize the global economic infrastructure in order to fully draw upon the U.S. and international infrastructures for commercial components in military systems, for technology, and for offshore production of military components or systems where appropriate."[53]

From the above discussion, one may conclude that an especially effective DOD technical infrastructure of the future would be flexible, innovative, willing to promote bypassing the next generation of technology, and able to support the military forces in effective utilization of the systems and technologies of both U.S. and international military and commercial activities. These objectives probably can be accomplished within the current command structures of the Services, provided that a leadership for a collective strategic vision is provided by DDR&E. Such a structure allows the best of both evolutionary and revolutionary worlds to coexist and to derive strength from their differing perspectives.

The fourth issue to be addressed is creation of an environment to draw the best and brightest into DOD and federal S&T enterprise of the future. One major external factor, employment opportunities for S&Es in the private technology sector, may be changing in favor of the DOD in a manner very similar to the late 1960s time period as the economy cools. If so, a small window of opportunity will exist again to bring in entry-level S&Es from an above-average talent pool.

If the current situation leads to an influx of young talent, it is especially important for the national technology base interests that the new crop is nurtured and provided incentives to grow and to innovate. Thus creation of opportunities to encourage innovation is vital. The past success of the Navy's 6.2 IED and the current success (and defensibility) of the NRL Base Program call for the creation of 6.2 base programs at DOD laboratories and warfare centers to support and encourage S&T revitalization in the areas of necessary DOD core competencies. The investment strategy would need to be closely monitored to verify the funding was accomplishing its desired goal. If not, alternatives for maintaining the competency elsewhere in the public and/or private sectors would need to be explored quickly, to minimize loss of the technical corporate memory.

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VIII. Summary Recommendations

1. Conduct an assessment of the DOD laboratories and warfare centers consistent with the Section 913 requirements to determine the state of S&T within the Department of Defense. Focus on the relevant DOD competencies and the requirements input of the Service Chiefs, Systems Commands and CINCs. Metrics for assessment should include the following:
    - Quality and military impact of the products of the organization;
    - Core Competencies of the organization;
    - Value-added of the organization;
    - Quality of the technical staff;
    - State of Physical Resources; and
    - State of Fiscal Resources.

2. Develop a strategy to ensure maintenance of the DOD S&T corporate memory as the current generation of senior scientists and engineers retires. Examine the potential for a window of opportunity to recruit the "best and brightest" into DOD and defense-related industry should commercial technology sector demand decrease.

3. Develop a strategic plan for the DOD S&T infrastructure of the future that defines the complementary roles of the DOD laboratories and warfare centers, academia, FFRDCs/UARCs and private industry. The future system should be flexible, innovative, willing to promote bypassing the next generation of technology and able to support the military forces in effective utilization of the systems and technologies of both U.S. and international military and commercial activities.

4. Establish and monitor closely a 6.2 Base Program within the DOD laboratories and warfare centers. Consider outyear program growth as appropriate, depending on the degree of success of the initial effort.

5. DDR&E should take the lead to carry out the above recommendations.

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APPENDIX A.
TEXT OF SECTION 913, CONFERENCE REPORT, NATIONAL DEFENSE AUTHORIZATION ACT FOR THE FISCAL YEAR 2000

SEC. 913. EFFICIENT UTILIZATION OF DEFENSE LABORATORIES.

(a) ANALYSIS BY INDEPENDENT PANEL. – (1) not later than 45 days after the date of the enhancement of this Act, the Secretary of Defense shall convene a panel of independent experts under the auspices of the Defense Science Board to conduct an analysis of the resources and capabilities of all the laboratories and test and evaluation facilities of the Department of Defense, including those of the military departments. In conducting the analysis, the panel shall identify opportunities to achieve efficiency by consolidating lead agencies or executive agents in cases considered appropriate. The panel shall report its findings to the Secretary of Defense and to Congress not later than August 1, 2000.

(2) The analysis required by paragraph (1) shall, at a minimum, address the capabilities of the laboratories and test and evaluation facilities in the areas of air vehicles, armaments, command, control and communications, and intelligence, space, directed energy, electronic warfare, medicine, corporate laboratories, civil engineering, geophysics, and the environment.

(b) PERFORMANCE REVIEW PROCESS. – Not later than 180 days after the date of the enactment of this Act, the Secretary of Defense shall develop an appropriate performance review process for rating the quality and relevance of work performed by the Department of Defense laboratories. This process shall include customer evaluation and peer review by Department of Defense personnel and appropriate experts from outside the Department of Defense. The process shall provide for rating of all the laboratories of the Army, Navy, and Air Force on a consistent basis.

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