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.

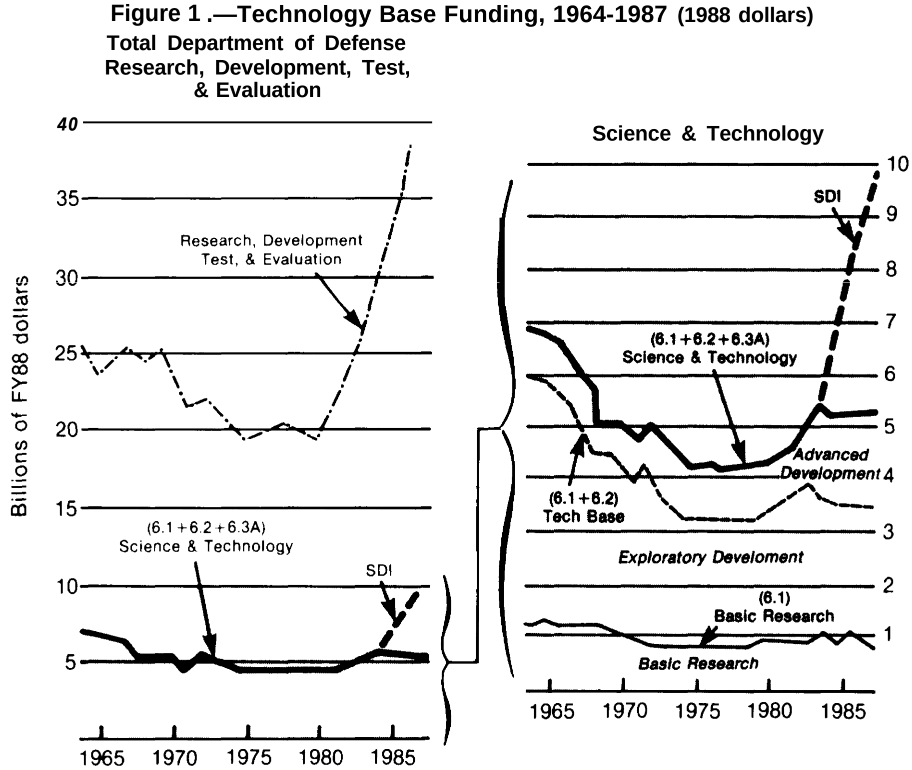
Those who reject the idea of congressional micro-management of defense programs urge caution. They point out that the DoD Science and Technology program is comprised of approximately 160 program elements, which are the basic "building blocks" of DoD's Planning, Programming, and Budgeting System, and 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 cutoutlays 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

5This 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 postwar 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 longstanding 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.