Chapter 2

Research and Development

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INTRODUCTION

The Nation and the Department of Defense (DoD) have along-standing policy of support for a vigorous research and development (R&D) program to meet immediate and long-term defense needs. Two of the desirable future DTIB characteristics described in *Redesigning Defense are* an advanced R&D capability and greater exploitation of civilian R&D.[1]

The national R&D base has had many successes in providing the military Services the technology they need, although questions persist about the efficiency, direction, structure, and size of defense R&D. These questions include concerns about whether the Nation is pursuing the correct technological paths (e.g., process or product technology) and whether the defense R&D effort is properly organized (e.g., among Service R&D efforts).

There is a broad national consensus today, reinforced by the Persian Gulf War experience, that the United States should preserve qualitative superiority in weapons performance. Unresolved issues that Congress should consider are: how great this qualitative superiority should be, how should it be maintained, and against what threats should it be measured? The most cautious alternative is to continue to compare U.S. weapons across the board to the best capability of any potential adversary. Given the waning military threat from the former Soviet republics and the global arms trade, this may mean U.S. weapons would be compared to the best systems available on the international market.[2]

Even with the world's best weapon performance as a benchmark, the magnitude of the desired performance edge remains a matter of debate. Some analysts argue that the United States should maintain a military advantage sufficient only to defend core national interests and that the weapons already in the pipeline have capabilities in excess of foreseeable needs; therefore defense R&D could be reduced or shifted largely to civil objectives. Other analysts counter that there will be severe political constraints on the casualties the United States will be willing to accept in any future conflict for stakes less than national survival and thus the required relative performance advantage must remain very high.

This assessment assumes that the needed rate of improvement in military systems will slow, but that the Nation will seek to preserve an advantage in key militarily unique technologies to at least match the best of the rest of the world and provide the potential for reduced U.S. casualties and collateral damage in any future conflicts.

This assessment also considers the advanced R&D capability needed to carry out the 'prototyping-plus" approach described in chapter 3. One of the findings of this assessment is that R&D must not be pursued, as in the past, according to the "pipeline" model in which research leads to near-term production. Rather, as the present DTIB shrinks and fewer systems are produced, R&D must be pursued with an eye to maintaining superiority in critical technical *capabilities* and as a hedge against technical breakthroughs by potential adversaries, even if the technologies are not incorporated immediately in new weapons. New technology can be demonstrated in laboratories and prototypes, and need not lead to advanced development and production.

Another function of the "advanced" R&D capability needed for the future DTIB is to keep the military community apprised of scientific and technical developments, both military and civilian, throughout the world. Should a global threat arise, the Nation's military establishment would be poised

[1] Throughout this report we use common definitions of 'research" and ''development. " ''Research'' is used to describe investigation intended to advance science and technology without necessarily being directed to a specific end product. The work that follows research and leads to production or specific application is called "development." The Department of Defense (DoD) defines ''reseruch' very narrowly to mean onty what is generally called 'basic research;'' for example, what the National Science Foundation classifies as "applied research' the DoD calls 'exploratory development. This report's use of 'research' corresponds to the activities covered by DoD budget categories 6.1 through 6.3a. ' 'Development" corresponds to budget categories 6.3b and 6.4. Some DoD documents refer to the activities funded under categories 6.1 through 6.3a as ''technology base" support but most include only 6.1 and 6.2. The meaning of 'technology base' has become muddled so the DoD has created a new category, "science and technology" that clearly includes 6.3a. Thus, figures for ''research' cited from DoD documents in this chapter are ''technology base'' (6.1 and 6.2) funds plus Advanced Technology Development (6,3a) funds.

[2] Weapons performance is just part of the story. As the Gulf War revealed, the quality, training, and organization of the people using the weapons is also an important determinant of the Nation's relative strength.

to exploit the best technology at hand to reconstitute a force that can meet the new challenge. Since a healthy civilian industrial base is an important reservoir of scientific and technical potential, an advanced military R&D capability should also be structured to encourage transfer of technology from the defense sector to the commercial sector.

To best meet future national security requirements, the variety of government laboratories and R&D centers, universities and other nonprofit institutions, and private defense and civilian industrial firms both in the United States and abroad, that carry out today's military R&D will have to change.

The Nation and Congress face fundamental choices regarding the future of defense R&D. What level of effort is appropriate? What should be its scientific and technical focus? Who should perform the R&D and how should it be organized and integrated? What is the proper balance between a near-term and long-term focus? The DoD's ability to influence the Nation's overall R&D base is declining, but its influence is still considerable. U.S. defense R&D, for example, was about 31 percent of all U.S. R&D in 1987 and almost 16 percent of the *total* R&D spending in the European Community, United States, and Japan.[3]

The following sections of this chapter examine how to maintain an advanced R&D capability. The first section reexamines the goals of an R&D effort. The next section addresses the priority of military R&D within the defense budget and the Federal budget as a whole. This is followed by a discussion of technical priorities for defense R&D and problems in the future organization of the defense R&D effort. Finally, the chapter discusses how Congress can affect defense R&D.

MAINTAINING A ROBUST R&D CAPABILITY

A robust R&D capability requires an overall R&D strategy, policies, organization, equipment and facilities, predictable funding, and skilled people to execute the strategy. These requirements are closely intertwined. For example, good people are attracted to research only in part because of salaries. Interesting and meaningful work is at least as important according to many researchers. Front-line research

Photo credi : Naval Research Laboratory

A radar being tested in 1937 on the roof of the Naval Research Laboratory. Some scien ific and technological advances result in revolutionary new military capabllil ies.

also requires state-of-the-art equipment and facilities. Thus, retaining good people requires meaningful work, good facilities, proper policy, and good management.

R&D National Security Goals in the New Environment

In the new security environment the United States faces two types of military threats with distinct and characteristic warning times:

1. a currently hypothetical major military threat that-were it to occur— would develop over years, and
2. smaller threats that might flare up with little or no warning.

As a.result, defense R&D must have two goals that are not completely complementary:

1. to maintain a scientific and technological capability to guard against surprise and to provide the basis for a buldup-perhaps over several years-of the forces needed to oppose an evolving military threat, and

[3] National Science Foundation, *International Science and Technology Data Update* (NSF-91-309) (Washington, DC: 1991), pp. 5, 9, and 13. These are the most recent published figures for which consistent comparisons between nations are possible.

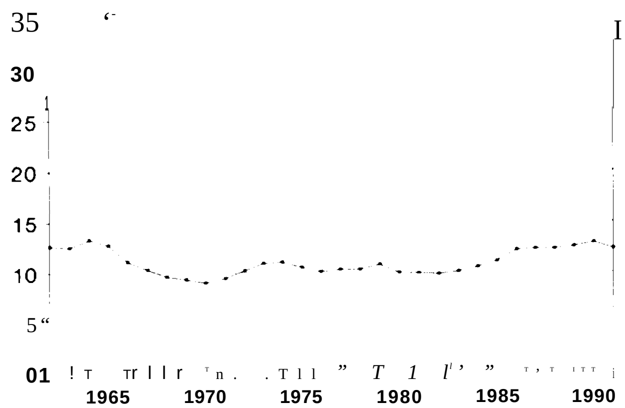
2. to continually provide standing forces with technology to meet smaller current threats at reasonable cost.

At present the United States is pursuing both paths, supporting R&D and moving to a smaller active military force at a high state of readiness.[4] The reemergence of a major military threat like that of the former Soviet Union (which the administration terms a ''reconstituted threat' would require the Nation to build up its forces at least as fast as any potential enemy can. However, until the need for such a buildup arises, the DoD emphasis will shift away from providing current capability toward maintaining potential capability. Current budgets already reflect an understanding that R&D must be maintained. The administration's fiscal year 1993 defense budget request included a 1.5 percent real *increase in* R&D but a 13 percent real *decrease in* procurement.[5]

Tradeoffs between current capability and future potential will affect allocation of resources *within the* defense R&D budget. If current capability is emphasized, a large proportion of R&D would go to development of specific weapon systems, as during the cold war. Emphasis on future capability, however, would shift funding away from development of specific weapons toward more generic research aimed at the development and demonstration of weapon technologies and perhaps to manufacturing technology to produce systems later as the need arises.

The fiscal year 1993 budget request sends mixed signals on the tradeoffs desired by the Administration. The request would cancel or delay several development programs, but development funds are still large and research priorities would not change dramatically. Defense research is proposed to rise from $10.4 billion in fiscal year 1992 to $11.8 billion in fiscal year 1993.[6]

Figure 2-l—Budget Authorization for Research, Development, Test, and Evaluation as a Percentage of Total Defense Authorization



SOURCE: Historical Tables of the Budget of the United States Government.

Funding for R&D

Over most of the last 30 years, spending on R&D, plus the test and evaluation that is a part of any development program (i.e., RDT&E), has been about 10 to 11 percent of the DoD budget.[7] (See figure 2-l.) If historical ratios continue, absolute funding for defense R&D will shrink along with the rest of the defense budget, unless there is a commitment to support R&D as a means of maintaining military potential.[8] The threats the Nation faces have not been reduced evenly across the board and there remains the possibility that a major military threat could emerge. Thus, even if a large reduction in current capability is warranted, it does not necessarily follow that investment in military R&D should be reduced proportionately.

Most independent projections are, however, that the resources for R&D will decline in the future. For example, the Electronic Industries Association (EIA) annually makes 10-year projections of defense spending that have been accurate in the past. The

4 Military planners appear to give a high priority to the training and readiness of whatever active force the Nation keeps. This may be reflected in press speculation about future shifts of resources from procurement to training. See, Andy Paztor, "Pentagon Weighs Cut of $50 Billion,'' The *Wall Street Journal*, Dec. 20, 1991, p. A3.

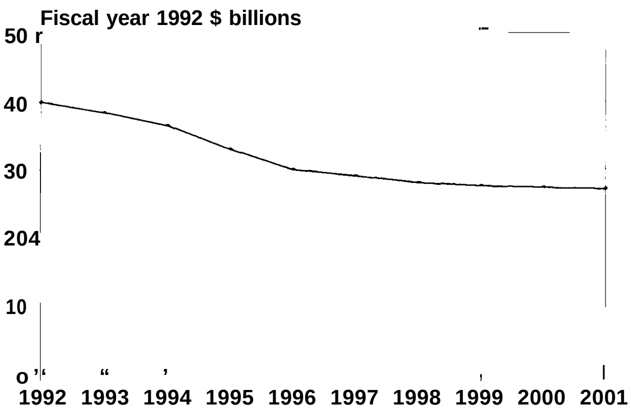
5 Dick Cheney, *Annual Report to the President and the Congress* (Washington DC: U.S. Government Printing Office, February 1992), p. 131.

6 Department of Defense, *RDT&E Programs (R-1)*, Jan. 29, 1992, p. III. These figures are the sum of the "Technology Base, ' that is, budget categories 6.1 and 6.2 and the ''Advanced Technology Development, ' that is, 6.3a.

7 Executive Office of the President, Budget of the United States Government, Fiscal Year 1992, Part 7, Table 3.2. Test and evaluation adds about 25 percent to the R&D budget.

8 Extensive prototyping, including limited production of weapons for operational testing, may be expensive compared to current development programs. Thus, a prototyping effort could dominate future R&D budgets if budgeted under development rather than production.

Figure 2-2—Nominal Decline in Future Spending for Research, Development, Test, and Evaluation



SOURCE: Electronic Industries Association

EIA forecast is based on an assumption that RDT&E's fraction of the budget will grow only very slightly, to 12.9 percent in 2001. Thus, their predicted defense budget of $208 billion in 2001 implies a decline from $40 billion today in total RDT&E spending to $27 billion in 2001 (all in fiscal year 1992 dollars). (See figure 2-2.)

The DoD's own plans also anticipate reduction in R&D over the next few years. Air Force RDT&E budgets will fall most steeply, from $15 billion in 1992 to $8 billion in 1997.[9] Current plans call for the Army's RDT&E budget to decline slowly from $6 billion in 1992 to $4 billion in 1997.[10] These budget projections should be viewed cautiously because changes in development funding for just a very few very expensive projects can skew the entire budget.

Maintaining an advanced R&D capability maybe relatively more expensive for the DoD in the future, since, with less production, firms will have little incentive to share in paying for R&D costs. But justifying a particular level of R&D spending is difficult. For generic research, the problem is to show a clear relationship between the effort and the result.11 Each Service terms its research a ' 'corporate investment, ' ' i.e., a cost of maintaining expertise. Research support requests for fiscal year 1993 are $1.8 billion for the Air Force, $1.5 billion for the Navy, $1.1 billion for the Army, and $7.2 billion for DoD agencies.[12] Private Companies ties determine levels of research spending on the basis of investment that they believe is needed to maintain a competitive edge over rivals. The Nation's military establishment should similarly monitor technology developments of other countries to determine the research needed to maintain the desired relative advantage in weapon performance.

The criteria for deciding development funding levels are changing. In the past, the Nation could decide on the needed rate of introduction of new weapons to maintain qualitative superiority over the Soviet Union. But in the future, to respond to a more ambiguous array of threats, the Nation will need to maintain a range of industrial, technical, and manufacturing skills, possibly through a prototyping-plus strategy, a big part of which would probably show up in the development budget. (See ch. 3.)

Allocation of Funds Among R&D Performers

Reduced defense R&D spending will change the *distribution* of R&D effort among industry, university, nonprofit, and in-house service laboratories. The current distribution for reasearch is shown in figure 2-3. Unless offsetting actions are taken, reduction in defense research funding will cause a relative increase in research activity by Service laboratories and a decrease by private industry. There will be less industry incentive to support research, while government laboratory managers may try to keep a relatively large slice of a shrinking pie in-house.

The trends for distribution of development funding are less clear. Over two-thirds of development now occurs in industry. Total developrnent funding may stay high if the Nation pursues a prototyping-plus strategy like that described in the next chapter. This activity would most likely remain in industry. Many companies argue, however, that current ap-

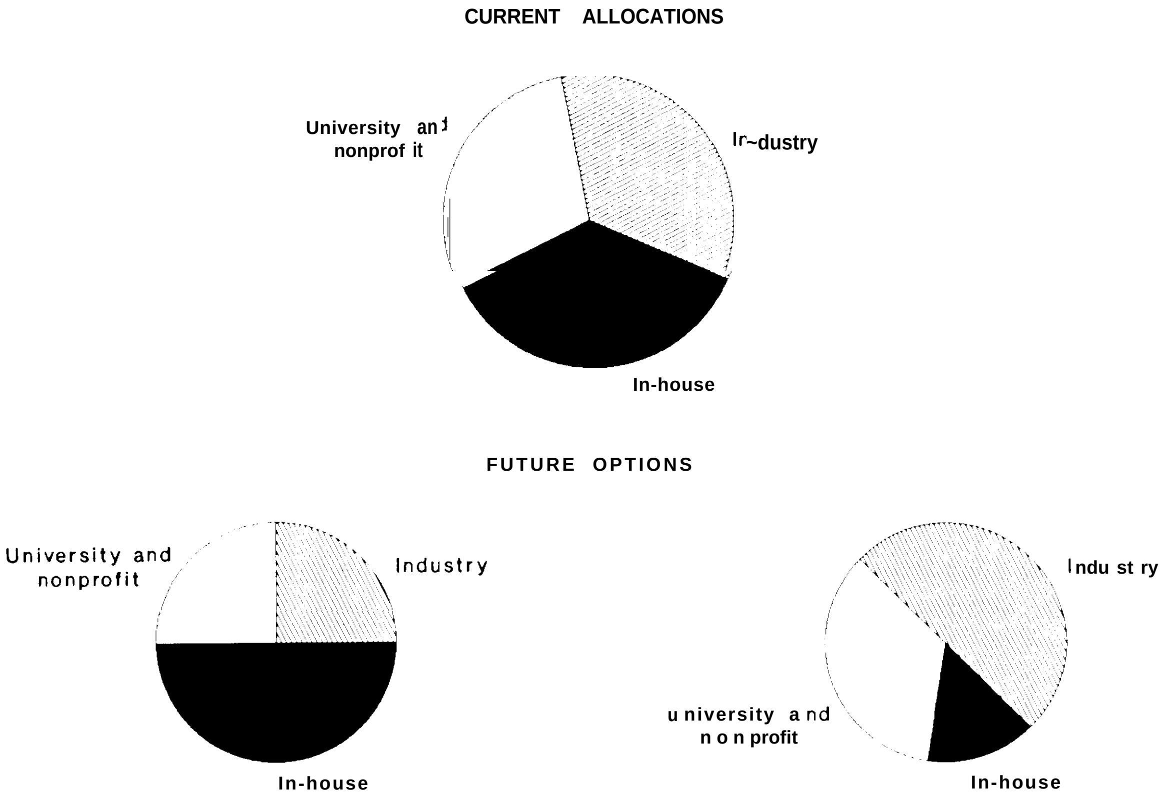
9 Congressional Budget Office, Staff Memorandum, "The Costs of the Administration's Plan for the Air Force Through the Year 2010," December 1991, p. 18. Some analysts argue that Air Force R&D figures are suspect because they may include huge seeret production programs.

10 Congressional Budget Office, Staff Memorandum, ''T'hecosts of the Administration's Plan for the Army Through the Year 2010,'' December 1991, p. 21.

11 See Genevieve J. Knezo, *Defense Basic Research Priorities: Funding and Policy Issues*, Congressional Research Service Report for Congress, Oct. 24, 1990, for a discussion of the problems of determining funding levels and setting research goals.

12 *Defense Daily, Special Supplement, Details of 1993 DoD Budget Request,* Jan. 31, 1992, pp. S-1 to S-3. Note that the research budget for the defense agencies is dominated by the Strategic Defense Initiative Organization.

Figure 2-3-Possible Distributions of Future Research Effort



Option 1: With emphasis on preserving militarily unique technology in government laboratories

Option 2: With emphasis on dual-use and commercial technology

SOURCE: National Sciene Foundation, *Federal R&D Funding by Budget Function,* and OTA.

preaches to prototyping are not commercially viable. Unless the DoD takes steps to make prototyping profitable for industry, design and prototyping activities might need to move into government laboratories or arsenals.

OTA's defense industry survey indicated that most companies, foreseeing reductions in production contracts, are planning to cut their own spending for R&D. "Independent research and development, ' or IR&D, is a company's R&D that is funded outside of explicit government R&D contracts.[13] Over the long term, the IR&D that can be recovered from production contracts as overhead will decline as procurement declines. Action has already been taken to counter some of these trends. Companies' allowed IR&D recovery rate was increased under legislation passed last year, for example. But direct DoD funding to industry may need to increase in critical R&D areas to maintain current levels of effort.

Any decline in government-funded R&D will exacerbate reductions in company -financed R&D. Most studies indicate a positive correlation between federally-funded R&D in a company and the company's own R&D expenditures.[14] This finding indicates a leveraging of Federal funding: a dollar of

[13] There is some confusion in the literature about the definition of 'Hi&D. ' The formal government definition is any noncontract-funded R&D. Thus, for example, all of the R&D of a company with no connection to the DoD at all is considered IR&D. (See Office of the Director of Defense Research and Engineering, *The Independent Research and Development Program, A Review of IR&D,* June 1974.) Many writers commonly use the term to refer to only that portion of a defense contractor's R&D that is potentially recoverable as an allowable overhead expense on a government contract. This section will refer to a company's overall effort as IR&D and the recoverable portion as recoverable IR&D if there is an ambiguity.

[14] For a survey of results, see Frank R. Lichtenberg, "The Effect of Government Funding on Private Industrial Research and Development: A Reassessment," *Journal of Industrial Economics,* vol. 36, No. 1, September 1987, pp. 97-104.

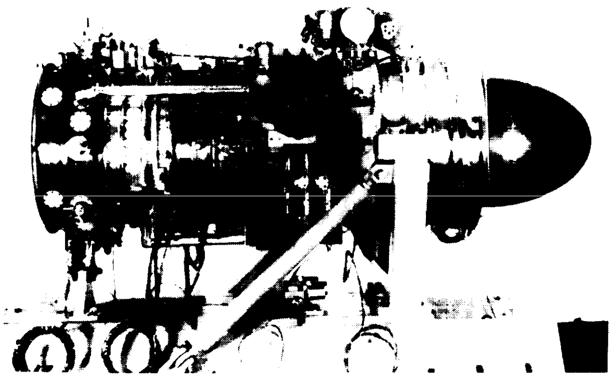


Photo credit: Pratt and Whitney

New technologies are first demonstrated and proven in this core engine before the manufacturer applies thereto anew or existing engine design. Most of the Nation's defense technical and expertise resides in companies.

Photo credit: Wright Laboratories

Research on new materials is conducted by the Air Force at Wright Laboratories. The Service laboratories are important centers of research and pride themselves on being closely tuned to the needs of the military users.

Federal funding creates more than a dollar of total R&D in both defense and nondefense sectors. presumably therefore, as Federal defense R&D support shrinks, overall R&D shrinks even more.

Service laboratories have built up important areas of expertise and are well tuned to Service military requirements. But critics of reliance on Service laboratories for DoD R&D note that they work for a single Service, and sometimes only one element within that Service, therefore their view may be too narrow and they may overlook technologies that do not promote current Service missions. In the extreme, this is essentially a legal restriction; for example, the Army cannot own, hence does not support R&D in, fixed-wing combat aircraft. Furthermore, civil service regulations are said to stifle research creativity in government laboratories. Critics of Service laboratories argue that private companies, universities, and other outside research organizations are likelier to think up a potential mission to illustrate a need for some new technology that they have just developed. Salesmanship usefully gets new ideas into consideration,

Service R&D activities are coordinated through the Office of the Secretary of Defense (OSD), but the Service laboratories also have their own group, the Joint Directors of Laboratories (JDL) under the auspices of the Service Secretaries. The JDL is made up of the directors of research or laboratories of each of the Services. In addition to meeting as a group, the JDL sets up various subpanels of Laboratory Technical Directors or Chief Scientists, to discuss and coordinate work in particular areas.[15]

Under the auspices of JDL, the Services are undertaking a major change in their approach to allocating research effort among themselves, under a directive from OSD to coordinate their technology support. The result is a program called "Tri-Service S&T Reliance" (previously called *Reliance*). The objective of this program is to minimize redundancy among Service laboratories. At the very least, similar efforts at different laboratories should be coordinated. Where appropriate, efforts will be physically consolidated at a single laboratory and one Service will be designated a lead Service. For example, the Navy recognizes the Army's extensive expertise in large-caliber guns, so all Services' relevant gun technology development will take place at the Army's Picatinny Arsenal. Similarly, fuel and lubricant research will take place at the Air Force's Wright Laboratory, while work on space-based infrared sensors will beat the Naval Research Laboratory.[16]

15 Fredrick R. Riddell *et al., Report of the Task Force for Improved Coordination of the DoD Science and Technology program* (Alexandria, VA: Institute for Defense Analyses, August 1988) vol. II, app. C.

16 Joint Directors of Laboratories, *White Paper on Tri-Service Reliance in Science and Technology, Office* of Naval Technology, January 1992.

Reliance is still in its early stages so it is too soon to evaluate results.[17] If current plans are carried through, however, it could bring a fundamental change in how the Services organize their technology research.

A robust civilian industial base is important to the DTIB. If the defense R&D effort is given the additional goal of helping civilian technology, R&D funded through the DoD could expand substantially. There is no consensus, however, on the degree to which the Federal Government should support civilian industrial R&D, nor on whether such support should come from the DoD.

Some advocates of direct government support of civilian industrial R&D argue that while such support is essential, the regulatory barriers that government has erected between military and civilian enterprise are so great that channeling the money through the DoD is extremely inefficient, Other advocates concede the inefficiency, but counter that the government has no current mechanism with adequate scope and experience other than DoD to mount such a program. Alternative programs supported, say, through the Department of Commerce, might take years to build up. Further, they argue that the political realities are that cuts in DoD R&D are not going to be transferred to some other research agency, such as the National Science Foundation or the Department of Commerce's National Institute of Standards and Technology (NIST). Thus, according to this argument, the alternative to supporting civil industry inefficiently through the DoD is not to do it at all.[18]

In fact, the alternatives are not so stark. Other government programs, while currently small, could be expanded. For example, the Advanced Technology Program (ATP) under NIST is growing, with a $50 million fiscal year 1992 budget and an administration request of $68 million for fiscal year 1993 and much support in Congress. OTA's assessment of industrial competitiveness, *Making Things Better,* argues through analogy with the Defense Advanced Research Projects Agency (DARPA) that the ATP could use effectively over $1 billion per year.[19]

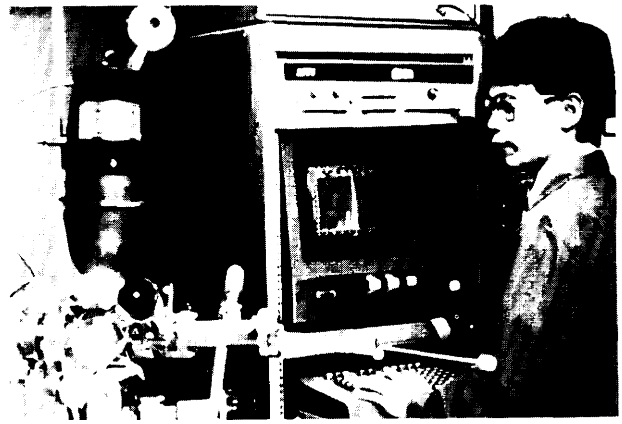


Photo credit: 3M Corp.

R&D in commercial laboratories is increasingly sophisticated and will be important for future military technology.

Proponents of greater civil-military integration argue that reducing bureaucratic barriers between military and civil industry would greatly increase the number of sources of new technology. Using more integrated commercial firms, however, will complicate the issue of foreign dependence since many of the large and most innovative companies are multinationals. These companies also offer, of course, ready access to valuable technology abroad. To make best use of civilian technology, changes in DoD procurement and contracting practice are required, as discussed below.

The Nation's universities have traditionally been strong in long-term basic research. Although basic research in universities is small in dollar terms when compared to the DoD budget, it is the primary source of fundamental scientific advances and, just as importantly, to the training of future scientists and engineers.

The Department of Energy operates the National Laboratories that are responsible for the development and testing of nuclear weapons. With the end of the cold war, further advances in nuclear weapons are far less urgent but nuclear weapon design know-how is something the Nation cannot afford to lose.

17 Implementing letters were signed only in September through November of 1991.

18 There is little agreement on the extent or net benefit of military R&D on the civilian economy. A recent report containing a review of the important existing literature is, David Gold, *The Impact of Defense Spending on Investment, Productivity, and Growth* (Washington, DC: The Defense Budget Project, 1990).

19 See U.S. Congress, office of Technology Assessment, *Making Things Better: Competing in Manufacturing*, OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, February 1990), p. 76.

Photo credit: MIT Lincoln Laboratories

This university laboratory developed thin films of superconducting materials. The Nation depends on universities for much of its long-term basic research.

To summarize, industry holds most of the defense technology and almost all the knowledge about manufacturing. Further, the increased importance of dual-use technology could make industry a better potential provider in the future. At present, however, it seems likely that industry will lose much of its incentive to maintain supporting defense technology. The DoD needs either to make the R&D profitable in its own right or become a truly innovative in-house technology developer. In the latter case, government laboratories and arsenals would have to take on more technology development, but they would need to be careful to maintain communication with potential manufacturers to ensure that designs are producible. The government should carefully consider maintaining current DoD support for university R&D and explore ways to utilize the civilian sector.

Setting R&D Technology Priorities in the New Security Environment

The new security environment is changing the relative importance of many military missions. Sometimes the technology implications of new mission emphases are fairly clear. For example, any Navy shift of emphasis from open ocean to shallow water operations will require more attention to countering mines. Similarly, if the Army is less concerned with building heavy tanks for war in central Europe and more with deploying armored forces to unpredictable trouble spots, its R&D emphasis should shift to making weapons lighter and easier to maintain under diverse field conditions.

There is a requirement to allocate R&D funds across technology areas. Congress is, of course, concerned about whether the allocation is correct but is not well-suited for setting detailed R&D goals with the current approach. Congress and the DoD set overall military missions and review needed technology developments but without complete coordination between these two processes.[20]

In the absence of any published DoD technology plan, Congress requested that the Office of the Secretary of Defense (OSD) prepare a "critical technology plan."[21] The resulting report continues to be criticized as providing merely a list of technologies rather than an investment plan that explains how to apply these technologies to military missions. Some critics argue that the list is of limited value in allocating resources because the technology areas are so broadly defined that very little is not considered 'critical.' They argue, furthermore, that this generality is a consequence of fears that the list will be used in a simple-minded way for funding decisions: if work is not labeled "critical" it will get cut. Others argue that the critical technology plan concentrates only on weapon technology and overlooks training or logistics, which are just as critical. to military strength.

The individual Services co have technology investment strategies that are coordinated through OSD. The Army's Technology Base Master Plan,[22] for example, lays out an investment strategy for implementing technology goals, an explanation of how to get from hereto there, and how much it will cost. The OSD has recently developed several Technology Thrust Areas that should make clearer

20 See U.S. Congress, Office of Technology Assessment Background Paper, *Evaluating Defense Department Resear :h*, June 1990.

21 P.L. 101-189103 Stat. 1512 Paragraph 2508(a) 'Annual Plan. — (1) The Secretary of Defense shall submit to the Co nmittees on Armed Services of the Senate and House of Representatives an annual plan for developing the technologies considered by the Secretary of Defense and the Secretary of Energy to be the technologies most critical to ensuring the long-term qualitative superiority of United States weapons ystems. The number of such technologies identified in any plan may not exceed 20. Each such plan shall be developed in consultation with the Secre ary of Energy.'

22 Deputy Assistant Secretary for Research and Technology, *Army Technology Base Master Plan*, vols. I-III (Washin;ton, DC: Department of the Army, November 1990).

Photo credit: DoD

This tank is only lightly armored. It is more vulnerable than a heavy tank but easy to transport by air. As the military threats facing the Nation change, the technical goals of defense R&D must be adjusted.

the route from the DoD's overall technology investment to its military missions. Currently, there are seven thrust areas-surveillance, precision strike, air superiority, antisubmarine warfare, land combat vehicles, readiness and training, and affordability[23]—but the areas could change in the future in response to new security or technical developments.

With slower deployment of new major weapon platforms, relatively more attention will be given to subsystems and upgrades of the platforms and the munitions that they carry. The development budget may include prototypes to demonstrate new technology or designs for which there is no immediate plan for actual development for quantity production. With falling budgets, some Service R&D planners see greater research emphasis on reliability, durability, and efficiency as away to reduce operating costs. The increasing complexity and decreasing number of weapon systems have led the DoD to emphasize designing for producibility and manufacturing process.

The changes in military requirements will have less effect on priorities at the research end of the R&D spectrum. For example, no matter what the threat, there is a strong consensus that R&D will continue or even increase its current emphasis on ''information technology, ' including sensors, data analysis, and displays, along with communications, computers, software, and storage and manipulation of data for manufacturing. However, even with a large shift in emphasis toward, for example, electronics, the basic goals of electronics research will remain much the same: reduced size, lower power requirements, higher speed, lower cost, and greater reliability, whether the end-result eventually appears in a ballistic missile or a shoulder-fired rocket. Similar arguments will apply for a range of technologies, from biotechnology to materials.

The general trend since the end of World War II has been for Congress and the Executive Branch to require ever clearer justifications of military R&D, usually in terms of final military application. This goal is most clearly stated in the Mansfield Amendment, P.L. 91-441 Title II Section 204:

> None of the funds authorized to be appropriated to the Department of Defense by this or any other Act may be used to finance any research projector study unless such project or study has, in the opinion of the Secretary of Defense, a potential relationship to a military function or operation.[24]

Although this requirement, if broadly defined, should be easy to meet, many R&D managers argue that it has had the effect of biasing project selection toward those whose military connection is not just ''probable' but most obvious, with the effect of narrowing the defense R&D base.

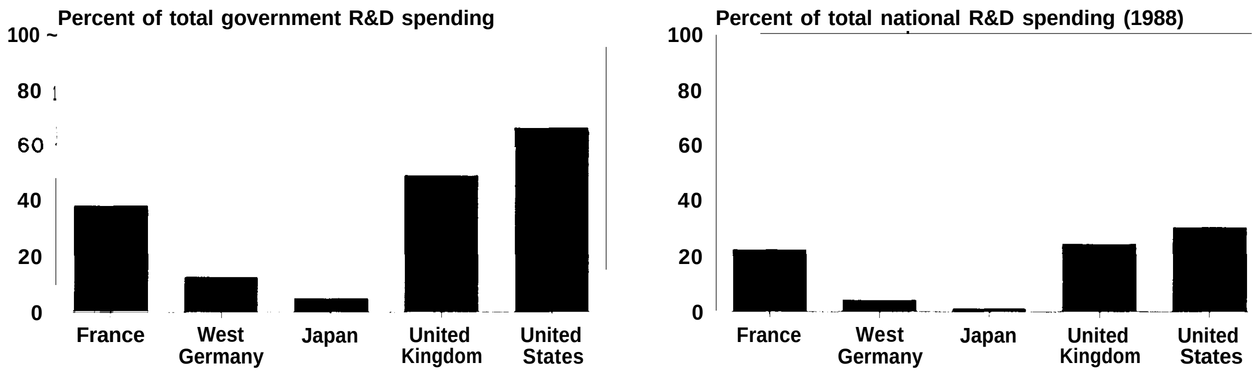
As the Nation broadens its definition of 'national security' to include international economic competitiveness, the past emphasis on the narrow military justifications for defense R&D will be challenged. Many observers are concerned about the Nation's industrial performance and view inadequate investment in civilian R&D as part of the problem, Since military R&D is almost one-third of the Nation's total public and private R&D expenditure-a higher fraction than that of other western industrial countries[25] one approach is to tap into military R&D to help civilian enterprise. (See figure 2-4.) This

23 Briefing from the office of the Deputy Director, Research and Engineering (Plans and Resources), Feb. 9, 1992.

24 This wording superseded the even stronger wording enacted the previous year that projects should have a '' . . . direct and apparent relationship to a specific military function. . . " (P.L. 91-121). The wording was altered again slightly in P.L. 100-370 to allow the DoD to spend R&D funds, "for purposes related to research and development for which expenditures are specifically authorized in other appropriations of the Department of Defense. ' This recent change indicates a reversal in the trend toward narrow military justification toward a concern with a broader national security.

25 National Science Foundation, *International Science and Technology Data Update: 1991*, NSF 91-309 (Washington, DC: 1991), pp. 10-15.

Figure 2-4-Defense R&D as a Percentage of Total Government R&D Spending and as a Percentage of Total National R&D Spending



SOURCE: National Science Foundation, *International Science and Technology Data Update: 1991.*

approach may include adding civilian industrial competitiveness to the criteria by which military R&D proposals are judged. Congress frequently has the dual objectives of military and commercial benefit in mind when it supports ostensibly military projects directed at improving manufacturing, such as the MANTECH and SEMATECH programs described in *Redesigning Defense*.[26]

The DoD and the administration resist this approach because of the difficulty of balancing civil and military objectives. Defense managers, while aware of the importance of industrial competitiveness, are hesitant to use it as a criterion for funding military R&D. Their general concern is that resources devoted to important military needs are already limited, if not inadequate, and that additional nonmilitary objectives would make fulfilling those needs even more difficult. Changes in the bureaucratic incentives for integration of civil and military R&D will have to be made at higher levels, i.e., Congress or the President, before managers adopt such criteria.

Another approach would be to keep current military R&D priorities and improve the transfer of military technology to the private sector. Whether government support for certain industrial technical development projects is warranted has been a subject of much debate. Until that debate is resolved, however, the question remains whether industrial development funds should be funneled through the DoD. As described below, the substantial barriers between defense and commercial business sectors resulting from the special legislative and regulatory environments created by the federal Government hamper the transfer of technology.

A third approach would be to maintain current defense R&D priorities but reduce the overall level of R&D funding funneled through the DoD. Released funds could support commercial R&D directly through some civilian government organization, or the funds could go to indirect support, for example, tax incentives for R&D. This approach would compel the DoD to obtain more of its technology from the civil sector and adapt its doctrine to suit available technology. R&D might also focus on strategic economic vulnerabilities that pose a threat to national security. For example, if an extensive R&D program had produced energy independence for the West, Iraq's invasion of Kuwait would have had a fraction of it; actual importance.

Organization of Governnment Support of Defense R&D

The organization of R&D must balance the needs of the operational military community, the R&D community, and the Nation's defense effort as a whole.[27] How to maintain this balance will be important in the years ahead as the DTIB shrinks.

[26] MANTECH is a program to support MANufacturing Technology and SEMATEC!Hagovernment-industry consortiu1 to develop SEmiconductor Manufacturing Technology. See *Redesigning Defense,* pp. 52-54.

[27] See U.S. Congress, Office of Technology Assessment, *Holding the Edge: Maintaining the Defense Technology Base,* OTA-ISC-420 (Washington, DC: U.S. Government Printing Office, April 1989) for a fuller discussion of DoD R&D management and organization.

This issue is of direct concern to Congress, since Congress has historically been involved in the organization of DoD R&D.

If the primary objective is relevance of R&D to the users' perceived immediate needs, then R&D should be closely tied to the acquisition function, which in turn should be under the control of the Services. The danger with this arrangement is that it might focus on short-term problems. If the objective is to emphasize long-term technological support, the earlier science and technology work could be given more visibility, perhaps by having the person in charge of R&D report to the secretary level in OSD or the Services, rather than through the person in charge of acquisition. Another issue of concern to Congress is that, in a declining budget environment, existing R&D groups may resist consolidation or redirection.

Present Structure and Consolidation Plan

Until 1986, the Director of Defense Research and Engineering reported directly to the Secretary of Defense. In response to the widespread perception that the acquisition process was not adequately managed, the Goldwater-Nichols reorganization of that year created an Under Secretary for Acquisition, to whom the DDR&E reported. This reorganization may have increased the communication between the acquisition and the R&D communities, but it also reduced the visibility of the R&D issues to the Secretary.

Assistant Service Secretaries in charge of R&D report through their Service chains of command, but also coordinate through OSD. Some critics contend that coordination is insufficient and more centralized control is needed. Advocates of increased centralized control argue that redundancy and inefficiency are inevitable if each Service handles its R&D separately. While R&D redundancy was desirable in an era of growing or level budgets, declining budgets should force greater coordination.

In contrast, Service R&D managers argue that independence from OSD is vital because the Services best understand the needs of the ultimate users of the technology. Moreover, rivalry among the Services produces alternatives that might not have surfaced if the research agenda were centrally controlled. A good example is the development of the Navy's Polaris submarine at a time when the strategic nuclear role was dominated by the Air Force. If there had been a central strategic nuclear R&D directorate at the time of Polaris' proposal, it probably would have been dominated by advocates of ICBMs and bombers and the submarine-launched ballistic missile, which has become the cornerstone of the U.S. nuclear deterrent, might never have been pursued.[28]

Each of the Services is reorganizing or planning to consolidate its laboratories. Service laboratories and research centers perform in-house R&D and administer projects contracted to private industry. There are 66 Service laboratories (76 if the laboratories making up the Air Force ''superlabs' are counted individually). In 1990, the laboratories employed 60,000 people of whom 26,000 were scientists and engineers. Total funding was $6.5 billion, over half of which went to externally performed contract R&D with part of the remainder going to management of these outside contracts.[29] The number of employees has shrunk somewhat since.

The Army has the most extensive reorganization plan, resulting from its ''Lab 21 study. It plans to consolidate most administrative control and many activities in a single Combat Materiel Research Laboratory in Maryland. Currently, similar technologies often are explored in different Army centers if they have different end uses. Some of these centers would be consolidated under the plan. For example, combat vehicle propulsion research is based in Warren, MI, the home of the Tank and Automotive Command, while aviation propulsion research is based in Cleveland, OH, on the site of NASA's Lewis Research Center. The Army believes that, at the research level, these two applications are similar enough to warrant future consolidation of the laboratories at Cleveland.[30]

2S James R. Schlesinger, *Defense Planning and Budgeting: The Issue of Centralized Control* (Washington, DC: Industrial College Of the Armed Forces, 1968), p. 18.

29 Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories, *Report to the Secretary Of Defense*, September 1991, p. 1.

30 See George Singley, testimony before the Subcommittee on Defense Industry and Technology, Committee on Armed Services, U.S. Senate, May 21.1991.

The Navy is consolidating its R&D activities into four existing Research, Development, Test and Evaluation Engineering and Fleet Support Centers, and one Service-wide research laboratory. Unlike the Army's technology-center approach, the Navy's centers are organized around war-fighting missions. For example, Navy R&D relating to air warfare will be headquartered at the Naval Air Systems Command, with a weapons division at Point Mugu and an aircraft division at Patuxent River. The other centers are the Naval Surface Warfare Center (which will include surface-based antisubmarine warfare), the Naval Undersea Systems Center, and the Naval Command, Control, and Ocean Surveillance Systems Center (which covers surveillance and communications). The Naval Research Laboratory, which explores abroad range of research areas, will remain as a Navy-wide laboratory under the Office of Naval Research,

The Air Force reorganization plan includes the consolidation of 14 laboratories into 4 ''super-labs.''[31] However, no laboratories are planned to close or move immediately, although management and administrative functions will be concentrated in the four central laboratories.

The Federal Advisory Commission on Laboratory Consolidation endorsed the Service consolidation plans almost without exception. According to the Commission report:

> The laboratories provide to the acquisition agents (i.e., the Services' program managers), an in-house, technologically qualified agent to oversee or evaluate the performance of the industrial developer as required to ensure that the design is technically sound, will satisfy performance requirements, and is producible and affordable.[32]

The possibility of laboratory mission changes and their implications for organization and size are not developed in the Commission's report,

Medical laboratories are examples of *cross-Service* consolidation. There is no reason in principle that other technologies in addition to medicine could not be similarly coalesced, as the Federal Advisory Commission suggests considering for microelectronics.

A number of alternatives for further consolidation exist. OSD could, for example consolidate research activities while leaving development to the Services, or OSD could, in the extreme, assume control of all Service R&D activities following the French R&D and acquisition model. The Services argue against consolidation on the grounds that R&D will become disconnected from their direct needs. And they argue that as long as the Services are responsible for acquisition, they should be responsible for the supporting R&D. But in a future circumstance of declining budgets and continuing need for technological advance, consolidation *across* Services may be as necessary as consolidation *within* each Service. There are also certain joint tasks that OSD might best oversee among the Services, such as communication, data fusion and dissemination, and attack coordination.

The OSD does not operate any laboratories, although it has two Federally funded Research and Development Centers (FFRDCs): the Institute for Defense Analyses (with $96 million in fiscal year 1990) and the Logistics Management Institute (with $21 million in fiscal year 199033). OSD also supports defense agencies like the Defense Nuclear Agency, the Defense Advanced Research Projects Agency, and the Strategic Defense Initiative Organization. While none of these are laboratories, they have resources to support R&D at Service laboratories or elsewhere. Total R&D funding of the organizations funded through OSD was $6.9 billion in fiscal year 1991.[34]

Issues for the Future

Congress might consider changing the balance between Service autonomy and OSD coordination of R&D. To reduce redundancy, it could funnel all R&D funds up to some level (perhaps 6.3a) through OSD, perhaps by extending the model of inter-Service medical laboratories to other areas. Alternatively, Congress could encourage the Services to continue the approach begun with Reliance, that is, to assign responsibility for each important technol-

31 *Report to the Secretary of Defense,* op. cit., footnote 29, p. 18.

32 *Report to the Secretary of Defense,* op. cit., footnote 29, P. C-1.

33 Dollar figures from Michael Davey, *Defense* Laboratories, *Proposals for Closure and Consolidation,* Congressional Research Service, 91-135 SPR, Jan. 24, 1991, p. 9.

34 Department of Defense, *RDT&E Programs (R-l),* February 1991, p. D-II.

ogy area to a single Service, which would support the other Services in that area.

As the DTIB gets smaller, Congress will want to have military R&D activities organized such that no important R&D mission is overlooked. For this, Congress will need abetter idea of how technologies relate to military missions and how the entire defense R&D effort is coordinated. Ideally, the system should be designed to foster new ideas and avoid parochialism, so coordination does not become stifling overmanagement. Achieving this state should be a key goal of R&D reorganization.

OTHER CRITICAL ISSUES

Congress will need to address a number of specific critical issues relating to the organization and function of the defense R&D base.

Defense R&D Personnel: Maintaining the Know-How

A critical objective of defense R&D policy in the new era is to maintain the core skills and knowledge that are key to the whole defense enterprise. Personnel reductions in defense R&D must be carried out carefully to retain key skills, and those that exist only in the defense base must be maintained there. Some knowledge and capability exists in groups of people rather than individuals. These groups may require special treatment if their skills are not to be lost. For example, a prototyping-plus strategy, discussed in the next chapter, can help' maintain critical pools of design and development talent.

Many of the concerns about government laboratory personnel long preceded the ongoing reduction in the size of the DTIB. Some problems may be exacerbated by future shrinkage, while others may be made more manageable. For example, the question of salary seems to be permanent.[35] Government pay for scientists and engineers lags behind that of comparable positions in industry. Measuring the lure of intangibles such as job security is, however, hard and thus predicting the exact effect of their loss is also difficult.

Some argue that salaries for scientists and engineers in private-sector defense firms are inflated by up to 15 percent relative to comparable nondefense sectors and, moreover, that this difference has drained the Nation's broader civilian industrial base of its best technical talent.[36] As international commercial competitiveness increases in importance relative to defense, the Nation may have less interest in maintaining whatever defense salary bonus might exist, and want to encourage good people to work in the civil sector.

If the mission of the Service laboratories changes—for example, shifting emphasis from oversight of contract R&D toward more direct involvement in R&D work—then the personnel requirements also change. If the Service laboratories increase their role as developers of technology, then the quality of their personnel may also need to improve. This may require further changes in pay scale. Just as important are changes in ''revolving door' policies that inhibit movement of personnel between government and industry. If the primary function of a government scientist is to be an adviser to a government buyer, then there is a need to forestall conflict of interest by maintaining a clean separation between the scientist and industry. If the role of government scientists is to develop new technology and promote technology transfer, then scientists should be positively encouraged to move back and forth between government laboratories and leaders in industrial technology.

The DoD is an important source of support of research in universities.[37] In electrical engineering, for example, the DoD provides the majority of university research support. In some other fields (e.g., aeronautical and mechanical engineering), the DoD is the largest single source of funds. Funds from the DoD support much research critical to the Nation's military capabilities, but another important function of DoD research funding for universities is the training of students who then enter the Nation's pool of scientific and engineering talent. A reduction in DoD funds for university research is possible as overall defense budgets shrink. Congress or the OSD may want to maintain funding of university research

35 *Bureau* of the Budget, *Report to the President on Government Contracting for Research and Development, May* 1962, Annex *5,* pp. 47-49.

36 Joel Yudken *and Ann* Markusen, Rutgers University, "?'he Labor Economics of Conversion: Prospects for Military-Dependent Engineers and Scientists," p. 15, a paper presented at the conference, "Engineers and Economic Conversions, ' University of Arizona, Tucson, July 15-17, 1991.

37 Knezo, op, cit., footnote 14, p. 24.

to continue to have access to this important source of technological strength.

As the DTIB shrinks, the need for scientists, engineers, and technicians will also decline. Meeting the lesser personnel demand should, in the long term at least, be an easier task than attracting adequate numbers was in the past. During the transition to a smaller base, however, the major danger is that past investment that has resulted in a huge reservoir of experience and knowledge, both in individuals and in groups, will be lost. Moreover, the smaller year-to-year demands of the DTIB for technical talent will not reflect the Nation's requirements if a major new military threat arises. Thus, the Nation should be mindful of where the DTIB technical talent goes as it leaves the base. There is a difference, both to national security and national prosperity, between moving scientific and technical talent between defense and civil work and not being able to use it in the economy at all. Industry will continue to supply the great majority of R&D personnel important to defense, which can increasingly include R&D talent outside of the traditional defense companies if civil-military barriers are reduced.

Independent Research and Development

Companies that have contracts with the U.S. Government negotiated on the basis of their costs, rather than market or bid prices, are allowed to charge as an overhead expense the ''normal' costs of doing business. Since before the Second World War, the government has considered limited R&D and other engineering efforts as allowable overhead costs.

In the past, the IR&D recovery scheme exacerbated the separation of military and civilian technology. If military and commercial business, including R&D, is mixed in one company division, then that portion of R&D judged to have a potential interest to the DoD must be prorated between the government and commercial business. If the optimal R&D investment in the government and commercial parts is not the same, then anomalies result. For example, if the military products warrant a higher rate of R&D investment than the commercial products, and IR&D recovery rules require prorating R&D costs, then the company's commercial products will be more expensive than those of a competitor that does no military R&D. Thus a company that does both commercial and military production and R&D has yet another incentive to separate its two customer lines, creating yet another barrier between commercial and military technology transfer.

Today the trend is toward encouraging civil application of recoverable IF.&D. To qualify for recovery as an overhead cost on a defense contract, R&D must now be shown to be of "potential interest" to the DoD.[38] The law states that IR&D regulations should encourage contractors to pursue R&D activities that

1. strengthen the DTIB,
2. enhance industrial competitiveness,
3. promote critical military technologies,
4. develop dual-use technology, and
5. develop technology to benefit the environment.

A broadening definition of what is of interest to the DoD combined with higher - recovery rates does not give companies a blank check to charge R&D to government contracts. Contract officers must still agree that the charges are reasonable.

Substantial additional changes in IR&D recovery rules may be needed to change the way companies support R&D. Recovery of IR&D as an overhead expense on procurement links R&D to production. This linkage will not be desirab e in the emerging era of production cuts. For example, production of many types of weapons may fall sharply during the transition to a smaller military, while the need for R&D will remain high. In these instances, contract R&D could make up for reduced overhead recovery of IR&D expenses. In additicn, if the DoD buys commercial technology incorporated into military-specific products, then companies will want some simple mechanism for folding past R&D costs into the price of the products.

Technical Data Rights

When the DoD acquires a product, it typically acquires some license right to the ''technical data" related to that product.[39] Technical data could be just "form, fit, and function' information, that is, a

38 Independent Research and Development: CFR, Title 48, Chap 2, sec. 231,205-18 and P.L. 101-510, sec. 824. P.L. 101-510 put "interest" in place of the earlier requirement for a ''relationship' and significantly broadened what is of 'interest' to the DoD to include international competitiveness.

39 CFR, Title 48, ch. 1, sec. 52.227-14.

description of what a device does and where the holes for bolting it in need to be drilled. At the other extreme, the government sometimes demands the right to manufacturing data detailed enough that another firm can produce the item. The government argues that it has vital national security responsibilities that transcend normal market requirements and just@ extensive data requirements. But many firms are concerned that technical data rights rules cause them to lose commercially useful technology.

Current policies toward technical license rights inhibit mixing of military and commercial R&D. If the government wants to assure a second source for some critical item, it may request only government-purpose license rights. This is technical data that allows the government or another of its contractors to build the item, but any contractor that does so must not use the data for any commercial purpose. No one can guarantee that such separation will be effective in all cases. Thus, companies that have technology of commercial interest are reluctant to sell products to the government along with license rights as they fear that the government will be a conduit to a competitor's drawing board.

Current data license right regulations, and the resultant loss of exclusive control of data, also discourage the commercialization of military technology, A successful R&D program is only the first step in getting a product to market. Successful marketing and sales can be even more difficult.[40] A company has little incentive to take the risk and make the investment needed to establish, or even explore, a market niche if, when successful, a rival already has the same technology via the DoD and is ready to compete.

Small subtier firms argue that they are harmed more by data-rights regulations than are large prime contractors. Small companies often survive on one or a few products. Sometimes their only commercial advantage is a unique expertise in one particular technology, which, if compromised, could mean the end of the firm. The large primes have additional special "products" that they can sell: systems integration and the ability to deal with the government. Neither kind of information is as easy to steal as is a manufacturing process. Thus, the primes have relatively less worry about license rights. Moreover, large primes often require that data license rights clauses of their contracts are passed down to subcontractors; thus small subcontractors often view big prime contractors as part of the problem, not fellow sufferers. Small firms charge that the government is worse than cavalier about protecting data rights, that indeed the government sees any exclusive control of technology as a challenge to be met. Unless there are changes in requirements, many small firms will continue to be reluctant to make their technology available to the government.

Data license-rights questions do not lend themselves easily to compromise. Government and industry agree on what the issues are, but see a clear conflict between their respective interests. The government will always want to negotiate for as much access as it can get, and industry will always want to give up as little as possible. The optimal solution will require a broader perspective including the long-term effects on industry's incentives to provide the DoD with the products of its best technology and the DoD's long-term need to maintain some technologies regardless of short-term fluctuations in need or rate of production. (See ch. 4 for further discussion of technical data rights.)

Import and Export Restrictions

Import and export restrictions inhibit the entry of some companies into defense R&D in many indirect ways. Interviews show that some commercial firms are hesitant to take defense R&D contracts if the resulting technology is not readily exportable. The United States, unlike most other countries, often exports military technology to allies with the provision that further export to third countries will be controlled. This reduces incentives for international R&D collaboration among multinational and foreign firms.

Import restrictions affect U. S,-based firms that are truly multinational (as opposed to domestic firms with strong exports). Thus, a multinational corporation will balk at a government-sponsored development project-or require higher prices-if the resulting product must be manufactured in North America. A company like IBM makes products all over the world for a variety of economic reasons, and import restrictions (that is, Buy American rules)

[40] For many industries, getting a technically successful product accepted by the market is harder than the technical research and development itself. SeeEdwin Mansfield, "How Economists See R& D," *Harvard Business Review*, vol. 59, November-December 1981, pp. 100-106.

would require a complete overhaul in the way it does business.

If the United States wishes to increase civil and military technical integration, then it must reexamine its approach to the buying and selling abroad of technology for military applications. This is different from an arms export policy. Rather, the technical marketplace is becoming increasingly international; thus greater use of commercial technology inevitably leads to greater international interdependence. Indeed, as market barriers are reduced, tracking the origin of particular parts and technologies becomes increasingly difficult.

SUMMARY

Without offsetting action by the Federal Government or Congress, the DoD R&D budget will shrink in the future as the overall DoD budget declines. The DoD RDT&E is expected to drop in real terms from $40 billion today to $27 billion by 2001.

Yet the new international security environment still requires that the Nation have what *Redesigning Defense* termed an "advanced" military R&D capability that can respond to warnings of even sophisticated threats by supporting weapons systems that can meet the threat and be manufactured and deployed in time.

OTA defines an ''advanced" DoD R&D capability as having

- a world-class manpower base (both individuals and teams);
- cutting-edge R&D able to guard against technological surprise, not only by sophisticated former adversaries, but by powers having access to the best weapons available on the international arms market;
- robust efforts in critical technologies;
- a balance between the near-term technology needs of each Service and the effort expended to meet the long-term R&D needs of U.S. defense overall;
- strong links to manufacturing, so the weapons systems proposed are producible and affordable; and
- strong links to civilian R&D, even in the absence of a national consensus about higher levels of Federal support for civilian technology programs.

Without offsetting actions, the likely shrinkage of DoD R&D will produce disproportionate cuts in private industry activities. Direct military-sponsored R&D in private companies will decline, as well as the investment private defense contractors make with their own funds.

Correspondingly, the fraction of military R&D effort done by Service in-house laboratories and FFRDCs would increase. While these institutions have a record of assisting the services' direct needs they would have to change to address either research needs or the technology development role currently well performed by private companies.

Current and proposed plans to consolidate the Service's structure of laboratories and centers, while important, will not create the integrated management structure which the R&D component of the future DTIB will require.

The DoD may have to make a special effort to filly fund development work performed by private contractors to assure that technology development goes forward in private industry on profitable terms, even when there is unlikely to be a future production contract that would allow such companies to recover R&D costs. This would include support for prototyping, as discussed in chapter 3.

Without offsetting actions, performers of military R&D will not improve their links to civilian R&D. Present IR&D rules create barriers within companies between their military and civilian R&D efforts. Current technical data license rights rules discourage specialized subtier fins--which are a critical source of the Nation's invectiveness in defense technology-from pursuing new technologies for both civilian and military usc, Import and export restrictions inhibit interchange between defense and nondefense sectors and prevent the DoD from drawing on technology developed abroad, even by U.S.-based multinational firms.

Without offsetting actions, DoD support for research in colleges and universities could decline as the overall defense budget shrinks. Thus, the DoD will miss some of the benefit of basic university research it has enjoyed for many years. The DoD would also have less chance to train the next generation of scientists and en enineers and familiarize them with the Nation's defense needs.