The Defense Technology Base: Introduction and Overview

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THE DEFENSE TECHNOLOGY BASE

INTRODUCTION & OVERVIEW

A Special Report of
OTA's Assessment on
Maintaining the Defense Technology Base

CONGRESS OF THE UNITED STATES OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

Keeping ahead of the Soviet Union technologically is a central element of U.S. national security strategy, and the Nation spends a large amount of money in order to do so. In recent years, however, there have been troubling indications that the U.S. technological lead is slipping, and that it is increasingly difficult to maintain a meaningful edge.

These concerns–expressed both by the Administration and within Congress—prompted the Senate Committee on Armed Services to request that the Office of Technology Assessment (OTA) undertake a major assessment on "Maintaining the Defense Technology Base. ' This special report is the first product of that assessment. It provides an overview of the subject, including specific concerns about the health of the defense technology base and the related issues before Congress. Subsequent reports will probe aspects of this immense problem in greater detail.

Concern centers on the health of those industries, both defense-oriented and civilian, that provide the technology that winds up in defense systems, and on the management of the Defense Department technology base programs and technology facilities. Within the Department, management is being reorganized in the wake of the Goldwater-Nichols Reorganization Act (Public Law 99-433). This report reflects the state of that management system as of February 1, 1988.

The cooperation of the Army, Navy, Air Force, and the Office of the Secretary of Defense are gratefully acknowledged.

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Introduction and Principal Findings

WHY BE CONCERNED?

For roughly three decades, U.S. national security planning has rested heavily on the premise that superior technology can offset Soviet advantages in numbers of military personnel and major military equipment. But in the past few years there has been mounting concern that the United States is not maintaining the necessary technical lead. If the United States cannot maintain a meaningful technological lead and there are no fundamental changes in the competition between the two superpowers, the nation will be faced with a choice among accepting a significantly decreased level of security, relying more heavily on our allies, or making major increases in the size of its armed forces.

There are several ways to assess a technological lead, but in defense the most important indicator of technological advantage-perhaps the only one that ultimately matters—is the technological lead in fielded military equipment. Wars are not fought or deterred by engineering drawings, but by existing forces.[1] However, major technical advances that are still under development can have profound effects on superpower relationships, as the Strategic Defense Initiative (SDI) has illustrated.

Maintaining a technological lead in fielded military equipment is a far more difficult task than catching up.[2] It requires a dynamic, creative, and innovative technology base, as well as an efficient industrial structure that can rapidly translate technical developments into meaningful numbers of effective products in the field. In trying to close the technology gap, the Soviets have the advantage of following rather than leading. They can learn from U.S. successes and failures, saving billions of dollars by adopting existing technology and avoiding activities already demonstrated to be unpromising. Furthermore, their massive military production capacity can quickly turn new system designs into large numbers of fielded systems. The Soviets could never overcome our lead if they only played catch-up, but they can also draw on a large and improving technology base of their own.

There are troubling indications that the U.S. technological lead in fielded equipment, as well as in some underlying technologies, is eroding. The Defense Department's position is that "In recent years, the U.S.S.R. has significantly reduced the lead previously held by the United States and its Allies *in* technologies of military importance."[3] Both the time to produce the next generation of major items of equipment (tanks, airplanes, ships, missiles, etc.) and the time to translate new technological discoveries into fielded equipment are increasing. The latter is particularly ominous because once a technology is discovered, the United States is more or less in a race with the Soviets to get it into the field. If, for example, the United States develops a particular technology 3 years before the Soviets learn about it, but takes 4 years longer than the Soviets do to turn it into fielded equipment, the U.S. lead will have been negated. Furthermore, if each year the Soviets produce three times as many pieces of equipment using that new technology as the United States does, the United States will find itself behind in fielded capability.

U.S. equipment tends to be complex and costly, and therefore tends to get built slowly

'Quality of equipment is not the only factor that matters. Numbers, particularly numbers of the most advanced equipment actually in the field, are important. So are factors such as training, leadership, geography, and logistics.

'The difficulty of maintaining a meaningful technological lead may itself call into question the validity of relying on a strategy that requires such a lead. That, however, is a separate topic. This report begins with the premise that the United States seeks to maintain its technological lead.

'U.S. Department of Defense, Soviet Military *Power,* 1986, p. ***103.***

once production starts. Much time is taken getting the "bugs' out of new systems and training crews to be proficient in their use. This reflects a technological emphasis on higher military performance at the expense of factors such as cost and maintainability, and an emphasis on the technology of design over the technology of production. Cost reductions on the subsystem and component levels generally fail to translate into less costly systems. On the bright side, once the bugs are out, many recent U.S. systems have proven more reliable, available, maintainable, and operable than their predecessors. And as Soviet equipment becomes more complex it also tends to be plagued with the problems attributed to U.S. systems.

Congress is concerned over the health of the defense technology base. Particular concerns include the apparently lengthening time to translate laboratory advances into effective and dependable fielded systems; declining U.S. leadership in vital high-technology industries; and a downward trend in the proportion of the defense budget devoted to the technology base. The Senate Committee on Armed Services has asked the Office of Technology Assessment (OTA) to examine the health of the U.S. defense technology base and suggest options for exploiting its strengths and remedying its weaknesses. This special report is the first product of that project. It describes the defense technology base, presents significant technology base problems now facing the Nation, and discusses the issues Congress will confront in dealing with those problems. It also describes how the Department of Defense is organized to manage its technology base programs and discusses the roles of the major government research organizations that contribute to the defense technology base. In the course of the discussion it mentions, but does not analyze, solutions that have been proposed to some of the problems. These suggested solutions, and others, will be explored in later OTA work.[4]

The remainder of this chapter presents the principal findings of this special report. Because this is an interim product, these are largely observations of the staff and outside experts. Chapter 2 is a summary of the report, which elaborates on the principal findings and provides background material. Chapters 3 through 5 present the data and analyses on which these findings are based.

[4]Solutions have been suggested and analyzed in the 1987 *Defense Science Board Study on Technology Base Management*, Office of the Under Secretary of Defense for Acquisition, March 1988.

PRINCIPAL FINDINGS

The health of the defense technology base depends on many complex factors and is affected by policy in diverse areas. It responds to actions Congress takes regarding the Defense Department technology base programs; overall government science and technology policy; and industrial, trade and fiscal strategies that are relevant to vital high-technology industries. In deciding what to do about the defense technology base, Congress faces two broad issues:

1. Are the government programs that affect the health of the defense technology base appropriately organized, staffed, managed, and funded; and what can be done to ensure that they are?
2. Do government policies toward industry support the existence and maintenance of a healthy industrial technology base, both defense-oriented and commercial, from which defense developments can be drawn; and what can be done to ensure that they do?

Resolving these broad issues will entail addressing a number of component issues.

- The defense technology base resides in a broad range of institutions that includes

DoD laboratories, other government laboratories, universities, private research facilities, defense industries, and "dual-use' civilian industries. As the civilian industries move increasingly to the cutting edge of technology, the defense technology base becomes embedded in—and largely inseparable from-the national technology base. The Defense Department technology base programs are major contributors to the defense technology base, but they are far from all of it.

The Defense Department's system for managing its technology base programs has recently been overhauled as part of the general reorganization of the acquisition system. But it remains to be seen whether this will lead to fundamental improvements in the way technology base programs are planned and managed. One basic question is whether the system works as well as can be expected, or whether major improvements can be brought about.

- Observers in government and industry believe that DoD is finding it increasingly difficult to attract and keep the skilled management personnel necessary to the functioning of its technology base programs. This appears to be, at least in part, a result of Civil Service salary structures and Congress' efforts to limit the movement of personnel between industry and the Defense Department.

- Funding for technology base programs is particularly vulnerable during times of tight budgets. The rapid spend-out rates of technology base programs mean that cuts in R&D go farther toward reducing deficits than similar size cuts in procurement programs. And the lack of obvious, tangible outputs from R&D projects makes the value of individual programs difficult to define. Technology base programs are particularly vulnerable to "raiding' to support programs in procurement or the later stages of development. Congress will have to determine what it thinks are proper levels of funding, which may entail acting as an advocate for technology base funding when DoD seeks to reduce it. The optimal level of funding is difficult, if not impossible, to gauge accurately. However, funding that fluctuates widely from year to year is inefficient and can be very disruptive. Congress faces the very difficult decision of whether it should be actively involved in the selection of technology base programs and the determination of specific funding levels, or whether instead it should give DoD managers wide latitude to construct programs within agreed overall funding levels.

- The government laboratories that together perform about one-third of the technology base program work have been the subject of a vast amount of study and discussion. There has been significant concern over the quality and *value* of their work, and the ability of the laboratories to attract and keep top-quality personnel. Many experts perceive them as uneven in quality and utility. Suggestions have been made regarding changing the relationships of some laboratories to their parent organizations, altering laboratory management structures (i.e., removing them from Civil Service), and improving their ability to compete for and compensate researchers.

- The United States is becoming increasingly dependent on foreign sources for defense technology. Some of this-like increasing involvement in NATO cooperative programs —is intentional. But much of it is a consequence of the movement abroad of high-technology industries, particularly those that deal primarily in the commercial marketplace. Reliance on foreign sources makes more technology available, distributes the costs of technical advances, and ties the Nation closer to its allies. But dependence on others risks losing access to technology, if political or economic conditions change. The United States faces basic policy issues of how much dependence on others for defense technology is advisable, and how much the Nation should spend to retain domestic sources of technology.

- The foreign dependence issue is most pronounced in the "dual-use" sector: those high-technology industries that sell primarily in the international commercial marketplace, but provide important technology and products as components of defense systems. High-technology products are increasingly manufactured outside the United States, raising concern that the ability to design at the leading edge will follow manufacturing, reducing DoD's access to the technology it needs. Other nations have national policies to attract, nurture, and protect high-technology industries. These tax, trade, and other policies contribute to the continuing deterioration of U.S.-based industries. Failure to counter conditions which cause U. S.-based companies to move offshore will allow the deterioration to continue, affecting national defense. If Congress chooses to address these issues, it is important that national security be part of that consideration.
- The defense industry is highly regulated. Government controls and regulations tend to discourage innovative small- and medium-sized companies from entering the business and create competitive advantages for those companies with experience in the specifics of selling to the government. Detailed specifications for military hardware tend to limit the availability of commercial products for defense needs. Moreover, many in industry believe that the government maintains an adversarial relationship with industry, to the detriment of the defense effort.
- There is concern that, in the defense sector, government regulations inhibit both product innovation and the application of advanced manufacturing technology to plant modernization. Companies can recover part of the cost of innovation from the government through the Independent Research and Development (IR&D) reimbursements. But this program has been controversial, in part because it has become complex and difficult to understand.
- Despite the United States' superior graduate education programs, there is concern—particularly within DoD and the defense industries-that U.S. citizens are not becoming scientists and engineers at a sufficiently high rate.
- Many experts believe that the long delays in getting new technology into the field arise not in the technology base, but in the subsequent programs that translate the products of the technology base into new systems. Full-scale development and production times are increasing, and the longer it takes to develop and build a system, the older its technology will be when it finally reaches the field. Unfortunately, adding new technology to a system already under development is likely to delay it still further. Inserting new technology through retrofitting fielded systems or block upgrades of systems in production might get new technology into the field faster than waiting for an entirely new system to be developed. Changes in the organizational links among developers, planners, operators, and technologists also have the potential for speeding the progress of technology into the field.

Chapter 2
Summary

WHAT IS THE DEFENSE TECHNOLOGY BASE?

The defense technology base is that combination of people, institutions, information, and skills that provides the technology used to develop and manufacture weapons and other defense systems. It rests on a dynamic, interactive network of laboratory facilities, commercial and defense industries, sub-tier component suppliers, venture capitalists, science and engineering professionals, communications systems, universities, data resources, and design and manufacturing know-how. It includes laboratories run by the Department of Defense (DoD), other government departments and agencies, universities, and industrial concerns. It draws on the work of scientists and engineers in other nations. Information circulates both through formal routes dictated by chains of command, research contracts and other agreements, and through informal contacts within specialized technical communities, interdepartmental projects, seminars, etc.

Department of Defense technology base programs-and the accumulated results of these programs-are an important part of the defense technology base, but are far from all of it. Although DoD officials tend to speak of the defense technology base and the Department of Defense technology base programs interchangeably, they are not the same. The defense technology base is an accumulation of knowledge, skills, capabilities, and facilities, while the Defense Department's technology base programs are a collection of thousands of individual research projects funded through the DoD budget, the results of which contribute to the defense technology base.

Almost all research and technology development can be drawn upon in producing defense systems, so that with the exception of classified research available only for defense applications, the defense technology base is largely the same as the national technology base as a whole. Of course, not all technology is of interest for defense applications, and not all is equally accessible to defense. Any research published in open sources (e.g., scientific journals) is available for use by engineers and scientists for defense applications. This includes foreign research and development, even work done in the Soviet Union. Proprietary work that is conducted by private companies, and remains unpublished in order to preserve competitive advantages, may also find its way into defense systems as those companies build the systems, subsystems, or components.

There are some practical limitations-amplified by recent government policy–on the transfer of technology between the defense and civilian sectors. [1] First, much defense technology is classified. Hence it is only available to those working on defense projects. Second, researchers and engineers working on defense projects tend to forma community that interacts through mechanisms such as defense-related professional society meetings. Communication with those in similar fields doing non-defense work exists, but is often more limited. Indeed, in companies that do both defense and commercial work, engineers in either "side of the house" tend to be isolated from those in the other.

There are also mechanisms that reduce technology transfer and communication from non-defense areas to researchers and engineers doing defense work. Companies that develop commercial products seek to protect their investments by concealing their best technology as long as possible. Thus, cutting edge technology may remain inaccessible to DoD until after it has been introduced into the commercial

[1] For example: Department of Defense Directive 5230.25, Nov. 6, 1984; and Executive Order 12356. For more detail see Science *Policy Study Background Report No. 8. Science Support By The Department of Defense,* prepared by the Congressional Research Service for the Task Force on Science Policy of the House Committee on Science and Technology, December 1986.

marketplace. Additionally, some scientists and engineers prefer not to do defense-related work. Finally, regulations on doing business with the government tend to enforce a separation between companies that work for the government and those that do not—including separations between divisions of the same company. Knowing how to do business with the government creates a competitive advantage for some, while government regulations and contracting procedures present barriers against others. Indeed some observers argue that the problems of doing government business—close scrutiny, regulation of profits, and excessive military specification of product characteristics-tend to discourage innovative small- and medium-size companies and steer them away from government work.

Thus, while in principle the defense sector can draw from a very wide technology base, there is some degree of isolation. Not all of that more general technology base flows into defense applications with equal ease.

DoD organizes its technology base programs into three categories which provide a working definition of the kinds of work and information that are considered part of the technology base. DoD's technology base programs consist of research into basic and applied sciences (funded under budget category 6.1), the exploratory development of practical applications of that research (budget category 6.2), and the building of prototypes to demonstrate the principle of an application (budget category 6.3A). Work funded under the remainder of the Defense Department's budget for research, development, test, and evaluation (most of DoD's RDT&E budget) is not part of the technology base.' In DoD jargon, "the tech base is 6.1, 6.2, and 6.3 A," but the defense technology base is actually the accumulated results of those 6.1, 6.2, and 6.3A programs and much more.

'Strictly speaking, by the Office of the Secretary of Defense definition, the technology base programs are 6.1 and 6.2. Technology base plus 6.3A are the science and technology programs. However, these definitions are often used interchangeably, and in recent years common useage has been to refer to 6.1, 6.2, and 6.3A as technology base programs while 6.3B and 6.4 are specific system developments linked closely to procurement.

Basic research, by definition, is almost entirely non-specific in its potential applications. Most could lead just as easily to defense applications, commercial applications, or no practical applications whatsoever. There are, however, a few areas in which the Department of Defense has a specific interest in basic research because the connection to defense systems is clear. Examples are underwater acoustics (important for submarine detection and hiding) and the physics of explosive nuclear reactions (of obvious application to the nuclear weapons programs run by the Department of Energy (DOE)).

As science leads to technology, potential applications become clearer, and a sharper delineation of technologies with defense applications becomes possible. Some technologies are almost entirely military while others have little, if any, defense application. This separation is heightened as military programs become classified. Nevertheless, many technology areas are pursued for both military and commercial applications.

As technologies lead to the development of defense systems, developments that had been pursued primarily for commercial reasons can, and do, work their way into the defense systems. Prime contractors call on subcontractors for subsystems, and subcontractors call on lower tier suppliers for the components of their subsystems. Many of these lower tier suppliers sell to both military and commercial buyers, and use their commercial technology to develop products that are used in defense systems. Commercial components are sometimes designed directly into defense subsystems.

A diverse group of organizations contributes to the defense technology base. A large portion of basic research is performed at universities, which also train the next generation of scientists and engineers. University research is funded by the Department of Defense, other parts of the federal government (e.g., the National Science Foundation and the Department of Energy), industry, and various private funds and endowments. DoD's university research program is growing and appears to have generated significant interest in the academic community. There appears to be more interest and capability than available funding permits DoD to support.

The Army, Navy, and Air Force maintain systems of research laboratories. Of the more than 140 individual laboratories, research and engineering centers, activities, and test facilities run by the Armed Services (Army, Navy and Air Force), about half contribute significantly to the technology base. The rest concentrate on activities such as testing production aircraft. In addition to conducting research, some of these laboratories fund and monitor research by other organizations.

Other government laboratories–primarily the Department of Energy national laboratories, the National Bureau of Standards, and NASA's research centers–contribute both directly and indirectly to the defense technology base. DoD contracts with the national laboratories and engages in cooperative research projects with NASA in areas of mutual interest. The results of research conducted at these institutions is generally available to organizations engaged in defense work.

A substantial part of the defense technology base is embedded in the defense industrial base, and in the broader national industrial base. Much of the technology that finds its way into defense systems is developed by defense contractors and subcontractors, and by commercial high technology companies. In addition, some companies—e.g., AT&T, IBM, and UTC–run research laboratories that do a great deal of basic and applied research, most of which is available for defense applications.

The large defense contractors—e.g., Lockheed, Martin-Marietta, General Dynamics, McDonnell-Douglas, Rockwell–primarily design, develop, and produce weapons and other defense systems. They develop technology inhouse and draw on technology developed elsewhere. They are both users of, and contributors to, the defense technology base. Because the defense industry sells only to the government, it operates under a special set of regulations.[3] And because there is only one customer (albeit one with many branches) and a limited type of competition, the defense market has evolved a unique set of business characteristics. There is controversy over whether this is the most efficient way to produce defense systems, and how to maintain sufficient capacity to meet surge requirements in the event of a conflict. These production issues are not a focus of this study, but the business structure of these companies strongly influences how they invest in technology. A more relevant issue is identifying the best methods for stimulating these companies to develop cutting edge technology for defense applications, draw on developments elsewhere, and incorporate the latest technology into products and production.

The industrial sector includes not just the defense industries that produce major defense systems, but also civilian industries. The so-called "dual use" industries, which produce primarily for the civilian market, provide components for defense systems, and stimulate technological advances that find their way into defense systems. Perhaps the best-known example of a dual-use industry is the semiconductor industry, the subject of a recent Defense Science Board study. In addition, laboratories run by companies that do very little defense work provide important basic technology that is eventually engineered into defense systems.

In some areas, civilian industries merely keep pace with or lag behind technologies that are being developed in the defense sector. But in other areas it is the commercial firms that drive the pace of technological development. In general, the Department of Defense exerts strong influence on industries that are primarily devoted to defense and on newly emerging technologies. But DoD has far less influence with industries that have large commercial markets. For those industries it is very much a minor customer: the civilian market shapes the industry and dictates the large investment in and consequent rapid progress of technical

[3]Those divisions of defense companies that sell in the civilian marketplace operate differently.

development. Defense production is a consumer of technology from these industries; defense interests are far less able to stimulate technology development in these industries than they are in the defense industries. If technologies that are dominated by the commercial market could not be transferred into defense applications, the defense sector would have to rely solely on technology developed in isolation, and would likely end up buying less advanced technology than is available in the commercial marketplace.

A major focus of this OTA study is identification and evaluation of the factors behind the erosion of important dual-use U.S. industries at the leading edge of technology, and the implications of this erosion for national defense. The concern here is much less shaping technology development—defense is often a minority customer with only limited leverage on the industries–than it is ensuring that the technology and technical capacity will be available when needed. If these industries deteriorate substantially, the source of the technology will be in question, and if they leave the United States, DoD may find that the technology is no longer available and secure. Thus DoD has a vital interest in the future of these industries. The government as a whole has an interest both from a national security perspective and a national economic perspective, although these two perspectives may not always coincide.

ISSUES

Maintaining this diverse defense technology base raises a large number of individual issues, which fall generally into the following seven categories:

1. DoD's mechanisms for making technology policy and determining investment strategy to implement that policy;
2. funding for DoD technology base programs;
3. the management of DoD laboratories and other government research institutions;
4. foreign dependence;
5. dual-use civilian high-technology industries;
6. the defense industries; and
7. the supply of scientists and engineers.

This section discusses these individual issues and the concerns from which they arise. These issues and concerns raise analytical questions that are not generally amenable to definitive answers, but provide a basis for analysis and informed debate. This section also presents—but does not analyze-some solutions that have been proposed. OTA reports these suggestions because they appear to merit exploration as Congress considers the issues, but OTA does not endorse them. OTA will explore some of these proposed solutions in further work on this project.

Department of Defense Mechanisms for Making Technology Policy and Technology Investment Strategy

The DoD science and technology program is a complex and sometimes bewildering array of 160 program elements encompassing thousands of individual projects, whose success is often difficult to judge. Consequently, there is widespread uneasiness that DoD may not be making the most effective use of its technology budget, and that its program may not be efficiently run. Some critics charge that technology base programs do not receive attention at a sufficiently high level, that Pentagon bureaucracies have no equivalent of a corporate vice president for research and development. Recognizing this problem, DoD has recently taken steps to address the situation. Other observers believe that the management system has developed the wrong focus: that performance is emphasized too highly over cost and quality, and product technology is emphasized to the virtual exclusion of process (manufacturing) technology.

There is also concern that "requirements pull" and "technology push" may be out of balance. Some argue that overly strict application of relevance tests in determining projects to be funded maybe stifling creativity, while others point out that excessive loosening of the ties between research projects and military needs could lead to a technology base program that produces little practical benefit. There is an overriding concern that communications between developers of technology and military operators and planners are not sufficiently well developed. Developers could be more aware of military needs and planners could be more attuned to technological opportunities.

Research is by nature disorderly and risky, Its twin goals of seeking breakthroughs–including serendipitous, unanticipated discoveries—and evolving previous discoveries into useful applications are somewhat contradictory. Overconcentration on either is a prescription for disaster sooner or later. It maybe that the apparent chaos of defense R&D programs is a reflection of these contradictions, and that it cannot and should not be managed in any more orderly fashion than it now is. Or it may be that valuable gains can be made through more effective management. Clearly, orderly evolution can benefit from orderly programs, but overly focused and controlled programs will inhibit the wide-ranging exploration that produces breakthroughs.

An area of growing concern is that of highly classified or "black" programs.[4] Congressional and bureaucratic oversight of these programs is very limited. Critics charge that black programs retard the diffusion and exploitation of important technology, while providing cover for poorly managed programs. Others claim that freedom from excessive oversight allows much more rapid progress and more efficient management. Some observers claim that technology transfers out of black programs slowly, if at all, but others claim that much of the technology in black programs came from "white" programs and only became highly classified when potential applications were identified.[5]

Some observers suggest that large-scale demonstration programs ought to be pursued as engines of technological innovation. They point out that projects such as Polaris and Apollo have served to focus the efforts of creative people and have produced much important technology. Like Apollo, such projects need not be confined to military goals. Some cite SD I and the National Aerospace Plane as current examples of such large-scale technology drivers. Others fear that such programs consume too much funding, driving less dramatic efforts out of existence, and that while providing a dramatic stimulus to technical and scientific development they are an indirect and inefficient path to developing the technology that is desired. These critics argue that such programs take on lives of their own, and that as funding levels decrease the secondary goal of spinning off technology is sacrificed to the primary goal of completing the program.

Each Service runs its own R&D program, and the Office of the Secretary of Defense (OSD) coordinates these along with the efforts of the Defense agencies, the Strategic Defense Initiative Organization, and a few special projects. The Armed Services have different systems for setting R&D policy and for implementing that policy. These systems, and OSD's, have recently been reorganized. (Current organizations for making R&D policy are described briefly in a later section of this summary and in more detail in the main body of this report.) It is reasonable to ask whether each Service's management system is optimized for its unique needs, or whether organizing them all along the same lines would be preferable, *taking* the best features of the three existing systems. Some observers believe that it would be useful to adopt management techniques used by other organizations that plan and manage R&D activities, such as private corporations and foreign governments. They claim that some of these organizations are better than DoD at setting and realizing technological

[4] See, for example, Alice C. Maroni, "*SpecialAccess Program and the Defense Budget: Understanding the "Black Budget,*" Congressional Research Service, Issue Brief IB87201, Dec. 2, 1987,

[5] Of course, these contentions can only be verified by those with access to the black programs. However, both are logical. If few people know about a project, there will be few opportunities to envision other applications for the technology. Very little technology is born highly classified; it only becomes worthwhile to limit access to information when its potential applications have been identified.

goals and moving technology forward into products. Some in industry believe that DoD's systems suffer from the lack of a chief technical officer at a very high level, and from an emphasis on managing programs rather than setting policy.

Some observers argue that DoD's ability to attract and keep skilled management personnel is declining. They point out that skilled people can work effectively within a flawed system, but that even a perfect system cannot function well without top-quality people. They see these problems flowing at least in part from legislated restrictions on career paths, particularly those aimed at closing the "revolving door" between industry and government. People may be willing to sacrifice salary to serve their country, but are much less willing to sacrifice their careers.

Congress faces some fundamental issues regarding technology base program management, including that of whether the DoD organization needs yet another shakeup, or a radical new management approach. Even if the system is less than ideal, it may not make sense to reorganize it frequently rather than allow it to settle down and do its job. Congress will be making implicit or explicit decisions regarding the extent to which it should be involved in detailed problems like organizing the DoD staff or selecting R&D programs and specifying their funding levels. Congress may wish to involve itself in the complex process of selecting technologies to be pursued and determining funding levels for each program. Alternatively, it may choose to limit its role to ensuring that the technology base programs have proper goals, adequate funding, and capable management.

DoD Technology Base Funding

Intimately tied to the issue of how DoD manages its technology base programs is that of the funding levels for those programs. This is a more immediate issue, since Congress wrestles with the budget each year. There are concerns that current levels may be inappropriate, and that within the overall totals funding may be misallocated. Imbedded in this latter concern is a worry that tech base program funding may not be adequately protected from "raiding" to support specific systems developments that are well beyond the tech base. Similarly, there is concern that large development programs like SD I or the Advanced Tactical Fighter tend to drain funds from technology base programs, and that the increasing emphasis on prototyping will be funded not with new dollars, but out of the existing technology base program. If the diversion of technology base budgets to support other programs turns out to be a significant problem, Congress may wish to consider taking measures to protect technology base program funding.

Gauging a proper level of technology base funding is difficult, as is the allocation of funding within that overall level. Since the output of a technology base program cannot be measured with any precision, the effect of adding or subtracting any particular sum of money cannot be calculated as it could be for programs such as procurement or maintenance. Some observers believe that it is most important to maintain a level of funding that is predictable and avoids dramatic fluctuations: constant changes in funding make it difficult to attract and keep staff.

The Strategic Defense Initiative (SDI) accounts for more than 40 percent of the technology base funding, and almost all of the increase in technology base funding since 1981. But SDI is outside the system that controls the remainder of the technology base programs. Major changes in SDI could have implications for technology base funding as a whole, particularly since many programs that have more general utility are funded through SDI.

If Congress sets, or endorses, guidelines on basic R&D policy issues–such as the proper balance within the program between the orderly exploration and exploitation of known phenomena and the search for new breakthroughs in areas that are not yet recognized–is there a straightforward methodology that can be employed to determine the allocation of funding to implement those guidelines?

The Management of Government Laboratories

There is concern that the large array of government research institutions that contribute to the defense technology base does not form a coherent system to support technology needs. At issue is whether it could, and whether coherence is, on balance, desirable. There is also concern that some reorganization or consolidation may be in order, particularly among the DoD laboratories, and that they could function more productively if the organizations that operate them—or their relationships to those organizations—were changed.

Many of the Service laboratories are attached to systems commands with charters to develop specific classes of military hardware (e.g., airplanes, communications equipment, missiles). These laboratories are more like product centers run for their 'customer' than they are technology centers. Others, like the Naval Research Laboratory, which the Navy views as a corporate lab and not a product lab, have greater latitude in their technical programs. There is concern that important areas of technology may be overlooked because of the narrow focus of parent organizations, and that innovative technologies that might ultimately benefit the overall mission of the command will be overlooked because they do not support the current major products of that command. Furthermore, unlike the contractor-operated Department of Energy laboratories, DoD's laboratories appear to have a relatively difficult time shifting as the focus of technology shifts, or otherwise adapting to change. Others believe that a product focus is necessary and proper if the labs are to produce anything useful, pointing out that ultimately the task is to put systems into the field. They claim that many labs are not responsive enough.

The actions that Congress may wish to take will depend on understanding whether there are laboratories with unnecessarily redundant programs, substandard programs, unnecessary functions, or functions that could be performed more effectively elsewhere. Depending on the answers to these questions, Congress may wish to take measures to ensure more efficient use of government laboratories—e.g., closing, merging, or consolidating facilities; altering the command of Service laboratories; making greater use of non-DoD laboratories; or setting up systems to enhance technology transfer.

Service R&D managers claim that it is becoming more difficult for the Service laboratories to attract and keep top technical talent, and that the United States may be risking deterioration of these important assets that have been built up over many years. Civil Service salary scales, never competitive with industry, are now in many instances not competitive with academia either. Aging physical plants are becoming increasingly less attractive relative to industry and academia. Finally, government service is becoming less prestigious. If these trends continue, are there measures that Congress could take to make defense laboratories more attractive to top scientists and engineers? Changing the management structure of these laboratories to allow compensation beyond that permitted under Civil Service rules has been suggested. This is being tried on a limited basis at the Naval Weapons Center (China Lake).

Foreign Dependence

This issue is intimately bound up with the next two—erosion of important civilian high-technology industries and problems in the defense industries. The United States is part of a global economy, particularly in high-technology industries. Foreign components are engineered into important defense systems, and other nations lead us in some areas of technology that are key to building defense systems. This is, at least in part, a result of the success of post-war U.S. policy to build up the economies of friendly states. Many economists argue that the United States has no choice but to buy what it wants on a dynamic global market, and that to do otherwise will have major adverse effects on our own economy.

But we are caught on the horns of a dilemma. The least-risk approach from a national security perspective is to satisfy all our needs from domestic suppliers, so that our ability to get what we need is under U.S. control alone. This is, however, almost certainly not the least-cost approach. And it may ultimately risk losing access to important technology that either is not developed here or can only be developed here at a prohibitive cost or with a significant delay. Saving money through foreign sourcing, while generally appealing as a principle, can become much less attractive on a case-by-case basis when the specific economic impacts of funding a foreign project rather than its American alternative are examined.

Thus, some argue that the United States is becoming (or is in danger of becoming) too dependent on others for our defense technology. Others take the opposite position, that we are missing out by failing to take full advantage of the technological capabilities of our friends and allies.

Foreign dependence can be helpful and desirable, harmful and avoidable, or just unavoidable. In general, it is a mixture of all of these, complicating policy formulation. In a perfectly competitive world market, exploiting the technology of our allies would permit a more efficient division of labor, with each nation concentrating its technological efforts on what it does best, rather than duplicating effort and spreading national resources too thin. It would allow us to exploit superior foreign technology where it exists, by contracting for foreign technology development, licensing foreign technology, or buying foreign products. In the real world of today's marketplace, realizing these benefits may require taking measures to ensure that the U.S. share of this pie is maintained. Some observers have suggested that the United States make a serious effort to exploit foreign technology by establishing organizations to target, transfer, and exploit leading edge foreign technology. This might include reverse engineering of foreign products (i.e., analyzing them to understand how they are designed).

But this dependence risks cut-off of supplies for either economic or political reasons. Foreign high-technology companies may be reluctant to commit resources to design specific items required by DoD when they find it more profitable to turn their energies in other directions. If the United States lacks a base of technical knowhow in a particular technological discipline in which foreign sources cannot be induced to make developments in militarily significant directions, the Nation would be faced with a choice between stimulating domestic development or doing without the desired technology.

If other nations dominate industries based on technologies that are important to U.S. defense efforts, the United States will have to decide either to buy what it needs from foreign sources, or to invest whatever is necessary to develop and keep a viable domestic technology and production base. This latter approach might involve inefficient measures to ensure domestic markets for domestic suppliers.

Ultimately, interdependence among nations may prove more advantageous to the United States than dependence on others. As the United States gets more deeply involved in reciprocal buy/sell relationships with its allies (particularly those with whom we have formal alliance ties), the risk inherent in relying on foreign suppliers is mitigated by mutual and interlocking military and economic dependence. Ties and interdependence are the political basis of alliance cohesion. This is qualitatively different from a situation in which the United States buys high-technology products in the international marketplace, and is at the mercy of the policies (or whims) of other nations.

Interdependence appears to be increasing in both the defense and commercial sectors. Within NATO, the United States participates in a number of groups working on cooperative development programs, and is involved in several major international development programs. The international nature of high-technology industry has led to interdependence among companies in various countries for components and finished products.

Congress is faced with the complex issues of whether the United States should: 1) exploit foreign technology to a greater degree; 2) look for ways to reduce foreign dependence; or 3) encourage development of strategic U.S. high-technology capabilities, insulating them from foreign competition, or at least preventing damage from unfair competition. A basic policy issue is how much the United States should become involved in cooperative defense programs, thereby increasing its dependence on allies and third parties for military technology. The United States will also have to decide how to respond to the movement offshore of high-technology industries that ultimately supply key technologies to defense systems, and to foreign ownership of U.S. high-technology companies.

Resolving these issues will involve understanding whether, on balance, it is in the national interest to rely on friends and allies for selected military technologies and to allow those capabilities to diminish in the United States. This will, in turn, depend on how confident we are that our friends will remain our friends and technology will remain available. Fostering economic, political, and defense interdependence may help. It will also depend on developing criteria to identify those areas in which increased foreign dependence would be desirable or undesirable, and on determining the risks to national security of certain technologies moving offshore. Ultimately, the United States will have to identify those technologies for which it is most important to maintain a domestic technology base. It maybe that some technologies are so important to national security that the United States cannot accept foreign dependence under any circumstances. This may be particularly so in the case of technologies that are important to many systems. Some believe that dependence for any important military technology is unacceptable. Realistically, what are the options to stop this movement and/or to take compensatory measures that will preserve a domestic technology base despite market forces?

"Dual-Use" Civilian High-Tech Industries

The foreign dependence problem is most pronounced in those industries—e.g., semiconductors, computers, machine tools, structural materials, and optics—that are vital lower tier suppliers for defense projects, but do most of their business in the commercial marketplace. These industries are the sources of much of the innovation in their fields. But the Department of Defense has relatively little influence over them.

The degree of foreign dependence varies from industry to industry. In some, such as semiconductors and machine tools, foreign companies hold a majority of the market and control a major share of the technology. In industries like computers and materials, the United States still holds a decisive lead in the technology, but foreign companies are taking an increasing share of the market. As the market shares move to foreign companies, the technology is likely to follow. In the past, many major technologies began in the defense sector and expanded into commercial markets, reducing DoD's share and leverage. This pattern is still strong, although perhaps not as prevalent as it once was.

These industries are strongly influenced by the global market. If political or market forces move them toward foreign manufacture, foreign management, or foreign ownership, or away from developments of interest to defense, that is where they are likely to go. There is a twofold danger in this. First, defense contractors may find it increasingly difficult to obtain the latest high-technology products. Some U.S. manufacturers believe that foreign suppliers of machine tools and computer parts sell U.S. companies products employing technology that is 2 to 3 years behind that of the products they sell their domestic customers. Second, DoD may find it increasingly difficult to induce those foreign companies that dominate a technology to use their R&D talents to develop specialized devices for military applications that are remote from most of their business. Ultimately, if the technical expertise moves entirely out of the United States, the Services would have little idea what new technical developments they should request of the foreign suppliers. This latter stage would mean an obvious decline in U.S. technological leadership over the Soviets, and to some degree a leveling of U.S. and Soviet access to the same advanced technology.

The government faces two problems with regard to these industries. First, from both defense and national economic perspectives, it faces the problem of keeping these industries viable here in the United States. Second, it has the problem of keeping the companies interested in doing business with the Department of Defense.

A number of rules and regulations pertaining to doing business with the Department of Defense inhibit companies from seeking government business and limit the flow of commercial products into defense systems. Innovative small- and medium-sized companies are particularly discouraged by conditions such as close scrutiny of their business, "red tape, " and regulation of profits. Military specifications (MILSPECs) can have much the same effect, keeping out high-technology products that might be able to do the job but have not been designed to meet a complex list of specifications. These regulations by and large serve useful functions, but their utility should be weighed against the roles they play in keeping companies and products out of defense.[6] They have served to create a situation where experience in doing business with the government is an important company asset in competing for more government business, and lack of such experience is a major obstacle to companies trying to enter the market. Indeed, within some companies separations exist between divisions that sell to the government and those that do commercial business, stifling the transfer of technology within the company.

[6]Some in industry see many of these regulations as unfair.

Most modern industrial nations have industrial policies and specific bureaucratic organizations responsible for industry. The movement of high-technology industries offshore can be attributed, at least in part, to other governments following policies that nurture these industries more effectively than do U.S. policies. Partnerships with industry, and the availability of 'patient capital, which encourages long-term results rather than short-term returns, are examples of the ways in which other governments encourage their industries. Developing and marketing high-technology products tends to be capital-intensive. The cost and availability of capital affect both the ability of companies to undertake long-term developments (which pay off handsomely but not soon) and their ability to rush a product to market once it is ready. The schedule for bringing a product to market can have a major effect on its share of the market. Some observers believe that the United States should be building the structure for a government-industry partnerhip to replace the current adversarial relationship. As Congress grapples with these problems, it will be important to understand the relationship between government policies and the deterioration of domestic high-technology industries that are important for defense. Are there realistic policy options that could reverse these trends?

This problem will raise before Congress the issue of whether the United States should have a more active national industrial strategy, and if so, what it should be, and what government agency should be responsible for it. It will be necessary to determine how defense needs would be taken into account and balanced against other needs in the formulation and implementation of that policy. Should the United States seek to maintain a viable domestic base for all industrial technologies that are of value for defense? Or would it make more sense to stimulate the international competitiveness of some U.S. industries and rely on the world market to meet the needs U.S. companies cannot provide? If the former is chosen, should the United States attempt to maintain, through government-funded projects, technical capabilities that are being lost in the commercial sector?

Defense Industries

For most technical developments of military significance, the road from laboratory to field runs through the large defense contractors. Each of these companies can perform a variety of important tasks, but their major roles are as prime system integrators, the companies that assemble the products of subcontractors and component developers into finished missiles, airplanes, submarines, etc. These companies, which both consume and develop new technology, have a unique niche in the economy, which results in unique business conditions.

There is longstanding concern that these conditions can inhibit technical development and efficient application of new technology. Like many corporations selling in the commercial market, defense contractors in the last few years have tended to plan for the short term rather than the long term. This de-emphasizes the value of investing in new technology which may only pay off 5, 10, or more years downstream.

Government procurement habits tend to reinforce this mode of planning. The method of government contracting has also tended to discourage both plant modernization and product innovation: the higher costs of operating inefficient plants can be charged to the customer, but the risk of failure due to trying new technology cannot. Much of the benefits from plant improvements–particularly large-scale improvements that pay back over relatively long terms—accrue to the government, further decreasing incentives for companies to fund such improvements. Of course, a company that can bid lower costs, because it will employ modern manufacturing technology or can produce a more capable product due to better technology, has an advantage in the competition for a contract. But it risks losses if it loses the competition despite investing in better technology. Congress may wish to consider whether government policies are inhibiting investment in modern manufacturing technology and what, if anything, should be done to stimulate these companies to develop and invest in better manufacturing technology. Related issues are whether (and how) government policies inhibit the transfer of technology to defense companies, discourage the entry of innovative companies into defense work, or encourage short-term planning rather than long-term planning. What options are available to correct these problems?

The IR&D (independent research and development) program has been controversial, especially within Congress, for many years. IR&D allows companies to recover some part of the cost of research programs initiated and funded by the company by treating it as a cost of doing business with, and developing products for, the Department of Defense. The cost is recovered as an allowable expense, similar to overhead, in contracts with DoD.[7] The companies decide what areas to work in and keep the commercial rights to their work. DoD judges the relevance of the work to defense needs and decides how much of the cost can be recovered, within an overall ceiling set by Congress. The remainder of the company's R&D costs are funded out of corporate profits.

In the view of the participating companies and other experts, IR&D benefits DoD because it allows the companies to stay current in areas of technology that are important to defense, and it encourages the generation of research ideas by company scientists and engineers. IR&D is treated very seriously by most companies and receives high-level corporate scrutiny. Industry spokesmen point to long lists of specific systems that have originated in work funded through IR&D. The companies contrast this to contract research-which they also do—in which, for the most part, government officials decide what areas to pursue, and exercise greater control over research projects. The companies are concerned that what they see as overcontrol by DoD will strangle IR&D.

‘The results of IR&D recovery (reimbursement) improve a company's competitive position by improving its technology base, but the addition to the company's cost basis reduces its competitiveness on future contracts.

DoD, on the other hand, is concerned about keeping IR&D relevant to defense needs. The program tends to create friction between OSD —which supports the latitude for innovation that IR&D is supposed to provide–and the Services, who want greater control over how their money is spent. Both DoD and industry agree that one benefit of the IR&D program is the communication it forces between government and industry researchers.

Congressional and other critics see IR&D as little more than a government giveaway, letting the companies bill the government for expenses they would incur anyway. They assert that the program is being abused. There is also concern that the incentives of the IR&D program are oriented toward short-term applications in which relevance can be demonstrated and cost recovered quickly, rather than to long-term advanced technology. One significant problem of IR&D is its complexity: even if all parties could agree that its goals are worthwhile, understanding the mechanisms of the program is very difficult. Some have suggested that the IR&D program be abolished in favor of simpler means to support company-initiated R&D.

Supply of Scientists and Engineers

Ultimately, a vibrant domestic defense technology base depends on a steady supply of highly capable scientists and engineers. Yet in recent years the rate at which U.S. citizens become scientists and engineers has fallen behind that of our allies and the Soviet Union. Furthermore, a large percentage of graduate students studying technical disciplines in the United States are foreign nationals, often supported by State and Federal grants and subsidies. Although about two-thirds remain in the United States at least 5 years after completing their degrees, many go home once their education is complete (or a few years thereafter), and contribute their talents to foreign companies competing with U.S. high-technology companies. As long as these foreign nationals remain in the United States, they contribute to the technology base. The fact that so many choose to study in the United States is an indication of the quality of U.S. technological training.

This raises the issue of whether there is a need for additional scientific and engineering manpower-either across the board or in selected disciplines–to satisfy both national security and commercial needs, and if so, what steps Congress could take to increase the supply. These might include measures to increase the attractiveness of science and engineering careers to U.S. citizens, and measures to increase the general quality of education. Congress may wish to consider the role of foreign nationals in the defense technology base, and whether steps are necessary to influence the number of foreign graduate students in U.S. universities.

EXPLOITING THE DEFENSE TECHNOLOGY BASE

An important element of getting new technology quickly into the field is how well the technology base can be exploited. Indeed, some observers believe that the major problems lie not in developing or maintaining the technology base, but in exploiting it, and that the major source of delay in getting technology from the laboratory to the field is not producing and developing the technology, but successfully designing it into military systems once it has been developed. Dr. Robert Costello, the Undersecretary of Defense for Acquisition, has cited the VHSIC program as an example of DoD's failure to get new technology rapidly into the field:

> While over 60 systems have VHSIC products in their plans, VHSIC parts are only in one current, deployed system . . , The technology is available and proven; and the Japanese are already using equivalent technology in commercial applications . . .[8]

[8]Quoted in *Defense Daily,* Dec. 3, 1987, p.203.

Exploiting the technology base is not, strictly speaking, part of maintaining it. But in practice, the two are inseparable. No clear line separates developing technology from developing technology for applications. Part of creating a technology is developing the means to build something based on that technology. It is precisely in this area of manufacturing technology that many observers believe the United States has sustained the greatest losses in technological capability. They believe that the United States is not so much slipping in applied science and the development of product technology, as it is in the craft and know-how of manufacturing devices: process technology must develop along with product technology if the product technology is to appear in actual devices. Moreover, designing a new technological advance into a useful device is itself a technology and may draw on several disciplines. For example, now that materials having superconducting properties at relatively high temperatures can be produced, the search is on both to find applications for these materials, and to fabricate them into useful forms.

A related problem is that many program managers are reluctant to design new technology into their systems. Over the several years it takes a system to go through full-scale development and into production, the technology in some of its subsystems and components is likely to fall behind the state of the art, especially in areas that are evolving rapidly. Ignoring new technology results in a system that is behind the leading edge, but changing the system to include new technology will introduce delays. Adding, new technology carries a risk that unforeseen factors will lead to additional delays. Thus, Service program managers have incentives to stay with the technology they know in order to minimize risks of schedule slippage.

One proposed solution is to insert new technology in retrofits to existing systems. Retrofitting takes less time than new developments and, therefore, gets the technology into the field faster. It also has the advantage of upgrading fielded capabilities without waiting for a new generation of major equipment.

A related approach is to include new technology in scheduled block upgrades of systems in production. Introducing new technology subsystems would not have to wait for the design and introduction of an entire new generation of the major system. A company that is now building a particular fighter airplane might also be working on an upgraded design that it would switch over to in a year or two. Both of these approaches are now used to some extent. Both require some degree of prior planning to ensure that new technology can be inserted with minimum disruption.

Yet another approach is through the organizational links between technology and systems development. For example, the Air Force has reorganized its technology base programs to be closely linked to the systems commands which are responsible for developing and buying equipment. This is an approach with attractive features, because it is supposed to make program managers more aware of new technology and make technology development more responsive to the needs of program development, thereby speeding the introduction of technology into systems. But linking technology too closely to development also risks stifling creativity-especially in areas that program managers do not currently recognize as being relevant to their missions.

HOW THE DEFENSE DEPARTMENT MAKES AND IMPLEMENTS TECHNOLOGY POLICY

The Defense Department's ability to manage its technology base programs is central to maintaining the defense technology base. In fiscal year 1988 DoD invested $8.6 billion in technology base activities. (See table 1.) One-third of the work was conducted "in-house;"

Table 1.—Department of Defense Fiscal Year 1988 Funding of Technology Base Programs (in millions of dollars)

	Army	Navy	Air Force	DARPA	Total
Research (6,1)	$169	$342	$198	$83	$902'
Exploratory development (6.2)	$556	$408	$557	$512	$2,033
Advanced exploratory development	$319	$227	$754	$202	$1,502
Total services and DARPA					$4,437
Strategic Defense Initiative					$3,604
Other defense agencies					$564
Total DoD technology base programs					$8,605

[a]This sum includes $110 million for the URI which OSD has not yet allocated among the three Services and DARPA.

SOURCE Office of Technology Assessment, 1988, from data supplied by the Office of the Secretary of Defense

more than half was contracted to industry,and universities performed the rest. Efficient management of the program-deciding what technology base policy is, allocating resources to implement that policy, avoiding unnecessary duplication of effort, and ensuring that important areas donot"fallbetween the cracks"that separate the elements of the program--will become all the more important if budgets become increasingly constrained.

Generally speaking, each Service department assembles a technology base program to suit its particular needs. OSD exercises oversight, and attempts to ensure that these programs are balanced and coordinated into a coherent whole with those of the defense agencies and the Strategic Defense Initiative Organization (which accounts for over 40 percent of DoD's technology base program funding). How all this works in detail is rooted in the structures of the various organizations within OSD and the Services that make R&D policy, but is not entirely determined by them. These structures are still undergoing reorganization in the wake of the Goldwater-Nichols Reorganization Act (Public Law 99-433). Consequently, what follows may well change in the months ahead. Once the structures are settled, it may take even more time for the process to adjust to the structure.

The three Services and the defense agencies (particularly the Defense Advanced Research Projects Agency (DARPA)) formulate their technology base programs with overall guidance from OSD. The Under Secretary of Defense for Acquisition has principal responsibility for all RDT&E activities except those of the Strategic Defense Initiative Organization (SDIO), which reports directly to the Secretary. For the Services, the principal focus for this guidance and the principal point of contact is the Deputy Under Secretary of Defense for Research and Advanced Technology (DUSD(R&AT)), a deputy to the Under Secretary of Defense for Acquisition. After the Services have formulated their programs, the role of the DUSD(R&AT) is to structure the overall program across service lines in order to eliminate gaps and overlaps, and enhance the return on investment. DUSD(R&AT) works continually with the services to help them achieve mutual interests and balance in their science and technology programs. DUSD (R&AT) coordinates activities with other government agencies and the scientific community.

Although DUSD(R&AT) is involved in coordinating Service programs with those of DARPA and the other defense agencies, he does not have oversight for the technology base programs of the defense agencies. However, since DARPA contracts most of its programs through the Services, much of its effort in fact receives DUSD(R&AT) oversight. The DUSD(R&AT) and the directors of all the defense agencies except DARPA report directly to the Director of Defense Research and Engineering (DDR&E), who reports to the Under Secretary for Acquisition. The Director of DARPA is also the Assistant Secretary of Defense for Research and Technology (ASD(R&T)) and reports directly to the Under Secretary for Acquisition.

DUSD(R&AT) runs some programs directly. The Computer and Electronics Technology Directorate of the DUSD(R&AT) manages: the Very High Speed Integrated Circuit (VHSIC) program; the Microwave/Millimeter Wave Monolithic Integrated Circuit (MIMIC) program; and the Software Technology for Adaptable Reliable Systems (STARS) program.

The three Service departments maintain structures for managing their technology base programs that are similar in some ways, but nonetheless have significant differences. Each has been planned to take into account the peculiar needs of the Service, and each is rooted in its own history. Each of the Services conducts an annual "top down, bottom up" planning exercise. From the top, each receives OSD's annual Defense Guidance Manual (as well as specific Service guidance), and from the bottom each research institution contributes a technology base plan. Outside advisory groups and in-house technical directors and staffs also contribute. Planning includes a review and evaluation of the previous year's programs. It culminates with decisions to start new programs, continue or terminate existing programs, or transition programs into a new category (e.g., from 6.1 to 6.2).

Of the three Services, the Navy has removed its technology base management institutions farthest from its procurement institutions. But relevance to Navy needs remains a powerful factor in selecting projects, particularly those beyond 6.1. Although it has the smallest overall technology base program, it has the largest research (6. 1) program, and performs the largest fraction of the work in-house. The 6.1 and 6.2 programs are run, respectively, by the Office of Naval Research and the Office of Naval Technology, both of which report to the Chief of Naval Research, who in turn reports directly to the Chief of Naval Operations (CNO) and the Assistant Secretary of the Navy for Research, Engineering, and Systems. Some Navy laboratories are run by the Office of Naval Research and others are run by the Space and Naval Warfare Systems Command (SPAWAR), which also reports directly to the CNO. Until recently the laboratories now run by SPAWAR were run by the "buying commands" such as the Naval Air Systems Command and the Naval Sea Systems Command. The decisions regarding *6.2* work to be done in SPAWAR laboratories are made by the Office of Naval Technology. Of the three Services, the Navy has the smallest advanced technology demonstration (6.3A) program; it is run directly by the Office of the CNO (OPNAV).

In contrast to the Navy's program, which is structured for finding and developing new technology of use to naval missions, the Air Force structure puts greater emphasis on getting technology into the field. The Air Force 6.3A program, which the Air Force sees as transition money, is five times as large as the Navy 6.3A budget. The technology base programs are run by Systems Command, the individual divisions of which are the Air Force's "buying commands. " These divisions run the laboratories which conduct and manage the 6.2 and 6.3A programs. Roughly two-thirds of the work is contracted out. The 6.1 programs are administered by the Air Force Office of Scientific Research, which is also part of Systems Command. Within Systems Command, the Deputy Chief of Staff for Technology and Plans has oversight responsibility for the science and technology programs, but these programs must be approved by the Director of Science and Technology Programs in the Office of the Assistant Secretary of the Air Force for Acquisition. The Air Force has recently taken a decision to treat its technology base program as a "corporate investment' that deserves a fixed fraction of the total Air Force budget.

The Army's structure is perhaps the most complicated and decentralized of the three Services. The Army has the smallest headquarters staff and relies the most on elements outside headquarters to run the technology base programs. Some aspects of the Army system are analogous to the Air Force system, while others are similar to the Navy 's. About three-fourths of the science and technology programs are run by the Army Materiel Command (AMC); other S&T programs are run by the Surgeon General of the Army, the Corps of Engineers, and the Office of the Deputy Chief of Staff for

Personnel. The offices within these organizations that are responsible for the S&T programs all report for oversight by Army headquarters to the Deputy for Technology and Assessment who, in turn, reports to the combined Office of the Assistant Secretary of the Army for Research, Development, and Acquisition (RD&A) and the Deputy Chief of Staff for RD&A. Within the Office of the Deputy for Technology and Assessment, it is the Director of Research and Technology who has responsibility for planning and coordinating the entire technology base program. The Army Materiel Command is analogous to the Air Force Systems Command.[9] It is organized into mission-specific "buying commands, " which run laboratories and technology base programs, and Laboratory Command (LABCOM) which, like the Office of Naval Research, runs laboratories and conducts generic research. Under LABCOM, the Army Research Office is responsible for AMC's 6.1 programs. Unlike the Office of Naval Research, the Army Research Office has no in-house capabilities and contracts all of its work out.

[9] The Navy equivalent, the Naval Material Command, was eliminated a few years ago in a reorganization. The component commands-e. g., the Naval Air Systems Command-now report directly to the CNO.

ROLES OF THE COMPONENT RESEARCH INSTITUTIONS

Nearly 200 Federal Government laboratories, research and engineering centers, activities, and test facilities contribute to the defense technology base. About 65 of these play a major role. Of these major centers, roughly 50 belong to the Army, Navy, and Air Force Departments, and the rest are run by the Department of Energy, the Department of Commerce, and the National Aeronautics and Space Administration (NASA). Many of the Department of Energy laboratories are Government Owned Contractor Operated (GOCO) facilities, permitting the hiring of personnel outside the Civil Service system. The defense agencies do not operate laboratories; however, DARPA maintains a close liaison with some Service laboratories.

Army

Within the Army Materiel Command, six "mission specific' systems commands run research, development, and engineering centers that conduct exploratory and advanced technology development into areas that are specific to the command's mission, while the Laboratory Command (LABCOM) operates laboratories that are focused on generic research and development, primarily at the 6.2 and 6.3 levels. The Army's research (6.1) program is almost entirely contracted out. Some of the mission-specific centers are more influential than LABCOM, and greatly influence the structure and priorities of the Army S&T program.

LABCOM runs the Electronic Technology and Devices Laboratory, the Materials Technology Laboratory, the Human Engineering Laboratory (the Army's lead lab for man-machine interface and robotics), the Ballistic Research Laboratory, the Atmospheric Science Laboratory, and the Vulnerability Assessments Laboratory. It also runs Harry Diamond Laboratories, which is involved in a variety of areas including ordnance electronics, electromagnetic effects, and advanced electronics devices. These laboratories do most of their work in-house, but contract out a substantial portion.

The facilities belonging to the systems commands conduct some exploratory development, but the main thrust is toward the "mature" end of the S&T program, leading to components, products, and systems. These centers conduct some in-house work, but the bulk is contracted out. For the most part, they bear the names of their parent commands, and their missions are specified by their names: the Armaments, Munitions, and Chemical Command; the Aviation Systems Command; the Missile Command; the Tank Automotive Command; the Communications Electronics Command; and the Troop Support Command.[10] The Missile Command Research and Development and Engineering Center has the capability to carry a concept nearly to production almost without outside help. The Night Vision and Electro-optical Laboratory, run by the Communications Electronics Command, is a recognized leader in infrared and other night vision devices for all three Services.

Navy

The in-house R&D capabilities of many Navy laboratories are substantial, through the tech base and into full-scale engineering development. Some can carry a system through development and almost to production, like the Army's Missile Commmand Research and Development and Enginering Center does. At least one Navy laboratory–the Naval Research Laboratory—does a substantial part of its work as the result of proposals by lab personnel to conduct R&D for the other Services and other parts of the government. The Naval Weapons Center has developed major missile systems to the production stage.

The Office of Naval Research oversees the activities of several laboratories—including the Naval Research Laboratory, the Naval Ocean Research and Development Center, and the Naval Environmental Prediction Research Facility. The Naval Research Laboratory is the Navy's principal research laboratory and, in some areas, DoD's. It conducts a broad-based program that includes such diverse fields as computer science, artificial intelligence, device technology, electronic warfare, radar, materials, directed energy, sensor technology, space technology, and undersea technology.

Aside from ONR's laboratories, all Navy development centers and activities are assigned to the Space and Naval Warfare Command. Although these facilities perform 6.2 and 6.3A work, the emphasis is on development. The major centers are the Naval Air Development Center, the Naval Ocean Systems Center, the Naval Weapons Center, the Naval Ship Research and Development Center, the Naval Surface Warfare Center, the Naval Undersea Systems Center, and the Naval Coastal Systems Center. Science and technology programs in these centers include electro-optics, acoustics, microwaves, artificial intelligence and knowledge-based systems, ocean science, bioscience, electronic materials, structural materials, ship magnetics, hydrodynamics, and charged particle beams.

Air Force

All of the Air Force laboratories are run by the systems divisions of Systems Command—Armaments Division, Aeronautical Systems Division, Electronic Systems Division, Space Division, and Human Systems Division—in support of the division's specific mission. Exploratory and advanced development (6.2 and 6.3A) are funded directly by the divisions, while research (6.1) is funded and managed by the Air Force Office of Scientific Research. The centers are the Air Force Armaments Laboratory, the Rome Air Development Center, the Geophysics Laboratory, the Air Force Weapons Laboratory, the Air Force Astronautics Laboratory, the Human Resources Laboratory, the Aeromedical Laboratory, and the Wright Aeronautical Laboratories. The Wright Aeronautical Laboratories is a cluster which includes the Aeropropulsion Laboratory, the Avionics Laboratory, the Flight Dynamics Laboratory, and the Materials Laboratory. Managed outside Systems Command, but coordinated with it, is the Air Force Engineering and Services Laboratory.

[10] For example, the Armaments, Munitions, and Chemical Command runs the Armament Research, Development, and Engineering Center and the Chemical Research, Development, and Engineering Center.

Department of Energy

The Department of Energy's laboratory system, established during World War II to develop nuclear weapons, has grown dramatically in scope and size. About 60 institutions employing 135,000 people and having a replacement cost of about $50 billion conduct research into physics, chemistry, cosmology, biology, the ecosystem, geology, mathematics, computing, and medicine, as well as a broad range of technologies that spring from these disciplines. Nine multiprogram laboratories and 30 specialized laboratories are involved in these fundamental science and technology activities. These laboratories maintain close ties with academic researchers, often subsidizing part of their work at the DOE facilities.

A primary focus of DOE work for national defense is the nuclear weapons programs. Moreover, some of the major multiprogram laboratories–Sandia National Laboratory, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Oak Ridge National Laboratory–do 10 to 15 percent of their work under contract to DoD on defense related research not directly related to nuclear weapons, and most of their work is available for exploitation by DoD or its contractors. Several other laboratories—Argonne, Brookhaven, Lawrence Berkeley, Idaho National Engineering Laboratory, and Pacific Northwest Laboratory–do little or no work for DoD, although they do basic and applied research that is available for exploitation for defense purposes.

The National Aeronautics and Space Administration (NASA)

NASA runs a number of major facilities, many of which are dedicated almost exclusively to the design and testing of space-launch systems and space systems. Several others, while they also support the space program, have a broader mandate. The major NASA field centers are the Ames Research Center, the Lewis Research Center, the Langley Research Center, the Goddard Space Flight Center, the Marshall Space Flight Center, the Johnson Space Center, the Kennedy Space Center, and the Jet Propulsion Laboratory. These centers conduct work in aeronautics, space, communications, propulsion, and computers, among other fields.

Other Federal S&T Activities

By far, the majority of federal science and technology activities with potential defense applications are conducted within DoD, DOE, and NASA. There are pockets of activity within other agencies that can, and do, contribute to the defense technology base.

The National Science Foundation funds three times as much university research as DoD. But NSF conducts no research of its own, and does not contract for research; it funds unsolicited proposals. NSF supports research projects in almost every area of science and technology.

The Commerce Department's National Bureau of Standards conducts a number of applied research projects that contribute to the defense technology base. NBS researchers, in partnership with others from industry, government, or academia, investigate areas such as electronic technology, information processing, biotechnology, chemistry, and manufacturing technology. This partnership arrangement is designed to get the technologies quickly into applications. NBS technical work is carried out in the National Measurement Laboratory, the National Engineering Laboratory, the Institute for Computer Sciences and Technology, and the Institute for Materials Science and Engineering.

The Department of Transportation-particularly the Federal Aviation Administration and the Coast Guard-the Department of Agriculture, the Department of Interior's U.S. Geological Survey, and the National Ocean and Atmospheric Administration all share interests with DoD, and conduct some research and development with potential defense applications.

University Research Programs

University laboratories perform a substantial portion of the basic and applied research conducted in the United States. They work in all areas of basic research and most areas of applied research and exploratory technology. University research is an area of potentially high leverage for DoD, since DoD funds less than 25 percent of it, but has access to almost all of it. DoD has generated great interest in its new programs for university research; many more requests have been received than could be funded. The two most significant are the University Research Instrumentation Program, to upgrade laboratory equipment, and the University Research Initiative, most of which goes to multidisciplinary research programs and programs to promote scientific training. DOD has also put money into creating university "centers of excellence" in selected disciplines.

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Part II

Background and Analysis

Chapter 3

Maintaining Defense Technology Capacity: Policy Overview

INTRODUCTION: AN INTERACTIVE PERSPECTIVE

The technology base on which our defensive strategy and capacities rest is a dynamic, interactive network of commercial and military industries, laboratory facilities, sub-tier component suppliers, venture capitalists, science and engineering professionals, communication systems, universities, data resources, and design and manufacturing know-how. These highly interrelated elements of the technology base are driven by and react to international market forces and policies of foreign governments that cannot be precisely anticipated by military or civilian planners, Congress, the executive branch, Wall Street, or anyone else. Yet Congress, even if it cannot exert close control, can do much to affect the general directions in which the technology base moves—if it is clear about its objectives and willing to incur the costs.

Conceptually, domestic technological structure can be divided into four broad groupings: 1) technologies and industries that are defense oriented, 2) those dual-use technologies that respond both to defense and to commercial demands, 3) those that are commercially dominated, but are useful for some defense purposes, and 4) those that are purely commercial in nature. There will always be extensive gray areas and overlaps when it comes to specific cases. It is also not unusual for particular technologies to start in one area and end up in another. Historically, analysts have argued that the direction of the progression has been predominantly from the defense sector into the dual-use arena. But there is substantial evidence that the flow from commercial industry has increased markedly in recent years.

If this shift corresponds to a change in the center of gravity for militarily relevant technological innovation and development, then it may presage or necessitate large-scale alterations in the way that business is conducted within the Pentagon and in the military sector of the economy. Some analysts argue that DoD will ultimately have to adapt its procurement regulations and contracting procedures to accommodate private sector business practices if it is to draw efficiently on the vast resources of the commercial economy. This would entail the elimination of many bureaucratic and regulatory barriers that have inhibited relations between DoD and commercial industry in the past. At a minimum, they suggest, DoD would have to exchange military for commercial specifications where possible.

The use of gallium arsenide (GaAs) wafers for semiconductor fabrication illustrates the fluidity of technology transition among the military, commercial, and dual-use sectors of the economy. GaAs wafer technology was developed by the military because of specialized needs for higher speed processing and radiation hardness. Today, it is entering the dual-use category as evidenced by increasing Japanese commercial R&D and marketing of GaAs processes and products. Japanese Government and industrial sources predict that the market for GaAs and related compound semiconductors could exceed $5 billion by 1992.[1] In such a market, the Defense Department would still be a major customer. But if the market for GaAs-related products and processes follows the pattern set by silicon-based microelectronics, it would increase by an additional order of magnitude by the late 1990s and would become dominated by the commercial sector. And in that case, significant barriers between

[1]Richard C. Eden, et al., "Integrated Circuits: The Case for Gallium Arsenide," *IEEE Spectrum*, December 1983, p. 33.

DoD and civilian suppliers-or a failure of U.S. GaAs producers to enter commercial markets —would have serious implications for the availability of such technologies for weapon systems in the future.

Each year the military Services compile lists of key technologies that are critical to the national defense. These include such dual-use items as fiber optics, high-temperature superconductivity, advanced semiconductors, very large-scale integrated (VLSI) circuit chips, supercomputing, biotechnology, and advanced materials. These are pervasive technologies that cannot easily be protected by special arrangements between the prime defense contractors and the Department of Defense. In many cases, they depend on continuous innovation on a scale that can only be stimulated by the competitive forces and the massive capitalization generated by commercial markets. At the same time, national assets in dual-use technologies appear especially vulnerable to erosion by world market forces as well as domestic fiscal, monetary, antitrust, and tax policies which have tended to encourage offshore production.

An initial step in disaggregating the technology base is to isolate a specific technology and ask how and to what degree it contributes to the national security. Is the orientation primarily to promote military security, or is it to contribute to economic competitiveness, or both? When this exercise is conducted, some technologies appear uniquely military in character, such as "brilliant" guidance, high-power directed energy, and broad spectrum signature control. It is difficult to imagine civilian applications to which these technologies could profitably be put. Indeed, some are contraindicated, such as the application of stealth technologies to commercial aviation.

But the matter does not end there. What the military calls brilliant guidance is a subspecies of precision navigation, and precision navigation technologies are used in commercial products. If the technology is traced backward from the military systems or prime contractor level, many of the subsystems and components would have much in common with a range of commercial products. The subsystems that go into brilliant guidance include computers, sophisticated microchips, sensors, mapping systems, and inertial guidance equipment. These are usually produced to military specification by second and third tier military subcontractors. But if these subsystems are further disaggregate, it is clear that some of the enabling and many of the pervasive[2] technology products will have been ordered off the shelf from suppliers whose business is primarily oriented toward civilian buyers.

The task of specifying technologies that are civilian or uniquely commercial is equally difficult. Even agricultural and medical technologies that are developed and marketed specifically to the commercial sector of the economy have military applications. Food produced by means of new fertilization, genetic alteration, and pest control technologies will be consumed by soldiers. And many commercial medical technologies, which are quickly adopted by military doctors, would become even more valuable and critical to the Armed Services in time of war.

The question is not whether a particular technology contributes to national security or to economic competitiveness goals, but rather, what actions Congress can take to ensure that DoD will be able to obtain technology that is necessary for the national defense in the future. In part the policy question turns on the issue of how the Department of Defense should invest $170 billion annually in procurement and RTD&E to maximize military security. It is also a question of how best to stimulate and organize the techno-industrial infrastructure that supports both national economic and security goals.

'The term "enabling technology is used in some military circles to designate a technology that makes possible the development of a specific weapons system, and "pervasive technologies" are those that can be applied to more than one—hopefully many—system concepts. *Project Forecast II, Final Report [u]*, vol. 1, Director's Report [u], June 1986, pp. 7-8.

POLICY AND THE HEALTH OF THE DEFENSE TECHNOLOGY BASE

In OTA's discussions with OSD and the individual Services, and with lab directors, academics, contractors, critics, businesspersons, congressional staff, high-ranking military officials, and others, a wide array of questions and concerns were voiced regarding the overall vitality of the technology and industrial sectors on which the national defense relies. These are grouped below in seven issue areas: 1) DoD technology base management, 2) funding for DoD technology base programs, 3) management of government laboratories, 4) military dependence on foreign technology, 5) health of the dual-use sector, 6) problems in the defense industries, and 7) supply of scientists and engineers.

DoD Technology Base Program Management

The fiscal year 1988 DoD Science and Technology Program is an $8.6 billion enterprise involving a complex matrix of DoD laboratories, research and development centers, universities, non-profit organizations, and industry. It includes the technology base programs of the Services, as well as those of the Strategic Defense Initiative Organization (SDIO), the Defense Advanced Research Projects Agency (DARPA), and the other defense agencies. (The structure of the DoD technology base program is described in chapter 4 of this report.)

Perhaps because of the magnitude of the S&T program, DoD technology policy lacks focus when it is compared to R&D programs in industry. There is no single chief technology officer as is found in large corporations. Instead, science and technology policy and strategy are formulated by a network of individuals located in diverse offices spread across the formal structure of the DoD S&T program. A principal concern is that this network may not be capable of producing a coherent, coordinated policy, and that techniques used to implement current policies may be insufficient to manage effectively an enterprise of this magnitude.

Stemming from this concern, recent discussion has focused on four basic issues that affect the overall shape and functioning of science and technology programs within DoD. First, is the question of how best to balance "technology push" against "requirements pull. " On the requirements side, the basic thrust is to organize technology base programs in response to the user and the situation he will face under battlefield conditions. If the warfighting requirement, for example, is for firepower with a designated range and accuracy, then technologies can be refined or invented for that purpose. Proponents of this approach often cite NASA's Apollo Program as a very successful example of requirements pull, where the President specified the goal of putting a man on the moon, and technologies were developed to satisfy that requirement.

Critics contend that requirements pull and relevance tests dominate the planning process within the DoD science and technology programs. They argue that radically different technological solutions—technology push—can change the nature of warfare and the way that we think about it. The introduction of nuclear weapons and satellites come readily to mind. These kinds of capabilities are not generated as a response to specific requirements in the field. Instead, major dramatic applications become apparent when new ideas are extended to their logical and technical limits. Some SDI technologies, such as high-energy lasers and railguns, have been funded on this basis—where the possibility of an application is suggested because the physics and principles of the potential technology are understood. On the negative side, some analysts argue that these SDI technologies demonstrate the weaknesses of technology push strategies in R&D management. They contend that enormous sums have been pumped into weapon systems that cannot be made to work and will never be deployed. The difficulty, of course, is to ascertain the best mix of both approaches, so that the specific threat is met, but at the same time, new technological opportunities are fully realized.

A second and closely related problem is the question of how much managerial emphasis should be placed on evolutionary development of known technologies as opposed to reaching for revolutionary breakthroughs where the U.S. achieves technical advances that its adversaries cannot quickly counter or duplicate. With the evolutionary approach, it is reasonable to expect technological progress that gradually enhances the military capacity of various systems over time. In this environment, it is easier to predict the magnitude of the investment that is required, and to balance it against the nature of the upgraded capability. In striving for revolutionary technological advances, there is greater uncertainty, both with regard to costs and with respect to the ultimate success of the project. But the potential payoff—both in terms of new military capacities and in terms of deterrence—may be very great indeed.

R&D management strategies that support incremental approaches tend to place the allocation authority in the hands of midlevel managers in the Services, who assess the state of a particular weapon system and ask what R&D is necessary to improve performance of the system. The alternative strategy would favor placing the funding decision in the hands of lab directors (or within special programs), and encouraging them to support higher risk projects designed to generate qualitatively different technical approaches. In many technology base projects, however, the greatest "measure of merit" is how quickly the new technology can be injected into weapon platforms or made operational in the field. Critics contend that this emphasis introduces a conservative bias into the technology development process, minimizing the likelihood that significant and unexpected breakthroughs will occur.

When it comes to allocation of resources, there will always be a tension and a need for balance between concentration on moving new technology out to the field as quickly as possible, and funding more indirect research that may have broad potential implications that cannot now be explicitly stated or exactly envisioned. Responsible and seasoned opinion supports both sides of this question. Some observers contend that the technology base programs must methodically provide new and improved technology to the user on a regular basis. Others emphasize the importance of supporting more abstract work by talented scientists who may make dramatic progress if they are permitted to operate in an environment where they can set the direction of the enquiry.

A third concern focuses on the appropriate management role that the Office of the Secretary of Defense should assume in the overall DoD Science and Technology Base Program. The issue is how much OSD should centralize and directly manage tech base programs, and how much authority it should exert in coordination and oversight of the Services. In recent years, an increasing percentage of research and development has been consolidated within OSD. The establishment of the SDIO in 1983 effectively split the Science and Technology program into two parts, planned and organized by two different administrative structures. The S&T program that preceded the establishment of SDIO is largely conducted by the individual Services and DARPA. In fiscal year 1988, it includes Research (6.1), Exploratory Development (6.2), and approximately one-third of DoD's Advanced Technology Development (6.3A). All phases of the Strategic Defense Initiative (SDI), however, are administered by OSD, and are funded under 6.3A. In fiscal year 1988, SDI accounted for about 41 percent of all DoD Science and Technology funds.

Those who adopt a Services-oriented perspective on this question argue that the Services need to operate the technology base programs and in-house labs so that they are in a position to obtain technology not only for future systems, but also for those in full-scale engineering development (FSED) or procurement. As it stands today, the linkage between R&D resources of the Services and projects that are already in or beyond FSED is weak because there is a tendency to contract out for needed technology, which could overlook relevant work in the universities and the DoD labs. Increasing OSD control over the S&T program would only encourage the Services' buying agents to ignore technology in the DoD labs because they would see the labs as outside of their primary organization and areas of influence and responsibility. In this view, the proper role for OSD is to provide general guidance and coordination, and to act as an advocate with Congress for the specific programs of the Air Force, Army, and Navy. Moreover, effective science and technology base programs must be geared closely to the needs of the user in the field, at sea, and in the air. The only way to ensure this fit is for the Services to conduct their own largely independent programs, constantly subjecting them to the scrutiny of those for whom they are ultimately developed.

Advocates of a stronger, more assertive role for OSD contend that a more integrated management system, beginning at the R&D level, is necessary to overcome longstanding inter-Service rivalries, and to obtain maximum cross-fertilization of research efforts. Some argue that it is necessary to promote commonality and inter-Service operability of military systems at the earliest possible stage of development. This can best be accomplished if the S&T programs are more directly controlled by a central authority. They suggest that higher level coordination is necessary to contain waste and eliminate duplication of effort which results from a decentralized system. As an example, they point to the fact that the Services have developed independent and largely incompatible communication systems for the field.

Some observers believe that DoD could learn a great deal from the organization, policies, and working methods of successful, large-scale R&D operations in foreign nations. Although the tremendous scale and scope of DoD programs tend to place the agency in a class by itself, important lessons might be learned by examining management techniques used by other governments as well as some private sector R&D functions. Japanese officials appear, for example, to be able to identify promising new areas of technology development at a national level, and then to assist industry with a variety of state resources to exploit those areas for economic gain.

Questions regarding congressional guidance and oversight of DoD's technology base programs raise a final set of concerns. With respect to the DoD Science and Technology program, there is considerable controversy as to what congressional action, if any, would be productive and appropriate—given the extraordinary complexity and technical breadth of DoD's activities in this area. Advocates of a strong oversight role for the Congress argue that the committees of jurisdiction should review the specific program elements (PEs) and allocate funds based on that review.

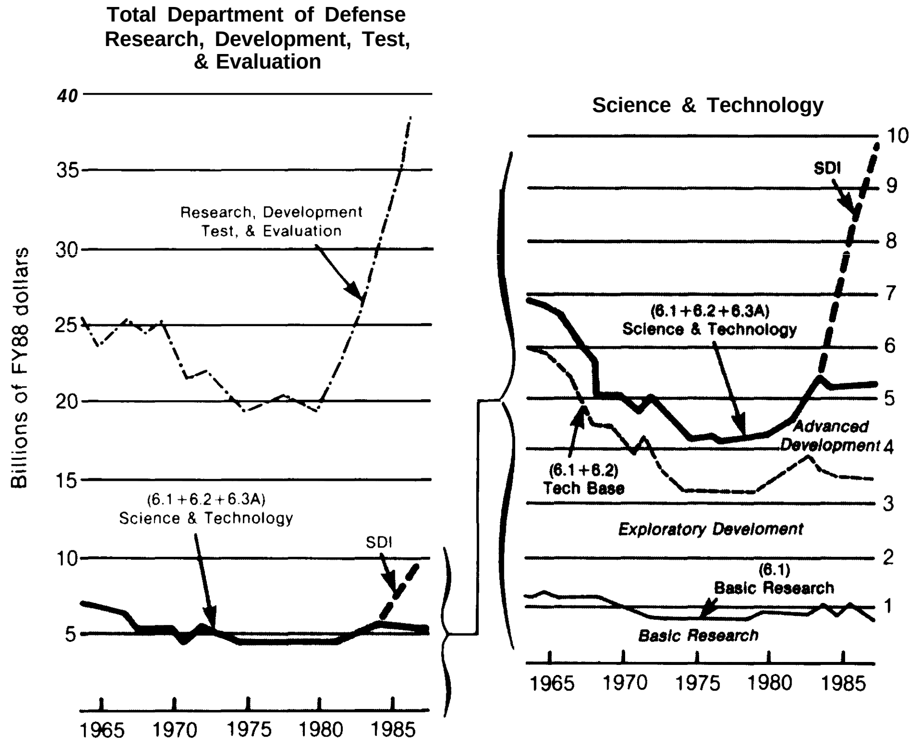
Those who reject the idea of congressional micro-management of defense programs urge caution. They point out that the DoD Science and Technology program is comprised of approximately 160 program elements, which are the basic "building blocks" of DoD's Planning, Programming, and Budgeting System, and that each PE is subdivided into many projects, which number in the thousands. Congress would be wasting its time to try to look into the intricacies of the S&T program-because this is daunting even for specialists who spend all of their time doing nothing but trying to understand and manage the existing system. In this view, Congress should confine itself to setting an overall direction for the S&T program consistent with the larger issue of national security policy, leaving the supporting science and technology apparatus in the hands of professional administrators.

Some Members of Congress have chosen to concern themselves with the overall health and maintenance of the defense technology base in the United States. Part of that choice involves developing some yardsticks with which to judge the organization, management, and content of DoD science and technology base programs. Does the present system result in the most efficient and equitable division of effort and funding? Does it provide an overall approach with sufficient integration and coordination? Does it result in an optimal balance between technology push and requirements pull, and between evolutionary and revolutionary R&D strategies? And finally, what lessons might DoD learn from other organizations that manage large-scale technology programs?

DoD Technology Base Program Funding

Funding for DoD Science and Technology programs (budget categories 6.1,6.2, and 6.3A) has varied considerably over the past *20 years.* The funding issue has generated a great deal of confusion, even among persons generally knowledgeable in defense matters. There are several distinctions that can help to clarify the situation, and there are unmistakable trends that can be sorted out. S&T funding must be clearly distinguished from the larger Research, Development, Test and Evaluation (RDT&E) budget, of which it is only about 20 percent. Figure 1 shows both RDT&E funding and S&T funding from the early 1960s to the late 1980s. The graph on the left shows the magnitude of the S&T budgets in relation to the much larger RDT&E budgets. In its discussions, OTA found that many persons mistakenly believe that funding for basic research (6.1) was substantially increased during the Carter-Reagan defense buildup because they knew that funding for RDT&E had increased by almost 100

Figure 1 .—Technology Base Funding, 1964-1987 (1988 dollars)



SOURCE: "Discriminate Deterrence," report of the Commission on Integrated Long-Term Strategy (January 1988), p. 46

percent. But a quick glance at the graph on the right indicates that in constant dollars funding for basic research has been relatively stable over the past 20 years and has not benefited substantially from recent increases in defense spending.

On the other hand, funding for exploratory development (6.2) fell dramatically from a high of approximately $4.6 billion[3] in 1964 to about $2.6 billion in 1974, reaching $2.5 billion in 1984. The trend for advanced development (6.3A), however, more nearly parallels the funding history of basic research (6.1), if the funds for SD I are excluded. The non-SD I advanced development (6.3A) figures are approximately as follows: $0.9 billion for 1964, $0.8 billion for 1974, and $1.7 billion for 1984. When the figures for 6.1, 6.2, and 6.3A are aggregated, exclusive of SDI, the overall trend is a sharp drop in funding throughout the late 1960s into the late 1970s with a modest recovery that levels off at about $5.2 billion after 1984. This represents a real decrease in funding of about 25 percent from 1964 to 1984.

Recent trends look very different if funds for SD I are considered as part of the S&T program than if they are treated as a separate "add-on. The graphs in figure 1 indicate that this is a matter of some significance because they were authorized by DoD and treat SDI as a distinct category. The Strategic Defense Initiative has accounted for over 40 percent of the S&T budget for the past two fiscal years, and has been exclusively funded through the advanced development (6.3A) budget category. Some analysts believe that SDI funds do not contribute substantially to the overall DoD S&T program, that R&D conducted by the SDIO is highly specific to anti-ballistic missile (ABM) warfare. Others contend that SDIO programs make and will continue to make a strong contribution to R&D throughout DoD's Science and Technology base programs.

If SD I funding is aggregated with the rest of the S&T budget, then the numbers alone indicate a dramatic increase in advanced development (6.3A), which almost doubles overall S&T funding since 1983. But even in this case, basic research (6.1) which has not been affected by SDIO funding has remained constant, even in a period of rapid buildup of defense spending. Accordingly, any substantial reduction in funding for basic research to accommodate overall decreases in defense appropriations would reduce basic research to its lowest level in 20 years. The same argument can be made for exploratory development (6.2). Finally, if SDI funds are excluded, a reduction in funding for advanced development (6.3A) of $0.8 billion would put that budget category at its lowest level in 20 years. These kinds of figures have led to a concern that Congress and military planners may not have provided for adequate reinvestment in the technology base.

Two major considerations bear on the question of whether congressional appropriations have been sufficient to maintain the DoD technology base. The first centers on the difficulty of measuring the impact of research and exploratory development on the military security of the Nation. Most observers accept the principle—as an article of faith-that research builds the foundation on which future technological advances rest. But the connection between today's specific research projects and future military products and technologies is not obvious, cannot be quantified, and is extremely difficult to render in explicit terms.' As a result, while everyone agrees that research is important, it is difficult to make an argument that research funding should be supplemented in any given appropriation.

By contrast, it is comparatively easy to argue that a particular weapon system would enhance the force structure and contribute to the

[3] A11 budget figures in this and the following paragraph are taken from figure 1 and are in constant 1988 dollars.

"'Studies of technological innovations have shown them to depend on research results that are decades old and often in seemingly unrelated fields . . . A highly successful basic research effort may never generate technological innovation or economic payoff if other factors in the economy are not conducive to technological change, U.S. Congress, Office of Technology Assessment, *Research Funding as an Investment: Can We Measure the Difference? OTA-TM-SET-36* (Washington, DC: U.S. Government Printing Office, April 1986), p. 5.

military security of the Nation. While the contribution of today's research may not become evident for 10 to 15 years or more, funds allocated for anew missile or bomber can be justified as necessary expenditure to meet a clear and present threat. Moreover, the results of cutting funds for technology base programs may not show up for years, and even then, it would be difficult to demonstrate a one-to-one or causal type relationship between insufficient R&D funding and future weaknesses in the force structure. It is far easier to grasp the implications of cutting funds for new military hardware-where a budget cut of $100 million would translate into a definite reduction in the number of new tanks or fighter aircraft that could be procured. For these reasons, while almost everyone would advocate increased R&D funding in the abstract, few are willing to trade more tangible programs for the vagaries of indefinite technological advances in the future.

These circumstances have contributed to a low priority status for technology base funds. But perhaps more important is the disproportionate vulnerability to which R&D funds are subjected during a period of budget reduction. Suppose, for example, that the Navy is instructed by the Secretary of Defense to cutout-lays by $150 million. This could be achieved in a number of ways. One method would be to cut all programs across the board. Opponents of this strategy contend that it fosters mediocrity by strapping the really good programs and by prolonging the lifespan of inferior projects. Another way to achieve the reduction would be to cancel the decision to build a new aircraft carrier. This is an unlikely decision because it would sacrifice a $3 billion carrier to save only about $150 million in the first year.

R&D, on the other hand, has a very high payout of approximately 50 percent. By cutting $300 million in R&D funding (which would, of course, be a draconian measure), the controller could gain the same savings as canceling an entire carrier. Thus funding for technology base programs is subjected to a kind of double jeopardy. In the first instance, its promoters and advocates are few and far between. And in the second, there are strong incentives for powerful program and budget managers to "raid' R&D funds as a means of saving more advanced, more visible and, therefore, more pressing programs.

The second funding issue focuses on internal allocation of funds within the technology base programs that takes place subsequent to and largely independent of congressional appropriation. There is concern that technology base funds (6.1 and 6.2) may not be allocated most efficiently among a variety of competing interests, that they may ultimately not find their way to the areas in which the most important technology research is taking place. There is a tendency for funds to go where it is easiest for them to go, instead of where they would do the most good. This is often tied to institutional mechanisms, and to historically based claims that may be difficult or impossible to resist. Critics argue, for example, that some DoD laboratories, which may not contribute significantly to the technology base, are nevertheless funded because closing them would be politically unpopular.

The policy issues related to funding of the technology base have not received a great deal of attention in the past. Is it necessary to take measures to change the allocation of funding among technology base programs? Is the technology base adequately funded relative to the overall DoD budget? With regard to this question, analysts have pointed out that technology base programs are historically the first to be cut during a budget crisis, and that they are among the last to be restored when fuller funding becomes available. Some have argued that the technology base functions best when funding is level and predictable. And they suggest that even if it may not be possible or advisable to put all of DoD on a multiyear budget cycle, it might make sense to put R&D programs on such a footing. And finally, is there significant misallocation of funding within the tech base programs? Are technology base funds redirected toward projects that are not tech base, and if so, what actions can Congress take to correct the situation?

Management of Government Laboratories

The U.S. Government supports an extensive network of laboratories funded principally by the Department of Defense, the Department of Energy, and NASA. Over the past decade, these labs, and particularly those run by DoD, have been the subject of many studies which have focused on problems such as inadequate pay, aging facilities, quality of work, and inappropriate allocation of workloads and resources.

There is considerable concern that the network of government laboratories does not form a coherent system to support technology needs —not for the military and not for commercial endeavors that also support military production. This concern is closely linked to the problem of hiring and retaining first rank scientific and engineering talent, particularly in the DoD laboratories. Some analysts suggest that the quality of personnel recruited for the defense labs will not be raised significantly until salaries are made competitive with industry. In some instances, they note, salaries in the DoD labs have failed to keep pace with salaries for similar positions in the universities.

Policy questions concerning the role of the government labs in the defense technology base focus on four concerns. First, is the work of the DoD labs skewed too strongly toward the development side of R&D and, if so, what are the implications of this trend? In recent years, basic research at DoD has become a progressively smaller proportion of the administration budgets. By any measure, research is a minuscule part of the Federal budget. And within DoD, basic research consumes only about 10 percent of Science and Technology funds.

Some observers argue that basic research is slighted or overlooked because its value as an activity cannot be quantified and does not result directly in new products or weapon systems in the field. Basic research is treated in some quarters as an expendable activity, they suggest, because it has few long-term advocates who are in a position to remind Congress and the public of its value. High-level appointees at the Pentagon tend to gloss over the importance of the research function in favor of high profile, big ticket acquisitions. Most hold their jobs for no more than a few years, and cannot be expected to take the long-term, apolitical perspective which is needed to understand and promote funding for basic research in a highly competitive, acquisition-dominated DoD environment.

Advocates of increased funding for basic research argue that of all R&D-related activities, basic research is probably the most amenable to centralized coordination and funding mechanisms. This is because the objective is to answer questions about the nature of physical reality and technology, and not to apply what has been learned. Applied research necessitates a specialized dialog, usually between the researcher and the ultimate user, to make sure that the products of the former are compatible with the needs of the latter. This relationship favors a decentralized organization. Basic research, on the contrary, presupposes no end user, and could, accordingly, be organized in a highly centralized manner. Proponents of such a move believe that consolidation of government research into a central organization would not only create new efficiencies, but would also give this activity the sponsorship and visibility that it presently lacks.

A second area for policy consideration concerns the role of the DoD labs as intermediaries between the government and industry. To what extent should the labs maintain inhouse capacities as opposed to contracting out research and development work? There are clearly two extremes that most observers agree should be avoided. The first is for the government to contract out so much R&D that it loses the capacity to assist the Services directly when a need arises, or loses the ability to set direction for and evaluate the work of contractors. At the other extreme, a lab or system of labs might find itself in direct competition with industry, denying commercial or contractor access to proprietary information developed in government labs.

Some industry spokespersons contend, for example, that the Navy does what it wants to do in its labs, and keeps what it does for the Navy. They claim that the Navy, which contracts out approximately 40 percent of its R&D, maintains excess in-house capacity. In this view, some major research facilities have set up rigid barriers that have introverted operations, withholding valuable information from DoD contractors. Some contractors feel that they are in competition with the Navy labs, and are, accordingly, far less willing to share their data and results with the Navy. They agree that the Federal Technology Transfer Act may help to ease this situation, but argue that the root of the problem is that government should not be in competition with the private sector.

Some observers suggest that the boundary between the government labs and industry needs to be a good deal more fluid than it presently is. Government labs should not be conducting research that has already been completed successfully in industry and vice versa. In this view, DoD needs to institute some mechanism to ensure that the labs and industry cooperate more closely and do not duplicate each others research when it is unnecessary.

The question of rigid mission orientation versus a more flexible approach to R&D forms a third issue area for laboratory management. All three Services attempt to construct plans and budgets on a mission-oriented basis. Indeed, the Congress required this approach in the 1974 Budget Reform and Impoundment Control Act. But there is considerable difference of opinion, both within and outside of Congress, concerning the interpretation of this requirement. Some suggest that the linkage between technology base activity and specific military mission ought to be tenuous and tentative in character.

If the work of the labs and their contractors is too closely tied to a particular mission or application, they contend, then the overall focus for R&D will be short range at best, and may lead to a kind of tunnel vision. This is particularly true of basic research, where the future applications and benefits of today's work cannot be known—almost by definition. Some observers argue that the Services should place a higher priority on basic research, and take a longer range view of the whole problem of generating technology for future weapons systems. Such a scenario is politically difficult because there is tremendous pressure to get equipment into the field as soon as possible in order to meet the threat and to have something to show for vast outlays of taxpayer and borrowed dollars.

A final policy problem centers on increasing coordination and cooperation between the extensive laboratory operations of the DoD, DOE, and NASA. Within DoD, there are different laboratory commands for each of the Services, and some believe there are too few institutional mechanisms for cross-fertilization between the DoD operations and the more expansive laboratory facilities both at NASA and at DOE. Some analysts suggest that the present decentralized system is necessary to meet the highly individualized needs of the various different organizations. They suggest that if the individual Services had to rely on a centralized system for R&D, it would greatly inhibit the process by which technology is transitioned into engineering development, and the essential connection to the end-user would be lost.

Others contend that the United States pays a price for operating a highly fragmented system with diverse R&D agendas. Such a system could result in unnecessary duplication of effort and in government support of labs that have long since stopped contributing to the leading edge of technology research and development. They believe that the present configuration of laboratory facilities is a consequence of tradition and uneven historical growth, rather than rational planning geared to late 20th century conditions of high-technology warfare and international economic competition. Some analysts suggest that the United States should identify a set of national technological goals, and then reorganize and consolidate its system of national labs to meet those goals. They attribute the success of the Apollo project to the fact that a goal was set, and resources were organized to meet the goal. They believe that the United States might already be in a good position to take a lesson from the Japanese, who have achieved remarkable success by selecting national technological milestones and working toward them. Various schemes—ranging from a single executive technology agency to a system of lead agencies, each associated with a different national technological goal-have been proposed. Proponents argue that the resulting benefits could be realized both by the military and by the commercial sector at the same time.

What steps, if any, should Congress take to ensure more efficient use of government laboratories, including closing, merging, or consolidating facilities? What actions might be taken to enhance technology transfer among the various labs and between the government and the *commercial* sector? What impediments could be removed? Are there measures that could be taken to make government laboratories more attractive places to work? Are programs being unnecessarily constrained because of the narrow focus of their parent organizations, and are important areas of research being overlooked? What alternatives to the present system might contribute significantly to the health of the defense technology base in the future?

Military Dependence on Foreign Technology

In recent years, complex weapon systems have come to exhibit some of the internationalization of labor, materials, and component parts that has long characterized the commercial sector. There is increasing concern that DoD is not immune from the larger economic forces that have produced the world car.

A coherent policy on military dependence on foreign technology will have to balance benefits obtained from access to foreign technology and products against the loss of technology base capacities that results from long-term dependence on other nations. It should be based on an assessment of whether or not internationalization of the defense technology base poses a threat to military security, and if so, it should take cognizance of the reasons for the decline of key technology areas in the United States. This, in turn, may suggest strategies that the United States can pursue to resist or reverse dependence on foreign sources.[5] Policy should be informed with the reality that some forms of dependence maybe harmful and avoidable, others helpful and desirable, and some others unavoidable whether we like it or not.

There are two significant dimensions to the problem of increasing military dependence on foreign technology. The first centers on growing foreign leadership and market domination in important dual-use technologies, i.e., technologies that have significant commercial as well as military applications. In some instances the United States appears to be losing market share in high-technology products as well as the leading edge in development of new technologies. In others, advanced technology already exists in foreign countries, but *is* not produced competitively in the United States. In part, this problem is compounded by continuous pressure for DoD to take advantage of efficiencies and superior products that international competition has brought to the commercial world. In the future, DoD may be driven to buy a larger share of foreign military products, particularly if foreign suppliers can achieve economies of scale, high quality, and low cost that have eluded domestic producers in recent years.

There are significant potential liabilities in dependence associated with commercial loss of capacity in dual-use technologies. It may be that the United States will be forced to maintain certain technologies because of their strategic importance. Military dependence on

'This dependence has not yet reached significant proportions in a great many technological areas. Many analysts believe that the United States still holds a commanding lead in most technologies that are military in character.

foreign dual-use technology will always have to be scrutinized when the technology is pervasive in character-i. e., essential to the production and maintenance of a great many military systems—especially when the domestic capacity is appreciably below state-of-the-art.

This is precisely the situation that the Defense Science Board (DSB) addressed in a study recommending the establishment of a semiconductor manufacturing technology institute, since named Sematech. The DSB report stated that U.S. military strategy depends on leading edge electronics, and specifically on semiconductors, that are essential to support U.S. warfighting strategy and capabilities. The DSB argued that decreased competitiveness by U.S. semiconductor makers would soon translate into loss of manufacturing know-how and the ability to fabricate future generations of semiconductors. At some point, loss of manufacturing technique would lead, inexorably, to an inability to design the most sophisticated chips domestically. The study concluded, accordingly, that the military would shortly depend on foreign sources to supply advanced semiconductors, and that this is an unacceptable condition.

Some observers argue that the Sematech concept addresses the symptoms and not the heart of the problem. The real issue, they contend, is the question of how the United States can stay at the leading edge of technologies that are crucial to the military defense of the Nation. Sematech may provide the near-term ability to design and fabricate silicon-based dynamic random access memory chips, but it will do nothing to maintain state-of-the-art capacity if global market forces push subsequent generations of equipment into gallium arsenide or optically based technologies. From this perspective, the real question centers on how to structure policy and markets to keep and maintain technological capacity in the United States.

Dependence on pervasive, dual-use technologies might be a critical factor even in peaceful and prosperous times, when trade is mutually advantageous between two countries. Consider a scenario, perhaps in the year *2000,* when DoD would place an order for the next generation of sophisticated GaAs-based integrated circuits made only in Japan. The Japanese, who reportedly expect a substantial commercial market by the turn of the century, might then be unwilling to produce the parts to military specification, at a price the United States could afford. The DoD order might not be large enough to justify the cost of new manufacturing technology or the diversion of technical resources from more profitable commercial markets. In this scenario, the alternative would be to attempt to build the chips in the United States. But if the domestic industry was not already fabricating the chips for commercial markets, the cost would be prohibitive because the order would have to pay for new factories as well. It is even possible that the capacity to design the desired product might no longer reside in the United States. And without recent experience, it is likely that the chips that could be produced would not match Japanese performance and reliability. Considering the military need for enhanced computational speed and for radiation hardness, such dependence would clearly be undesirable, even in the best of times.

On the other hand, depending on allies for advanced dual-use technology can be beneficial on a number of grounds. First, it increases economic interdependence which, if properly managed, leads to strong incentives for continued alliance and cooperation. Second, it can provide access to state-of-the-art technologies that simply are unavailable in the United States. In today's global economy, it is no longer possible for the United States to dominate—and at present the United States is not even competitive in—a full range of commercial technologies and markets. And finally, in many cases, internationalization of technology makes possible a wide range of economies of scale and manufacturing expertise that would be difficult to achieve domestically.

The second significant dimension of the issue of military dependence on foreign technology arises because DoD prime contractors produce major weapon systems that incorporate components and subsystems developed by foreign defense firms. Both economic and political considerations contribute to "offset" agreements where U.S. allies contract to buy a portion of the run for a particular missile, airplane, or submarine, thereby lowering the unit cost of procurement and increasing military and economic cooperation within the alliance. In return, the prime contractors agree to purchase a certain percentage of the components and subsystems from participating allies. In addition, the United States has entered into a number of cooperative agreements for conventional defense development programs with its NATO allies pursuant to congressional direction.

There are substantial benefits to be realized from mutual and interlocking dependence among allies in the development of military technologies. To this end, the United States participates in the NATO Conference of National Armaments Directors, is a major supporter of the SHAPE Technical Center located in the Hague, and is a member of the NATO-sponsored Advisory Group on Aerodynamic Research and Development in Paris. Technological interdependence tends to strengthen the alliance itself because it raises the costs for any ally that would choose to withdraw from the alliance. International division of labor also creates an opportunity for the United States to gain access to superior military component technologies that it cannot get at home. Few observers believe it is still possible in a global economic environment for any country to maintain leading edge technology across the entire range of significant military capabilities. Just as international competition creates winners and losers in commercial markets, innovation and leadership in military technologies is increasingly dispersed across a spectrum of highly capable firms with different national orientations and loyalties. Under these conditions, maintaining state-of-the-art military capabilities requires that the United States draw on the best products emerging from an international defense technology base.

On the other hand, certain liabilities are associated with dependence on foreign components used in U.S. weapon systems. One can envision an international division of labor where the United States would produce the components and systems for which it had developed the requisite technology base, and then would buy or trade with its allies to procure parts and systems supported by their leading edge technologies. While this kind of cooperation is probably necessary and unavoidable in some technology areas, it presupposes a peaceful world in which free and open trade are the norm in an interdependent world economy. Citing rising international economic tensions and increasing regional military conflict, some analysts argue that the relatively stable post-war economic and political order may be rocked by significant changes in the future. For this reason, they caution that excessive military dependence should be avoided, even with allies and friendly trading partners.

There is, in addition, the issue of timely delivery of parts or components of military importance. In some cases, it might be more lucrative for a firm to delay its deliveries to the Department of Defense, giving priority to a preferred customer. If the company is located in the United States, DoD or the prime contractor would have more leverage to press for delivery of scarce items. It is much more difficult to ensure continuity in timing and supply when the firm in question is located in another country.

Governments now and in the future will seek to create market advantages for their own domestic firms irrespective of whether they are organized primarily for commercial or military production. While a blanket policy that opposes military dependence on foreign technology might enhance security in the near term, it might also tend to undermine significant benefits that are realized through selected and intelligent cooperation with our allies, even though such relationships might ultimately lead to a system of interlocking dependencies.

It is, accordingly, important to look at the issue of foreign dependence not as an article of faith, but rather in relation to specific technologies, industrial sectors, and political and economic realities that constrain our choices. Under what circumstances should the United States rely on its allies and trading partners for selected military technologies, even when such reliance leads to diminished domestic capacities? By what criteria could areas be identified in which the United States should reduce dependence on foreign technology? What policies—R&D, tax, trade, or otherwise—might help minimize dependence, and at what cost? And finally, what and how severe are the risks to United States national security when selected dual-use technology industries move offshore?

Health of the Dual-Use Commercial High-Tech Sector

Strong interaction between the military and the civilian economy has characterized the growth of high technology in the United States in the post-WWII period. Today, commercially produced dual-use technologies-e. g., microelectronics, computers, fiber optics, and advanced composites—are necessary for the design and production of a wide range of weapon systems. Recent losses in competitiveness and leading edge technical capacities by commercially oriented domestic firms raise concern, principally for two reasons.

The first is that DoD depends on the dual-use sector to develop and transfer new technologies that are of military significance. This can be a critical resource, even when the military uses only a small fraction of the products resulting from a given technology. Civilian contributions to new and evolving technologies are especially important because military hardware in some fast-moving areas can be 5 or more years behind the leading edge of the commercial sector.

The second cause for concern is that the military relies on commercially oriented firms for high-technology products that are incorporated into military hardware. In general, the Pentagon will designate a single prime contractor both for the development and manufacture of a major weapon system. If the project is on the scale of a nuclear submarine, for example, the prime will contract, in turn, with hundreds of subcontractors for the design and production of subsystems and specific components. Some of the subcontractors may execute additional agreements with other companies, and soon down the line. At some point in this chain, many of the components and parts that end up in the final product will be bought off the shelf from corporations that do most of their business in civilian markets.[6]

In terms of defense technology policy, decline in critical dual-use high-technology industries can be addressed both from an in-house and from an economy-wide perspective. In the first case, DoD can create a new capacity, or “farm industry, ” within the defense contractor community and in the government laboratories to meet specified needs for advanced technology. In the VHSIC (very high speed integrated circuit) program, for example, OSD sought to extend conventional silicon technologies and to increase the pace of development in design tools, advanced production equipment, and semiconductor device designs.[7] But high-ranking Pentagon officials indicate that the VHSIC technologies have only been deployed in one weapon system to date. This kind of remedial action is extremely expensive, and can probably only be maintained on a modest scale.

The second option is to stimulate, directly, those high-technology industries in the commercial sector that are deemed necessary to the development and manufacture of the next generation of military hardware. In many cases, however, the DoD share of the market for a given technology is not enough to pull the industry forward. Under such conditions, the resources and capital formation of commercial markets are necessary to stimulate development and leadership in high technology. It

[6] In addition, the Pentagon buys a great deal of office equipment, such as computers and typewriters, directly from commercial firms.

[7] Kenneth Flamm, *Targeting the Computer: Government Support and International Competition* (Washington, DC: Brookings Institution, 1987), pp. 77-78.

is likely, for example, that loss of competitiveness in high-volume semiconductor markets by U.S. companies would lead, in time, to military dependence on foreign sources for a wide range of enabling technologies. Accordingly, the continued ability to produce state-of-the-art weapon systems that are superior in the field may finally depend on the Nation's capacity to produce high-technology products that are competitive in world commerce.

Because both of these options have severe limitations, it maybe necessary to go beyond the arena of defense policy and to consider additional alternatives from a broader economic perspective. Some analysts argue that avoiding dependence on foreign high technology requires a better understanding of the relationship between the development of new knowledge, the manufacturing process itself, and the formation of capital for industrial purposes. They suggest that one strategy, sometimes pursued by the Japanese, is to begin operating in a technology area where an industry must accept a certain degree of foreign dependence at the outset. But a primary objective (en route to establishing a viable market share) is to acquire technological know-how and the manufacturing ability as a national asset, severing relations with foreign industry as domestic capacity increases. To accomplish this transition, industry must have access to domestic arrangements and sources for capital formation that are superior to those extended in foreign countries.

Executives in high-technology industries argue that when the venture is capital-intensive, the ability to design new leading edge products will be closely tied to the manufacturing process, which will be physically located where the most advantageous arrangements for capitalization can be made. It will also be tied to the ability to transition new concepts and technology breakthroughs into an efficient production process. In this view, the capacity to mobilize the technology base is a technology in its own right—one that must be mastered before competitive new products can be introduced to the marketplace. For example, it requires specialized skills and techniques to discover a new high-temperature superconductor. But once it is made the first time, and the research is published, other researchers can duplicate the process. Even so, designing high-temperature superconductors into products that are useful and producible is extremely difficult. It is costly and will require sophistication and further research in a wide range of technologies.

In addition, the capital requirements for mobilizing a new technology-of bringing new ideas out of the universities and into efficient mass-market production operations—can be enormous. The difference between a capital cost of 7 percent and one of 9 percent may make the difference between success and failure. Cost of capital affects the time it takes to get the product to market, and determines, in part, the kinds of activities that stockholders are willing to fund. When two companies are in competition to produce a comparable product, the one that can acquire an equity base that enables it to get its product to the market 1 year before the other will win. Some business persons are concerned that government does not understand the relationship between the cost of capital and the capacity of their companies to transition new technology into the marketplace. They cite the easy credit arrangements that governments of some Pacific Rim and European nations extend to industry. They believe that anti-trust law can significantly disadvantage American manufacturing, particularly in high-technology sectors, because it has tended to block the formation of combined capital resources that may be required if an industry is to survive in the international competition.

Under such conditions, a failure to provide capital incentives to locate high-technology industries in the United States will have predictable consequences on the process of technology innovation. These can be expressed as three distinct steps in losing a technology. In the first, an industry moves its manufacturing operations offshore, perhaps because cheaper capital can be obtained or because production costs, including labor, are lower. The United States may also retain a manufacturing capability, but may not be able to produce at a competitive cost. Second, when the technology evolves to the next generation, the U.S. part of that industry may find that it has lost the ability to manufacture the new products on a stateof-the-art, competitive basis. At this stage, costs of getting back into the manufacturing end of the business maybe prohibitive. And finally, when the technology evolves yet again, and is now two or three generations away from the original product line, it will be difficult, if not impossible, for U.S. companies to design leading edge new products. To do so, the industry would have to find designers with access to the proprietary information generated in the production process associated with the previous generation. In this scenario, a nation loses a high-technology industry because it fails to pursue capital incentives sufficient to keep the industry at home, and this leads, in turn, to a simultaneous degeneration of process and design know-how which may be combined with loss of market share and investment capital.

Some observers believe that government policies have contributed to an overall decline in the competitiveness of American industry. They argue that government has not only failed to stem the migration of U.S. factories to foreign countries, but has also neglected to support the interests of American business at home and abroad. In this view, U.S. companies have had to compete with foreign industry that enjoys advantages-such as protected home markets, low cost capitalization, and R&D subsidies-that are the constituent parts of carefully orchestrated national industrial strategies. One result, they claim, is that the dual-use infrastructure of domestic technology is weakening. In addition, fiscal and monetary policies have, until recently, kept the dollar artificially propped up against foreign currencies, making imports relatively less expensive than domestically produced goods. A massive trade imbalance, high interest rates, and excessive foreign investment have exacerbated a comparative disadvantage in capital formation for domestic firms. In addition, some argue that tax incentives, like the investment tax credit, are not carefully enough tailored to benefit most industries upon which the military depends.

Others think that U.S. free trade policies have led Congress and the administration to be indifferent to the inability of technologically oriented American companies to compete more successfully in world markets and with foreign competitors at home. They argue that American business cannot “go it alone’ against unfair combinations of state power and industrial might in the international marketplace. The belief that American companies can sustain market share against the concerted national economic policies of their trading partners is, they contend, a potentially disastrous holdover from a bygone era of American military and economic hegemony.

There is great diversity of opinion as to what Congress should do about the loss of world market shares of some American high-technology industries, and the resulting damage to the dual-use technology base in the United States. Some observers believe that Congress should do nothing because it is faced with what amounts to an intractable dilemma. If the Pentagon pursues a policy of buying the best available high-tech products at the lowest price, then it will introduce foreign dependence to the weapons procurement process over the long run. This course of action would tend to advantage foreign competitors at the expense of American companies. But these circumstances might also create strengths in the military capacity of our allies, encouraging them to shoulder more of the defense burden in the future. On the other hand, if the United States adopted a policy to buy only from American companies, then it would lose access to some state-of-the-art technology, and might have to pay excessive costs associated with domestic production. In this view, Congress should continue to stay on the sidelines because any course of action is likely to create extensive dislocation and unacceptable adjustment costs.

Advocates of a more coherent industrial strategy argue that the United States cannot afford to lose certain essential industries. They point out that other countries have taken steps to avoid such losses, steps that have, in some cases, damaged U.S. economic interests. Under these circumstances, the United States should now consider legislative action not only to protect critical high-technology markets, but also to adopt tax and monetary policies which guide American business toward greater productivity and profitability. Such a perspective, they acknowledge, envisions a more central role for government in the affairs of business. But they also contend that such measures will be necessary if U.S. corporations are to remain competitive in the face of what amounts to concerted Japanese and European economic policies that are structured to create advantages for domestic firms in foreign markets. At a minimum, they argue, government should adjust macro economic and other policies to slow or halt the decline of American high-technology industry. They do not expect a return to the overwhelming economic and military leadership that the United States enjoyed in the immediate postwar decades, but they would hope to arrest its decline.

Others oppose both the "do nothing" and the "high-tech industrial strategy" scenarios in favor of a negotiated middle ground. They contend that Congress must not allow the demise of a range of technological capabilities and industries that are of strategic military importance. They seek national economic self-sufficiency and independence for a limited group of high-technology industries that are necessary for numerous weapon systems. While it is not possible for the Department of Defense to underwrite every industry that produces high-tech products for military systems, careful planning and prudent investment might support a stable of technical capacities that are essential to the national security.

Some argue that DoD could do a great deal more to support the dual-use technology base in the United States. In this view, DoD has concentrated too many of its resources in a small number of defense prime contractors on the assumption that R&D and procurement funds will ultimately filter down to the lower tier subcontractors where many dual-use technologies are developed. They contend that the R&D base for the dual-use infrastructure of American industry could be enhanced if DoD would commit a greater percentage of its funds directly to the sub-tier industries. But they also note that this approach would require major simplifications in DoD contracting and reporting processes, as well as substantial substitution of commercial for military specifications in future weapon systems.

Many analysts believe that the United States should seek to avoid dependence on foreign manufacturers for high-technology products that are critical for the defense of the Nation. This objective is particularly difficult to achieve in many dual-use industries, where the Department of Defense is at best a minor customer. Nevertheless, if the United States is to avoid foreign dependence, then state-of-the-art design and manufacturing capacities must remain in the United States for an array of technologies that are critical to the development of defense systems.

A central difficulty is that for many of the most important technologies, the pace and direction of rapid innovation are driven by developments in the commercial sector by industries that are typically multinational in scope. Moreover, the capital requirements for R&D, design, and manufacture of successive generations of many high-technology products are enormous. Because DoD cannot fund the full spectrum of technologies that are essential to the national defense, the health of these industries will depend on profits from sales in the commercial marketplace.

High-technology manufacturing in the United States cannot be expected to survive if the American market is dominated by foreign imports. The United States has pursued a trade policy that assumes fair and open trade, and encourages Americans to purchase goods of the lowest price for a given quality, regardless of where they were made. In pursuit of lowest cost or access to foreign markets, many American firms have moved manufacturing operations offshore. In addition, many foreign firms sell goods in the United States. At the same time, many foreign governments prohibit U.S. firms from selling similar products in their home markets.

Recognition of the power of governments to create and alter international economic environments through trade, tax, non-tariff barriers, and various industrial policies has led some observers to propose new approaches to structuring the U.S. high-technology market and industrial base that go well beyond the limits of existing U.S. policy. One such approach would impose prohibitions against importing key high-technology products made by foreign industry as well as by American-owned operations located in foreign countries. Instead, both U.S. and foreign-owned firms would be required to manufacture those key products in the United States if they intended to sell them in the United States. Such a policy would force some definite portion of the high-technology manufacturing base to be located permanently in the United States. Presumably, other countries would institute similar restrictions. Reciprocal arrangements would have to be negotiated to establish mutually acceptable manufacturing and merchandizing rights among participating nations, with the result that each nation would consider the interests of the larger trading block in forming its own policies. Proponents agree that while this approach might create more stable manufacturing conditions, the turmoil of transition would be unprecedented.

Most observers agree that it is essential to view the issue of the health of the dual-use industries both in terms of military needs for the next generation of weapon systems, and from the perspective of structural dislocation of the wider economy. Is it necessary and feasible to establish policies to preserve selected high-technology industries, together with governmental institutions to carry them out? If so, how would DoD's interests be represented? What degree and kind of government intervention, if any, will be necessary to ensure the future health of the dual-use sector of the American economy? Are there specific government policies that have weakened important domestic high-technology industries? Are there areas where government inaction has contributed to the problem?

Problems in the Defense Industries

For most technical developments of military significance, the road from laboratory to field runs through a select and highly concentrated group of large defense contractors. While these companies can perform a variety of major tasks, their principal role is to act as prime system integrators. These are the companies that assemble the products of subcontractors and component makers into finished missiles, aircraft, submarines, and other defense systems. Over time, the prime contractors have developed a unique relationship of mutual dependence with the government. Unusual business conditions have created a situation in which there is only one buyer, the Department of Defense, and following contract award, only one supplier. The trend over the past quarter century has been toward greater concentration and fewer contracts, resulting in winner-take-all sweepstakes for many major weapon systems.

Because the defense industry both consumes and develops new technology, there is long-standing concern that its unique relationship with the government may inhibit technical development and the most efficient application of new technology. The most prominent of these concerns fall into three closely related areas, each of which influences the health of the defense technology base: 1) unstable business conditions, 2) inducements for corporate R&D, and 3) outmoded manufacturing technology.

The Department of Defense and the prime contractors have argued for years that Congress should adopt a multiyear budgeting cycle which would provide greater stability in the complex and demanding business of building advanced technology weapon systems. If DoD could authorize a prime contractor to produce 500 aircraft at a rate of 50 per year for 10 years, stable business conditions could be achieved. Instead, economies of scale and other efficiencies are sacrificed when Congress appropriates funds for limited production runs on a year-to-year basis. Or, alternatively, OSD or one of the Service buying commands may decide to shift funds away from a particular program, creating the same perturbations. Under these circumstances, rational business principles and planning processes cannot readily be applied.

Critics argue that unstable business conditions exist in all markets, and that establishing predictability is what planning and marketing is all about. Like many firms in the commercial sector, defense contractors tend to plan only in the short term of 12 to 24 months. Preoccupation with near-term sales discourages the defense sector from making long-range investments in basic and applied research. Such practice, they contend, deemphasizes the value of investing in new technical developments, a kind of investment that may not pan out for as much as 5 to 10 years. Government procurement processes and regulations may reinforce this trend, providing few inducements for defense contractors to put money back into the technology base.

A second and highly related problem concerns independent research and development (IR&D), a principal mechanism through which government encourages the defense contractors to develop technologies that can result in new products with defense applications.[8] As presently constituted, IR&D is a major factor in building and maintaining the defense technology base because the cost to DoD is equivalent in size to approximately one-fourth of the overall science and technology base activities (6. 1-6.3A, including SDI) funded by the Department of Defense. As it stands now, administration of DoD's funding of IR&D is so complex that even senior administrators and experts who study the problem have difficulty agreeing on the basic components and concepts of the program. Accordingly, a central policy issue is the question of what incentives the IR&D mechanism actually provides for industry, and whether it is an efficient device for meeting national goals. Congress may wish to leave it alone, adjust its operation, or abolish the IR&D mechanism—substituting in its place a program that offers significant inducements for company R&D, but which can be more easily monitored and evaluated.

In general, research and development conducted by the DoD contractors is either carefully specified under contract with the government or it is initiated independently (and not under any contract). Under the IR&D funding mechanism, a portion of the costs of independent research is recovered as part of an overhead charge on all contracts which a company enters into with DoD. Typically, major defense contractors will present to DoD a description of the IR&D they propose to conduct–to receive a technical evaluation, and to negotiate the terms and conditions for reimbursement. Although it is often referred to as a "program" by DoD officials, and Congress annually approves a ceiling for IR&D on an advisory basis, there is no line item for IR&D funds in the defense budget.

Companies that choose to conduct IR&D, and receive DoD approval of their work, are able to recover a portion of their IR&D costs as an additional, negotiated increment of overhead (historically about 2 percent of the contract cost) on their contracts with the Department of Defense. In addition, these companies retain proprietary and data rights for the R&D that is conducted. Such rights become a significant asset for the company, can generate future contracts with DoD, and can lead to additional future IR&D.

Within DoD there are actually two mechanisms–IR&D and B&P (bid and proposal)–which are managed as essentially a single element, although the objectives and criteria of each are different. IR&D is research, development and design activity conducted by defense contractors that is not directly in support of funded DoD contracts. The word "independent" is used to indicate that the companies re-

[8] For a comprehensive review of the history and present status of the IR&D question, see U.S. Congress, Congressional Research Service, "Science Support by the Department of Defense" (transmitted to the Task Force on Science Policy, Committee on Science and Technology, U.S. House of Representatives, Science Policy Background Report No, 8, Serial II, Washington, DC, December 1986), ch. VIII.

tain final authority on what research is conducted, but it is somewhat confusing because DoD usually reviews and evaluates the research in advance. In addition, the term is used to distinguish non-contractual (independent) R&D from R&D that is performed under contract with DoD. (It can also refer to R&D that the company performs on its own that is not submitted to DoD for reimbursement.) The term "B&P" refers to costs that contractors incur when they respond to government RFPs (request for proposals) or prepare unsolicited proposals directed toward anticipated military needs.

DoD requires that B&P efforts not be directed toward actual design and development. In addition, data rights do not result from activities conducted with B&P funds because the purpose of these reimbursements is to offset the costs of submitting project proposals to the Department of Defense. In actual practice, however, companies do intermingle IR&D and B&P funds, and it is difficult for DoD to impose accountability and control mechanisms in this area. Indeed, regulations now permit companies to shift costs between prenegotiated B&P and IR&D cost ceilings for any given year, and B&P is not monitored as closely as IR&D. Critics charge that companies are able to conduct virtually any type of activity they deem necessary to gain and maintain a competitive edge, and that the government pays without obtaining any rights to the design data or the right to procure the product from another source. While it is true that government does not acquire proprietary or data rights, and the companies do have wide latitude in the selection of IR&D projects, DoD has placed substantial controls on IR&D/B&P reimbursements in an effort to ensure that such work, when conducted by industry, is directed toward the needs of the national defense.

There is considerable debate as to the effectiveness of the DoD regulations that control IR&D. Many industry leaders and some DoD managers believe that DoD regulations go well beyond those envisioned by Congress when it enacted Section 203 of Public Law 91-441, which contains the requirement that IR&D activities show potential military relevance (PMR). Due to ambiguity in the language of Section 203, however, some projects that are used to calculate the IR&D/B&P ceilings do not meet the PMR test. DoD administrators maintain that they have brought this matter to the attention of Congress, and that Congress has not taken corrective action. In the absence of further congressional direction, DoD requires that "the total portion of the ceiling allocable to DoD contracts must be matched by IR&D work having a potential relationship to a military function or operation, " even though individual IR&D funded projects may not meet the PMR requirement.[9]

Detailed IR&D Technical Plans are prepared by participating companies each year. These submissions include future plans as well as a review of past activities. Through OSD, the military Services review these plans to ensure that a potential military relationship exists, and to assign numerical scores, based on the technical quality of the plans. In addition to this technical documentation by each company and the rating process by DoD, onsite reviews of IR&D efforts are conducted at major companies on a 3-year cycle. These reviews are often quite detailed, typically requiring 2 or 3 days of presentations to the review team.

While this review process is costly and time-consuming, the fact remains that the bulk of the defense contractors receive almost automatic approval of their IR&D plans. In addition, IR&D is highly concentrated in a few companies. Roughly 90 companies receive 95 percent of IR&D funds, with wide distribution of the remaining 5 percent to approximately 13,000 firms.

The initial funds to conduct IR&D/B&P activities are committed by the individual companies, and the portion of the costs deemed "allowable" by DoD negotiators is accepted for allocation to all of the company's business. DoD does not permit the entire costs of company R&D to be recovered, and government

[9]DoD fact sheet entitled "DoD Implementation of Public Law 91-441, Section 203. "

"share' is negotiated annually.[10] For example, in fiscal year 1986, US defense contractors told DoD that they spent roughly $7.39 billion for IR&D/B&P ($4.97 billion for IR&D and $2.42 billion for B&P). Of that, DoD recognized $5.26 billion ($3.51 billion for IR&D and $1.75 billion for B&P) as costs that could legitimately be associated with products sold both to government and to commercial customers. Of this total, the government's share came to $3.50 billion ($2.16 billion for IR&D and $1.34 billion for B&P). The overall ceiling for IR&D is set annually by Congress.[11]

The propriety of IR&D/B&P reimbursements has been questioned by several Committees of Congress, and has been the object of sustained controversy over the past 20 years. The defense contractors argue that IR&D is the lifeblood of their business, providing a means for them to conduct innovative research that contributes to the maintenance of the defense technology base in the United States and results in major new weapon systems. From their perspective, it is analogous to new product R&D conducted in the commercial sector, with the difference that the element of risk is largely shifted to the government because DoD has agreed to cover its share of the costs in advance.

A panel of senior officials with extensive defense experience has concluded that:

> the substantial R&D undertaken by U.S. defense industry (reimbursed in part by the Department of Defense) has changed significantly in its character. While this effort was highly innovative in the 1950s and 1960s, it has become increasingly conservative in the 1970s and 1980s. Today, it has become far more an effort to reduce technical risk than to innovate. In some measure the Pentagon is responsible for the new emphasis. The main criterion for reimburse ment used to be the innovativeness of the work; today the controlling question is apt to be whether industry's R&D is sufficiently related to an ongoing weapons program.[12]

Defense industry executives argue that IR&D is the mechanism through which their companies build up internal technology bases. They contend that IR&D is not a partnership with the government, but rather that relations with DoD are sometimes strained and that there is a good deal of tugging and pulling over this issue. Many see IR&D as a creative alternative to government regulation. In this view, when the government lets an R&D contract, it is DoD bureaucrats and not industry technologists who determine the direction of R&D programs within industry. The IR&D mechanism has the benefit that it originates in the defense companies and represents the best thinking on technology that the private defense sector can provide. It is, they contend, the central mechanism that enables industry to tell the government where major R&D emphasis and projects should be placed. According to industry executives, IR&D proposals receive internal corporate review at the highest levels of management and represent fundamental decisions concerning the direction of future corporate research.

Some observers contend that IR&D is, at best, an inefficient means of supporting research in the defense industries, and at worst, a gigantic government giveaway. They point out that the bulk of IR&D goes to fewer than 20 contractors, and argue that it tends to strengthen existing companies and to inhibit competition by handicapping new firms that are not already doing business with DoD. Others are concerned that IR&D funds are targeted toward short-term technical applications

[10] The government "share' of accepted costs is allocated as overhead to government contracts and the government's "allocable share" is determined as a percentage of the total business that the firm does under contract with the government. The level of costs to be allowed is usually negotiated. Firms recover a larger portion of B&P costs then IR&D costs from DoD, either as a percentage of incurred or accepted costs. See U.S. Congress, Congressional Research Service, "Defense-Related Independent Research and Development in Industry, " (prepared by Joan Dopico Winston, CRS Part No. 85-205S, Washington, DC, Oct. 18, 1985), app. III.

[11] In fiscal year 1986, DoD tended to be more generous in its reimbursement for B&P than for I R&D, reimbursing 76.6 percent of recognized B&P and only 61.2 percent of recognized IR&D.

[12] From "Discriminate Deterrence, Report of the Commission on Integrated Long-Term Strategy (January 1988), p. 46.

for which relevance can easily be demonstrated and costs recovered quickly. In this view, it contributes little to long-term research and development on which the health of the defense technology base depends.

Are the interests of government best served by the IR&D/B&P system as presently constituted? Is industry technically enhanced as a result of IR&D, or could these funds more effectively support the defense technology base through some alternative mechanism? Does the system of IR&D reimbursements discourage new companies from contributing to the defense technology base? Does IR&D inhibit DoD from drawing more widely on the commercial sector?

A third area of concern centers on antiquated and inefficient manufacturing practices within the defense industries. For more than two decades, DoD has supported the Manufacturing Technology Program (ManTech) and, more recently, the Industrial Modernization Incentives Program (IMIP).[13] But these efforts have not provided sufficient incentives to encourage modernization of many plants that build advanced weapons systems. The result is that inefficiencies and excessive costs, that would not be tolerated in the commercial sector, have come to characterize a large portion of the defense industries.

Critics charge that many prime contractors have largely neglected the manufacturing process, despite the fact that a few have built state-of-the-art demonstration facilities. In this view, contractors have tended to emphasize labor-intensive product technologies that strive to reach the outside limits of performance. They contend that many contractors concentrate on fancy, expensive new product technologies that will catch the eye of some project manager in DoD. When the contract comes through, they assert, the defense companies have not developed sophisticated manufacturing facilities capable of delivering the new product on time, at agreed costs, and up to military specifications. They conclude that a myopic focus on super high-tech, complex systems, has led to shortfalls in manufacturing technologies that cannot be sustained indefinitely.

Other observers contend that the system of government contracting, particularly the cost-plus-fee instrument, creates disincentives for firms that would like to modernize their manufacturing processes.[14] They argue that such contracts encourage high production costs because profit, overhead, and other fees are calculated as a percentage of the total cost of production. In the defense industry, where firms are comparatively more insulated from international competition, supply, demand, and other market forces, there is less incentive (and less progress) to contain costs and to increase efficiency by upgrading outmoded manufacturing practices. Indeed, increased manufacturing costs can translate into increased profits and other fees on future contracts.

There are additional disincentives. If a contractor attempts to modernize manufacturing technology, he must face the risk that the new process may not work in the short run, or may introduce significant delays into production that may result in angry program managers, negative publicity, investigative reporting, audits, and congressional ill will. In addition, some analysts contend that government has failed to provide sufficient inducements to support research, development, and implementation of costly new process technologies, ManTech and IMIP to the contrary notwithstanding.

And finally, some observers argue that when industry makes major investments in more ef-

[13] The National Research Council concluded, "The actual impact of the [ManTech] program, however, was limited . . . Several groundless but widely held myths have been used to support the erroneous belief that manufacturing technology was either an unimportant or an inappropriate concern of DoD. Continued acceptance of these myths could be devastating for the next generation of weapon systems. " National Research Council, *Manufacturing Technology: Cornerstone of a Renewed Defense Industrial Base* (Washington, DC: National Academy Press, 1987), p. 16.

[14] " The defense procurement system creates a business environment that provides inadequate incentives for process improvement. Both the nature of competition among contractors and the contract pricing policies act to inhibit emphasis on production efficiency." National Research Council, *The Role of DoD in Supporting Manufacturing Technology Development* (Washington, DC: National Academy Press, 1986), pp. 10-11.

ficient process technology and manufacturing plant, the benefits accrue only to the government, and may even damage the position of the defense contractor. This would occur typically when a future contract is negotiated with the government, and the company's cost base is reduced, decreasing profits and other fees. In such circumstances, the company might be unable to recoup the investment that it had made in new manufacturing technology. This mechanism, it is argued, encourages small and incremental improvements where the costs can be recovered in a single contract run. It is a direct disincentive to major upgrading of manufacturing facilities, and acts particularly to the detriment of small companies that cannot withstand losses which would result from less favorable terms on future contracts.

With regard to the defense industries, the policy question turns on the issue of what can be done to stimulate large defense contractors to plan and invest in longer range technology, and to invest in modem manufacturing or process technologies. Should Congress substantially alter the relationship between DoD and the defense contractors? Do government policies inhibit the transfer of technology to defense companies or the entry of innovative companies into the defense business? Does the emphasis on short-term planning inhibit technological innovation and, if so, what government policies would have to be changed to reverse this orientation?

Supply of Scientists and Engineers

Because the vitality of the defense technology base ultimately depends on the supply of qualified scientists and engineers, demographic trends that forecast shortfalls and a change in the national character of the supply have aroused widespread concern. Is there a military or economic requirement that a certain number of American citizens be trained as scientists and engineers? If so, is it likely that sufficient numbers of Americans will enter advanced degree programs in technical fields over the next decade?

Various studies indicate that over the next 10 years the United States will experience a decline of up to 25 percent in the number of young people entering college. This includes an expected increase of 20 to 30 percent in the number of minority students who, historically, have not entered advanced degree programs in science and technology in large numbers. If these trends persist, they could exacerbate an already significant decline in the number and percentage of U.S. citizens receiving advanced degrees in science and engineering. In previous work, however, OTA has found this scenario unconvincing. OTA concluded in 1985 that "it is entirely possible that supply of people trained in science and engineering will not decline at all, despite the drop in college-age population."[15]

The decrease of U.S. citizens entering these advanced degree programs has generated special concerns both within DoD and in the defense industries because demand for engineers and scientists in specialized fields significantly outpaces supply. In 1981, for example, there were 10 jobs for each new degree holder in computer sciences and 4 jobs for each new nuclear engineer. Defense analysts also cite shortfalls in the area of aeronautical engineers, and in the fields of avionics, computer software, and electrical systems, among others.[16]

Recent strong demand has been coupled with a long-term increase in the number and percentage of foreign nationals enrolled in graduate degree programs in science and engineering. In the 20 years between 1964 and 1984, the proportion of foreign Ph.D. candidates in these disciplines increased from 17 to 26 percent. Among engineering Ph.D. candidates alone, the proportion of foreign nationals ad-

[15] U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force-A Technical Memorandum*, OTA-TM-SET-35 (Washington, DC: U.S. Government Printing Office, December 1985), p. 4. Issues concerning the supply of technical personnel are discussed further in the forthcoming OTA assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (in press), anticipated to be released in May 1988.

[16] Report of the Defense Science Board Task Force on University Responsiveness to National Security Requirements, January 1982, DTIC #ADA 112070, pp. 2-3 and 2-4.

vanced from *22* to *56* **percent.**[17] Some observers are alarmed at the growth in the percentage of U.S.-trained foreign scientists and engineers, which has occurred at the same time as a reduction in the number of U.S. citizens trained in technical areas. The total number of students in graduate school has increased, while Ph.D. degrees have remained the same.

If present trends continue, the DoD labs and the companies that do business with the military will be faced with three choices. They could elect to employ fewer persons, but hire only American citizens. They could maintain the number of American scientists, but pay more to attract them. And finally, they could elect to hire increasingly more foreign nationals over time. A principal security consideration is that it is difficult to exercise effective national controls over persons whose citizenship and allegiance is with another country.

The broader problem, of course, centers on the possible loss of domestic capacity to undertake leading edge scientific research and development. Here, the dual-use technology industries are as much at risk as the government laboratories and contract industries specifically associated with the Department of Defense. Some analysts suggest that the role for foreign scientists may be in the industries which support both commercial and military technologies. They assert that increasing numbers of foreign scientists and engineers plan to live permanently in the United States, and they urge immigration authorities to facilitate the stateside plans of these valuable persons.

The other side of the coin is that many U. S.-trained scientists and engineers return to their own countries. Indeed, many Japanese and European nationals have received their training in the United States, but have gone to work for firms at home that are in direct competition with companies in the United States.

The policy question centers on what steps, if any, should be taken to increase the number of projected U.S. scientists and engineers, and whether it is necessary or wise to take steps to affect the number of foreign graduate students in U.S. universities.[18] Is there a need for additional scientific manpower to satisfy both national security and commercial needs? What roles should foreign scientists play in the defense technology base in the United States?

*'U.S. General Accounting Office, "Plans of Foreign Ph.D. Candidates: Postgraduate Plans of U.S. Trained Foreign Students in Science/Engineering," GAO/RCED-86-102FS, p. 7. The GAO data is taken from "Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook, " NSF 86-305 (Washington, DC, 1985).

"See U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School, OTA-SET-377 (in* press), ch. 4, anticipated to be released in May 1988.

Chapter 4

Managing Department of Defense Technology Base Programs

INTRODUCTION

The Department of Defense (DoD) appropriation for its technology base programs[1] exceeds $8.6 billion in fiscal year 1988, of which almost half (see table 2) is funding for the Strategic Defense Initiative (SD I). This represents less than 4 percent of the entire DoD budget. Nevertheless, many inside and outside of the Pentagon consider DoD's technology base programs a crucial investment in the Nation's overall national security. The military's technology base programs consist of a broad spectrum of 'front-end" technology development, beginning with a broad base of basic research support and extending through the demonstration of technology that may make up future defense systems. The scope of interests within DoD's technology base programs ranges across diverse technological concerns from meteorology to autonomous guided missiles capable of differentiating among various targets.

[1]For purposes of this study, technology base programs refer to budget categories 6.1 (basic research), 6.2 (exploratory development), and 6.3A (advanced technology development). DoD usually considers 6.1 and 6.2 as its technology base programs, with 6.1 through 6.3A normally referred to as its "science and technology programs. "

In fiscal year 1988, more than half of the Pentagon's technology base program was performed by industry, another third by DoD's own in-house laboratories, and the remainder by universities. According to DoD, each of these performers plays an important part in the successful operation of its technology base program, and extensive cooperative efforts among the three groups yields a significant return on DoD's investment.

The universities perform over 50 percent of DoD's basic research activities. In addition, DoD contends that its in-house laboratories provide the Armed Services with the ability to meet special military needs that cannot be met by the Nation's industrial base. These laboratories focus attention on short- and long-term defense needs, and they enable the military to act as a smart buyer of technology and equipment. The primary role of private industry is to develop technology and apply it in new military systems.[2]

[2]Martin, Dr. Edith W., "The DoD Science and Technology Base Programs: Some Management Perspectives, " *Army Research, Development, and Acquisition Magazine,* Sept. -Oct. 1983, p. 3. At the time this article was written the author was DUSD(R&AT).

Table 2.—Department of Defense Fiscal Year 1988 Funding of Technology Base Programs (in millions of dollars)

	Army	Navy	Air Force	DARPA	Total
Research (6.1)	$169	$342	$198	$83	$902[a]
Exploratory development (6.2)	$556	$408	$557	$512	$2,033
Advanced exploratory development	$319	$227	$754	$202	$1,502
Total services and DARPA					$4,437
Strategic Defense Initiative					$3,604
Other defense agencies					$564
Total DoD technology base programs					$8,605

[a]This sum includes $110 million for the URI which OSD has not yet allocated among the three services and DARPA

SOURCE Office of Technology Assessment. 1988, from data supplied by the Off Ice of the Secretary of Defense.

Goals and Objectives

According to DoD, its diverse technology base programs attempt to achieve six major goals:[4]

1. *Offset Soviet Numerical Superiority.* The U.S. does not attempt to match the Soviet Union and the Warsaw bloc on a person-for-person or weapon-for-weapon basis. It relies instead on technology to achieve the desired military advantage.
2. *Keep Ahead of the Growing Soviet Threat.* Although this is increasingly more difficult, the United States must maintain its technological lead in order to offset the Soviet threat.
3. *Reduce Complexity and Costs.* The technology that is produced by the military must be designed to reduce the cost and complexity of future weapon systems.
4. *Improve Productivity of the Industrial Base.* Maintenance of a strong industrial base, vis-a-vis the Soviet Union, is one of the most important advantages for the United States.
5. *Sponsor the Highest Quality of Science and Technology (S&T) Work.* DoD must make sure that the S&T work performed by industry, universities, and its in-house labs is of the highest quality and scientifically sound.
6. *Enhance Return on Investment.* Finally, DoD always tries to receive the greateest possible return on its S&T investment.

The Department of Defense contends that the military's science and technology programs have played, and will continue to play, a crucial role in maintaining the military and civilian science and technology (S&T) base. Examples of this include:

- early development of lasers and incorporation of their unique capabilities into weapon systems;
- early development of integrated circuits and their application to mission-critical capabilities;
- development of aircraft technology which provides substantially improved capabilities in maneuverability, flight, fire control, and firepower; and
- development of the carbon-carbon composite material nosetip for the TRIDENT D-5 re-entry vehicle.

Funding Categories for DoD's RDT&E Activities

The Department of Defense does not employ the National Science Foundation's (NSF) familiar categories of basic research, applied research, and development when reporting its Research, Development, Test, and Evaluation (RDT&E) activities.[4] Instead the Pentagon uses a series of six RDT&E functional categories numbered 6.1 to 6.6. They are defined by DoD as follows:[5]

- 6.1 *Research.* Includes scientific study and experimentation directed toward increasing knowledge and understanding in those fields of the physical, engineering, environmental, biological, medical, and behavioral-social sciences related to long-term national security needs. It provides fundamental knowledge for the solution of military problems. It also provides part of the base for subsequent exploratory and advanced development in defense-related technologies and of new or improved military functional capabilities in various scientific fields.
- 6.2 *Exploratory Development.* Includes all the efforts directed towards the solution of specific military problems, short of major development projects. This type of effort may vary from fairly fundamental applied research to quite sophisticated

[4]Ibid., p. 4.

[4]According to NSF, when DoD provides NSF with its RDT&E spending levels, DoD breaks it down into NSF's three corresponding categories in the following manner: 6.1 research is reported as "basic research' 6.2 exploratory development is reported as "applied research"; and categories 6.3-6.6 are reported as "development."

[5]U.S. Department of Defense, INST 7720.16 (OPNAV 3910. 16). enclosure(3), p.2-7 and 2-8. Department of the Navy, Budget Guidance Manual, 7102.2. Quotations in the following section are from this source; the remaining material is paraphrased from this source.

breadboard hardware, study programming efforts.

> . . . The dominant characteristic of this category of effort is that it be pointed toward specific military problem areas with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters.

- 6.3 *Advanced Development.* Includes all projects which have moved into the development of hardware for experimental or operational test. It is characterized by line item projects, and program control is exercised on a project basis. The focus of Advanced Exploratory Development (6.3A) lies in the design of items being directed toward hardware for testing of operational feasibility, as opposed to items designed and engineered for eventual Service use.
- 6.4 *Engineering Development.* Includes all those development programs being engineered for Service use but which have not yet been approved for procurement or operation. This area is characterized by major line item projects and program control by review of individual projects.
- 6.5 *Management Support.* Includes research and development efforts directed toward support of installations or operations required for general research and development use. Included would be: test ranges; military construction; maintenance support of laboratories, operations and maintenance of test aircraft and ships; and studies and analysis in support of the R&D program. Cost of laboratory personnel, either in-house or contract-operated, would be assigned to appropriate projects or as a line item in the Research, Exploratory Development, or Advanced Development Program areas, as appropriate. Military construction costs directly related to a major development program will be included in the appropriate element.
- 6.6 *Operational Systems Development.* Includes research and development efforts directed toward development, engineering and test of systems, support programs, vehicles, and weapons that have been approved for production and Service employment. 6.6 is not an official category as are 6.1-6.5, but is a term used for convenience in reference and discussion. Thus, no program element will exist numbered 6.6.

> All items in this area are major line item elements in other programs. Program control will thus be exercised by review of individual research and development effort in each Weapon System Element. Activities in categories 6.3-6.6 receive the bulk of RDT&E funding (91.5 percent in fiscal year 1987 estimated).

Funding for DoD’s technology base programs is appropriated to the individual Services, SDIO, and the Defense agencies such as the Defense Advanced Research Projects Agency (DARPA) and the Defense Nuclear Agency (DNA). As table 2 indicates, in fiscal year 1988, SDIO supported the largest technology base program, followed by the Air Force Army, Navy, and DARPA.

An Overview of Defense Research Programs (6.1)

The Armed Forces have supported research since the early days of the Nation. The 1804 expedition of Lewis and Clark, for example, was funded by the Army. With the establishment of the Office of Naval Research (ONR) in 1946, the military became the first Government organization to support a major program of university-based basic research. This commitment continued with the establishment of the Army Research Office (ARO) in 1951, and the Air Force Office of Scientific Research in 1952. The Advanced Research Projects Agency (ARPA, later DARPA) was established in 1958 as part of the U.S. response to Sputnik.

DoD funded the bulk of federally sponsored research prior to the establishment of such Federal research agencies as the National Science Foundation and the National Aeronautics and Space Administration. In the 1950s and early 1960s, DoD sponsored about 80 percent of all federally funded basic research. However although DoD funds about 66 percent of all Federal R&D, it is the fourth largest supporter of basic research, accounting for approximately 13 percent of all federally sponsored basic research.

In fiscal year 1988 DoD will spend about 2.1 percent of its RDT&E budget ($902 million) on basic research. This is down from an average of 4.6 percent in the 1960s and 3.6 percent in the 1970s. During fiscal year 1988, approximately 50 percent of DoD's research will be performed by universities, with another 30 percent by DoD's in-house laboratories, and the remaining 20 percent by industry and nonprofit organizations.

The Department of the Navy will support the largest research program in fiscal year 1988, funding 37 percent of all DoD's research. The Army and Air Force will support about 19 and 23 percent respectively, with DARPA and the other Defense agencies supporting the remaining 21 percent.

The Pentagon views its research program as a crucial source of its future technology. However, DoD research activities differ from other technology base activities because research is not necessarily expected to result directly in a military product. The Services support research into the nature of basic processes and phenomena, and contend that they select research projects based on the quality of science and their potential relationship to the DoD mission.

The three Services and DARPA support research activities in such fields of science as:

- physics
- astronomy
- electronics
- mathematics
- mechanics
- materials
- oceanography
- atmospheric sciences
- behavioral sciences
- radiation sciences
- astrophysics
- chemistry
- computer science
- energy conversion
- aeronautical sciences
- terrestrial science
- medical and biological sciences

Work in these fields is applied to space technology, computer science, electronics, surveillance, command and control, communications, propulsion, aerodynamics, night vision, chemical and biological defense, structures, medical and life sciences, and other areas of military importance.[6]

Most successful research programs lead to further efforts in exploratory development (category 6.2) which focus on more applied configurations with military relevance. This research and development process led, for example, to the injection of laser technology into military systems. The laser was primarily supported by DoD soon after the time of its invention, when its potential military relevance appeared quite remote.

The Office of the Secretary of Defense (OSD) and the Services contend that research accomplishments are transferred or quickly passed onto the military R&D community and potential laboratory program managers.

Extramural contractors, primarily universities and industry, are not expected to justify their (6.1) research proposals in terms of possible DoD applications. However, in-house researchers, because of their laboratory association, are expected to demonstrate a closer association to specific military applications. The most important criterion for funding research is the quality of science, followed by its potential relationship to the DoD mission. Other criteria include:

- the potential of the proposed research to lead to 6.2 work;
- whether a civilian R&D agency should support the proposed research;
- the possibility that the research will lead to radically new scientific discoveries;
- the track record of the researcher(s) submitting the proposal; and

[6]Col. Donald I. Carter, "The Department of Defense Statement on Science in the Mission Agencies and Federal Laboratories," before the Task Force on Science Policy of the House Committee on Science and Technology, Oct. 2, 1985, p. 7.

- the extent to which a proposal fits into a particular Service's 6.1 funding priorities.

The basic research programs in the three Services are comprised of three major program elements (PE):[7] Defense Research Science; the In-House Laboratory Independent Research Program (ILIR); and the University Research Initiative (URI). The Defense Research Science program is the largest of the three programs, making up 90 percent of the 6.1 budget. At 6 percent of the research budget, ILIR is designed to give laboratory directors flexibility in order to take advantage of new technological opportunities and to help maintain a research base in the laboratories. (DARPA and the Army do not support ILIR programs.) The remaining 4 percent of the research budget is devoted to the URI program.

Pursuant to the 1984 Competition in Contracting Act, all of the Services and DARPA publish an annual broad agency announcement (BAA). The BAA outlines the specific research interests of each Service and DARPA, and the procedures for submitting research proposals. DoD contends that all proposals falling within the guidelines of each BAA are considered competitive and satisfy the Act.

DoD believes that supporting 6.1 work is important for its in-house laboratories. By supporting the military's research program, DoD feels laboratory researchers are able to keep abreast of new discoveries and engage in important interactions with the scientific community. According to DoD, laboratory performance of research increases the technical abilities of the laboratories and helps to attract imaginative scientists and engineers.

Technical Review of Research Proposals and Programs

Each of the Services, and DARPA, conducts an extensive technical review of all research proposals. The Army Research Office subjects proposals to a three-level technical review process: a peer *review* in the external scientific community for technical excellence, an Army laboratory review both for excellence and military relevance, and an ARO internal review to make a final funding decision. The Services encourage researchers to discuss their proposal ideas with the appropriate DoD technical person before submitting a formal proposal. Those researchers who follow this suggestion have an approximate 50-percent success rate, compared to a lo-percent funding rate of proposals received without prior contact.

The Navy's technical review is completed primarily in-house by their scientific officers. Of the three Services' research programs, the Office of Naval Research has the largest number of staff scientific officers, about 80. Due to a smaller professional staff, the Army Research Office (ARO) and the Air Force Office of Scientific Research (AFOSR) rely primarily on outside review of their research proposals although they also use in-house expertise to review proposals. (Each has about 40 professional people located at its research office.) The National Academy of Sciences (NAS) has a contract with the ARO and AFOSR to arrange formal technical reviews of research proposals. DARPA relies primarily on the three Services and the external scientific community to review its research proposals.

In most cases, the Service laboratories form technical review panels, made up of the laboratory director and various technical program directors, to decide which research proposals will be funded within the laboratory. The Naval Research Laboratory, for example, uses a Research Advisory Committee, consisting of the laboratory and program directors, that determines which in-house research proposals will be supported.

An Overview of DoD's Technology Base Activities in the Laboratories

The Department of Defense laboratories perform research and development in diverse areas of science and technology in support of military and civil works programs of DoD.

[7] The PE is the basic building block in DoD's program, planning, and budgeting system (PPBS). There are approximately 180 PE's in DoD's entire technology base program, with each PE consisting of all costs associated with a research activity or weapon system.

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There are currently 68 DoD RDT&E laboratories (31 Army, 23 Navy, and 14 Air Force) that have a combined annual cash flow of nearly $10 billion for technology base and other development activities. The responsibilities and operations of the various laboratories differ within the three Services in order to meet their individual mission requirements. DoD's laboratories actually perform only about one-third of the technology base activities, while industry performs over 50 percent and the Nation's universities and nonprofit organizations perform the remainder.

The Pentagon contends that its laboratories play a crucial role in solving science and engineering problems, deficiencies, and needs that are unique to the military. DoD states that the primary purpose of its laboratories is to develop new technologies to support each of the respective Service's missions. According to DoD, the role of the laboratories in the development and improvement of technology and weapons systems is fundamental to improving national security. DoD believes that the laboratories have a responsibility to maintain a strong continuity of scientific activities, free from commercial pressures, directed toward meeting specific military needs. Further, according to DoD, the laboratories provide a fast reaction capability to solve immediate critical problems that may confront the Services. Other responsibilities include the following:

1. ensure the maintenance and improvement of national competence in technology areas essential to military needs;
2. avoid technological surprise and ensure technological innovation;
3. pursue technology initiatives through the planning, programming, and budgeting process; allocate work among private sector organizations and government elements;
4. act as a principal agent in maintaining the technology base of DoD;
5. provide material acquisition and operating system support;
6. stimulate the use of technical demonstrations and prototypes to mature and exploit U.S. and allied technologies; and
7. interface with the worldwide scientific community; provide support to other government agencies.[9]

The Pentagon asserts that its technology base capabilities should serve as a strong complement to the civilian technology base, as emphasized in a recent DoD report to the Senate Armed Services Committee:

> A strong free enterprise economy and industrial base–here and abroad–are the essential underpinning of our defense posture. Investment in our technology base and maintenance of our technology strength are critical to the long term security of the U.S. and our allies.[10]

Over the past several years DoD officials have been trying to resolve a number of difficult laboratory issues. The Pentagon has been struggling with such concerns as improving communications within and among the different laboratories, increasing the management flexibility of the individual laboratory directors, meeting scientific and technical personnel needs, upgrading facilities, developing mechanisms for evaluating the performance of the laboratories, and improving DoD's overall management of its laboratories.

Special Technology Base Initiatives

DoD has initiated a number of special programs to help address specific technology base problems. Most of these initiatives center around such concerns as communication between DoD and various research performers, scientific communications and technology transfer, and support of the research infrastructure.

In 1982, DoD established the 5-year, $150 million University Research Instrumentation

[8]There is about an equal number of other centers that do not perform traditional RDT&E activities, but rather are special facilities with very specific missions, such as flight testing new or refurbished aircraft. The R&D activities of DoD's laboratories are discussed further in chapter 5.

[9]U.S. Department of Defense, "Report (for the Committee on Armed Services) on the Technology Base and Support of University Research," Mar. 1, 1985, p. 42.

[10]Ibid., p. 53.

Program (URIP) to improve the capability of universities to perform research in support of the national defense. This program provides funding for large items of equipment ($50,000 to $500,000) that would not be funded in a typical research grant.[11] This program was considered a success by DoD. But judging by the response, it will not come close to meeting all the instrumentation requests; in the first year alone, it received 2,500 proposals seeking a total of 646 million dollars' worth of equipment.

In 1983, at the recommendation of the Defense Science Board, DoD established the DoD University Forum. The Forum consists of an almost equal number of DoD and university members and was originally co-chaired by the Under Secretary of Defense for Research and Advanced Technology and the President of Stanford University. The Forum has issued reports dealing with such subjects as scientific secrecy and technology export control, engineering and science education needs, and DoD's response to those needs. More recently, the forum's working group on engineering and science education issued a report which endorsed the major components of the University Research Initiative (URI) to foster greater DoD-University cooperation.

According to the Department of Defense, the URI would "address some of the concerns expressed by Congress regarding DoD support for the infrastructure of science and technology in the United States, " particularly at colleges and universities.[12] DoD proposed to spend $25 million in fiscal year 1986 and $50 million in fiscal year 1987 for the University Research Initiative. Congress responded by appropriating $88.5 million in fiscal year 1986, $35 million in fiscal year 1987, and $110 million in fiscal year 1988.

DoD's URI program consists of two major program elements. The first element consists of multidisciplinary research contracts designed to enhance interdisciplinary research efforts between universities, industry, and DoD laboratories. Generally, these contracts will receive support for 3 to 5 years, with review and evaluation after 3 years. These research centers will conduct research in a range of disciplines (mathematics, engineering, and the physical, biological, and social sciences) important to the Pentagon. The centers will increase overall defense funding for high risk basic research in support of critical defense technologies, as well as continue support (in place of URIP) for equipment and instrumentation.[13]

The second major URI program element is the "Programs to Develop Human Resources in Science and Engineering. " This program element is designed to increase DoD's support for fellowships, postdoctoral, young investigators, and scientific exchange programs, in order to promote interaction between scientific and engineering personnel in DoD laboratories and universities conducting DoD-sponsored research.

DoD asserts that its laboratories are in the forefront of the effort to transfer technological expertise from the Federal Government to State and local governments and private industry. The Federal Laboratory Consortium for Technology Transfer was originally established by the Department of Defense in 1972. Further, in response to the Stevenson-Wydler Technology Innovation Act, the Department of Defense established its domestic technology transfer program under the responsibility of the Deputy Under Secretary for Research and Advanced Technology. The primary goal of this effort is to accelerate the domestic transfer of unclassified technical and scientific expertise to both the university community and the private sector.

DoD sponsors a number of educational programs to help ensure an adequate supply of

[11] According to DoD, funding for a typical l-year single investigator research contract would fall in the range of $50,000 to $100,000.

[12] Col. Donald I. Carter., USAF Acting Deputy Under Secretary of Defense for Research and Advanced Technology, Testimony Before the Subcommittee on Research and Development of the House Armed Services Committee, Apr. 2, 1985.

[13] U.S. Department of Defense, Office of the Under Secretary of Defense for Research and Engineering, fiscal year 1986 University Research Initiative Program Overview, December 1985, p. 2.

highly trained scientific and engineering personnel. All three Services support a large number of science and engineering graduate students as well. DoD's direct funding for research at universities provides the Pentagon with its largest base of graduate student support. A 1980 study, conducted by the Office of Naval Research, estimated that on average a million dollars of university research funding supported 10 to 15 full-time or part-time graduate students. Based on those figures, the Pentagon estimated that it supported between 4,000 and 4,500 graduates students in fiscal year 1987.

At the graduate level all three Services sponsor activities to increase the supply of scientific personnel. The fellowship programs of both the Army and Navy support graduate students in such fields as computer sciences, electrical engineering, and life sciences. The Air Force fellowship program is aimed at more mission-specific activities, sponsoring students in such areas as advanced composite structures and aircraft propulsion technology. According to DoD, the Services supported about 200 graduate fellowships in fiscal year 1987; of this total, the Navy supported about 145. The Services also provide opportunities for faculty and undergraduate and graduate students to conduct research at various DoD laboratories during the summer months.

Planning

All of the Services conduct an extensive annual top-down, bottom-up planning exercise in order to develop a 5-year program objective memorandum (POM) and annual technology base investment strategy. From the top the Services receive the annual Defense Guidance Manual, prepared by the Office of the Secretary of Defense, which provides them with guidance on developing their entire RDT&E programs. Planning usually begins with a review and evaluation of the previous year's research activities. When this review is completed, the Services decide which activities to continue, which to transition (e.g., from 6.1 into 6.2 programs), and which activities to stop. Each of the Services develops an annual technology base strategy, such as Army's Mission Area Material Process, or utilizes special studies—such as the Air Force Forecast II project—which serve as major guides for their respective research programs.

The laboratories attached to a particular Armed Service contribute to its technology base plan. Outside advisory bodies such as the National Academy of Sciences, the National Science Foundation, individuals in the scientific community, and in-house technical directors and their respective staffs also make recommendations. The Services also have scientific advisors or science boards that participate in planning activities. The individual Services can also request that their science boards conduct a review of some particular area of the technology base programs to assure its scientific merit and/or responsiveness to particular Service needs. There are inter-Service cooperative groups, such as the Joint Logistics Commanders and the Joint Directors of Laboratories, which meet and review past and future laboratory activities to reduce duplication while increasing awareness of existing laboratory activities.

Finally, DoD has an elaborate scientific and technical advisory mechanism, with ad hoc and permanent scientific advisory committees at many levels, to advise individual laboratories, military Service chiefs, and OSD. At the level of the Office of the Secretary of Defense, the Defense Science Board deals with both specific and broad policies that address such issues as scientific manpower, defense industrial preparedness, the quality of the technology base, technology transfer, and standardization of weapon systems in NATO. Each branch of the military also has a scientific advisory body analogous to the DSB: the Army Science Board, the Naval Research Advisory Committee, and the Air Force Scientific Advisory Board.[14]

"Science Policy Study Background Report No. 8, "Science Support by the Department of Defense, " prepared by the Congressional Research Service for the Task Force on Science Policy, Committee on Science and Technology, U.S. House of Representatives, 99th Congress, p. 405. Hereafter referred to as "Science Support by the Department of Defense. "

OVERSIGHT AND MANAGEMENT IN THE OFFICE OF THE SECRETARY OF DEFENSE

The Office of the Secretary of Defense exerts oversight responsibility for all of DoD technology base programs. Oversight refers to the process of formulating and developing policy guidance for a particular program, in this case DoD's technology base programs. It includes: developing an investment strategy for a particular program; assigning management responsibility for the program; coordinating research programs; establishing policy; developing program evaluation procedures; and recommending appropriate programm a t i c changes.

OSD *is* primarily concerned with making sure that DoD's technology base programs are well balanced and reflect the overall needs of DoD. In addition, the Services and DARPA each assign specific individuals within their respective organizations oversight responsibilities for technology base programs. At this level, individuals responsible for oversight are primarily concerned with protecting and helping to manage and coordinate their organization's technology base programs.

Programmatic management involves the direct day-to-day management of a certain technology base activity. Programmatic management includes responsibility for the successful completion of an R&D activity, including: timely completion of R&D tasks; meeting projected costs; evaluation of R&D activities; and facilitating the transitioning or phasing out of research activities. The Services, DARPA, and SDIO each assign specific individuals, within their respective organizations, day-to-day management responsibility of various technology base activities.

As a result of the Military Reform Act of 1986 (sometimes referred to as the Goldwater-Nichols Act), DoD has reorganized the management of its RDT&E activities. The Act abolished the office of Under Secretary of Defense for Research and Engineering and replaced it with the Under Secretary of Defense for Acquisition (USD(A)). The legislation also re-created the Director of Defense Research and Engineering (DDR&E), who reports to the USD(A).

Until 1986, the Under Secretary of Defense for Research and Engineering had responsibility for the research and development activities of DoD and chaired the Defense System Acquisition Review Council (DSARC), which made decisions about which major weapon systems to purchase. In 1985 the functions of the Office of the Under Secretary were trimmed when Secretary of Defense Weinberger removed from the office "primary responsibility y for overall production policy and some key production decisions. " The effect of the reorganization, according to *Science* magazine, was to drive a wedge between those responsible for research and development and those responsible for production, with the hope that fewer faulty weapon systems would get from the laboratory to the factory.[15] The President's Private Sector Survey on Cost Control (known as the Grace Report) and the Packard Commission had criticized the combination of research with production. Consequently the Goldwater-Nichols Act created the Under Secretary for Acquisition (USD(A)) and the DDR&E to maintain a separation between R&D and acquisition decisions. 'G

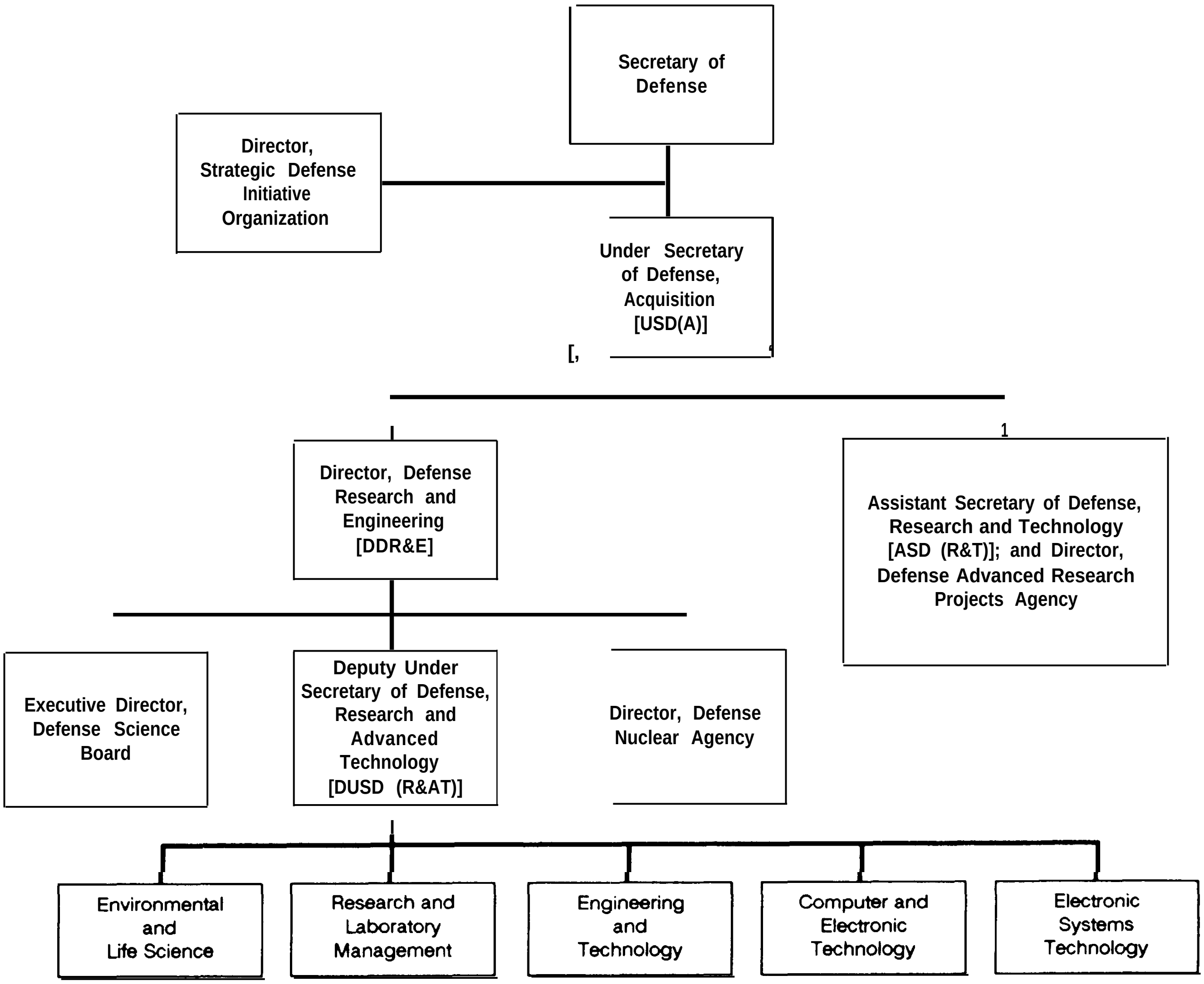
The USD(A) has oversight responsibility for DoD's technology base program, with the exception of SDIO (see figure *2).* The DDR&E has oversight responsibilities for the Services and the DNA's technology base programs.

According to the USD(A), the DDR&E has five primary responsibilities: 1) to oversee development and acquisition of weapon systems through full scale engineering development; 2) to oversee force modernization; 3) to oversee design and engineering; *4)* to oversee develop-

[15]R. Jeffrey Smith, "DoD Reorganizes Management, " *Science,* Feb. 8, 1985, p. 613.

"For further details see Science Support by the Department of Defense, " p. 63.

Figure 2.-Management of the Department of Defense Technology Base Program



SOURCE: Office of Technology Assessment, 1988

mental test and evaluation; and 5) to oversee basic research, exploratory development, and advanced technology development. As figure 2 indicates, the Director of the Defense Nuclear Agency and the Executive Director of the Defense Science Board, which is the principal advisory body within the OSD, also report to the DDR&E.

As a "corporate guardian" of DoD's entire technology base program (except for SDIO), the DDR&E is responsible for ensuring that the technology base programs of the three Services, DARPA, and DNA are following overall technology base guidance developed by the OSD. The DDR&E also acts to ensure that disagreements pertaining to technology base responsibilities and priorities are settled in a way that best represents the science and technology interests of the Department of Defense.

According to DoD, the Assistant Secretary of Defense for Research and Technology—ASD(R&T)—will also serve as the Director of the Defense Research Projects Agency (DARPA). The Director of DARPA reports to the USD(A), but will work closely with the DDR&E to coordinate DARPA's technology base programs, which are contracted through and managed primarily by the three Services. Prior to the recent reorganization, the Deputy Under Secretary of Defense for Research and Advanced Technology (DUSD(R&AT)) reported directly to the Under Secretary of Defense Acquisition (USD(A)). However, the DUSD (R&AT) now reports to the USD(A) through the DDR&E. The primary responsibility of the DUSD(R&AT) office is to provide oversight for the three Services' technology base programs, and to serve as their DoD point of contact. The primary functions of R&AT are to: structure the technology base program across Service lines, in order to eliminate overlaps and gaps; resolve technical differences; and enhance return on investment.

The R&AT office also develops the planning, programming, and budgeting system (PPBS), writes the technology base portion of the Defense Guidance Manual, and if required responds to the Services' Program Objective Memoranda. The R&AT office must also review the 2-year budget proposals of the Services and assure that those expenditure plans have the appropriate balance among the various proposed programs. Finally, the DUSD (R&AT) is supposed to work continually with the Services to help them achieve mutual science and technology interests.

With overall guidance from the Office of the Secretary of Defense and the R&AT office (primarily through the annual publication of the Defense Guidance Manual), the three Services and DARPA formulate their technology base programs. Determining the scope of technology base work involves an evaluation of the operational needs of each participant and the technological opportunities for meeting those needs. The needs are primarily derived through a comparison of the future projected military threat with planned U.S. military capability and doctrine. Finally, the R&AT office must be sure the Service technology base programs establish new research initiatives in order to meet the long-term science and technology requirements of the three Services.

The Research and Advanced Technology office has itself recently been reorganized into five major directorates, as shown in figure 2. There are approximately 30 professional scientists and engineers spread among the five directorates. The Research and Laboratory Management Directorate is responsible for: oversight of the Service research (6.1) programs; oversight of the DoD laboratories; related research and development in the industrial sector, including Independent Research and Development (IR&D);[17] and the flow of scientific and technical information. The office meets with representatives from the three Services, DARPA, and SDIO to: coordinate research-related policymaking; help facilitate inter-Service cooperation; suggest solutions to managerial problems; and address urgent research needs. In addition to coordinating research in-house, the Research and Laboratory Management office also works with different Federal R&D agencies, such as the National Science Foundation (NSF), and with the U.S. scientific community. The remaining four directorates have oversight responsibilities-and in one instance management responsibility—for exploratory (6.2) and advanced technology development (6.3A) conducted in-house by DoD labs or extramurally by outside contractors.

The Electronic Systems Technology Directorate is responsible for oversight of programs in surveillance, communications, electronic warfare, optical countermeasures and tactical directed energy weapons. In the area of search and surveillance, concepts are being refined to improve day/night/all-weather capabilities. This particular research complements thrusts in precision-guided weapons and activities to develop automatic high-resolution target identification, classification, and tracking technology.

The Engineering Technology Directorate is often referred to as the "firepower and mobility" directorate, with oversight responsibility for four related areas: combat vehicles, propul-

[17] See ch. 3 for a discussion of IR&D.

sion and fuels, conventional weapons, and materials and structures. One of the major goals of the directorate is to facilitate technology transition through advanced technology demonstration to better match the technological needs of the various Services. Consequently, this directorate has oversight responsibilities for a large portion of DoD's advanced technology development activities (6.3A). This directorate also has responsibility for spacecraft propulsion and the National Aerospace Plane, for logistics R&D, and for the Army Corps of Engineers laboratories.

The Environmental and Life Sciences Directorate deals with four supporting disciplines: training and personnel technology; medicine and life sciences; chemical warfare and chemical/biological defense; and environmental factors. In the area of training, work is being conducted in the area of computer-based training and performance aids for operations and maintenance tasks. In the environmental sciences, major efforts involve modernizing data acquisition and processing capabilities and the upgrading of DoD's radar technology, tactical sensors, and tactical decision-aid capabilities.

The Computer and Electronics Technology Directorate operates differently than the other four directorates. This directorate is what DoD refers to as a "thrust directorate" because it manages considerable program funding. In addition to oversight responsibilities, its director has a direct management role in the planning, execution, and evaluation of various programs. The director has direct management responsibility for the SEMATECH program,[18] the Very High Speed Integrated Circuit (VHSIC) program, the Microwave/Millimeter Wave Monolithic Integrated Circuit (MIMIC) program, the Software Technology for Adaptable Reliable Systems (STARS) program, and several others.

DoD contends that this directorate's direct management responsibilities address three important management needs: 1) to focus the military's needs on computer and electronics-related technology, 2) to ensure that both the hardware and software receive appropriate attention, and 3) to place more emphasis on the transition of computer and electronics technology to operational systems.

[18]The SE MATECH program will attempt to rectify the problem of U.S. competitiveness in worldwide semiconductor markets by pooling the resources of the semiconductor industry, with assistance from the Federal Government. These resources will be used to create a central production facility from which new manufacturing processes would be made available to the U.S. semiconductor industry. Congress has agreed to begin funding for this proposal and has provided $100 million in funding (to be managed by DoD) for fiscal year 1988.

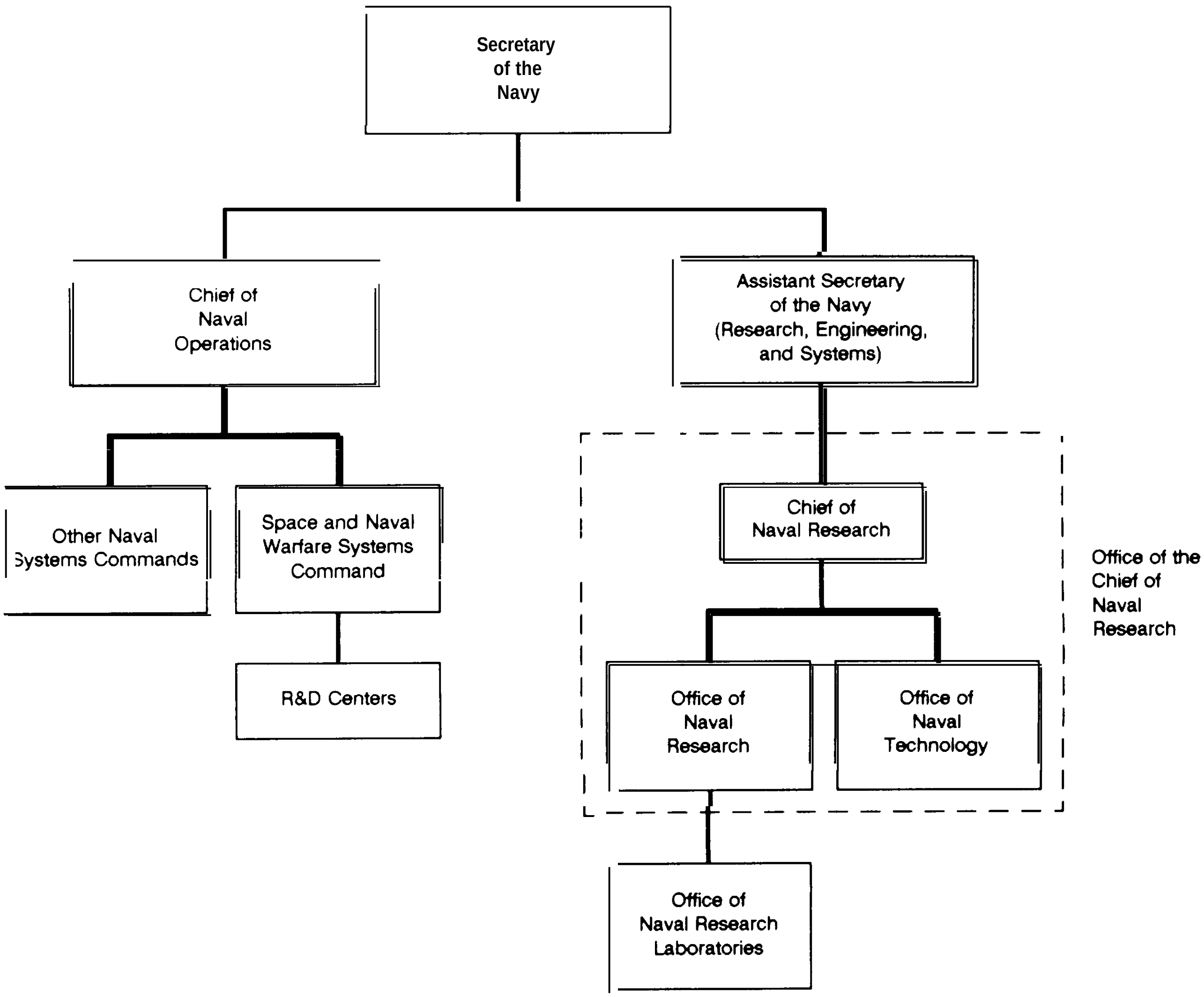
THE DEPARTMENT OF THE NAVY

The Office of Chief of Naval Research (see figure 3) is responsible for the Department of the Navy's basic research (6.1) and exploratory development (6.2) programs. The Chief of Naval Research reports to the Assistant Secretary of the Navy for Research, Engineering, and Systems and to the Chief of Naval Operations for policy guidance, planning, and execution of the Navy's basic research and exploratory development programs. The Chief of Naval Research serves as the scientific advisor to the Chief of Naval Operations (CNO) and the Commandant of the Marine Corps (CMC). Since 1985 he has also had oversight responsibility for all Navy's laboratories.

Management of the Navy's Research (6.1) Program

The Office of Naval Research (ONR, see figure 4) is responsible for the daily activities of the Navy's research programs. The director of ONR reports to the Chief of Naval Research, who is ultimately responsible for planning, review, and approval of the Navy's various research activities. ONR was established by Congress in 1946 as the first Federal organization to support university-based basic research. ONR was responsible for developing a number of mechanisms which are still in use today to

Figure 3. –Navy Organization for Science and Technology



SOURCE: Office of the Chief of Naval Research

support research at the Nation's universities. They include:

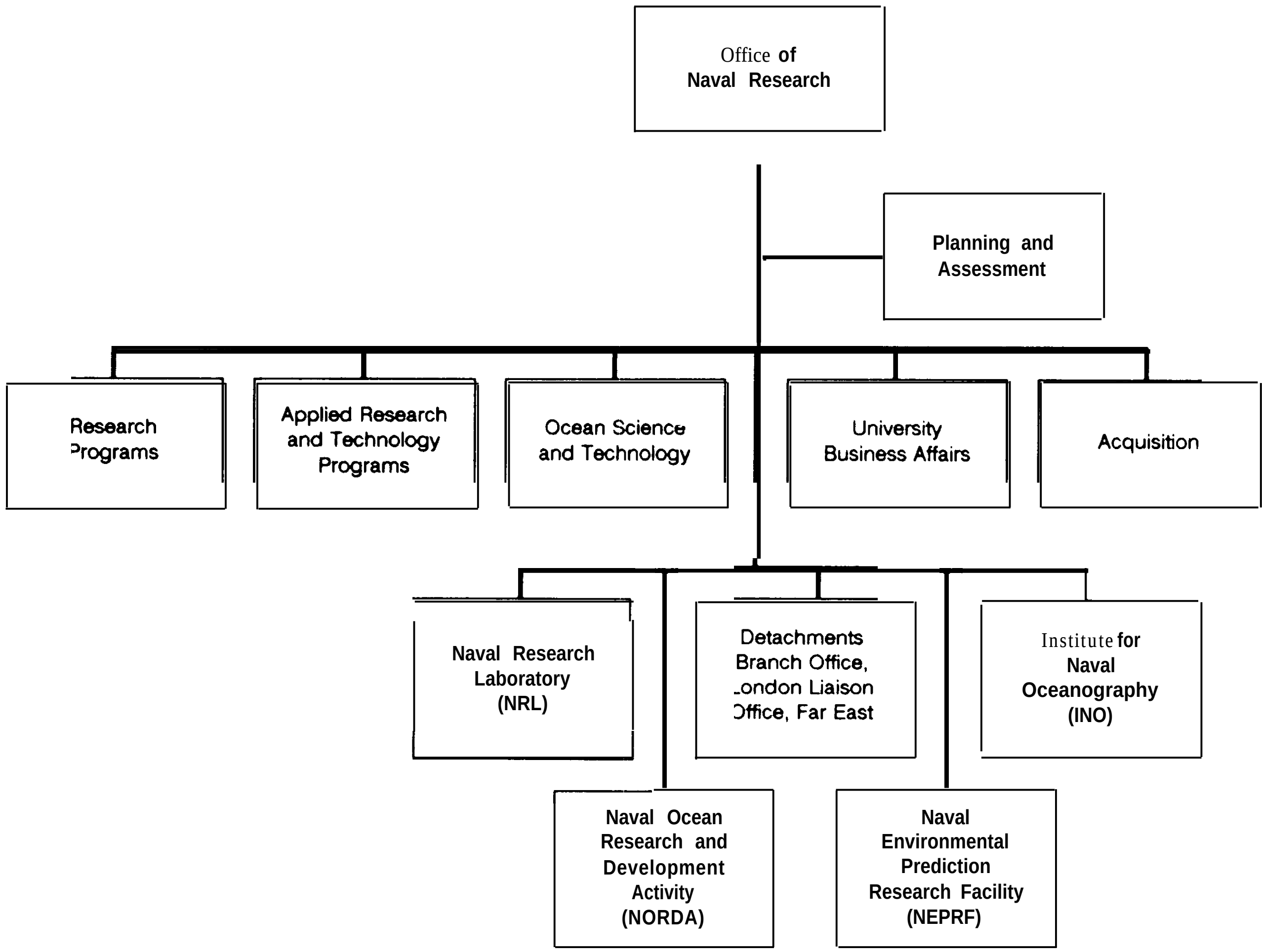
- funding project grants for individual researchers at colleges and universities;
- establishing a peer review process to evaluate research proposals;
- purchasing of expensive specialized equipment;
- funding the construction of large facilities, operated by a consortium of universities; and
- funding for special-purpose research at institutions such as Woods Hole Oceanographic Institute.[19]

According to ONR, the primary goals of its research programs are:

- to sustain U.S. scientific and technical superiority for Naval power and security;

[19]U.S. Congress, House Committee on Government Research, Federal Research and Development Programs Hearings, Nov. 18., 1963, p. 33.

Figure 4.-Office of Naval Research



SOURCE: Office of Naval Research

- to provide a source of new concepts and technical options;
- to support theoretical and experimental research in each directorate;
- to retain a vigorous scientific manpower and laboratory base; and
- to apply the results of research to Naval warfare and warfare support areas.

The research program of ONR supports a broad spectrum of scientific disciplines. ONR plans to fund 342 million dollars' worth of research in fiscal year 1988. Sixty percent of those funds will go to universities. ONR's four laboratories (the Naval Research Laboratory, the Naval Oceanographic Research and Development Activity, the Institute for Naval Oceanography, and the Navy Environmental Prediction Research Facility) will receive 21 percent; other Navy laboratories will get 12 percent; and for-profit and nonprofit organizations will receive the remaining 7 percent.

Founded in 1923, the Naval Research Laboratory (NRL) is the principal laboratory of ONR. It receives almost 90 percent of the 6.1 funds that go to the ONR laboratories. This research funding is about 24 percent of the laboratory's total in-house funds, and it plays a major role in NRL's total in-house operation.

The NRL performs and supports research in a broad range of areas including computer science and artificial intelligence, directed energy weapons, electronic warfare, space science and technology, materials, radar, information management, surveillance and sensor technology, environmental effects on Naval systems, and underwater acoustics.

ONR relies on four major research directorates to carry out its contract research programs: Mathematics and Physical Sciences, Environmental Sciences, Engineering, and Life Sciences. As might be expected, the directorate which receives the largest share of research funds is Environmental Sciences, with its focus on oceanography activities. The Navy's Ocean Sciences Division covers the range of disciplines from physical oceanography of both the open ocean and coastal zones, through ocean biology and ocean chemistry, to marine meteorology.

A fifth ONR directorate, the Applied Research and Technology Directorate, has primary responsibility for adapting and extending generic basic research toward applied research, thereby helping to transition research results into the Navy's exploratory development program. This directorate is also responsible for working closely with the Navy's exploratory development program in order to identify and implement high-leverage opportunities for joint research and exploratory development funding. The Navy is the only Service that operates a research directorate with this type of responsibility.

The Applied Research and Technology Directorate is also an agent and a project manager for selected programs sponsored by the Deputy Chief of Naval Operations for Submarine Warfare, DARPA, the Strategic Defense Initiative Organization (SDIO), and other defense organizations and industry. The ONR, with the assistance of this directorate, manages the largest SDIO basic research program of the three Services. ONR expects to manage between $80 and $90 million, primarily in the research category, for SDIO in fiscal year 1988.

Forty percent of ONR's research program consists of Accelerated Research Initiatives (ARIs) designed to concentrate resources in specific areas of research which offer a particularly attractive scientific or Naval opportunity. ARIs, which are normally funded for 5 years, are sprinkled throughout the four research directorates and the laboratories of ONR. These initiatives represent an accelerated or enhanced program in a basic scientific area which is potentially attractive to future Navy needs.

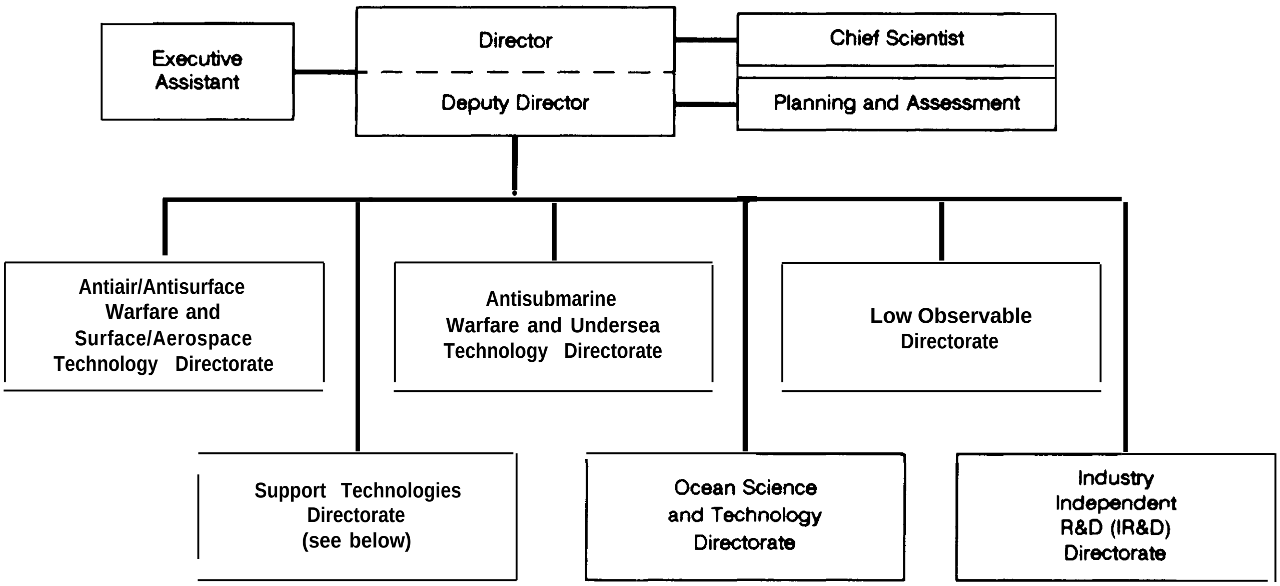
Some of the ARI research areas include: arctic oceanography, composites, interracial science, and electrochemical properties of membrane proteins as the basis of specialized cellular functions. ARIs are selected from research options developed by the scientific community and by ONR's scientific officers, and are reviewed and ranked as part of ONR's annual research planning and budgeting process. ARI selection is based on how well the proposed activity meets the goals of the Navy's research program and is done through an expert panel-based peer review process.

Management of the Navy's Exploratory Development and Advanced Technology Development Programs (6.2 & 6.3A)

The Navy's entire exploratory development program is managed by the Office of Naval Technology (ONT) within the Office of Chief of Naval Research. ONT (see figure 5) was created in 1980 by the Secretary of the Navy to "provide for a more clearly defined process of planning, execution and transition of programs within the technology base and into advanced technology development . . ." ONT currently has a professional staff of 55 people to carry out its responsibilities.[20]

[20] From 1980 through 1985, ONT reported to the Deputy Chief of Naval Material (Technology) [DCNM(T)]. In May 1985, when the Naval Material Command was abolished, the CNR was assigned the additional responsibility of managing those Naval R&D Centers that had reported to the Chief of Naval Material. In 1986, management of the Navy's R&D centers were placed under the newly created Space and Naval Warfare Systems Command (SPAWAR).

Figure 5.—Office of Naval Technology



Support Technologies Include:

- **Command, Control, and Communications**
- **Mission Support Technologies**
  (Personnel and Training; Biomedical; Logistics; Chemical/Biological/Radiological Defense)
- **Systems Support Technologies**
  (Electronic Devices; Materials; Human Factors; Oceanography; Computer Hardware, Software, and Architecture; Artificial Intelligence)

SOURCE: Office of Naval Technology

ONT is primarily responsible for all programmatic oversight of the Navy's exploratory development program, which includes such activities as program planning, approval, funding, review, and evaluation. One of the most important activities of the ONT is the development of the investment and mission area strategies, which are the heart of the 6.2 program management system. These strategies are developed in consultation with OSD, the Office of the Secretary of the Navy, the CNO, the Commandant of the Marine Corps, ONR, the Director of Navy Laboratories at the Space and Naval Warfare Systems Command (SPAWAR), and the other Naval System Commands.

The Director of Navy Laboratories (DNL) at SPAWAR, where about half of the ONT's 6.2 program is performed, is responsible for establishing laboratory policy and management procedures. This includes resolving disputes-between the laboratories involving research emphasis and responsibilities. However, the DNL does not have any responsibilities for the development and selection of research projects that are supported by the various SPAWAR laboratories.

Through its R&D Centers, the Navy performs much more of its 6.2 and 6.3A program in-house than do the other Services, for which 6.3A work is primarily performed by industry. Navy R&D Centers have a much stronger emphasis on development activities beyond the tech base than do the laboratories of the other Services.

In fiscal year 1988, the Navy will support the smallest exploratory development program of the three Services, conducting 59 percent of its 6.2 activities in-house. Industry will conduct 31 percent, universities 7 percent, and the remainder will be conducted by other government agencies. Although the Navy has over 20 laboratories, the majority of 6.2 and 6.3A activities are performed by the eight SPAWAR R&D Centers and the three ONR laboratories.

As figure 5 indicates, ONT consists of six major directorates. Three of them—the Antiair/Antisurface Warfare and Surface/Aerospace Technology Directorate, the Support Technologies Directorate, and the Antisubmarine Warfare and Undersea Technology Directorate—fund about 80 percent of the Navy's 6.2 program. The remaining three directorates have specific responsibilities primarily with oversight and coordination of related exploratory development programs.

The Industry IR&D Directorate is responsible for all oversight of the Navy's IR&D programs. The office is responsible for working with industry insetting IR&D priorities, evaluating IR&D activities, and maintaining yearly records of what type of IR&D activities are actually conducted.

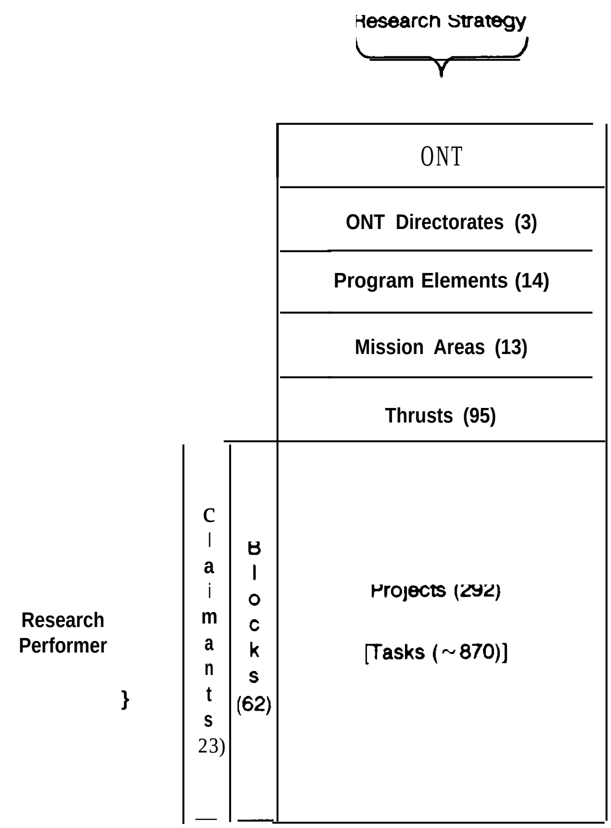
The entire 6.2 program is built around the Navy's 13 mission area strategies. ONT conducts an extensive top-down, bottom-up process to define its key mission area strategies. Since the six different Navy systems commands (SYSCOMS) are the ultimate users of the technology, they play an important role in the overall development of the Navy's exploratory development investment and mission area strategies. Besides the SYSCOMS and the laboratory/center technical directors, other inputs are sought from the Navy Secretariat, from the maritime strategy developed by OPNAV, from the CMC, and from internal and external scientific advisory groups.

The Navy develops a strategy for each of its 13 mission areas based on such concerns as current mission deficiencies, near-and far-term technological opportunities, the needs associated with DoD's overall maritime strategy, and potential military threats. According to ONT, a mission area strategy should be described where possible in terms of objectives that relate to a specific technology. For example, the Navy has broad mission strategies for anti-surface ship warfare, anti-submarine warfare, and mine warfare. Because mission areas do not often change, the focus of this activity is on updating the strategy associated with each mission area.

In developing each mission area strategy, ONT establishes what it calls technology thrusts (see figures 6 and 7). According to ONT each technology thrust has a single operational/performance objective or several very closely related ones supporting the warfighting objectives of its mission area. ONT utilizes two definitions of technology to help identify a particular technological thrust:

- a science or engineering discipline specific to an application, such as:
  –laser communication technology,

Figure 6.–Navy 6.2 Program Structure



SOURCE: Office of Naval Technology

Figure 7.–Navy 6.2 Program Strategy

SOURCE: Office of Naval Technology

–fiber optic sensor technology, and
—optical signal processing; or

- a group of technologies applied to the same or closely related warfare, weapons, or platform objectives, such as:
  —ocean surveillance technology,
  —airborne electronic warfare,
  —air launch weaponry, and
  —torpedo propulsion.

In fiscal year 1987, the Navy supported its 95 technological thrust areas through the establishment of 62 block programs. A block program is an integrated group of technology projects with closely related applications and/or technical objectives; each block program is assigned to a given lead laboratory or SYSCOM program manager. For example, the Naval Air Development Center is responsible for a block program in airborne surveillance, while the SPAWAR SYSCOM is responsible for the block program in directed energy technology. Usually a block program encompasses the 6.2 program's effort (with an average funding level of $7 to 8 million) in a warfare technology area, as identified above. It is most often composed of a number of projects, each of which may address a different technology thrust and/or mission area. Each project consists of a number of specific tasks performed by a particular researcher or group of researchers.

Beginning in the fall of each year, all block programs are reviewed by ONT and the various SYSCOMS. This review is followed by an evaluation of the current mission area strategies, which leads to the establishment of new technological thrusts as well as new block programs for the following fiscal year.

ONT also sponsors an Independent Exploratory Development program, which provides the technical directors of the Navy R&D Centers with a small amount of funding (usually about 5 percent of their 6.2 programs) to support activities aimed at achieving the centers' assigned missions. Through this mechanism, the technical directors are allowed to support innovative programs without the formal approval process which could delay funding of a new idea. Normally, a specific program cannot be supported with Independent Exploratory Development funding for more than 3 years.

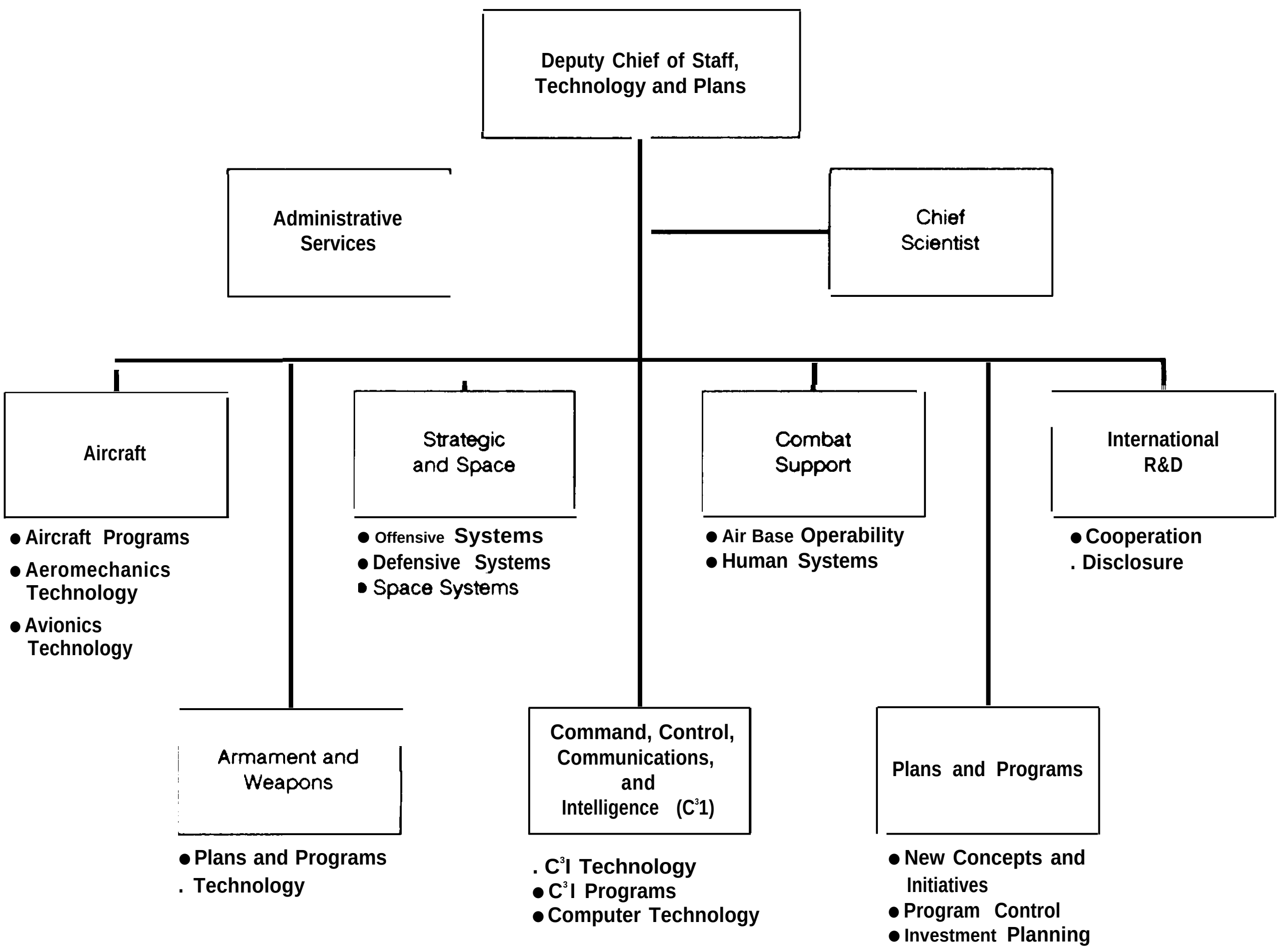
The Navy's advanced technology demonstration (6.3A) program, with a proposed fiscal year 1988 budget of about $30 million, is the smallest of the Services'. The Navy is the only Service that manages its 6.3A program separately from its 6.1 and 6.2 activities. Within the office of the Assistant Secretary of the Navy (Research, Systems, and Engineering), the Director of Research, Development, and Requirements (Test and Evaluation)—DRD&R(T&E)–has oversight responsibilities for the 6.3A program. The 6.3A program is managed by the Technology Assessment Office, which reports to the DRD&R(T&E). The Navy is now in the process of rebuilding its Advanced Technology Demonstration (ATD) program. In fiscal year 1988, the ATD program will sponsor three to five advanced technology demonstrations. The technologies are selected by the ATD director with the assistance of OPNAV, the SYSCOMS, and ONT, and are performed at the appropriate SYSCOM for up to 3 years.

THE DEPARTMENT OF THE AIR FORCE

The Deputy Chief of Staff for Technology and Plans- DCS(T&P)-of Air Force Systems Command (AFSC) is responsible for the daily operations and oversight of Air Force technology base programs (see figure 8). The DCS (T&P) reports to the Commander of the Air Force Systems Command, who reports to the Air Force Chief of Staff. The DCS(T&P) was created in October 1987 with the merger of the offices of DCS for Science and Technology with the DCS for Plans and Programs. The primary purpose of the merger was to enhance communication and coordination between the office responsible for evaluating and planning new weapon systems and the office that is responsible for conducting the research and advanced technology development for the new systems.

Within the office of the Secretary of the Air Force, the Assistant Secretary for Acquisition –ASAF(A)–is responsible for the entire Air Force's RDT&E program. And within the ASAF(A) office, the Director of Science and Technology (DS&T) is responsible for oversight of the Air Force technology base programs. The DCS(T&P) (in the headquarters of

Figure 8.–Air Force Systems Command R&D Organization



SOURCE Air Force Systems Command

AFSC) works with the DS&T (in the Office of the Secretary of the Air Force) in developing both an annual and a 5-year technology base investment strategy for the Air Force. One of the primary responsibilities of the DS&T is to ensure that the DCS(T&P) investment strategy is well balanced and capable of meeting the short- and long-term needs of the diverse Air Force technology users.

To help raise the visibility of its science and technology programs, the Air Force now treats its entire technology base program asa"corp~ rate investment. " Consequently, when budgets are being examined by the Air Force, the entire technology base program, rather than the 44 individual program elements, is examined for proper balance and emphasis. The goal is to raise technology base funding to 2 percent of the Air Force's total obligational authority. The technology base program is now classified as 1 of the 35 executive Air Force programs, equal in stature to such executive programs as the Advanced Tactical Fighter.

Management of the Air Force's Research (6.1) Program

The Air Force Office of Scientific Research (AFOSR) is responsible for the planning and management of the Defense Research Science program and the University Research Initiative program of the Air Force. The In-House Laboratory Independent Research Program (ILIR) is managed directly by each individual laboratory director. The Commander of the AFOSR reports to the Systems Command DCS(T&P), who has oversight responsibilities for AFOSR programs and for the integration of 6.1 research with 6.2 and 6.3A programs. AFOSR supports research which has a "potential relationship to an Air Force function or operation. " It conducts a program of extramural research contracts and grants (primarily grants); oversees the research programs (in-house and extramural) of the Air Force Laboratories; and manages three subordinate units.

The three subordinate units are the European Office of Aerospace Research and Development in London, AFOSR Far East in Tokyo, and the Frank J. Seiler Research Laboratory in Colorado Springs. The London and Tokyo offices gather information about foreign research and act as liaisons between Air Force scientists and engineers and their foreign counterparts. The Seiler Laboratory performs in-house research in such areas as optical physics, aerospace mechanics, fluid mechanics, and chemistry.

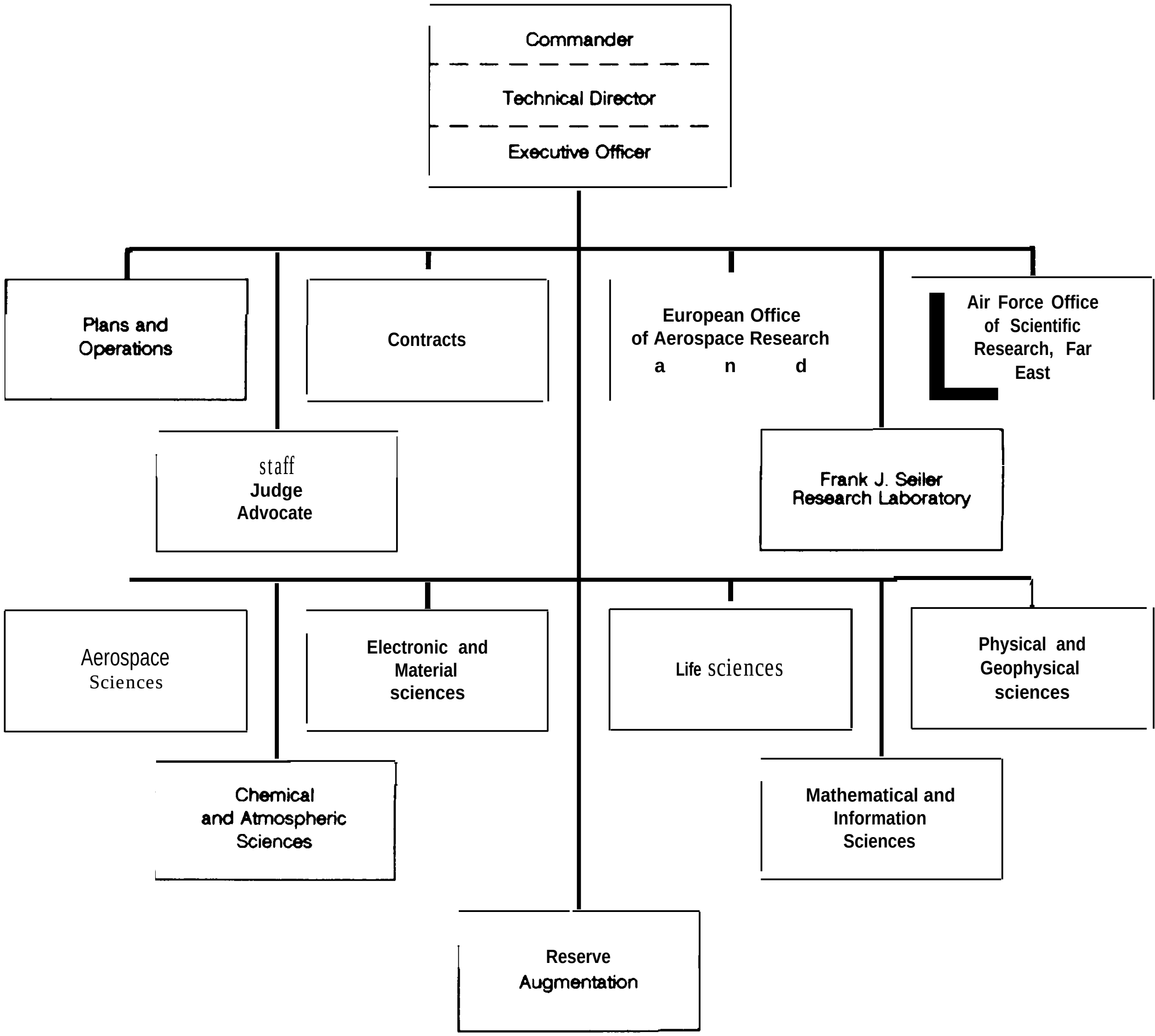
Of the $198 million the Air Force will spend on research in fiscal year 1988, about 60 percent will be given to colleges and universities. The Air Force in-house laboratories will receive 15 percent, industry and nonprofits 20 percent, and the remaining 5 percent is for overhead.

As figure 9 indicates, the AFOSR science programs are divided into six areas: Aerospace Sciences, Chemical and Atmospheric Sciences, Electronic and Material Sciences, Life Sciences, Mathematical and Information Sciences, and Physical and Geophysical Sciences. Each of the program areas has a scientific director, who is responsible (along with the Commander and Technical Director of AFOSR) for planning, managing, and implementing the various research programs. As might be expected, the majority of AFOSR research funds are spent in aerospace sciences, chemical and atmospheric sciences, and electronic and material sciences.

The AFOSR supports a number of special research programs to further strengthen the Air Force technology base program. They include the Air Force Thermionic Engineering Research Program, the Research in Aircraft Propulsion Technology Program, the University Resident Research Program, the Resident Research Associateship Program, the Laboratory Graduate Fellowship Program, the Advanced Composite Structures Program, the Graduate Student Summer Support Program, and the Summer Faculty Research Program.

In conjunction with industry, the AFOSR sponsors university-based manufacturing research centers at Stanford University and at the University of Michigan. Students perform

Figure 9.-Air Force Office of Scientific Research



SOURCE: Air Force Office of Scientific Research

research at the university centers or at participating companies. The Air Force provides the assistantship funds for M.S. and Ph.D. candidates, with Stanford and Michigan responsible for selecting the students. AFOSR funding for the two centers is scheduled to be phased out at the end of fiscal year 1988 as industry support increases.

Management of the Air Force's Exploratory and Advanced Technology Development Programs (6.2 and 6.3A)

The DCS(T&P) serves as the "corporate manager" of the Air Force's technology base program and is primarily responsible for developing the overall investment strategy that guides laboratory operations. The primary responsibility of the DCS(T&P) is to ensure proper integration and balance of these programs, while meeting the needs of the various operational commands, in line with OSD and Air Force Headquarters guidance. While having traditional oversight responsibilities for the 6.1 and 6.2 programs, the DS&T in the Air Force Secretariat exerts more active influence and direction on the large advanced technology development (ATD) program.

The office of the DCS(T&P), with approximately 70 professionals, consists of five major research directorates: Aircraft; Armament and Weapons; Strategic and Space; C^3I; and Combat Support. Each of the five Directorates works primarily with a particular AFSC product division and has oversight and coordination responsibilities for that division's lab(s). The Director of the Aircraft Directorate works with the four laboratory directors assigned to the Aeronautical Systems Division. The Armament and Weapons Directorate coordinates with the Armaments Laboratory of the Armament Division and the Weapons Laboratory of the Space Technology Center of Space Division. The Strategic and Space Directorate oversees the activities of the other two Space Division laboratories. The Director of C^3I is responsible for the research activities of the one laboratory assigned to Electronic Systems Division. Finally, the Combat Support Directorate works with the three laboratory directors of the Human Systems Division and the Air Force Engineering and Services Center.

However, this laboratory oversight arrangement does not mean that the director of a particular laboratory conducts research for only one of the five directorates. Obviously, the interdisciplinary nature of research requires the various laboratory directors to manage 6.2 and 6.3A activities for a number of product divisions and applications that cut across the major air commands.

Within the office of the DCS(T&P), the director of Plans and Programs works with the directors of the five research directorates to ensure their broad technology base investment strategy considers both the near- and long-term technological needs of the various Air Force users. The Plans and Programs office also works with the directorates to ensure that their respective technological thrusts are capable of meeting current and future needs of the Air Force.

Since 1980, the laboratories of the Air Force have been aligned under the parent product divisions: Electronics System Division (ESD), Armament Division (AD), Human Systems Division (HSD), Space Division (SD), and Aeronautical Systems Division (ASD). Each of the Divisions has responsibility for one or more laboratories which perform research, exploratory development, and advanced development in support of that division's mission as well as the missions of other divisions. For example, the Materials Laboratory, under ASD, meets the technology needs of Space Division as well. Unlike the other two Services, the Air Force laboratories are not full spectrum R&D laboratories. With the exception of the Rome Air Development center, which performs some 6.4 work, the remaining laboratories primarily conduct 6.1-6.3A activities. The Air Force supports the smallest in-house technology base program, actually conducting only 20 percent of its activities in its 14 laboratories. In contrast, the Air Force supports the largest 6.3A program, reflecting its interest in technology transition.

The directors of the laboratories have a dual reporting responsibility. The directors report their laboratory activities and accomplishments to both the DCS(T&P) as well as to the commander of their respective product divisions. (The four laboratory directors at Wright-Patterson Air Force Base report through the Commander of the Wright Aeronautical Laboratories to the Commander of ASD.) As with the other Services, each of the laboratory directors is ultimately responsible for the activities in his laboratory. This includes determining research priorities, developing new initiatives, determining who will be responsible for managing various research projects, whether to use in-house or outside expertise, and when to transition or stop a research activity.

The Air Force contends that placing its laboratories within the product divisions increases the linkages between the developers and ultimate users of the various weapon systems. The Air Force asserts that closer interaction between the product divisions and their respective laboratories will strengthen long-term technology base planning capabilities and the transition of mature technologies into systems applications. Further, the Air Force believes that this closer coupling will reduce the time it takes to develop and deploy more reliable and less expensive weapon systems.

The Air Force's advanced technology development (ATD) program has grown from $159 million in fiscal year 1975 to almost $754 million in fiscal year 1988 (see table 2). The ATD program represents 50 percent of the entire Air Force technology base program. Almost all of the ATD program is conducted by defense industries under contract to the different product division laboratories. The Air Force believes that its contractors will incorporate new technological advances more rapidly if they actually participate in the successful development and testing of a new technology.

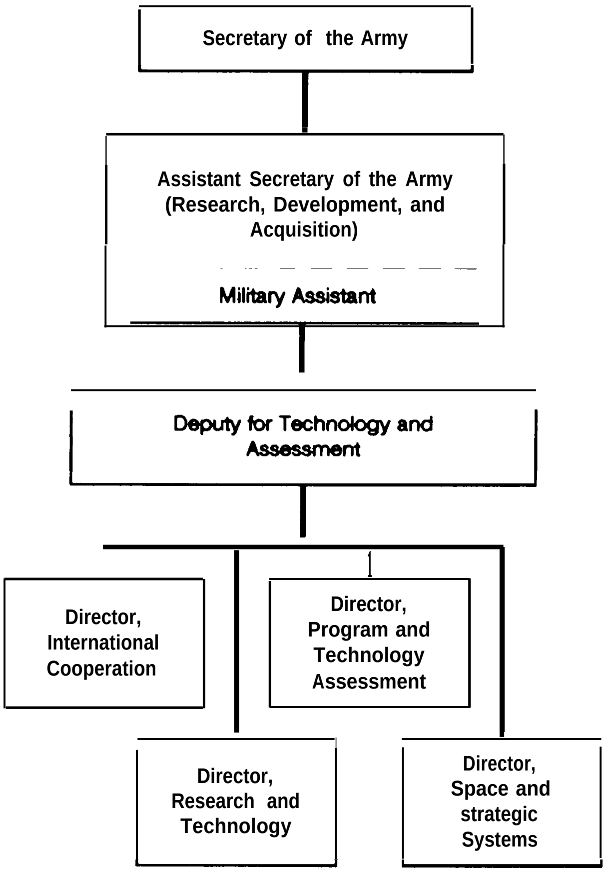
Like the other Services, the Air Force conducts an annual iterative planning activity. Much of the planning and programming activities at the Air Force laboratories are primarily driven by the future needs of the combat commands. This process begins in the second quarter of each fiscal year, when the DCS(T&P) develops an investment strategy to guide planning for the next 5 years. The results of this investment strategy, along with other guidance from DS&T, OSD, and inside and outside scientific advisory groups, are used to refine short-term plans and develop long-term plans by the laboratories. As part of their overall planning responsibilities, the product divisions identify a number of potential next generation system concepts to meet future warfighting needs. These warfighting requirements, in turn, are defined by the users.

The Air Force's Project Forecast II is another key consideration for developing an overall technology base strategy in the laboratories. Completed in 1986, the primary goal of Forecast II was to identify potential technological opportunities that could change the nature and design of future systems, while concomitantly improving the Air Force's warfighting capabilities. The Project was chartered by the Secretary of the Air Force and directed by the Commander of Air Force Systems Command (AFSC). It was supported by a team of 175 military and civilian experts drawn from within AFSC, the operational commands, and various outside advisory panels. From the ideas generated by the Air Force laboratories, industry, universities, and technology panels, 40 technological initiatives were identified for funding within the technology base. Research progress in these technological initiatives is monitored, and appropriate changes of emphasis are made as the technology matures. The purpose of this planning activity is to ensure that the Air Force technology base program is sufficiently broad to prevent technological surprise by potential adversaries, while at the same time is in position to take advantage of new technological opportunities.

THE DEPARTMENT OF THE ARMY

The newly created office of the Deputy for Technology and Assessment (DT&A) is responsible for the Department of Army's entire technology base program. The DT&A reports to the Assistant Secretary of the Army for Research, Development, and Acquisition—ASA(RD&A)–who replaced the Deputy Chief of Staff for Research, Development, and Acquisition—DCS(RD&A) —(see figure 10). The Army has combined both military and civilian oversight responsibilities for its RDT&E program in one office.

Figure 10. -Army Research and Development Organization



SOURCE: Assistant Secretary of the Army (Research, Development, and Acquisition).

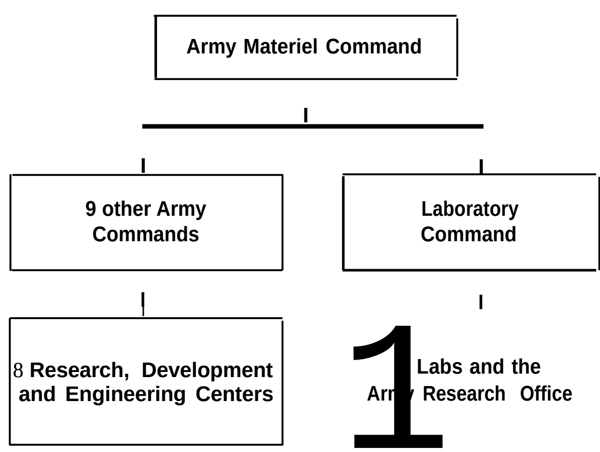
As a result of the Goldwater-Nichols Act, the Army has also designated the DT&A as its Program Executive Officer (PEO) for the technology base programs. The DT&A provides programmatic planning guidance to the Army's 31 Research and Development organizations. DOD's planning guidance is used by the Army to help develop its annual and 5-year technology base Program Objective Memorandum (POM).

Subordinate to the DT&A is the office of the Director of Research and Technology (DR&T, see figure 10), which is responsible for planning and coordinating the Army's entire technology base program. The remaining three offices under DT&A, the Director of International Cooperation, the Director of Program and Technology Assessment, and the Director of Space and Strategic Systems, work with the DR&T on various special aspects of the technology base program. Since this is a completely new organization, the exact responsibilities of these offices have yet to be determined.

The Army operates its technology base programs differently from the other Services and tends to have a more complicated organizational structure. The Army divides its technology base programs among four major components: the Army Materiel Command (AMC), the Surgeon General of the Army (TSG), the Corps of Engineers (COE), and the Deputy Chief of Staff for Personnel (DCSPER). For oversight purposes, the directors of all four of these organizations report to the Deputy for Technology and Assessment at Army headquarters.

AMC is responsible for the development and acquisition of all the Army's combat and combat support systems (see figure 11). AMC receives 75 percent of the Army's technology base funding and is programmatically responsible for eight research, development, and engineering (RDE) centers, seven army laboratories, the technology base work of the project

Figure 11.-Army Materiel Command R&D Organization



SOURCE: Army Materiel Command

manager for training devices, and the Army Research Office. The Surgeon General manages 14 percent of the technology base programs and is responsible for medical R&D activities at the Army's nine medical laboratories. The Corps of Engineers operates four laboratories and utilizes 6 percent of the technology base funding to support research in such areas as construction engineering, cold weather combat, and hydrology. The Army Research Institute for Behavioral and Social Sciences (ARI), which reports to the DCSPER, receives about 1 percent of the technology base funding for research in personnel-related areas. The remaining 4 percent is for overhead and the ILIR program. However, due to budgetary constraints the Army did not propose any funding for ILIR in fiscal year 1988.

Management of the Army's Research (6.1) Program

The Army is the only Service that manages its basic research program through more than one office. The majority of the 6.1 program is managed by the Army Research Office (ARO), located at Research Triangle Park in North Carolina. ARO is under the Army's Laboratory Command (LABCOM) structure, with the Director of ARO reporting to the DT&A through LABCOM and AMC. Compared to equivalent organizations in the other Services' research offices, ARO is lower in the chain of command and appears to have less visibility. In fiscal year 1988, AMC will receive a little over two-thirds of the Army's 6.1 budget. Half of AMC's 6.1 funding will go to the ARO and the other half will go to the AMC laboratories and RDE centers. Although ARO does not manage the portion that goes to the Army laboratories and centers, it does make recommendations to the Director for Research and Technology, Army Headquarters, regarding the in-house research program content and size.

The ARO program is a mix of short- and long-term programs that are responsive to the needs of the Army laboratories. Recently, ARO has worked closely with the Army Training and Doctrine Command (TRADOC) and its schools to assist in shaping ARO's research program according to Army mission area needs. TRADOC, along with AMC, is responsible for evaluating the current and future technological needs of the Army.

The ARO provides the major interface between the Army and the university community. The university community receives 83 percent of ARO's 6.1 budget; industry gets 10 percent and nonprofit organizations *receive* the remaining 7 percent. The ARO research program consists of seven divisions: Electronics, Physics, Chemistry and Biology, Engineering, Material Science, Mathematics, and Geosciences.

The laboratories' in-house research programs are organized along the lines of the laboratories' mission responsibilities. For example, each laboratory research effort is supported by a single project fund (SPF) more closely tied to its mission, rather than to some specific scientific discipline. The content of each SPF is determined by each laboratory's technical director and his staff. Research in the laboratory is really designed to be the first step in the development chain. ARO contends that research tasks within an SPF are intended to lead eventually into development programs. The technical content of each SPF is reviewed annually by each Command headquarters and by the Deputy for Technology and Assessment (DT&A).

Since 1982, ARO has sponsored a "centers of excellence" program, supporting selected colleges and universities. ARO operates centers in five research areas: electronics, mathematics, rotary wing aircraft technology, artificial intelligence, and optics. These centers are usually funded from 5 to 10 years. Each center has a program advisory panel with members from the different universities, ARO, the appropriate laboratory within AMC, and industry. For example, the Army Aviation Systems Command Research Development and Engineering Center works with three universities that are the Army's rotocraft centers of excellence.

Army's Management of Exploratory and Advanced Technology Development Programs (6.2 and 6.3A)

The Director for Research and Technology (DR&T) is also responsible for the exploratory and advanced technology development programs of the Army. There are four Deputy Assistant Directors that have specific responsibilities for various aspects of the Army's science and technology programs. These four areas are: 1) aviation—unmanned air vehicles and missiles, etc.; 2) ballistics-sighting mechanisms, armaments, munitions, chemical warfare, etc.; 3) electronics-artificial intelligence, command, control, communications, and intelligence, robotics, etc.; and 4) soldier support–ground combat, troop support, and ground vehicles.

Within the office of the DR&T there are five science and technology professionals (the Director and the four Deputy Assistant Directors) responsible for planning, budgeting, and setting priorities for the Army's technology base programs. Consequently, the Army utilizes a much more decentralized management approach in operating its laboratories than do the other Services. Although the DT&A has primary oversight for planning, budgeting, and setting priorities, many of these activities are directed and performed by the Army Material Command (AMC) office and the newly created Laboratory Command (LABCOM) (see figure 11).

The Army's LABCOM has only been in existence for a little over 2 years. According to Army officials, the long-term goal of AMC is to have ARO and the seven laboratories under LABCOM primarily responsible for generic technology base work, while the eight Research, Development, and Engineering Centers would be primarily responsible for engineering and development activities that are more systems related. The goal is to have the laboratories "hand-off" certain technology base programs to the RD&E centers to initiate appropriate systems engineering and development activities.

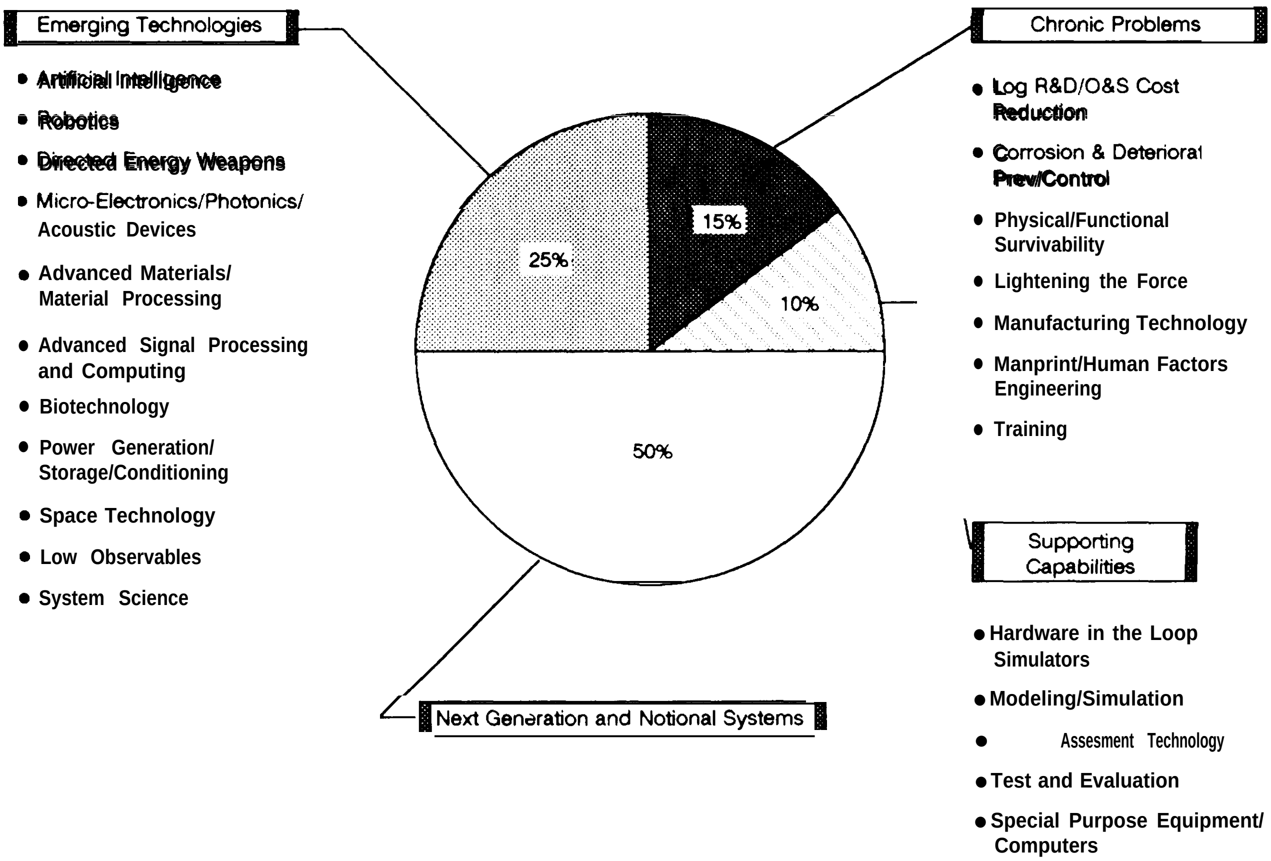
In 1986 LABCOM published its first comprehensive technology base investment strategy. According to the Army, the purpose of the investment strategy is to meet future user battlefield requirements while preserving the Army's ability to exploit technological opportunities. The investment strategy is also used to determine resource allocation for technology base activities, and it provides a strategic vehicle for articulating the direction of the AMC technology base activities. The AMC breaks its strategy into four basic elements (see figure 12): next generation and notional systems (NGNS); emerging technologies (ET); chronic problems; and supporting analytical capabilities.

Nearly half of the AMC's technology base resources are planned for next generation/notional systems. Next generation systems are usually defined as those beyond the systems currently in engineering development; they represent relatively well-defined solutions to battlefield problems of the next 5 years. Notional systems, on the other hand, are more conceptual solutions to problems anticipated 10 to 15 years down the line. This distinction provides a range of targets for technology base efforts, from mid-range to long term.

As figure 12 indicates, emerging technologies support 25 percent of the technology base strategy. These are technologies such as robotics, artificial intelligence, and biotechnology which may not yet have coalesced into spe cific systems applications. The Army admits that the difference between ETs and NGNS is "fuzzy;" nevertheless, ETs are judged to be so important that they deserve special emphasis through visibility and funding emphasis. Most of the ET activities are focused on exploring new technological concepts that could be used by the Army 15 to 30 years in the future.

Certain chronic problems, such as corrosion prevention and manufacturing problems, are endemic to the ability of the Army to perform its mission but often do not receive technology base support. Although these may be less

Figure 12.-Army Technology Base Investment Strategy



SOURCE: Army Materiel Command/Laboratory Command

glamorous than developing new weapon systems, 15 percent of the technology base support is now devoted to these concerns.

Supporting analytical capabilities include modeling, simulation, advanced demonstration projects (ADP), and other infrastructure activities aimed at increasing the Army's ability to perform quality R&D and improve its acquisition across the entire spectrum of the material life-cycle. This category, representing the remaining 10 percent of technology base funding, is devoted to future operational capabilities and improving the research infrastructure.

The Army asserts that the AMC laboratories and the RD&E centers, ARO, and to a lesser extent the Corps of Engineers' laboratories are required to formulate their technology base strategies within this investment strategy framework. However, this does not necessarily mean that every lab or center must be working on every element of the strategy, or that its budget must reflect the exact percentage allocation for each element. Nevertheless it does mean that:

> ••• each organization should plan their technology base work to address (within their mission area) the technological barriers represented by the specific set of NGNS, and that they should give emphasis to the other elements of the strategy before pursuing other work, which may nevertheless be important in its own right.[21]

"A *LABCOM White Paper* "The AMC Technology Base Investment Strategy, " June 7, 1987, p. 43.

The technology base investment strategy is developed through an annual analysis of the Army's 13 major mission areas (e.g., close combat (light), close combat (heavy), air defense, mine/counter-mine, etc.). The mission area analyses, which are conducted by TRADOC with support from AMC, COE, TSG, and ARI, result in the publication of a Battlefield Development Plan that outlines both near- and mid-term battlefield deficiencies and opportunities. Directed by AMC, the Army then conducts what is called a mission area materials process (MAMP) to address the various deficiencies and opportunities in the context of the four elements of the mission area strategy.

The technology base investment strategy and the MAMP drive the technology base activities in several ways. They are used as strategic planning tools, laying out the projected development time schedules of the systems planned for the future. Further, both TRADOC and AMC review the 13 mission area strategies for duplication and opportunities for collaborative efforts among the labs and centers to help meet deadlines and reduce technology base costs.

Since the next generation and notional systems are intended to focus on near- and long-term technological barriers, a large percentage of the 6.2 and 6.3A budget is spent in this area. For example, almost all of the 6.3A budget is spent on approximately 60 specific technology demonstrations. Each year the Army publishes a document that describes the "Top-20' demonstrations and identifies the laboratory responsible for managing the demonstration. Each demonstration can last from 3 to 5 years.

Like the other Services, the Army performs an annual top-down, bottom-up guidance and direction exercise. This evaluation begins in the fall when each lab and center presents a review of its accomplishments, along with plans for meeting next year's technology base strategy. The Army utilizes a Technology Base Advisory Group to set project priorities. This group works with representatives from TRADOC and the Department of the Army headquarters in establishing the overall project priorities for the technology base investment strategy.

THE DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)

At just under $800 million in fiscal year 1988, the technology base program of the Defense Advanced Research Project Agency (DARPA) is larger than those of the other defense agencies combined. The other agencies are: the Defense Nuclear Agency (DNA); the Defense Communications Agency (DCA); the National Security Agency (NSA); and the Defense Mapping Agency (DMA). DARPA was established in 1958 partly due to the pressures forced by the launching of the Sputnik satellites. The President and Congress also recognized that DoD needed an organization which could take the "long view" regarding the development of high-risk technology. DARPA was thus setup to be DoD's "corporate" research organization, reporting to the highest level (currently the USD(A)) and capable of working at the "cutting edge" of technology. DARPA's organization allows it to explore innovative applications of new technologies where the risk and payoff are both high, but where success may provide new military options or applications—or revise traditional roles and missions. In theory, since DARPA has no operational military missions, it should be able to maintain objectivity in pursuit of research ideas which promise quantum technology advancement.

DARPA executes its programs mainly through contracts with industry, universities, nonprofit organizations, and government laboratories. DARPA now has a limited inhouse contracting capability. This means that DARPA can contract directly with defense contractors, rather than going through the

Services. However, the Services and other government agencies usually provide this function. In these cases, technical monitoring and support are often provided as well, thus establishing a "joint program atmosphere. According to DARPA, close relationships with the Services facilitate subsequent technology transfer when research projects reach a mature stage and are linked to operational requirements.

Organization

The DARPA organization is tailored for the agency's role and is often "adjusted" to accommodate priorities. DARPA consists of the Director's office (including the new Prototype Office and two Special Assistants-one for Strategic Computing and one for the National Aerospace Plane), two administrative support offices, and the following eight technical offices:

1. Tactical Technology Office,
2. Strategic Technology Office,
3. Defense Sciences Office,
4. Information Science and Technology Office,
5. Aerospace Technology Office,
6. Naval Technology Office,
7. Directed Energy Office; and
8. Technical Assessment and Long-Range Planning Office.

DARPA's programs are divided into two broad categories: Basic Technology Projects and Major Demonstration Projects. The Basic Technology Projects focus on long-term research in the areas that are related to a specific technical office. As some of these technology investigations begin to show promise, feasibility demonstrations are conducted, often in cooperation with the military Services, in an attempt to transfer the technology as rapidly as possible into system development—thus matching technology with requirements.

The Prototyping Office was established this past year in response to a recommendation of the Packard Commission on Defense Acquisition. Prototype projects will consist of "brassboard" models, feasibility demonstrations, and experimental vehicles. Some concerns have been expressed that this new responsibility, if improperly managed, could jeopardize DARPA's basic charter-that of examining high-risk technologies, proving feasibility, and quantifying risk without the pressures for demonstrating military applications. It is too early to tell if this concern is justified.

Programs and Priorities

DARPA's scope of programs and responsibilities is broad and appears to be growing as more joint programs are being added to DARPA's overall responsibilities. Among the key projects underway are the X-29 Advanced Technology Demonstrator, being conducted in conjunction with NASA Ames Research Center; the X-Wing Demonstrator; Advanced Cruise Missile Technology; Particle Beam Technology; Strategic Computing; and a high-priority effort to examine technology for armor/anti-armor. DARPA also has a growing materials program investigating advanced composites, other complex materials, and electronic materials including gallium arsenide.

THE STRATEGIC DEFENSE INITIATIVE ORGANIZATION

Headed by a Director who reports directly to the Secretary of Defense, the Strategic Defense Initiative Organization (SDIO) is a centrally managed defense agency with both technical and administrative offices. The offices address ongoing scientific research, broad policy issues, and overall funding issues. There are five technical program directorates (Surveillance, Acquisition, Tracking, and Kill Assessment; Directed Energy Weapons; Kinetic Energy Weapons; Systems Analysis and Battle Management; and Survivability, Lethality and Key Technologies) and a program manager for Innovative Science and Technology. Although the entire SDI program is funded under the Advanced Technology Development category (6.3A), much of the work supported by the Innovative Science and Technology office could be classed as generic research or exploratory in nature.

As with the "traditional" S&T program, specific SDI projects are executed primarily through the Services (Army, Navy, and Air Force), with some additional efforts through other executive agents including DARPA, DNA, the Department of Energy, and the National Aeronautics and Space Administration.

SUMMARY

The Department of Defense will invest almost $9 billion in technology base activities in fiscal year 1988. DOD's complex technology base program is planned, organized, and implemented by DARPA, SDIO, and the three Services, with oversight and guidance provided by the Office of the Secretary of Defense (OSD). The majority of the technology base program is conducted by industry (50 percent), with universities performing 20 percent and the DOD in-house laboratories conducting the remaining 30 percent. The primary goal of the technology base program is to counter Soviet numerical manpower and weapons superiority through the development of superior technology for future weapons systems. Thus, DOD contends a growing technology base program is critical to the successful execution of the Nation's defense policies.

Within the last 3 years, each of the three Services and the OSD have reorganized their technology base programs. As a result of the Goldwater-Nichols Act, the USD(A) was established and given responsibility for all RDT&E activities except for those of the Director of SDIO, who reports directly to the Secretary of Defense. The Goldwater-Nichols Act also reestablished the Director of Defense Research and Engineering (DDR&E) as the primary spokesman for DOD's technology base activities.

Within OSD, the DDR&E is primarily responsible for providing an overall corporate emphasis and balance for DOD's entire technology base program, except for SDI. Once the Services have formulated their technology base programs, the primary role of the DUSD (R&AT) is to ensure that their proposals have responded to OSD guidance. The Deputy for R&AT must also be sure that the Services' programs are well balanced, do not duplicate effort, and attempt to meet the current and future technological needs of DOD.

Each of the three Services operates and manages its technology base activities differently. The Army uses a more decentralized approach in managing its technology base programs; it relies its major field commands-AMC headquarters, the Corps of Engineers, the Surgeon General, and the DCS for Personnel–to help develop and implement its technology base investment strategy. This is primarily due to the small size of the Army's technology base headquarters staff. The Deputy for Technology and Assessment (DT&A) is considered to be the Army's Program Executive Officer (PEO) for the technology base programs. The DT&A is responsible for coordinating technology base programs of AMC, the Surgeon General, the Corps of Engineers, and the DCS for Personnel. AMC headquarters is responsible for oversight and management of the Army's eight laboratories, seven RD&E Centers, the project management training device, and the Army Research Office.

Unlike the other Services, the Navy, which recently reorganized its laboratory organization, performs the majority (60 percent) of its technology base programs in-house. Many of the Navy laboratories are considered to be full spectrum labs, capable of performing the entire range of RDT&E activities. The Navy's basic research program is the oldest and largest of the Services, whereas its advanced technology demonstration program is the smallest. The Navy contends it is in the process of rebuilding its advanced technology development program, which, unlike the other Services, is not managed in the same office as its 6.1 and 6.2 programs.

As of November 1, 1987, the Deputy Chief of Staff for Technology and Plans was established to oversee the Air Force technology base programs. The DCS(T&P) is also the PEO for, and the single manager of, the Air Force technology base program. The Air Force Chief of Staff has recently designated the technology base program as a "corporate investment" to help raise its visibility and to provide a long-term stable funding base. The Air Force operates the largest extramural technology base program. Its technology base activities are more centralized than those of the other Services. The Air Force laboratories are more closely linked to product divisions than are those of the other Services, and this linkage influences the types of 6.2 and 6.3A activities each laboratory performs.

The role of DARPA appears to be changing with the recent establishment of the Prototyping Office. There is some concern that this might compromise DARPA's support of high-risk technologies (only 11 percent of DARPA's budget is for research), as well as its role of proving feasibility and quantifying risk without the pressure for demonstrating military application. The majority of DARPA's budget is contracted through the three Services to industry (75 to 80 percent) and universities (20 percent), with only a small fraction of DARPA's technology base activities actually conducted by the military.

The SD I program is centrally managed with its director reporting to the Secretary of Defense. Less than 5 percent of the SDI budget is spent on basic research, with the remainder divided between exploratory development and advanced technology development. The majority of SDI projects are executed through the Services, with some additional efforts through other executive agents including DARPA, DNA, the Department of Energy, and the National Aeronautics and Space Administration.

Chapter 5

Research Institutions and Organizations

The Department of Defense technology base program has been described in chapter 4 of this special report, and the contribution of private industry is addressed in chapter 3. This chapter describes the contributions made to the defense technology base by government-funded laboratories—both defense and non-defense—and it also discusses how civilian government agencies foster the technology base that is drawn on by the Department of Defense. In addition, various types of nongovernment, nonprofit laboratories are discussed at the end of the chapter.

DEFENSE DEPARTMENT LABORATORIES

Defense Department laboratories are owned and operated—under a variety of different philosophies-by the military services. Their activities are coordinated, to some degree, by the Office of the Secretary of Defense, and they are staffed mostly by Civil Servants and some military officers rotating through on short tours of duty.

Army Laboratories

Department of the Army technology base work is performed by 31 research and development organizations attached to the Army Materiel Command (7 laboratories, 8 research, development, and engineering centers, the Army Research Office, and the Project Manager Training Device), the Office of the Surgeon General of the Army (9 laboratories), the Army Corps of Engineers (4 laboratories), and the Office of the Deputy Chief of Staff for Personnel (1 laboratory). The major Army laboratories are described below.

Army Materiel Command (AMC)

Laboratory Command (LABCOM).–Laboratory Command, within the Army Materiel Command, operates seven facilities that are responsible primarily for 6.2 and 6.3 research in specialized areas of technology relevant to Army requirements. These are:

Atmospheric Sciences Laboratory (ASL), White Sands Missile Range, NM (390).[1]*–The* Atmospheric Sciences Laboratory is AMC's principal laboratory for atmospheric and meteorological technology and equipment development. Basic investigations into atmospheric sensing technologies and applications are conducted to assess the potential impact of atmospheric conditions on advanced Army weapons and systems.

Ballistic Research Laboratory (BRL), Aberdeen Proving Ground, MD (730). –This laboratory conducts research into the vulnerability and lethality of Army weapons (e.g., guns, cannons, missiles). It addresses weapons systems from the drawing board to the field and from small arms and ammunition to large missiles and their warheads.

Electronics Technology and Devices Laboratory (ETDL), Ft. Monmouth NJ (310).–This is the primary Army laboratory for electronics, electron devices, and tactical power supplies. This laboratory is the lead laboratory for the Army for the Very High Speed Integrated Circuit (VHSIC) and Microwave/Millimeter Wave Monolithic Integrated Circuit (MIMIC) programs.

[1]The numbers in parentheses give the total work force (scientists, engineers, managers, support staff, administration, etc.).

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Harry Diamond Laboratories (HDL), Adelphi, MD (730).—Harry Diamond Laboratories is involved in exploratory and advanced development of a variety of technologies including fuzing, target detection and analysis, ordnance electronics, electromagnetic effects, materials, and industrial and maintenance engineering. This laboratory is AMC's lead laboratory for fluidics and nuclear weapons effects.

Human Engineering Laboratory (HEL), Aberdeen, MD (220).–This laboratory is responsible for the "man-machine' interface for advanced Army systems. It has assumed the role of lead Army laboratory for robotics research and human factors engineering.

*Materials Technology Laboratory (MTL), Watertown, **MA*** (660).–The Materials Technology Laboratory is responsible for managing and conducting research and exploratory development programs in materials and solid mechanics, including basic research in advanced metals, composites, and ceramics.

Vulnerability Assessment Laboratory (VAL), White Sands Missile Range, NM(260). –This laboratory provides an independent assessment of the vulnerability of Army weapons and communications electronics systems to hostile electronic warfare (e.g. jamming).

Research, Development, and Engineering (RDE) Centers.–The six Systems Commands of the Army Materiel Command each operate one or more research, development and engineering centers which conduct exploratory and advanced technology development in support of the specific commands' mission responsibilities. These centers are organizational entities and are not necessarily physically located at a single site. (If there is no single primary site, the location given below is that of the parent Systems Command.) Although the RDE Centers conduct some in-house research and development, the bulk of their work is contracted out to industry (the largest contributor), nonprofit organizations, and some universities. The centers are oriented toward the development end of the technology program, leading to components, products, and systems.

Armament RDE Center (ARDEC), Picatinny Arsenal, NJ (4,150).—ARDEC concentrates its efforts on two main areas-weapons and munitions. ARDEC is managed by the Armaments, Munitions, and Chemical Command (AMCCOM), centered at Rock Island, IL.

Chemical RDE Center (CRDEC), Aberdeen Proving Ground, MD (1,400).–CRDEC is the Defense Department's lead laboratory for chemical and biological defense-related matters. Like ARDEC, CRDEC is an RDE center for the Armaments, Munitions, and Chemical Command.

Aviation RDE Center, St. Louis, MO (1,430). –This center, operated by the Aviation Systems Command (AVSCOM), is responsible for Army aviation research and development including airframes, propulsion systems, and avionics. Two major activities are operated in support of Army aviation R&D efforts. First is the Aviation Research and Technology Activity, co-located with NASA's Ames Research Center, Moffett Field, CA. This Activity has subordinate offices at (or near) two other NASA centers: Lewis Research Center and Langley Research Center. These locations reflect the close relationship between Army aviation and NASA's research into advanced short takeoff and landing (STOL) flight concepts and propulsion systems. The second Activity supporting the Aviation RDE Center is the Avionics Research and Development Activity, Ft. Monmouth, NJ, which is co-located with the Army's electronics and communications experts—the Communications-Electronics Command and the Laboratory Command's Electronic Technology and Device Laboratory.

*Communications-Electronics Command **(CECOM) RDE** Center, Ft. Monmouth, NJ* (1,930).–The CECOM RDE center is responsible for research in the areas of command, control, communications, intelligence, and electronic warfare. In addition to the Ft. Monmouth effort, a number of subordinate facilities and centers focus on specialized electronics and sensor research and development. The Night Vision and Electro-Optical Laboratory, Ft. Belvoir, VA, is a recognized leader in infrared and other night vision devices for all three Services. The Signals Warfare Laboratory, Vint Hills Farms Station, VA, conducts programs related to surveillance, reconnaissance, and electronic warfare (including signals intelligence, communications intelligence, electronic countermeasures and electronic counter-countermeasures). Other activities under the CECOM RDE Center include: the Electronic Warfare and Special Sensors group; the Airborne Electronics Research Activity, Lakehurst, NJ; the Center for C^3 Systems; and the Life-Cycle Software Engineering Center.

Missile Command (MICOM) RDE Center, Redstone Arsenal, AL (1 ,470).—This center is responsible for the development, acquisition, and production of all Army missile systems. It is the Army's lead organization for guidance and control, terminal homing, and high power/ high energy laser technology. With the capability to carry a concept through to prototype almost without outside help, it is very influential in the overall direction and progress of Army guided weapons programs.

Tank Automotive Command (TACOM) RDE Center, Warren, MI (810).–This center is responsible for technologies and systems associated with vehicular propulsion, structure, and advanced armor. As exemplified by its location, it has a close relationship with the U.S. automotive industry. Substantial exploratory work is also underway on robotics, vetronics (integrated vehicle electronics), propulsion, and vehicle survivability.

Belvoir RDE Center, Fort Belvoir, VA (1,080).–The Belvoir RDE Center is responsible for combat engineering, logistics support, materials, fuels, and lubricants. It falls under the Troop Support Command (TROSCOM), headquartered in St. Louis, MO, which is responsible for developing systems and equipment to support the soldier.

Natick RDE Center, Natick, MA (l,090).– The Natick RDE Center, also falling under the Troop Support Command, is dedicated to ensuring the maximum survivability, supportability, sustainability, and combat effectiveness of the individual soldier in all combat environments.

Office of the Surgeon General (OTSG)

The Army Medical Research and Development Command, under the authority of the Surgeon General of the Army, operates nine laboratories that investigate medical areas of interest to the Army. These laboratories employ a total of 2,710 personnel. The largest is the Walter Reed Army Institute of Research (1,000 personnel), which performs research in the areas of military disease hazards, combat casualty care, Army systems hazards, and medical defenses against and treatments for chemical weapons. Other facilities also examine these topics and others such as crew workload and stress; treatment of dental injuries; investigation of the problems, complications, and treatment of mechanical and burn injury; the biomedical effects of military lasers; the effects of temperature, altitude, work, and nutrition on the health and performance of soldiers or crews; acoustics; and vision.

Corps of Engineers (COE)

The Corps of Engineers operates four laboratories.

Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH (300).– This facility investigates problems faced by the Corps of Engineers in cold areas of the world.

Construction Engineering Research Laboratory (CERL), Champaign, IL (260).–This laboratory conducts research and development in facility construction, operations, and maintenance.

Engineer Topographic Laboratories (ETL), Fort Belvoir, VA (300).–This laboratory provides the military community with research and development in topographic sciences and terrain analysis.

Engineer Waterways Experiment Station (WES), Vicksburg, MS (1,660).–The five technical laboratories at this facility-the Hydraulics, Geotechnical, Structures, and Environmental Laboratories and the Coastal Engineering Research Center–support the military and civilian missions of the Army, other federal agencies, and allied nations.

Deputy Chief of Staff for Personnell/Army Research Institute for Behavioral and Social Sciences

The Deputy Chief of Staff for Personnel (DCSPER) operates one laboratory, the Army Research Institute for Behavioral and Social Sciences (ARI). This lab, employing 400 personnel, is the Army's lead lab for soldier-oriented research.

Navy Laboratories

The Navy's research and development system, as described in chapter 4, incorporates a greater in-house research and development capability than that of the Army or the Air Force. Many Navy laboratories and development centers not only have the capability to conduct in-house research and exploratory development (6.1 and 6.2), but also can carry a design almost to the production level through the more "mature" stages of advanced systems development (6.3B) and engineering development (6.4). The various Navy laboratories are described below.

Office of Naval Research (ONR)

The Office of Naval Research operates four laboratories.

Naval Research Laboratory (NRL), Washington, DC (3,540/l,550).[2]-Founded in 1923, NRL is the Navy's principal "in-house" research laboratory. Indeed, in some areas of technology, it is DoD's principal laboratory. NRL conducts a vigorous research program in the fields of computer science, artificial intelligence and information management, device technology, electronic warfare, materials, directed energy weapons, surveillance and sensor technology, and undersea technology. In addition, a major space systems technology effort has recently been undertaken by the Laboratory. Roughly one-fourth of NRL's activity is funded by the Navy's research budget. The balance of the activity is funded as a result of proposals by NRL personnel to conduct R&D for Navy development work, other DoD/Service laboratories, and other U.S. Government departments. The "contracts" won by NRL involve 6.1, 6.2, 6.3A/B, and 6.4 activities. NRL also maintains an active exchange program with other laboratories, both in the United States and internationally, and with universities.

Other ONR Laboratories (490/250).-In addition to the Naval Research Laboratory, the Office of Naval Research operates smaller laboratories conducting research in specialized subject areas. The Naval Oceanographic Research and Development Activity (NORDA) and the Institute for Naval Oceanography (INO), in Bay St. Louis, MS, conduct research, development, test, and evaluation programs in ocean science and technology and in ocean forecasting, respectively. The two labs employ 424 people, 215 of whom are scientists or engineers. The Navy Environmental Prediction Research Facility (NEPRF) in Monterey, CA, conducts research and development in various areas of atmospheric science.

Space and Naval Warfare Systems Command (SPAWAR)

Prior to the 1985 reorganization of the Navy science and technology program, each of the major Naval Systems Commands (e.g., Naval Air Systems Command) had responsibility for the operation of mission-specific development activities and centers. This concept has been replaced by one wherein the Space and Naval Warfare Systems Command (SPAWAR) serves as the focal point for most exploratory (6.2) and advanced technology (6.3A) development activities. The other Systems Commands (e.g., the Naval Air Systems Command, the Naval Sea Systems Command, and the Naval Space Command) have primary responsibility for developing "platforms" (e.g., aircraft,

*The first number in parentheses gives the total number of employees at the lab and the second gives the number of scientists and engineers. Note that the definitions of scientist and engineer may vary from facility to facility, and therefore these numbers may not be directly comparable.

ships, space systems). Basic “safety-of-flight’ or “sea-keeping” equipment remain their responsibilities as well, but mission payloads and other specialized equipment are increasingly becoming the responsibility of SPAWAR. In line with this philosophy, all Naval Development Centers and activities have been assigned to that Command. This gives SPAWAR a “high-leverage’ role in the Navy’s overall strategy for systems development.

In addition to their responsibility to SPAWAR for carrying out the science and technology program, the Centers retain a role in providing technical management for major systems programs. In this capacity, the Centers are responsible to their pre-1985 “masters”; i.e., the Systems Commands charged with developing the respective air, sea, and space systems. Seven major development centers are now the responsibility of SPAWAR.

Naval Air Development Center (NADC), Warminster, PA (2,310/1,510).—This Center is responsible for the development of aircraft and aircraft systems, including electronic warfare and anti-submarine warfare systems. In addition to weapons system development, science and technology programs there involve electro-optic, acoustic, and microwave technologies.

Naval Ocean Systems Center (NOSC), San Diego, CA (2,970/l,540).--The Naval Ocean Systems Center is the Navy’s lead Center for surface command and control and for combat direction systems. It has been a continuing leader in ocean surveillance systems (e.g., acoustic, electromagnetic, etc.), and is emerging as a leader in artificial intelligence and knowledge-based systems to support the Navy’s combat-decision-aid programs. The Center is also the Navy’s development organization for undersea weapon systems. S&T activities include ocean science, bioscience, electronics, and electronic materials research.

Naval Weapon Center (NWC), China Lake, CA (4,970/1,820).-China” Lake is responsible for the development of air-to-air weapons and Naval air-delivered ordnance. The AI M-9 Sidewinder missile was developed initially by China Lake more than 20 years ago, and versions of the missile are still state-of-the-art as a result of the Center’s continuing efforts. The development of anti-radiation missile technology and weapons has been carried to a mature state by China Lake. Additionally, China Lake engineers and scientists are considered leaders in sensor technologies (infrared, electro-optic) and missile engineering.

China Lake is of particular interest in that it is one of the sites where the Navy is experimenting with a more flexible salary structure for scientific and technical personnel. Government laboratory managers have stated that Civil Service pay scales for technical personnel, lagging behind industry and even academia, have hampered efforts to maintain high-quality technical staffs.

David W. Taylor Naval Ship Research and Development Center (NSRDC), Carderock, MD and Annapolis, MD (1,130/580).—This Center is responsible primarily for hull designs and advanced ship protection systems (e.g., demagnetizing systems, etc.). It maintains major modeling and test facilities and provides technical management for surface and submarine propulsion systems. Its S&T activities include ship acoustics, magnetics, materials and structures, hydrodynamics, advanced propulsion, and ship survivability.

Naval Surface Warfare Center (NSWC), White Oak, MD (4,870/2,430).—This Center, with its major subordinate facility for weapon systems at Dalghren, VA, serves to develop Naval surface warfare systems, including weapons and systems for the detection and attack of surface and subsurface targets. In addition to weapons system development, NSWC also has a strategic role, serving as the Program Office for the submarine-launched ballistic missile. A broad range of S&T activities are supported at the Center, including energetic materials, charged-particle beams, and sensors.

Naval Undersea Systems Center (NUSC), Newport, RI (3,490/1,930).—AS the Navy’s primary organization for anti-submarine warfare, the Naval Undersea Systems Center is responsible for advanced developments in sonar and other undersea detection technologies. The

Center also provides technical direction for submarine combat systems.

Naval Coastal Systems Center (NCSC), Panama City, FL (1,130/580).-This Center is responsible for mine countermeasures and shallow water undersea weapons. Significant test and evaluation facilities are maintained and operated there.

Summary

The Navy's laboratories and Development Centers have historically been influential throughout the acquisition cycle, up to–and including-production phases. The management reorganization in 1985 that eliminated the Chief of Naval Material-the Navy analogue of the Army Materiel Command and the Air Force Systems Command-consolidated all Naval Development Center activity under SPAWAR. Nevertheless, the job functions, reporting responsibilities, and priorities of many of the scientists and engineers in the field did not change substantially.

Air Force Laboratories

Air Force Systems Command (AFSC)

The exploratory (6.2) and advanced technology (6.3A) development elements of the Air Force S&T program are conducted under the five Systems Divisions which report directly to AFSC: Aeronautical Systems Division, Armaments Division, Electronic Systems Division, Human Systems Division, and Space Division. Each Division provides oversight for one or more laboratories, through which research, exploratory development, and advanced technology development are conducted in support of Air Force-wide requirements. The laboratories in the AFSC organization are described below, with staffing levels given in parentheses for each laboratory. Not explicitly described here is the Air Force Office of Scientific Research, also part of Air Force Systems Command. This Office is responsible for the Air Force basic research (6.1) program, which is conducted primarily outside the Air Force laboratories. The AFSC laboratories are:

Air Force Wright Aeronautical Laboratories (AFWAL), Wright-Patterson Air Force Base, OH (see staff breakdown below) .–Under the Aeronautical Systems Division (ASD) is a "cluster" of laboratories which comprise the Air Force Wright Aeronautical Laboratories—four laboratories, a staff and a Signature Technology Office.

The Aeropropulsion Laboratory (490) is responsible for exploring and developing technologies associated with aircraft and aerospace vehicle power, including turbine engines, ramjets, aerospace power components, fuels, and lubricants.

The Avionics Laboratory (870) is the lead Air Force laboratory for the development of avionics systems and technologies. Major efforts are underway in microelectronics, microwave devices, advanced electro-optics, target recognition technologies, radar systems, and electronic warfare.

The Flight Dynamics Laboratory (1,000) is responsible for aerodynamics, aircraft design, aerospace structures (including research into applications of complex composites), and flight-control systems such as fly-by-light systems. Basic investigations are being conducted into advanced flight mechanisms including hypersonic flight, short take-off and landing, and advanced maneuvering technologies. The Forward Swept Wing (X-29) Program has been a major effort in conjunction with DARPA and the NASA Ames Research Center.

The Materials Laboratory (420) is responsible for materials research and development, including electronic and electromagnetic materials, metals, composites, and the recently discovered high-temperature superconductors. The Materials Laboratory conducts comprehensive nondestructive testing and nondestructive evaluation programs as part of its ongoing effort to develop advanced, high-strength, low-weight structures for aircraft and aerospace vehicles.

Air Force Armament Laboratory (AFATL), Eglin Air Force Base, FL (530).—This laboratory reports directly to, and is co-located with, the Armaments Division. It is charged by the Armaments Division to explore technologies applicable to Air Force non-nuclear weapons, both offensive and defensive. Thus substantial efforts are underway in munitions, seekers (electro-optical, radiofrequency, etc.), structures, and advanced guidance systems for air-to-surface and air-to-air weapons. Although much of the effort involves technology development, a substantial analytical capability can be found there, particularly in the areas of vulnerability, weapons effectiveness, and simulators.

Rome Air Development Center (RADC), Griffiss Air Force Base, NY (1,210).–Rome Air Development Center is the only laboratory operated by the Electronics Systems Division. Among its main activities are investigations into advanced C^3 concepts, information processing, and ground-based and strategic surveillance systems. It is conducting a vigorous pro gram in support of SDIO's battle management/ C^3 effort. RADC maintains two directorates at Hanscom Air Force Base, MA—Electromagnetics and Solid-State Sciences. The first is involved in basic investigations into antennas and electromagnetic phenomena, and the second focuses on solid-state electronics, devices, materials, and systems. An effort underway at the latter facility is focused on radiation-hardened electronic technologies—of interest to both SDIO and the Air Force's strategic C^3 missions.

Air Force Geophysics Laboratory (AFGL), Hanscom Air Force Base, MA (560).-This laboratory reports to the Air Force Space Division through the Air Force Space Technology Center, a management headquarters at Kirtland Air Force Base, Albuquerque, NM. It supports the Air Force's mission in developing and deploying space, airborne, and ground-based systems. Research is conducted into atmospheric science, Earth sciences, infrared technology, and other disciplines related to the space and terrestrial environment.

Air Force Weapons Laboratory (AFWL), Kirtland Air Force Base, NM (1,110).—The Air Force Weapons Laboratory, like the Air Force Geophysics Laboratory, reports to Space Division through the Space Technology Center. It is the lead laboratory involved in the development of technologies related to nuclear weapons effects, directed energy weapons, and radiation hardening. A close association has therefore developed between the Air Force Weapons Laboratory and the two Department of Energy laboratories in New Mexico that are involved in nuclear weapons–Sandia National Laboratories and the Los Alamos National Laboratory. The Air Force Weapons Laboratory has assumed an increasingly important role in the SDI program, especially with regard to the weapons development efforts. The Laboratory's experience and ongoing activities in advanced radiation technology and high-power laser technology have placed it as a leader in directed energy weapon research.

Air Force Astronautics Laboratory (AFAL), Edwards Air Force Base, CA (400).-The Astronautics Laboratory, formerly the Rocket Propulsion Laboratory, is the third laboratory reporting through the Space Technology Center to Space Division. It plans and executes research, exploratory development, and advanced development programs for interdisciplinary space technology and rocket propulsion.

Human Resources Laboratory (AFHRL), Brooks Air Force Base, TX (410).—The Human Resources Laboratory manages and conducts research, exploratory development, and advanced development programs for manpower and personnel, operational and technical training, simulation, and logistics systems.

Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL), Wright-Patterson Air Force Base, OH (980).—The three divisions of AAMRL seek to protect Air Force personnel against environmental injury and provide protective equipment; study human physical and mental performance so that human capabilities can be integrated into systems with maximum effectiveness; and identify and quantify toxic chemical hazards created by Air Force systems and operations.

Air Force Engineering and Services Laboratory (AFESL), Tyndall Air Force Base, FL (100)

Not formally part of Air Force Systems Command, the Engineering and Services Laboratory is the lead agency for basic research, exploratory development, advanced development, and selected engineering development programs for civil engineering and environmental quality technology. It is part of the Air Force Engineering and Services Center, which has responsibility for developing and providing the technology base for the tools and training of the military engineer.

Summary

Unlike the Navy, the Air Force philosophy emphasizes developing the expertise to effectively contract with industry, rather than performing substantial research and development in-house. This philosophy brings programs out into private industry earlier, introducing competition at an earlier stage. Therefore, Air Force labs are not generally viewed as being in competition with the private sector; in fact, Air Force exploratory development programs are viewed by industry as important "seed" programs that will serve to build a company's future business base.

DEPARTMENT OF ENERGY NATIONAL LABORATORIES

Background

The Department of Energy's (DOE's) National Laboratory structure is comprised of about 60 facilities, including the nuclear weapons production facilities, that are involved in a broad range of research, advanced development, and production. With activities located in almost every State, the fiscal year 1986 budget for this complex was over $10 billion (excluding the Strategic Petroleum Reserve and the Power Marketing Administrations). Approximately 135,000 people are now employed within this Laboratory system. Only about 5 percent of these are Federal employees; there-mainder are employed by the industries and universities which operate most of the facilities. The replacement cost of all field facilities is estimated to total well over $50 billion.

Stemming from the Manhattan Project of World War II, the DOE National Laboratory system has now evolved in several major directions. One major responsibility is the design and production of all U.S. nuclear weapons, including uranium enrichment and special nuclear materials (e.g., enriched uranium and plutonium) production. DOE is also responsible for development and production of nuclear reactors for the Navy's submarine fleet. Research and development, production and maintenance, and nuclear materials production for nuclear weapons and other defense activities are each funded at a level of about $2 billion annually.

The research functions and capabilities of the Department of Energy have also broadened beyond their original concentration on nuclear physics to encompass a wide spectrum of research into fundamental sciences. The present scientific and technological capabilities of the DOE National Laboratories make possible investigations including the study of chemical reactions, cosmology, the operation of biological cells, the process of genetic information coding, the ecosystem, the geosphere, mathematics and computing, and medicine. There are nine "multiprogram" laboratories and some 30 specialized laboratories involved in these fundamental science and technology activities, accounting for slightly more than 40 percent of the total field budget and employing more than 60,000 people—more than half of whom are scientists, engineers, and technicians. DOE research and technology areas of interest, and its major test and evaluation facilities, make possible significant contributions in areas of direct relevance to the defense technology base.

The DOE laboratories interact with private industry and with the academic community through mechanisms such as cooperative programs, visiting staff appointments, patent licensing, subcontracting, and use of DOE facilities. Major, capital-intensive, and often unique experimental facilities located at the DOE laboratories are made available to academic researchers for fundamental scientific experiments without cost, provided that the research results are published. Cooperation extends to major U.S. universities, industrial researchers, and international scientists.

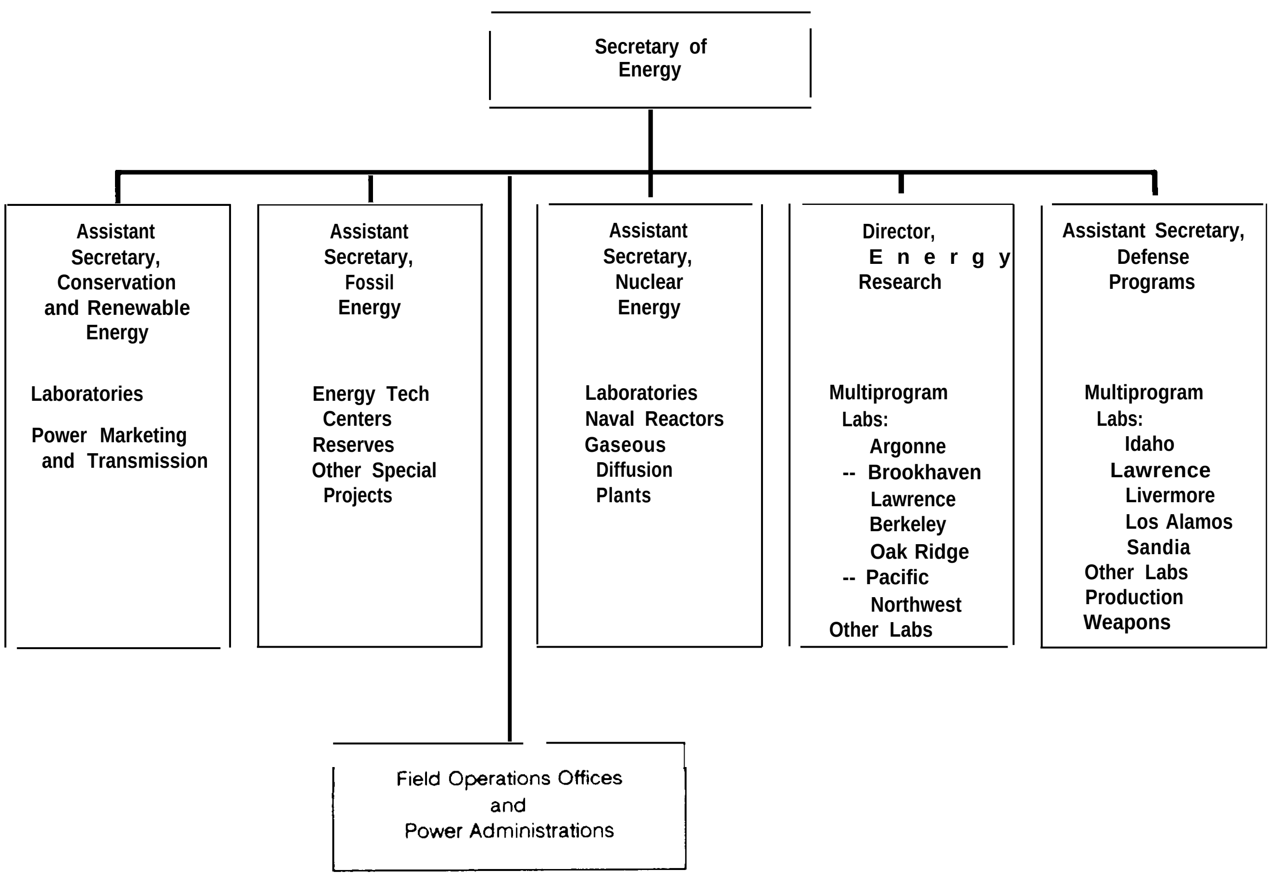
Organization and Management

The complexity of DOE's mission and the diversity of its laboratory complex have resulted in an equally complex management organization. Figure 13 outlines the management structure emanating from the Washington, D.C. headquarters. Of particular concern to the defense technology base are the activities and responsibilities of the Energy Research, Defense, and Nuclear Energy programs. The key functions of the DOE headquarters management offices are summarized below.

Energy Research

The Office of the Director of Energy Research (figure 13) manages the bulk of DOE

Figure 13.– Management Structure for DOE Field Facilities



SOURCE: Department of Energy

fundamental scientific research programs, including: high-energy physics; nuclear physics; the physical, biological and mathematical sciences; magnetic fusion energy; and environmental and health effects. It also supports university research and university-based education and training activities. Moreover, the Director of Energy Research serves as scientific advisor to the Secretary of Energy for all DOE energy research and development activities. The Office also maintains oversight of the multiprogram and other laboratories under the jurisdiction of the Department, with the exception of the nuclear weapons laboratories. Five multiprogram laboratories and 14 program-dedicated facilities are administratively assigned to the Office of Energy Research.

Defense Programs

The Office of the Assistant Secretary for Defense Programs (figure 13) manages DOE's programs for:

- nuclear weapons research, development, testing, production, and maintenance;
- laser and particle-beam fusion;
- safeguards and security programs;
- international safeguards programs; and
- information classification.

In addition, this Office is responsible for the nuclear materials production program, the defense nuclear waste programs, and oversight of the DOE nuclear weapons production complex.

Nuclear Energy

The Office of the Assistant Secretary for Nuclear Energy (figure 13) manages DOE programs for:

- nuclear fission power generation and fuel technology;
- the evaluation of alternative reactor fuel-cycle concepts, including nonproliferation considerations;
- development of space nuclear power generation systems;
- Navy nuclear propulsion plants and reactor cores; and
- nuclear waste technology.

Much of the Nuclear Energy effort is directed toward technology and engineering development programs.

Conservation and Renewable Energy

The Office of the Assistant Secretary for Conservation and Renewable Energy (figure 13) manages a series of programs focused on developing technologies to increase usage of renewable energy sources (including solar heat and photovoltaic energy, geothermal energy, biofuels energy, and municipal waste energy) and to improve energy efficiency (e.g., transportation, buildings, industrial, and community systems, etc.). These programs involve the support of high-risk, high-payoff research and development that would not otherwise be carried out by the private sector; results of this research are disseminated to private and public sector interests.

Fossil Energy

The Office of the Assistant Secretary for Fossil Energy (figure 13) has the responsibility to develop technologies that will increase domestic production of fossil fuels. Specifically, this office supports long-term research toward an improved capability to convert coal and oil shale to liquid and gaseous fuels, and to increase domestic production and use of coal.

Laboratory Management

Eight major operations offices and a series of specialized field offices provide administrative services and day-to-day oversight of the management and operation of DOE's field complex. Much of DOE contracting for R&D and other services is done by these operations and field offices. With the exception of its national security activities, DOE uses its budget more as a catalyst for the development of generic technologies than for acquiring goods and services for its own use. This process involves a significant Federal assistance effort with universities, non-profit organizations, and state and local governments.

A unique feature of DOE laboratory management philosophy is the "Government Owned–Contractor Operated" (GOCO) concept in extensive use throughout the laboratory system. This concept, which was initiated during the Manhattan Project, permits DOE to provide the massive capital investment necessary to create and maintain field facilities and, at the same time, obtain experienced management under contract with industry and universities.

Multiprogram Laboratories

DOE nuclear weapons R&D and nuclear materials production are of obvious interest to DoD, but the DOE multiprogram laboratories also make extensive contributions to the defense technology base in general. These laboratories all conduct defense-related research and development not directly associated with nuclear weapons. Some of them–notably Lawrence Livermore, Los Alamos and Sandia National Laboratories–have DoD as a significant "customer," with an average of 15 percent of these laboratories' work done under contract to DoD. However, DOE restricts the amount of "work-for-others" that its laboratories can perform to keep them from becoming too dependent on funding not under DOE control. The missions and program priorities for the nine multiprogram laboratories are described below.

Sandia National Laboratories (SNL), Albuquerque, NM; Livermore, CA; Tonopah, NE (8,250 total employees)

The principal mission of Sandia National Laboratories is to conduct research, development, and engineering for DoD's nuclear weapon systems—except for the nuclear explosive itself. Operated by AT&T Technologies, Inc., Sandia also conducts energy research programs in fossil, solar, and fission energy and in basic energy sciences. In these and other fields, Sandia has the capability to conduct large, interdisciplinary engineering projects that are sophisticated, but are considered technologically risky. Sandia's management seeks to combine fundamental understanding with technological development—thus generating new products and processes that are unlikely to be produced as readily in universities or industrial laboratories. Nearly 60 percent of Sandia's work is dedicated to nuclear weapon development and production, and 17 percent represents more broadly based research and advanced development for DoD. Much of this research is related to SDI.

Los Alamos National Laboratory (LANL), Los Alamos, NM (8,010)

The Los Alamos National Laboratory was established in 1943, as part of the World War II "Manhattan Engineer District," to develop the world's first nuclear weapons. Operated by the University of California, Los Alamos' primary mission today is the application of science and technology to problems of nuclear weapons and related national security issues. Nuclear weapon R&D thus remains a primary responsibility, including the design and test of advanced concepts. A broad spectrum of energy-related research in nuclear fission and nuclear fusion technologies is also conducted at Los Alamos, with additional programs in life sciences, health, environmental sciences, and basic energy sciences. The latter involve materials; chemical, nuclear, and engineering sciences; and geoscience.

Nuclear weapons research and development accounts for nearly one-half of Los Alamos' DOE-supported activity; an additional 15 percent is in support of DoD programs including SDI, non-nuclear weapons research, conventional ordnance, and materials technology. An emerging role for Los Alamos, in conjunction with the Air Force Weapons Laboratory and Sandia National Laboratories, is support of the SDI program. The Laboratory has also been conducting research into the manufacture of high-temperature superconductors and is seeking a major national role in this area.

Lawrence Livermore National Laboratory (LLNL), Livermore, CA (8,060)

The University of California operates the Lawrence Livermore National Laboratory as a scientific and technical resource for the Nation's nuclear weapons programs. While Livermore is involved in other programs of national interest, the Laboratory's primary role—like that of Los Alamos–is to perform research, development, and testing related to design aspects of nuclear weapons at all phases in a weapon's life cycle. Other important programs underway at Livermore involve inertial fusion, magnetic fusion, biomedical and environmental research, isotope separation, and applied energy technology.

Nuclear weapons-related programs at Livermore account for nearly 50 percent of the Laboratory's DOE-funded activities. Another 12 percent of the lab's activity is "on-contract" work for DoD.

Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (4,960)

This Laboratory is primarily involved in all aspects of the nuclear fission fuel cycle, with a secondary but growing involvement in the development of nuclear fusion energy technology. Oak Ridge National Laboratory also conducts generic research into problems related to energy technologies such as materials, separation techniques, chemical processes, and biotechnology. Energy technology development includes residential and commercial energy conservation, renewable energy sources, and coal conversion and utilization. The Laboratory is also the major national source of stable as well as radioactive isotopes. Oak Ridge is operated by Martin Marietta Energy Systems, Inc.

Argonne National Laboratory (ANL), Argonne, IL (3,900)

Established by the Atomic Energy Act of 1946, Argonne National Laboratory conducts applied research and engineering development in nuclear fission and other energy technologies. A primary Argonne role is to develop and operate research facilities for members of the scientific community. In doing so, it maintains a close relationship with universities and industry and aids in the education of future scientists and engineers. To fulfill this role, Argonne directs scientific and technical efforts in several related areas. Nuclear fission programs focus mainly on breeder and other advanced reactor systems. These programs emphasize fast-reactor physics, reactor safety and analysis, steam supply, and the exploration of new design concepts for reactor facilities using "inherently safe" features and cost-competitive design. In the field of fossil fuel energy, ANL concentrates on advanced conversion systems, including instrumentation and control and related technologies. Argonne also has applied research programs in nuclear applications, materials, and solar conversion systems.

Argonne conducts a variety of basic research projects in areas such as chemistry, atomic and nuclear physics, materials science, and biological and environmental sciences concerning nuclear and non-nuclear effects on organisms. The laboratory is operated under contract by the University of Chicago and performs nearly 90 percent of its work for DOE; 2 percent of the laboratory's work is "on-contract" for DoD.

Brookhaven National Laboratory (BNL), Upton, NY (3,220)

The Brookhaven National Laboratory, operated by Associated Universities, Inc., designs, develops, constructs, and operates research facilities for studying the "-fundamental properties" of matter. Brookhaven also conducts basic and applied research in related technology areas, including high energy, nuclear, and solid-state physics; chemistry; and biology. The physical, chemical, and biological effects of radiation, and chemical substances involved in the production and use of energy, are also studied. Other research programs are directed toward combustion research (processes and emissions, physical and chemical cleanup of combustion gas, meteorological dispersion, etc.), atmospheric chemistry, structural biology, the development of radiopharmaceuticals, and nuclear medicine applications. The research facilities at Brookhaven include: the 33 GeV Alternating Gradient Synchrotrons; the High-Flux Beam Reactor; the Tandem van de Graaf Facility; and the National Synchrotrons Light Source. In addition, there are several smaller accelerators, a medical research reactor, and two scanning transmission electron microscopes. DoD work, such as evaluating the effects of radiation on microcircuits, constitutes 1 percent of Brookhaven's budget.

Lawrence Berkeley Laboratory (LBL), Berkeley, CA (2,520)

Operated by the University of California, the Lawrence Berkeley Laboratory was founded in 1931 to advance the development of the cyclotron invented by Ernest Lawrence. Today, LBL's primary endeavors include conducting multidisciplinary research in energy sciences, developing and operating national energy experimental facilities, educating and training future scientists and engineers, and linking LBL's research programs to industrial applications. The Centers for Advanced Materials and X-Ray Optics have been created to enhance interaction with industry.

In addition to LBL's experimental programs, major research efforts are underway in nuclear and high-energy physics, materials science and chemistry, medical and biological science, energy conservation and storage, environmental dynamics, instrumentation, and advanced accelerator designs. Advanced electron microscopes and heavy-ion accelerators are operated at LBL and are available for use by industrial and other researchers. DoD-sponsored research constitutes a very small fraction of LBL activities.

Idaho National Engineering Laboratory (INEL), Idaho Falls, ID (5,750)

This Laboratory was established in 1949 primarily to build and test nuclear reactors and support equipment. The Idaho National Engineering Laboratory now focuses on nuclear waste management. Among its tasks are reprocessing and recovering of spent nuclear fuel from selected test reactors, the Navy's nuclear fleet, and other nuclear noncommercial reactors, and the processing of liquid waste into calcine form for intermediate storage. To accomplish these tasks the laboratory operates a radioactive waste management complex for storage and disposal of low-level waste, and it conducts associated programs in materials testing, isotope production, irradiation services and training, and test support. Other INEL activities include:

- serving as the lead laboratory for the multi-megawatt space reactor program and fusion reactor safety research;
- supporting DOE non-nuclear energy research (e.g., research and development in geothermal and industrial conservation);
- supporting R&D by other laboratories (at INEL) on defense and civilian nuclear power; and
- directing the Three Mile Island "Technical Information and Examination Program."

With the exception of nuclear waste transportation and management, INEL conducts virtually no work for DoD—basic research or otherwise.

Pacific Northwest Laboratory (PNL), Richland, WA (2,570)

The Pacific Northwest Laboratory has two principal missions: first, to develop and apply technologies for energy security; and second, to provide technical support and environmental surveillance for operations at the colocated Hanford weapons material production reactors. Current applied research programs include advanced nuclear reactor systems, nuclear waste management, dense materials production, energy conservation, and renewable energy systems. PNL also studies the environmental and health effects of radionuclides, inorganic chemicals, and complex organic mixtures encountered in energy production.

PNL maintains a staff of scientists and engineers skilled in the relevant disciplines. These disciplines are grouped to form technical "centers-of-excellence" in life sciences, materials sciences and technology, earth sciences, chemical technology, engineering development, and the information sciences. Operated by Battelle Memorial Institute, PNL works closely with the private sector and also maintains strong ties with university research teams. PNL's activities include a substantial percentage (10 percent) dedicated to DoD research and development.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LABORATORIES AND CENTERS

Background, Organization, and Management

The National Aeronautics and Space Administration (NASA) was established in 1958 as a successor to the National Advisory Committee for Aeronautics (NACA) to oversee the Nation's efforts in the research and exploration of technologies related to aeronautics and space flight. The program has grown into a multidisciplinary effort which involves the management of a diverse complex of laboratory activities and flight test centers. For fiscal year 1988 the NASA budget is $9.0 billion.

NASA Headquarters in Washington, DC, exercises management over the space-flight centers, research centers, and other installations through six program offices. These offices formulate programs and projects; establish management policies, procedures, and performance criteria; and evaluate progress at all stages of major programs. Because of the highly public nature of NASA's work and the resulting political sensitivity, there appears to be a stronger "top-down" management emphasis than in DOE—or even DoD.

The Office of Aeronautics and Space Technology is responsible for planning, executing, and evaluating all of NASA's research and technology programs. These are programs conducted primarily to provide a broad fundamental technology base and to evaluate the feasibility of a concept, structure, component, or system which may have general application to the Nation's aeronautical and space objectives. This office is responsible for Ames Research Center, Mountain View, CA; Langley Research Center, Hampton, VA; and Lewis Research Center, Cleveland, OH.

The Office of Space Flight is responsible for developing concepts and systems for manned space flight and other space transportation systems. The Office plans, directs, executes, and evaluates the research, development, acquisition, and operation of space flight programs. Included in these programs is the National Space Transportation System, of which the Space Shuttle is a key element. The Office of Space Flight also develops and implements policy for all shuttle users and promotes improvements in safety, reliability, and effectiveness. Further responsibilities of the Office of Space Flight include the use of expendable launch systems for NASA and other civil government programs and other developmental space-based transportation systems. The Office of Space Flight has institutional responsibility for the Johnson Space Center, Houston, TX; the Kennedy Space Flight Center, FL; the National Space Technologies Laboratory, Bay St. Louis, MS; and other facilities such as the White Sands Test Facility in New Mexico and the Slidell Computer Complex in Louisiana.

The Office of Space Station is responsible for overall policy and management aspects of the Space Station program. This has become a highly visible office in light of the "political and fiscal heat" the program is taking-heat that is likely to continue. The goals of the program include developing a permanently manned Space Station by the early 1990s, encouraging other countries to participate in the program, and promoting private sector investment in space through enhanced space-based operational capabilities. NASA centers responsible for the Segments, or principal portions, of the Space Station are the Johnson Space Center, Marshall Space Flight Center, Goddard Space Flight Center, and Lewis Research Center.

The Office of Space Science and Applications is responsible for NASA's unmanned spaceflight program. Directed toward scientific investigations of the solar system, the program utilizes ground-based, airborne, and space techniques, including sounding rockets, Earth satellites, and deep-space probes. This has historically been one of the most successful and cost-effective U.S. space programs, and its scientific contributions have been continuous and substantial.

This Office is responsible for research and development leading to the application of space systems, space environment, and space-related or space-derived technology. These activities involve engineering and scientific disciplines such as weather and climate, pollution monitoring, Earth resources survey techniques, and Earth and ocean physics; active programs are also underway in life sciences and microgravity sciences and applications. The Office is responsible for the Jet Propulsion Laboratory, Pasadena, CA, and Goddard Space Flight Center, Greenbelt, MD.

The Office of Space Tracking and Data Systems is responsible for activities related to the tracking of launch vehicles and spacecraft–and for the acquisition and distribution of technical and scientific data obtained from them. This Office is also responsible for managing NASA's communications systems and for operational data systems and services.

The Office of Commercial Programs is responsible for encouraging the commercial use of space. The Office is responsible for the "Technology Utilization Transfer" program, the Small Business Innovative Research program, new commercial applications of existing space technology, "unsubsidized" initiatives for transferring existing space programs to the private sector, and establishing Centers for the Commercial Development of Space.

Field Centers

Ames Research Center, Moffett Field, CA (3,500 employees at Moffett and Dryden facilities)

Founded in 1940 by the National Advisory Committee for Aeronautics as an aircraft research laboratory, the Ames Research Center became part of the new NASA organization in 1958. In 1981, the Dryden Flight Research Center (see below) was merged with Ames, and the two installations are now referred to as "Ames/Dryden" and "Ames/Moffett."

Ames/Moffett specializes in scientific and exploratory research and applications for space and aeronautics in a wide and growing number of fields. Today, the Center's program interests include computer science and applications, computational and experimented aerodynamics, flight simulation, flight research, hypersonic aircraft, rotorcraft and powered-lift technology, aeronautical and space human factors, space sciences, solar system exploration, airborne science and applications, and infrared astronomy. As the lead NASA center for research in the life sciences, continuing programs relate to medical problems of manned flight, both space and atmospheric.

The Center also provides technical support to DoD programs, the Space Shuttle, and civil aviation projects. Recent NASA/DoD efforts include providing design leadership for the airframe studies for an advanced, supersonic short take-off/vertical landing (STOVL) aircraft, a joint U.S./U.K. study effort. These "extramural" projects and responsibilities will evolve as NASA's internal needs (and budgets) change.

Roughly 60 percent of the personnel at the two Ames facilities are Federal employees, with the balance being contractor personnel. Ames maintains a close link with universities through cooperative projects; a significant number of university students and university faculty members work at the center.

Ames Research Center/Hugh L. Dryden Flight Research Facility, Edwards, CA (staff included in Ames/Moffett total)

Ames/Dryden provides NASA with a highly specialized capability for conducting flight research programs. The facility's location, at Edwards Air Force Base in California's Mojave Desert, is at the southern end of a 500-mile high-speed flight corridor and is adjacent to a 65-square-mile natural surface for landing. The site provides almost ideal weather for flight testing.

Primary research tools include a B-52 "carrier" aircraft, several high-performance jet fighters, and the X-29 Forward Swept Wing aircraft. Ground-based facilities include a high-temperature, loads-calibration laboratory for ground-based testing of complete aircraft and structural components under the combined effects of loads and heat, an aircraft flight instrumentation facility, a flight-systems laboratory (capable of avionics system fabrication, development, and operations), a flow visualization facility, a data-analysis facility for processing flight research data, a remotely piloted research vehicles facility, and extensive test range communications and data transmission capabilities. The Facility participated in the approach and landing tests for the Space Shuttle Orbiter Enterprise and will continue to support Shuttle orbiter landings and ferry flights.

A close association has naturally evolved between Ames/Dry den and DoD S&T programs —especially with Dryden's "collocation" at Edwards AFB with the Air Force Flight Test Center. One of Ames/Dryden's major DoD cooperative projects is the X-29, in which NASA and DARPA are exploring a variety of advanced technologies. Another joint NASA/ DoD program is the Advanced Fighter Technology Integration F-1 11, conducted in conjunction with the Air Force Flight Dynamics Laboratory.

Lewis Research Center, Cleveland, OH
(3,690 total staff)

NASA's Lewis Research Center was established in 1941 by the National Advisory Committee for Aeronautics, and developed an early reputation for its research on early jet propulsion systems. Today Lewis is NASA's lead center for research, technology, and development in aircraft propulsion, space propulsion, space power, and satellite communications. In this role, numerous joint programs have been conducted with DoD components, with one of the most recent being the development of engines to power advanced supersonic STOVL aircraft. Lewis also had managed two launch-vehicle programs, the Atlas-Centaur and the Shuttle-Centaur; however, the Shuttle-Centaur program was terminated after the explosion of the Space Shuttle Challenger.

Lewis has recently assumed the responsibility for developing the space power system for the Space Station, the largest ever designed. In addition, the center will support the Station in other areas, such as auxiliary propulsion systems and communications. In support of the Department of Energy's Solar Energy programs, Lewis is working on wind energy systems. Initial testing is on a 100-kilowatt wind turbine—with larger sizes to follow. Solar photovoltaic arrays are also being tested and demonstrated under this effort.

Major facilities include a zero-gravity drop tower, wind tunnels, space environment tanks, chemical rocket-thrust stands, and chambers for testing jet-engine efficiency and noise. Lewis also operates NASA's Microgravity Materials Science Laboratory, a unique facility to qualify potential space experiments. The Center is staffed by 2,690 Federal employees and approximately 1,000 onsite contractors.

Goddard Space Flight Center, Greenbelt, MD
(3,680 Civil Service personnel)

This Center has one of NASA's most comprehensive programs of basic and applied research directed toward expanding NASA's knowledge of the solar system, the universe, and the Earth. It is responsible for the development and operation of several near-Earth space systems, including the Cosmic Background Explorer, which will measure radiation generated early in the universe's history when the universe was much hotter and denser than it is today; the Gamma Ray Observatory, which will gather data on the processes that propel energy-emitting objects of deep space (e.g., exploding galaxies, black holes, and quasars); and the Upper Atmosphere Research Satellite, which will look back at the Earth's upper atmosphere to gather data on its composition and dynamics. Goddard also has responsibility for the development of science instruments and the operations, maintenance, and refurbishment of the Hubble Space Telescope—a large, space-based optical telescope to be deployed by the Space Shuttle.

Goddard is also the responsible Center for NASA's worldwide ground and spaceborne communications network, one of the key elements of which is the Tracking and Data Relay Satellite System with its orbiting Tracking and Data Relay Satellite and associated ground tracking stations. One of the prime missions for this system will be to relay communications to and from the Space Station.

For the Space Station, Goddard is responsible for Segment III, an external, free-flying platform to be placed in polar orbit. The Center is also responsible for developing instruments attached to the outside of the Station and the orbiting platform.

A portion of the Center's theoretical research is conducted at the Goddard Institute for Space Studies in New York City. Operated in close association with universities in that area, the Institute provides supporting research in geophysics, astronomy, and meteorology. Goddard's Wallops Island Facility, located off the coast of Virginia, prepares, assembles, launches, and tracks space vehicles, and acquires and processes the resulting scientific data. Its facilities are utilized by NASA's scientists and engineers, other governmental agencies, and universities.

Jet Propulsion Laboratory (JPL),
Pasadena, CA (4,110 total **staff)**

The Jet Propulsion Laboratory, a federally funded research and development center managed by the California Institute of Technology, is engaged in activities associated with automated planetary and other deep-space missions. These activities include subsystem and instrument development, data reduction, and data analysis. JPL also has the capability to design and test flight systems, including complete spacecraft, and to provide technical direction to contractor organizations. In addition to the Pasadena site, JPL operates the Deep Space Communications Complex, one station of the worldwide Deep Space Network located at Goldstone, CA.

Current JPL projects include the planetary/solar probes Voyager, Galileo, Magellan, and the Mars Observer, and major instruments for other NASA missions. Non-NASA work at JPL currently includes tasks for DoD, DOE, and the Federal Aviation Administration. JPL has been supporting DoD programs in many areas, including artificial intelligence, tactical-data fusion, and specialized training systems based on "Expert System" technology.

Langley Research Center, Hampton, VA
(2,910 Civil Service personnel)

Langley's primary mission involves applied research and development in the fields of aeronautics, space technology, electronics and structures. The Center also conducts programs for environmental monitoring, having developed a range of instruments for atmospheric measurements.

In aeronautical technologies, programs have been directed primarily toward improving the efficiency of transport aircraft and high performance supersonic military aircraft. The Center is also developing technology for future transonic transport aircraft and has been active in studies of hypersonic powerplants. A variety of wind tunnels are available to support basic and applied aeronautical research.

Research interests at Langley include materials, flutter, aeroelasticity, dynamic loads and structural response, fatigue fracture, electronic and mechanical instrumentation, computer technology, flight dynamics, and control and communications technology. Langley is now assuming a role in developing technologies for the National Aerospace Plane, and has continuing work on the Space Shuttle and Space Station (e.g., experiments, sensors, communications equipment, and data handling systems). Other research programs include investigations of effects such as heat, vacuum, noise, and meteoroids on space vehicles; the use of advanced composite and polymeric materials for structures and thermal control systems; and electronics technology.

Marshall Space Flight Center, Huntsville, AL
(3,450 Civil Service personnel)

Marshall serves as one of NASA's primary centers for the design and development of space transportation systems, elements of the Space Station, scientific and application payloads, and other systems for present and future space exploration. It has the principal role for large rocket propulsion systems, Spacelab mission management, the design and development of large, complex, and specialized automated spacecraft, solar and magnetospheric physics, and astrophysics. Using the gravity-free environment of space, Marshall seeks to develop materials processing techniques to enhance Earth-based processes and to fabricate space-unique materials.

Marshall has responsibilities for manned space vehicle development such as the Spacelab and has sustaining engineering duties in support of the Space Shuttle. Advanced program efforts focus on the analysis and definition of propulsion/transportation systems to meet the nation's needs over the next 25 years. Marshall is currently leading the planning for an unmanned cargo version of the Space Shuttle called Shuttle-C; efforts for an Advanced Launch System are also underway.

Marshall also plays a principal role in payload development, instrument development, and mission management for space science and applications missions as assigned. Responsibilities include the Hubble Space Telescope, the Advanced X-Ray Astrophysics Facility, and automated servicing/resupply/retrieval kits. Its Space Station responsibilities include the development of pressurized structures, crew and laboratory modules, logistics, environmental control, and life support.

Two other sites are managed by Marshall: the Michoud Assembly Facility, New Orleans, LA, where the Space Shuttle external tanks are manufactured, and the Slidell Computer Complex, Slidell, LA, which provides computer services support to Michoud and Marshall.

Lyndon B. Johnson Space Center, Houston, TX (3,440 Civil Service personnel)

Johnson Space Center manages the design, development, and manufacture of manned spacecraft; the selection and training of astronaut crews; and the conduct of manned space flight missions. Its principal roles include Space Shuttle production and operations, production of the replacement Orbiter, and support to NASA Headquarters management for the Shuttle system. It also has responsibility for the development of new manned space vehicles and supporting technology.

Johnson is a major development center for specific Space Station elements, including the truss structure, airlocks and nodes, and additional subsystems. It has principal program activity in the field of life sciences and medical research to solve space medical problems, and it has supporting roles in lunar and planetary geosciences, technology experiments in space, and remote sensing. It is also responsible for directing the operations of the White Sands Test Facility, located on the western edge of the U.S. Army White Sands Missile Range in New Mexico.

Kennedy Space Center, FL (2,200 Civil Service personnel)

Kennedy Space Center, located east of Orlando on the Atlantic Ocean, serves as the primary NASA center for the test, checkout, and launch of space vehicles. This responsibility includes ground operations for Space Shuttle preparation, launch, and landing and refurbishment. Other responsibilities include Expendable Launch Vehicle operations. The Space Station effort at Kennedy Space Flight Center includes system integration and engineering, operational readiness, and delegated ground support equipment program management.

National Space Technology Laboratories, Bay St. Louis, MS (150 Civil Service personnel)

The National Space Technology Laboratories provide NASA's prime test facility for large liquid propellant rocket engines and propulsion systems such as the Space Shuttle main engines. It also conducts applied research and development in the fields of remote sensing, environmental sciences, and other selected applications. The Laboratory provides facilities and support through interagency agreements to other Federal government agencies and the States of Mississippi and Louisiana.

OTHER FEDERAL ACTIVITIES

By far, the majority of Federal Science and Technology activities with potential defense applications are conducted within DoD, DOE, and NASA. There are "pockets" of S&T activit y within other government departments and agencies which contribute to the defense technology base. However, because of the magnitude of investment in military technology by DoD, one often finds the reverse is the case; for example, U.S. Coast Guard technologies and systems often result from U.S. Navy research and technology programs.

A major exception in which non-DoD funding dominates research in a field of relevance to the defense technology base is medical technologies. The National Institutes of Health (NIH) of the Department of Health and Human Services will finance more in health research in its fiscal year 1988 budget than DoD will spend in its entire research and exploratory development (6.1 and 6.2) program. NIH's fiscal year 1987 research budget was near $6.0 billion, $3.6 billion of which supports university research. For reference, the entire Federal FY87 budget for basic research was $9 billion, of which the DoD 6.1 program constituted less than $1 billion. Less than $0.5 billion of those DoD 6.1 funds supported university research.

In the past, biological sciences have not been as important to the defense technology base as physical sciences and engineering. In the future, however, biotechnology will likely become increasingly important to the defense technology base, and more of the government investment in life sciences may have direct relevance to DoD needs.

National Science Foundation

The National Science Foundation (NSF) was established in 1950 to advance scientific progress in the United States. NSF supports scientific and engineering research and related activities, and under congressional pressure has more recently devoted some attention to improving science and engineering education. NSF does not conduct research itself nor does it typically contract for research. It provides most of its support in the form of grants in response to unsolicited research proposals. Proposals are evaluated through a review process that selects primarily on the basis of scientific or technical merit. Most NSF grants result from proposals submitted by academic institutions. Small businesses also submit unsolicited research proposals and receive awards; however, most NSF awards to small businesses are grants made in response to proposals under the Small Business Innovative Research program.

NSF supports basic research projects in nearly every conceivable area of science and technology, including physics, chemistry, mathematical sciences, computer research, materials research, electrical, computer, and systems engineering, chemical and processing engineering, civil and environmental engineering, mechanical engineering and applied mechanics, physiology, cellular and molecular biology, biotic systems and resources, behavioral and neural sciences, social and economic sciences, information science and technology, astronomical sciences, atmospheric sciences, earth sciences, ocean sciences, and interdisciplinary combinations of these. NSF also supports science resources studies, policy research and analysis, and studies in industrial science, technological innovation, and other scientific and technical areas.

For fiscal year 1987, NSF-sponsored university basic research totaled about $1 billion, approximately twice that of DoD. The total NSF R&D budget that year was $1.5 billion.

Department of Commerce

National Bureau of Standards

The National Bureau of Standards (NBS) is the Nation's central reference laboratory for physical, chemical, and engineering measurements. The measurement and data services that NBS provided in 1987 included calibrations, production and distribution of standard reference materials and data, and laboratory accreditation. The Army, Navy, Air Force, and Defense Agencies (including their contractors) make extensive use of these services.

While the Federal Government has a substantial capital investment in instrumentation and facilities at NBS, the actual research budget is modest and is augmented by cooperative research projects conducted jointly between NBS and other organizations. NBS conducts specialized research programs for the Department of Defense on a contractual basis. These programs draw on NBS's unique capabilities, and range from fundamental physics and chemistry studies to more applied work, such as developing calibration techniques for a particular piece of defense hardware. Research topics encompass fields such as electro-optics, microwave and millimeter wave measurements, electronics, physical measurements (e.g., temperature, pressure, shock, and vibration), automated metrology, materials characterization, and applications of computer systems. NBS also hosts technical conferences and workshops for DoD and consults on a variety of subjects, particularly those relating to instrumentation and measurement.

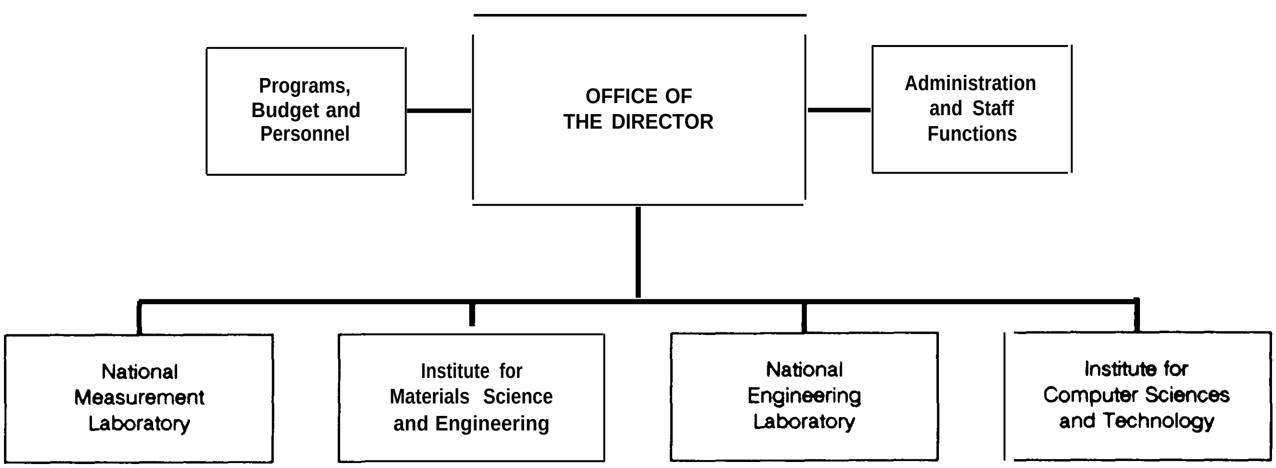
NBS is the only Federal laboratory with a primary mission of supporting U.S. industry. To accomplish this mission, NBS is organized into four laboratories and institutes (figure 14): the National Measurement Laboratory, the National Engineering Laboratory, the Institute for Materials Science and Engineering, and the Institute for Computer Sciences and Technology.

The National Measurement Laboratory (NML) conducts research in physics, radiation chemistry, analytical chemistry, and chemical properties and processes. NML produces fundamental measurements and data that underlie national measurement standards. It also furnishes advisory and research services to other government agencies and provides standard reference data and calibration services.

The National Engineering Laboratory (NEL) conducts research in electronics and electrical engineering, chemical engineering, manufacturing engineering, mathematical sciences, and the construction and performance of buildings and fire protection. This laboratory produces new engineering knowledge, techniques, and databases for the design, development, prediction, and control of industrial processes. Improved quality assurance and reduced costs of manufacturing are two principal goals of the work.

The Institute for Materials Science and Engineering (IMSE) performs research in ma-

Figure 14. –National Bureau of Standards



SOURCE: National Bureau of Standards

terials characterization, nondestructive evaluation, metallurgy, polymers, and ceramics; it produces measurement methods, standards, data, and other technical information on processing, structure, properties, and performance of materials. The goal of these activities is to support generic materials technologies to permit manufacture of advanced materials with increased reliability and quality and reduced cost.

The Institute for Computer Sciences and Technology (ICST) performs research in computer sciences and engineering. This research is designed to establish Government-wide standards and guidelines for automated data processing systems. The Institute also provides technical support for the development of national and international voluntary standards.

Under Public Law 100-202, the Final Omnibus Appropriation Bill for fiscal year 1988, NBS is to establish "Regional Centers for the Transfer of Manufacturing Technology. " These centers will be designed to accelerate technology transfer to organizations that need to implement new automated manufacturing techniques. Such techniques are being developed for the Navy in NBS's Automated Manufacturing Research Facility. This facility is developing applications of automated manufacturing technology in piece-part manufacturing at shipyards and depots.

NBS fiscal year 1988 appropriations are $145 million. Total resources for the same year, totaling $314 million, include $95 million in work for other Federal agencies, $22 million from the sale of calibrations, testing services, and standard reference materials, and $52 million in private sector contributions of staff and equipment. Total full-time equivalent NBS staff for fiscal year 1988 is 3,090.

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) explores, maps, and charts the global oceans and their mineral and living resources. The agency monitors and predicts the characteristics of the physical environment and warns against impending hazards such as hurricanes, tornadoes, floods, seismic sea waves, and other destructive natural events. NOAA monitors the gradual changes of climate and environment and predicts the impact of such changes on food production, resource management, and energy utilization.

NOAA provides a focus within the Federal Government for the objective scientific assessment of the ecological consequences of specific actions, such as petroleum exploration, development, and shipment, and marine mineral extraction. The major operating elements of NOAA are:

- the National Weather Service,
- the National Ocean Service,
- the National Marine Fisheries Service,
- the National Environmental Satellite, Data, and Information Service,
- the Environmental Research Laboratory, and
- the Office of Oceanic and Atmospheric Research.

Department of Transportation

The Federal Aviation Administration and the U.S. Coast Guard-components of the Department of Transportation (DOT) –develop and acquire hardware and systems. However, the bulk of DOT's research is analytical in nature and is directed toward setting and enforcing regulations and toward investigating deviations (e.g., accidents). DOT's research branch is the Research and Special Programs Administration, which has the responsibility for planning and management of programs in all fields of transportation research and development.

Research and Special Programs Administration

The Research and Special Programs Administration (RSPA) maintains the capability to perform program management, "in-house" research and development, analysis in transportation planning and socioeconomic effects, and technological support in response to DOT policies. Particular efforts are made on transportation systems problems, advanced transportation concepts, and on "multi-modal" transportation. RSPA also develops and maintains vital statistics and a related transportation information database.

RSPA is composed of the following functional groups:

- The Transportation System Center provides support to DOT and other Federal agencies in the fields of technology assessment, industry analysis, strategic planning support, and research management for transportation systems.
- The Materials Transportation Bureau is responsible for the safe transportation of all hazardous materials. As part of this mission, it establishes and enforces hazardous materials and pipeline safety regulations.
- The Office of Program Management and Administration coordinates the university research program, which focuses on high-priority transportation problems (e.g., issues pertaining to transportation systems engineering, advanced transportation planning, and telecommunications). Its Transportation Safety Institute, located at the Mike Monroney Aeronautical Center in Oklahoma City, OK, develops and conducts training programs.
- The Office of Emergency Transportation coordinates the development and review of emergency preparedness policies, plans, and related programs.

Federal Aviation Administration

The Federal Aviation Administration (FAA) has a research and development program that is largely oriented toward establishing standards for the design and performance of aircraft monitoring, communications, and navigation equipment and toward the acquisition and management of air traffic control systems. In this regard, there is a substantial convergence of interest and activities with DoD—especially the Air Force. For example, the structure and management of the Nation's air traffic control system and planned conversion to the microwave landing system require close cooperation with the Air Force. Because of the size of the Air Force budget in these areas, the "technology transfer" from the Air Force to the FAA may be substantially greater than vice versa. However, the joint USAF/FAA responsibilities and interests remain, with attendant contributions to defense technology.

U.S. Coast Guard

The U.S. Coast Guard is involved in the development and acquisition of the communications systems and facilities, aircraft, and vessels which are required to accomplish its coastal monitoring mission. A close association naturally exists between the Navy and the Coast Guard in this regard and a significant technology transfer process exists. The Coast Guard simply does not have a budget of sufficient size to conduct a broad and independent R&D program; it must rely on the Navy research budget. However, Coast Guard requirements and deployment concepts contribute to the formulation and execution of Naval and other DoD research science and technology projects. Thus there is, as with the FAA/Air Force relationship, a synergistic effect–albeit not substantial in financial terms.

Other Federal Agencies

There are scores of other Federal agencies, departments and special groups involved in some way in science and technology which would have applications to and could contribute to the defense technology base. The Department of Agriculture and the Department of the Interior/U.S. Geological Survey conduct modest research programs which can have defense technology base fallout.[3] Examples are the remote sensing programs which are sponsored in these departments. Utilization of data from LANDSAT, defining collection requirements, and supporting spacecraft and sensor development programs can complement DoD's

[3]The Department of Agriculture supports a university research program which amounts to roughly $200 million per year.

image processing and remote sensing requirements. Although the magnitude of funding available on the defense side may "overpower' these programs, the expertise growing in applications and the cost-effective utilization of remote sensing systems could have beneficial returns to defense programs.

The Federal Communications Commission exerts influence over telecommunications policies, which can affect DoD programs. Thus, the Commission's activities are closely coordinated with DoD, and its actions impact on requirements (if not on actual programs themselves).

Small Business Innovative Research (SBIR) Program

An interesting government program offering incentives to the private sector that can stimulate contributions to the defense technology base is the Small Business Innovative Research program.[4] The SBIR program was established with the enactment of the Small Business Innovation Development Act in 1982. In 1986, the program was reauthorized through fiscal year 1993. Under SBIR, Federal agencies with research and development budgets which exceed $100 million must establish an SBIR program, with the funding contribution derived from fixed percentages established for each participating agency. Eleven Federal agencies now participate in SBIR:

- Department of Agriculture,
- Department of Commerce,
- Department of Defense,
- Department of Education,
- Department of Energy,
- Department of Health and Human Services,
- Department of Transportation,
- Environmental Protection Agency,
- NASA,
  National Science Foundation, and
  Nuclear Regulatory Commission.

The program consists of three phases of contracting and is designed to encourage small business to overcome their "angst" when dealing with the Federal Government (e.g., too much paperwork, complete auditing procedures, etc.). Phase I contracts are focused on evaluating the scientific and technical merit and/or feasibility of an idea. Awards are normally up to $50,000, with an average period of performance of 6 months. Under Phase II the results of Phase I feasibility studies are expanded to pursue further any development opportunities. Only those small businesses which have conducted Phase I contracts are eligible for Phase II. The size of the contracts are normally $500,000 or less and the period of performance roughly 2 years. Under Phase III, the government seeks to commercialize the results of Phase II through the use of private, or non-SBIR Federal, funding (e.g., DoD RDT&E funds).

The participating agencies and departments publish their lists of SBIR solicitation topics on a quarterly basis. DoD—the Departments of the Army, Navy, and Air Force; the Defense Advanced Research Projects Agency; the Defense Nuclear Agency; and the Strategic Defense Initiative Organization-lists hundreds of topics. Most of these topics would be classed in the research and exploratory development categories of DoD's S&T program. Since the program's inception in fiscal year 1983, more than 5,000 Phase I and 1,000 Phase II contracts have been awarded and the total dollar amount is in excess of $655 million. In fiscal year 1986,$98 million in Phase I and $200 million in Phase 11 programs were awarded and roughly $400 million will be awarded for both phases in fiscal year 1987. A quick review of the DoD topic list reveals that the return in defense-related technology development could be substantial.

'For additional information on this program, see the Science Policy Study Background Report No. 8, "Science Support by the Department of Defense, " prepared by the Congressional Research Service for the Task Force on Science Policy, Committee on Science Policy, U.S. House of Representatives, 99th Cong., pp. 310-314.

PRIVATE NONPROFIT LABORATORIES

A considerable amount of DoD technology base work is performed by federally funded research and development centers (FFRDCs) and other nonprofit laboratories that, in many ways, have organizational characteristics between those of government laboratories and those of private corporations. Like government laboratories, these facilities need not consider potential profitability in their choice of research activities. However, they have more flexibility in their operating procedures—and particularly in their personnel policies—than do government laboratories.

FFRDCs serve various branches of the Federal Government. Ten are sponsored by Department of Defense. Six of these–the Center for Naval Analyses, the Institute for Defense Analyses, three divisions of the Rand Corp. (Project Air Force, Rand National Defense Research Institute, and the Arroyo Center), and the Logistics Management Institute—primarily conduct studies and analyses for the Services and the Office of the Secretary of Defense and do not perform much technical research or development. The other four—The Aerospace Corp., the MITRE Corp. C^{3}I Division, the Software Engineering Institute, and Lincoln Laboratory–have a significant technical role and are described below.

Other nonprofit institutions, organized differently than FFRDCs, also perform significant technical work for the Defense Department and other federal agencies. Their management structures range from university affiliates to independent, nonprofit organizations. Selected examples of these institutions are also presented below.

Federally Funded Research and Development Centers

The Aerospace Corp., **El Segundo, CA (3,800/2,100)**[5]

The Aerospace Corp. performs technical work on military space systems and related technologies. Its services are provided principally for for the Space Division of the Air Force Systems Command, although it also works for other agencies. Aerospace Corp. provides general systems engineering and integration services, which involve formulating requirements, designing specifications, monitoring technical progress, resolving problems, certifying completion, and assistance during operation. Its single largest responsibility involves certifying spacecraft and launch vehicles for launch.

The MITRE Corp., C^{3}I Division, Bedford, MA **and Washington, DC (4,000/2,140)**

The C^{3}I division of MITRE Corp. performs systems engineering and integration services in the field of command, control, communications, and intelligence (C^{3}I) under Air Force sponsorship. Its primary sponsor is the Electronic Systems Division of the Air Force Systems Command. (Metrek Division, another division of MITRE Corp., serves as a nonprofit contractor for civil agencies of the government.)

Software Engineering Institute, Pittsburgh, PA (14O/1OO)

The Software Engineering Institute is operated by Carnegie Mellon University under contract to the Electronic Systems Division of the Air Force Systems Command. However, it works for all the Services to promote use of the most effective technology to improve the quality of operational software in mission-critical computer systems.

Lincoln Laboratory, Lexington, MA (2,100/760)

Lincoln Laboratory's particular emphasis is on electronics. It is operated by the Massachusetts Institute of Technology under prime contract with the Electronic Systems Division of the Air Force Systems Command. Established in 1951 to assist the Air Force with the then-emerging technology of digital computers, it continues as a pioneering technical center in the areas of radar, communications, and com-

‘(Total Staff/Scientists and Engineers).

puters. Programs range from fundamental solid state science to the design, development, and demonstration of prototype systems. It works for all the Services and for several DoD agencies. The Air Force limits the degree of participation of other clients to less than 50 percent.

University Affiliates

Many federally funded laboratories are managed by universities under a variety of different structures such as FFRDC (e.g., Lincoln Laboratory, managed by MIT for the Air Force) and management contract (e.g. Los Alamos, Lawrence Livermore, and Lawrence Berkeley National Laboratories, managed by the University of California for the Department of Energy). Yet another management approach is as an independent university division, such as the Johns Hopkins Applied Physics Laboratory. This laboratory, and other examples of university-affiliated research centers, are described below.

Johns Hopkins Applied Physics Laboratory, Howard County, MD (2,800/1,600)

The Applied Physics Laboratory is a division of the Johns Hopkins University, operating in parallel with the university's academic divisions. The lab is run primarily under a single contract with the Navy's Space and Naval Warfare Systems Command, but it performs work for all DoD-sponsored activities and most other Federal activities. With a history of work in proximity fuzes, guided missiles, and systems engineering, the lab currently works in the areas of Navy ship systems, submarine systems, strategic systems, naval warfare analysis, space research and development, aeronautics, and biomedical research. Basic and applied research are also conducted in a number of areas that underlie current and future laboratory interests.

Georgia Tech Research Institute, Atlanta, GA (1,360/580)

The Georgia Tech Research Institute is a nonprofit organization affiliated with the Georgia Institute of Technology. It performs engineering, scientific, and economic research in electronics, electromagnetic, energy, materials sciences, and a number of other areas. Various defense and non-defense government agencies are the principal clients, but up to 20 percent of the work is done for private industry.

IIT Research Institute, Chicago, IL (1,750/1,200)

The I IT Research Institute is a nonprofit research organization affiliated with the Illinois Institute of Technology. It works for both government and private clients, with the number of projects about evenly split between the two, but with Federal contracts representing about 80 percent of its funding. Research topics include electronics, communications, toxicology, chemical defense, environmental science, petroleum research, ordnance, and advanced manufacturing technology.

Independent Nonprofit Laboratories

Battelle Memorial Institute, Columbus, OH (7,800)

Battelle is an independent, nonprofit, international organization providing research and development, technical management (primarily management of the Department of Energy's Pacific Northwest Laboratory), and technology commercialization services. Battelle's research and development is now being concentrated primarily in the areas of advanced materials, biological and chemical sciences, biotechnology, electronics, engineering and manufacturing technologies, and information systems.

Charles Stark Draper Laboratory, Cambridge, MA (2,000/1,000)

Draper Labs, at one time affiliated with the Massachusetts Institute of Technology, is now an independent nonprofit research institution. Its major business activities are avionics, strategic systems, undersea vehicle systems, precision pointing and tracking, and advanced space systems. Draper has had major responsibility for guidance, navigation, and control systems for strategic ballistic missiles, NASA spacecraft, and a variety of Air Force systems.

SRI International, Menlo Park, CA (3,600)

SRI International is an independent non-profit research institute once affiliated with Stanford University. It is organized into four divisions–Engineering; International Business and Consulting; Sciences (Physical and Life); and the David Sarnoff Research Center. The Sarnoff research center, originally the RCA corporate research laboratory, was sold to SRI when RCA was acquired by General Electric. About 60 percent of SRI's work is for the Federal Government, with the remainder for private clients.

Glossary of Acronyms

AD —Armaments Division (Air Force Systems Command)
ADP —Advanced Demonstration Project
AFAL —Air Force Astronautics Laboratory (Air Force Systems Command)
AFATL —Air Force Armament Laboratory (Air Force Systems Command)
AFESL —Air Force Engineering and Services Laboratory
AFGL —Air Force Geophysics Laboratory (Air Force Systems Command)
AFOSR —Air Force Office of Scientific Research
AFSC —Air Force Systems Command
AFWAL —Air Force Wright Aeronautical Laboratories (Air Force Systems Command)
AFWL —Air Force Weapons Laboratory (Air Force Systems Command)
AMC —Army Materiel Command
AMCCOM —Armaments, Munitions, and Chemical Command (Army Materiel Command)
ARDEC —Armament RDE Center (Army Materiel Command)
ARI —Accelerated Research Initiative (U.S. Navy)
ARI —Army Research Institute (Army Deputy Chief of Staff for Personnel)
ARO —Army Research Office
ARPA —Advanced Research Projects Agency (now DARPA)
ASA(RD&A) —Assistant Secretary of the Army for Research, Development, and Acquisition
ASAF(A) —Assistant Secretary of the Air Force for Acquisition
ASD —Aeronautical Systems Division (Air Force Systems Command)
ASD(R&T) —Assistant Secretary of Defense for Research and Technology
ASL —Atmospheric Sciences Laboratory (Army Materiel Command)
ASN(RE&S) —Assistant Secretary of the Navy for Research, Engineering, and Systems
ATD —Advanced Technology Demonstration
AVSCOM —Aviation Systems Command (Army Materiel Command)
B&P —Bid and Proposal
BRL —Ballistics Research Laboratory (Army Materiel Command)
C^3I —Command, Control, Communications, and Intelligence
CECOM —Communications-Electronics Command (Army Materiel Command)
CMC —Commandant of the Marine Corps
CNO —Chief of Naval Operations
CNR —Chief of Naval Research
COE —Corps of Engineers (U.S. Army)
CRDEC —Chemical RDE Center (Army Materiel Command)
CREL —Construction Engineering Research Laboratory (Army Corps of Engineers)
CRREL —Cold Regions Research and Engineering Laboratory (Army Corps of Engineers)
CRS —Congressional Research Service
DARPA —Defense Advanced Research Projects Agency (formerly ARPA)
DCA —Defense Communications Agency
DCS(T&P) —Deputy Chief of Staff for Technology and Plans (U.S. Air Force)
DCSPER —Deputy Chief of Staff for Personnel (U.S. Army)
DDR&E —Director of Defense Research and Engineering
DMA —Defense Mapping Agency
DNA —Defense Nuclear Agency
DNL —Director of Navy Laboratories
DoD —Department of Defense
DOE —Department of Energy
DOT —Department of Transportation
DR&T —Director of Research and Technology (U.S. Army)
DRD&R(T&E) —Director of Research, Development and Requirements, Test and Evaluation

DSARC —Defense System Acquisition Review Council
DSB –Defense Science Board
DT&A –Deputy for Technology and Assessment (U.S. Army)
DUSD(R&AT)–Deputy Under Secretary of Defense for Research and Advanced Technology
ESD —Electronic Systems Division (Air Force Systems Command)
ET –Emerging Technologies
ETDL –Electronics Technology and Devices Laboratory (Army Materiel Command)
ETL —Engineer Topographic Laboratory (Army Corps of Engineers)
FAA –Federal Aviation Administration (U.S. Department of Transportation)
FFRDC –Federally Funded Research and Development Center
FSED —Full-Scale Engineering Development
GaAs —Gallium Arsenide
GOCO –Government Owned/Contractor Operated
HDL –Harry Diamond Laboratories (Army Materiel Command)
HEL –Human Engineering Laboratory (Army Materiel Command)
HSD —Human Systems Division (Air Force Systems Command)
ILIR —In-House Laboratory Independent Research Program
IMIP —Industrial Modernization Incentives Program
INEL –Idaho National Engineering Laboratory (U.S. Department of Energy)
INO –Institute for Naval Oceanography (Office of Naval Research)
IR&D –Independent Research and Development
JPL –Jet Propulsion Laboratory (National Aeronautics and Space Administration)
LABCOM –Laboratory Command (Army Materiel Command)
LBL –Lawrence Berkeley Laboratory (U.S. Department of Energy)
ManTech –Manufacturing Technology (Program)
MICOM –Missile Command (Army Materiel Command)
MILSPEC –Military Specifications
MIMIC –Microwave/Millimeter Wave Monolithic Integrated Circuit
MTL –Materials Technology Laboratory (Army Materiel Command)
NADC –Naval Air Development Center (Space and Naval Warfare Systems Command)
NAS —National Academy of Sciences
NASA –National Aeronautics and Space Administration
NATO –North Atlantic Treaty Organization
NBS –National Bureau of Standards (U.S. Department of Commerce)
NCSC –Naval Coastal Systems Center (Space and Naval Warfare Systems Command)
NEPRF —Navy Environmental Prediction Research Facility (Office of Naval Research)
NGNS –Next Generation and Notional Systems
NIH –National Institutes of Health
NOAA –National Oceanic and Atmospheric Administration (U.S. Departmemt of Commerce)
NORDA –Naval Oceanographic Research and Development Activity (Office of Naval Research)
NOSC –Naval Ocean Systems Center (Space and Naval Warfare Systems Command)
NRL –Naval Research Laboratory (Office of Naval Research)
NSA –National Security Agency
NSF —National Science Foundation
NSRDC –Naval Ship Research and Development Center (Space and Naval Warfare Systems Command)
NSWC –Naval Surface Warfare Center (Space and Naval Warfare Systems Command)
NUSC –Naval Undersea Systems Center (Space and Naval Warfare Systems Command)
NWC –Naval Weapons Center (Space

and Naval Warfare Systems Command)

ONR —Office of Naval Research

ONT —Office of Naval Technology

OPNAV —Office of the Chief of Naval Operations

OSD —Office of the Secretary of Defense

OTA —Office of Technology Assessment

OTSG —Office of the Surgeon General (U.S. Army)

PEO —Program Executive Officer

PMR —Potential Military Relevance

PNL —Pacific Northwest Laboratory (U.S. Department of Energy)

POM —Program Objective Memorandum

PPBS —Planning, Programming, and Budgeting System

R&AT —see DUSD(R&AT)

R&D —Research and Development

RADC —Rome Air Development Center (Air Force Systems Command)

RD&A —Research, Development, and Acquisition

RDE —Research, Development, and Engineering

RDT&E —Research, Development, Test, and Evaluation

RFP —Request for Proposal

RSPA —Research and Special Programs Administration (U.S. Department of Transportation)

S&T —Science and Technology

SBIR —Small Business Innovative Research

SCC —Slidell Computer Complex (National Aeronautics and Space Administration)

SD —Space Division (Air Force Systems Command)

SDI —Strategic Defense Initiative

SDIO —Strategic Defense Initiative Organization

SEMATECH —Semiconductor Manufacturing Technology Institute “

SPA WAR —Space and Naval Warfare Systems Command (U.S. Navy)

SPF —Single Project Fund (U.S. Army)

STARS —Software Technology for Adaptable Reliable Systems

STOVL —short take-off/vertical landing

SYSCOM —Systems Command

TACOM —Tank Automotive Command (Army Materiel Command)

TBAG —Technology Base Advisory Group (U.S. Army)

TRADOC —Training and Doctrine Command (U.S. Army)

TROSCOM —Troop Support Command (U.S. Army)

TSG —Surgeon General of the Army

URI —University Research Initiative

URIP —University Research Instrumentation Program

USD(A) —Under Secretary of Defense for Acquisition

VAL —Vulnerability Assessment Laboratory (Army Materiel Command)

VHSIC —Very High Speed Integrated Circuit

VLSI —Very Large Scale Integration

WES —Waterways Experiment Station (Army Corps of Engineers)