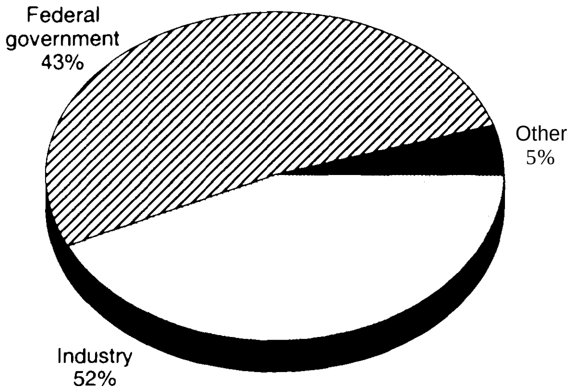
Nuclear Weapons Laboratories: From Defense to Dual Use 3

The Federal Government pays for nearly half the research and development (R&D) done in the United States, and defense dominates the government's share. In 1992, Federal spending for military R&D was $41.5 billion, or nearly 60 percent of all government R&D, amounting to $69.8 billion. It was over one-quarter of the Nation's $157.4 billion total bill for R&D, spent by industry, government, universities, and nonprofit institutions (figures 3-1 and 3-2).[1]

The predominant role of defense in Federal R&D has held for many years, and indeed was an even more prominent part of the government's, and the Nation's, R&D in earlier decades. Through its sponsorship of cutting edge technologies and its sheer size, defense R&D spending over the years has been an important source of technology advances that spilled out into the whole economy, sometimes fostering the growth of entire new industries, e.g., semiconductors and computers. As a spur for civilian technology advance and economic growth, military R&D was unfocused and unpredictable but often it worked—especially when the Department of Defense (DoD) also served as a large, reliable first customer of the new technologies. It was this

[1] The total of $41.5 billion for military R&Din fiscal year 1992 included $38.7 billion by the Department of Defense and $2.8 billion by the Department of Energy for defense-related atomic energy R&D. (National Science Foundation *National Patterns of R&D Resources: 1992, NSF-92-330* (Washington, DC: 1992), table B-21 and unpublished data provided to the Office of Technology Assessment by the National Science Foundation). This figure does not include Independent Research and Development (IR&D) with potential military relevance done by private fins. Private IR&D amounted to $3.8 billion in 1989 (the last year for which data are available), of which the government (the Department of Defense and National Aeronautics and Space Administration) reimbursed $1.8 billion.

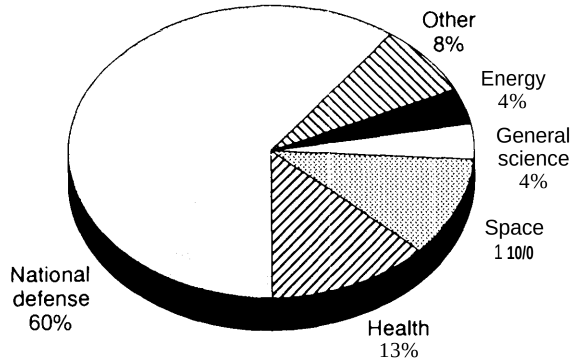
Figure 3-l-National R&D Spending by Source, 1992



Total $157.4 billion

SOURCE: National Science Board, *Science and Engineering Indicators-1991* (Washington, DC: U.S. Government Printing Office, 1991), table 4-1.

Figure 3-2-Federal R&D Funds, by Budget Function, 1992



SOURCE: National Science Board, *Science and Engineering Indicators—1991* (Washington, DC: U.S. Government Printing Office, 1991), table 4-17.

combination of defense R&D and defense purchases that launched the semiconductor and computer industries.

The long-term decline in defense spending following the end of the Cold War will almost certainly mean eventual declines in military R&D.[2] This raises some issues of prime importance to the civilian side of the economy. Continued American preeminence in R&D-historically a strength of the U.S. economy—is not assured; after rising for years, R&D spending has remained essentially flat since 1988. Sustained losses in military R&D spending will rob civilian enterprises of one important source of technology advance, unless they are made up in some other way. A related issue is what use can be made of the research institutions and people, many of them highly skilled scientists and engineers, who have served a defense purpose that is now declining or vanishing. Are there ways to turn these resources to good use on the civilian side of the economy and thus help to improve our competitive performance? These issues are the subject of this chapter.

Another implication of the decline in defense R&D is that future weapons systems may come to depend more on technologies and devices developed for civilian uses; already, many electronics devices in commercial use are far more advanced than those developed for strictly military purposes. One of the central policy questions for defense planners in the post-Cold War era is how to foster dual-use technology development and encourage the armed services to buy commercial products when they are cheaper or better than products custom designed for the military.[3]

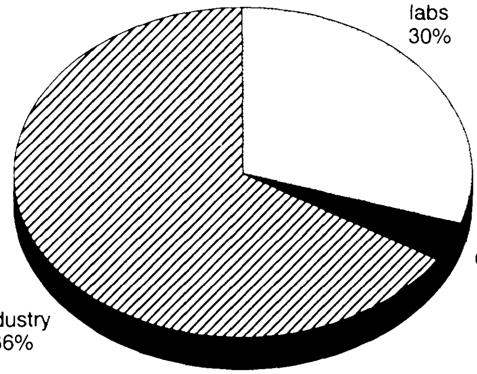
2 It may, however, hold Up better than procurement. In fiscal year 1993, DoD funding included a 1 percent real increase in R&D but a 13 percent decrease in procurement. Over the longer run, R&D will probably decline, but to a lesser degree than procurement it may assume a relatively more prominent part in a new post-Cold War defense strategy. For discussion of such strategies, see U.S. Congress, Office of Technology Assessment, *Building Future Security: Strategies for Restructuring the Defense Technology and Industrial Base,* OTA-ISC-530 (Washington DC: U.S. Government Printing Office, June 1992).

3 For years, critics of military procurement have urged review of audit and recordkeeping requirements that discourage many commercial companies from selling to the military, and reform of the antiquated system of designing and building to military specifications. Change has been minimal. However, deep and sustained cuts in military budgets have created urgent new reasons for modernizing procurement. Ibid., pp. 100-103.

Though dual-use technology development and production is not as central to commercial competitive performance as it is to managing a smaller, leaner defense system, it is still relevant. Defense is going to remain a major source of R&D support, and it will still be a big market for goods and services from private firms even at half the size it was in the 1980s.[4]

In considering how to compensate for losses of military R&D and how to use the people and resources formerly devoted to it, public policy can have most effect in research institutions that the government operates or supervises. Although two-thirds of defense R&D dollars are spent in private industry (figure 3-3), public policy has a stronger and more direct influence on the conduct of government R&D than on how private firms manage their laboratories and research teams. The focus of this chapter is therefore on government laboratories that, up to now, have put most of their effort toward military goals. Singled out for special attention are the Department of Energy's (DOE) three big weapons laboratories—Los Alamos, Lawrence Livermore, and Sandia National Laboratories-which, beginning with the Manhattan Project at Los Alamos, have designed and engineered the Nation's arsenal of nuclear weapons for half a century. With the collapse of America's rival nuclear superpower, that mission is much diminished.

Figure 3-3-Department of Defense R&D Spending by Performer, 1992



NOTE: Figures do not include DOE spending for nuclear weapons R&D.
SOURCE: National Science Foundation, Federal *Funds for Research and Development: Fiscal Years 1990, 1991 and 1992,* Volume XL, NSF 92-322, (Washington, DC: 1992), table C-9.

FEDERAL LABORATORIES

Out of a total Federal R&D budget of more than $70 billion in 1992, $25 billion went to the hundreds of laboratories owned or principally funded by the U.S. Government.[5] About $18 billion was spent in government-owned, government-operated labs (GOGOs), while the other $7 billion went to government-owned, contractor-operated labs (GOCOs) and to Federally Funded Research and Development Centers (FFRDCs), which are owned and administered by nongovernment institutions (e.g., universities) but do most of their work for a government agency[6] (table 3-l).

It is misleading to think of all the labs and the entire $25 billion as equally available (or conversely, equally limited) for helping to advance commercial technologies. The Federal laboratories are a varied lot, ranging from vast campuses with thousands of researchers to single offices within an agency or university staffed by 5 or 10 people. Many of the labs are relatively small outfits, and even the big ones have widely differing potential for forming industrial partner-

[4] See chapter 5 of this report for a discussion of some of the dual-use projects supported by DoD's Advanced Research Projects Agency, and the implications for competitiveness.

[5] The figure of 726 Federal labs is often used but is misleadingly precise; the number varies depending on definition. There is no readily available count of all Federal labs using a consistent definition, but "hundreds" is the right order of magnitude, R&D figures given in this section are estimates for fiscal year 1992, and are Federal obligations for total R&D not including *expenditures* for R&D plant and equipment. The source is National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1990,1991, and 1992,* NSF 92-322, Detailed Statistical Tables (Washington, DC: 1992).

[6] Lincoln Laboratory, sponsored by the Air Force and administered by the Massachusetts Institute of Technology, is a leading FFRDC.

Table 3-l—R&D by Selected Government Agencies and Laboratories, FY 1992 (millions of dollars)

Department/Agency	Total R&D	Total Lab	Intramural	FFRDCs[a]
Department of Defense	$38,770	$11,596	$9,890	$1,707
Department of Energy	6,499	4,698	449	4,249
National Aeronautics and Space Administration	8,543	3,499	2,613	886
Health and Human Services	9,781	2,039	1,966	74
National Institutes of Health	8,253	1,559	1,486	73
Department of Agriculture	1,256	826	826	•
Department of Commerce	539	431	431	0
National Institute for Standards and Technology	186	144	144	0
National Oceanic and Atmospheric Agency	337	272	272	
Department of the Interior	562	482	479	3
National Science Foundation	2,102	211	89	123

•Indicates amount less than $50,000
a FFRDCs: Federally Funded Research and Development Centers.

SOURCE: National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1990, 1991, 1992.* Volume XL, NSF-92-322 (Washington, DC: 1992), table C-9.

ships and developing technologies with commercial promise.

About half the money going to government labs is spent for nondefense purposes, much of it by agencies that already have close, longstanding relationships with private industry. The Department of Health and Human Services, which runs the National Institutes of Health (NIH), had a lab budget of $2 billion in 1992;[7] in addition to its strong emphasis on basic research, NIH supports applied research of immediate interest to the pharmaceutical, medical device, and biotechnology industries. The National Aeronautics and Space Administration (NASA), which operates the largest of the nondefense laboratories, spent $3.5 billion in its labs in 1992. About 10 percent of NASAs R&D is in aeronautics, which over the years has been closely aligned with the needs and interests of the commercial aircraft industry; in fact, that is part of the agency's statutory mission. NASA's space R&D, on the other hand, has less direct links with commercial markets (even though Earth-orbiting satellites and remote sensing have ultimately affected the civilian economy in remarkable ways).

Other major, but smaller, players among civilian agencies are the Departments of Agriculture, Commerce, and the Interior, some of them having important industry ties. The central mission of the Commerce Department's National Institute of Standards and Technology (NIST) and its labs is to serve industry's needs; NIST labs received $144 million from their pa-rent agency in 1992, but contributions from other agencies and private industry collaborators brought the total up to about $450 million. A large share of the $575 lab budget of the Agricultural Research Service is for applied research that is more or less directly useful to American farmers, and at least a part of the $147 million spent in the Forest Service's labs is likewise useful to the timber and wood products industries. On the other hand, research in the Commerce Department's National Oceanographic and Atmospheric Administration labs (funded at about $272 million in 1992) is usually on scientific subjects of less immediate interest to industry.

[7] Note that the figures given here are only for R&D done in laboratories that the agency operates, owns, or funds, not for its entire R&D spending. For example, HHS had an R&D budget of $9.8 billion in 1992 (table 3-l), with universities and colleges the major performers. NASA's whole R&D budget in 1991 was $8.3 billion (mostly for space), and private industry was the main performer.

The government's defense labs have traditionally focused on their primary mission, which is to develop military technologies, with any benefits to the civilian side of the economy more or less fortuitous. True, some big defense R&D programs have been sold to Congress and the public partly on the basis of potential spinoffs to commercial industry. A prime example is the Strategic Defense Initiative. The same has often been true of NASA's costly space R&D which, like military R&D, is targeted to a noncommercial government mission. However, for the past dozen years, starting with the Stevenson-Wydler Act of 1980, Congress has shown increasing interest in urging Federal labs to transfer the technology they develop for government purposes to private industry. Federal labs with defense missions are big spenders, and are the object of most of the urging.

Topping the list of government spenders for in-house R&D is the Department of Defense, with a 1992 lab budget of $11.6 billion. However, less than half of the money going into DoD labs is spent on research, development, testing and evaluation (RDT&E) activities within the labs; the rest is passed through to outside performers, mostly defense contractors.[8] With few exceptions (e.g., the science-oriented multiprogram Naval Research Laboratory), the Defense Department's R&D labs pass through well over half of their budgets while testing and evaluation (T&E) centers, such as the Navy Weapons Center at China Lake, California, spend more than half in-house (see ch. 6).[9]

The next biggest spender was the Department of Energy, with $4.7 billion.[10] In contrast with the DoD labs, most of the funding DOE provides its labs is spent in-house, and indeed is supplemented by about $1 billion from other Federal agencies, mostly DoD. DOE labs also differ from most DoD labs (and most other Federal labs as well) in that they are GOCOs, owned by the government but run by contractors-universities, other nonprofit institutions, and private industrial firms (some of the latter on a not-for-profit basis, but some for profit). As discussed in chapter 4, their status as GOCOs makes a difference, sometimes favorable and sometimes not, in the DOE labs' abilities to work with industry in developing advanced technologies.

This report, with its focus on redirecting government R&D resources from strictly military to dual-use and commercial applications, concentrates on the DOE nuclear weapons laboratories. The term "weapons lab" usually refers to Los Alamos and Lawrence Livermore, which design

[8] *Department of Defense In-House RDT&E Activities* for Fiscal Year 1990, prepared for the Office of the Secretary of Defense, Office of the Deputy Director of Defense, Research and Engineering/Science and Technology (Washington, DC: The Pentagon, n.d.). This document reports spending for total and in-house RDT&E activities in 91 Army, Navy, and Air Force facilities, employing about 100,000 civilian and military personnel. Spending for the total RDT&E program was $8.4 billion, with $3.9 billion (46 percent) spent in-house in fiscal year 1990. These figures are not exactly comparable with R&D data collected by the National Science Foundation. They are mostly limited to RDT&E activities where funding for in-house RDT&E is at least 25 percent of the in-house portion of the facility's budget; they do not include spending in FFRDCs. See also Michael E. Davey, "Defense Laboratories: Proposals for Closure and Consolidation" Congressional Research Service, Library of Congress, Jan. 24, 1991, p. CRS-6.

9 Ibid. For example, at the big RDT&E complex at Wright Patterson Air Force Base, the six R&D labs spent only 17 percent of their RDT&E budgets ($131 million of $789 million) in-house in 1990, while the one T&E center spent 70 percent ($66 million of $96 million) in-house. The R&D centers are the Aero Propulsion and Power Laboratory, the Aerospace Medical Research Laboratory, the Avionics Laboratory, the Electronic Technology Laboratory, and the Materials Laboratory. The T&E center is the 4950th Test Wing. Overall, in 1990, the Defense Department's R&D labs spent 41 percent of their budgets in-house compared with 59 percent at the T&E centers.

10 Again, note that these figures are only for R&D performed in government-owned, -operated, or -funded labs. DoD's total 1992 budget for R&D, excluding expenditures for R&D plant and equipment, was an estimated $38.8 billion. DOE's was $6.5 billion.

nuclear warheads, and Sandia, which develops field-ready weapons using the warheads.[11] These labs are in a class by themselves. They are very large, with collective budgets of $3.4 billion in fiscal year (FY) 1993, and over 24,000 regular employees.[12] Nuclear weapons activities took from 50 to 61 percent of their operating budgets (least for Lawrence Livermore, most for Los Alamos); if the labs' work for DoD is added in, funding for military-related activities ranged from 67 percent at Lawrence Livermore to 78 percent at Sandia. These labs also have a history of substantial nondefense work.

Among Federal R&D institutions, the nuclear weapons labs face the clearest need to change with the end of the Cold War. Their mission of nuclear weapons design is fading; in 1993, no new nuclear weapons were being designed. Nonetheless, funding for the labs continued to rise (in constant dollars, taking inflation into account) through FY 1992 and barely dropped in FY 1993. This growth was partly due to steep increases for a massive environmental cleanup job, plus more modest amounts for non-proliferation work, decommissioning existing weapons, and safety and security of the remaining nuclear stockpile; all these activities are funded by the nuclear weapons account. Spending for nuclear weapons-related activities, after declining from the late 1980s through 1991, turned up in 1992 and again in 1993. The fact remains that the nuclear weapons labs are looking at a future that is very different from their past.

THE DOE WEAPONS LABORATORIES

The DOE's laboratory complex consists of the nine multiprogram laboratories (including the weapon labs), which are usually called the national labs, plus eight single-program energy labs.[13] They are funded by six program areas: Defense Programs (DP) and related nuclear weapons offices, which include work in all aspects of nuclear weapons design, safekeeping, non-proliferation, and environmental restoration of the damage from 50 years of weapons work; Energy Research, which supports fundamental scientific research; the Nuclear Energy, Fossil Energy, and Conservation and Renewable Energy programs, which concentrate on applied energy R&D; and the Environmental Restoration and Waste Management program.

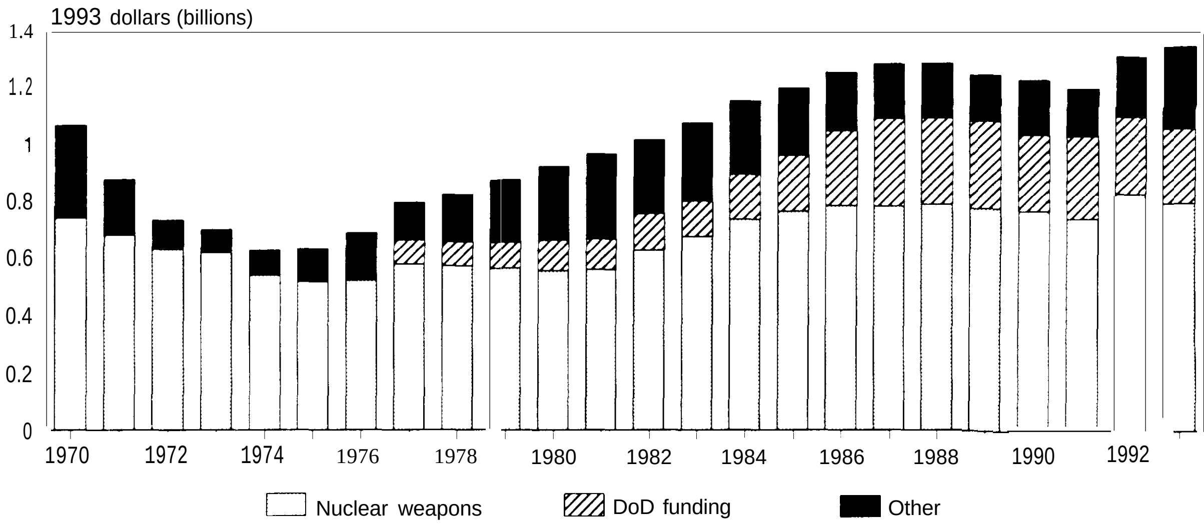
The weapons labs dominate the DOE lab complex. In 1992 they got over one-half of the funding for all the DOE labs. The biggest part of their funding comes from DOE's atomic energy defense weapons account (including Defense Programs and related nuclear weapons offices); DoD contributes an additional, though declining, share (figures 3-4, 3-5, and 3-6). The weapons labs grew rapidly in the military buildup of the 1980s, increasing their operating funding (in real noninflated dollars) by 58 percent from 1979 to 1992, while the energy labs' funding rose 15

11 The Idaho National Engineering Laboratory (INEL), which handles defense waste and materials production programs, is Sometimes included among the weapons labs. So is the weapons part of the Y-12 facility at Oak Ridge National Laboratory, which processes nuclear fuel (uranium and lithium) and does precision machining of weapons components.

12 This counts only regular employees. (h-site contract employees amount to many more. IN 1993, Sandia's 8,450 regular employees were supplemented by 2,000 on-site contract employees; Los Alamos, with about 7,600 regular employees, had some 3,000 on-site contractors.

13 The number of DOE labs differs as counted by various sources. If small specialized labs are included, the number can be as high as 29. The figure of 17 comes from Secretary of Energy Advisory Board, "A Report to the Secretary on the Department of Energy National Laboratories,' mimeo, July 1992. The other national labs are the six energy multiprogram laboratories: Argonne National Laboratory, Brookhaven National Laboratory, Idaho National Engineering Laboratory, Lawrence Berkeley Laboratory, Oak Ridge National Laboratory, and the Pacific Northwest Laboratory. DOE's eight single-program laboratories include: Ames Laboratory, Continuous Electron Beam Accelerator Facility, Fermi National Accelerator Laboratory, National Renewable Energy Laboratory (formerly the Solar Energy Research Institute), Princeton Plasma Physics Laboratory, Stanford Linear Accelerator Center, Stanford Synchrotrons Radiation Laboratory, and the Superconducting Super Collider Laboratory.

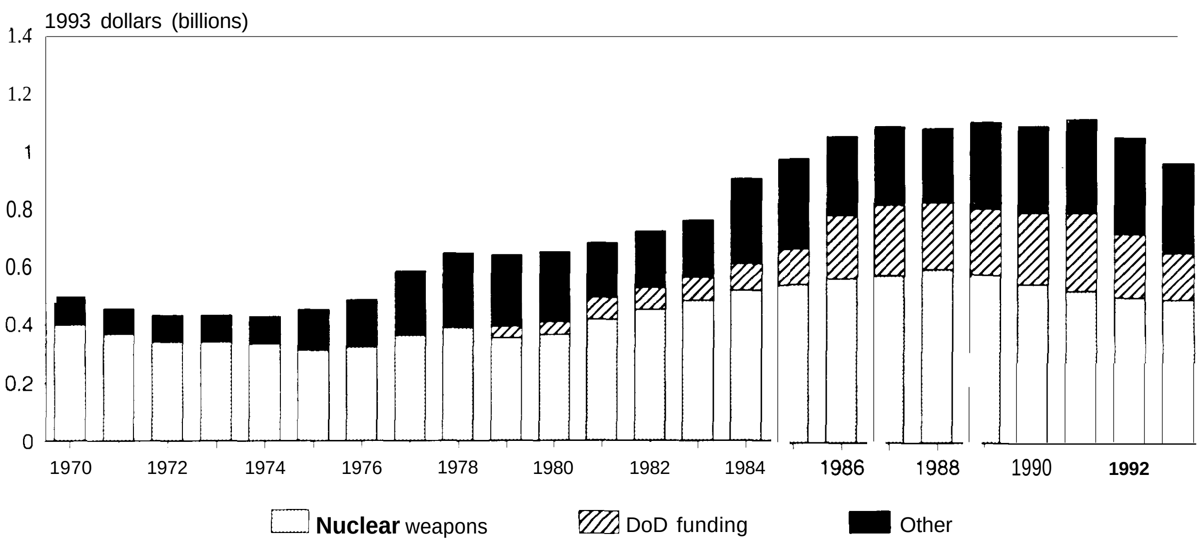
Figure 3-4-Nuclear Weapons and DoD Funding for Sandia National Laboratories



NOTE: Operating budget only. DoD funding not available prior to 1977.

SOURCE: Sandia National Laboratories, 1993.

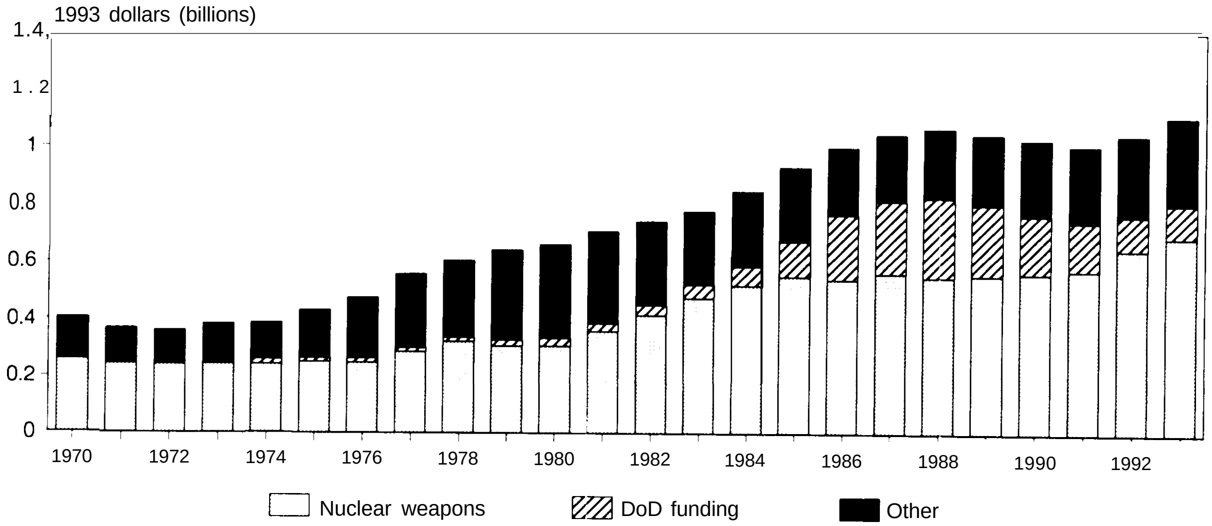
Figure 3-5-Nuclear Weapons and DoD Funding for Lawrence Livermore National Laboratory



NOTE: Operating budget only. DoD funding not available prior to 1979.

SOURCE: Lawrence Livermore National Laboratory, 1993.

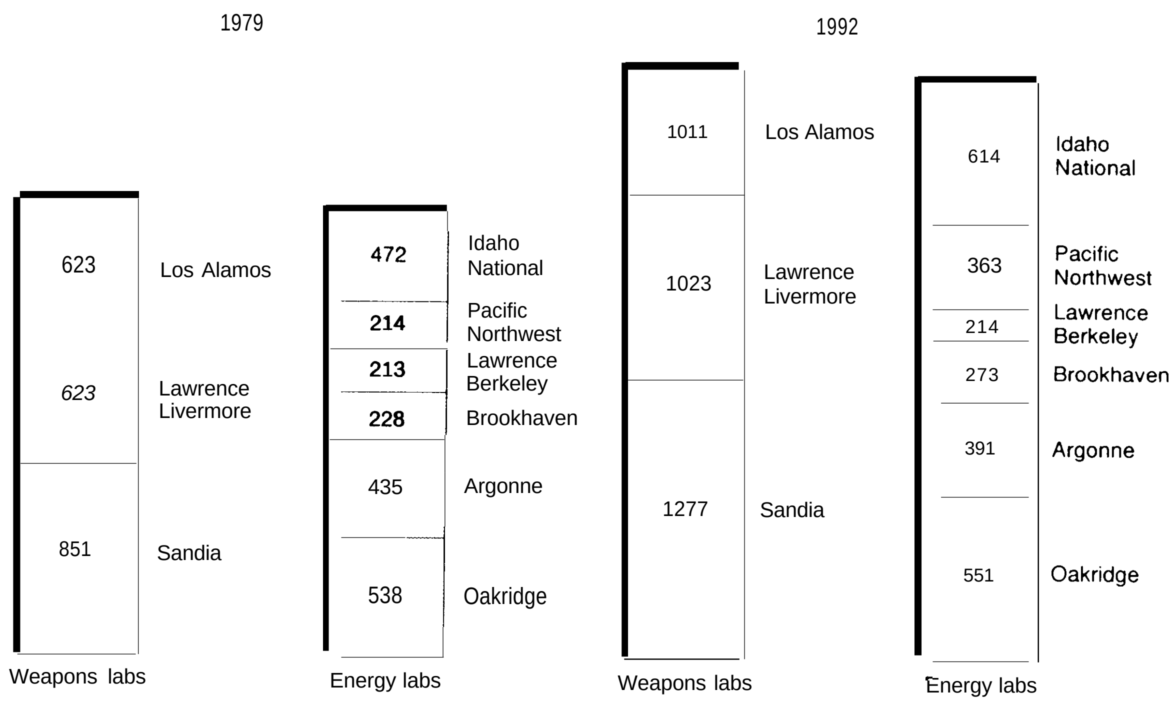
Figure 3-6-Nuclear Weapons and DoD Funding for Los Alamos National Laboratory



NOTE: Operating budget only. DoD funding not available prior to 1974.

SOURCE: Los Alamos National Laboratory, 1993.

Figure 3-7—DOE Multiprogram Laboratories Funding in 1979 and 1992
(In **millions** of 1992 dollars)



NOTE: Operating budgets only.

SOURCE: U.S. Department of Energy, ***DOE Multiprogram Laboratories: 1979 to 1988A Decade of Change;*** U.S. Department of Energy; Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories.

percent (figure 3-7).[14] The weapons labs' budgets continued to climb through 1993, when their combined funding was almost two and one-half times what it was at the low point in 1974 (figure 1-12). In 1993 only Lawrence Livermore took a substantial cut; funding for Sandia and Los Alamos continued to rise.

Table 3-2 shows details of funding of nuclear-weapons related activities at the three labs. (Note that these figures are in current dollars.) In constant 1993 dollars (table 3-3) the total for the three labs was at a 6-year high in 1993, but a growing share of this was for activities that are not really military (see the discussion below).

Mix of Military and Civilian Activities

Despite their dominant size and focus on military R&D, the big three weapons labs share with the other national labs some varied nonmilitary functions and much of their history. The origin of four of the national labs—Argonne, Brookhaven, Los Alamos, and Oak Ridge-was in the Manhattan Project during World War 11.[15] After the war, on the reasoning that the A-bomb was too important to be left to the generals, the Atomic Energy Act of 1946 put control of both atomic weapons and civilian applications of atomic energy in the hands of a civilian agency, the newly created Atomic Energy Commission (AEC). Additional national labs were created under the aegis of AEC; they were charged not only with continuing weapons work but also with developing atomic energy for peaceful purposes and, as a foundation for both, the advancement of basic scientific research in nuclear and high energy physics. Eventually, after DOE was formed in 1977, all the AEC labs were transferred to the new department.

At one time or another, all nine national labs have had responsibilities for both military and civilian activities. Lawrence Berkeley, the least military of them all today and one of the smallest, had no funding from Defense Programs by 1988 and just 2 percent of its money from DoD, but during World War 11 it was almost wholly devoted to the Manhattan Project.[16] Brookhaven, which concentrates heavily on fundamental scientific studies, nonetheless owed 8 percent of its funding to Defense programs and DoD in 1988. Oak Ridge, the largest and most diverse of the energy labs, got 21 percent of its support from the military side; Argonne, another large and versatile lab, was 19 percent military. Both the Pacific Northwest and the Idaho National Engineering (INEL) labs received 45 percent of their financial support from the military; INEL in fact is sometimes classified as a weapons lab. Both concentrate much of their work on management of nuclear wastes, prominently including defense wastes.

Conversely, the weapons labs have at times had quite a substantial mix of nonmilitary projects. Los Alamos, founded by physicists, has kept an emphasis on basic scientific research, including

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14 U.S. Department of Energy, unpublished data from the Institutional Pl arming Database, US DOE ST-311. These calculations include the Idaho National Engineering Laboratory (INEL) among the energy labs. INEL is sometimes categorized separately as a "nuclear energy" laboratory because its work is concentrated largely in producing nuclear materials (mostly for weapons) and handling nuclear wastes. Argonne, Brookhaven, Lawrence Berkeley, Oak Ridge, and Pacific Northwest National Laboratories are considered "energy research" laboratories. Excluding INEL, the total funding for the energy research labs rose about 10 percent from 1979 to 1992.

14 US. Department of Energy, unpublished data from the Institutional Plarming Database, US DOE ST-311. These calculations include the Idaho National Engineering Laboratory (INEL) among the energy labs. INEL is sometimes categorized separately as a "nuclear energy" laboratory because its work is concentrated largely in producing nuclear materials (mostly for weapons) and handling nuclear wastes. Argonne, Brookhaven, Lawrence Berkeley, Oak Ridge, and Pacific Northwest National Laboratories are considered "energy research" laboratories. Excluding INEL, the total funding for the energy research labs rose about 10 percent from 1979 to 1992.

15 Lawrence Berkeley Laboratory, the oldest of the national labs, was founded in 1931 to advance the development of the cyclotron, invented by Ernest Lawrence.

16 Information on budgets of national labs is drawn from U.S. Department of Energy, *Multiprogram Laboratories: 1979 to 1988—A Decade of Change* (Washington, DC: 1990).

Table 3-2—Funding for Nuclear Weapons-Related Activities in t he DOE Weapons Laboratories, 1988-1993
(In millions of dollars)

Program	FY 1988 Actual	FY 1989 Actual	FY 1990 Actual	FY 1991 Actual	FY 1992 Actual	FY 1993 Budget
Nuclear weapons RD&T						
Lawrence Livermore	314.9	*315.6*	297.7	267.8	287.0	253.5
Los Alamos	285.5	*288,7*	276.4	267.7	298.1	273.1
Sandia	439.2	*445.7*	443.9	429.1	467.9	449.8
Technology Commercialization						
Lawrence *Livermore*				0.2	2.8	30.5
Los Alarms				0.5	5.2	15,0
Sandia				*1.3*	8.3	38.0
Inertial Confinement Fusion						
Lawrence Livermore	66.1	*64.6*	67,7	77.2	84.1	90.0
Los Alamos	29.0	*29.9*	30.9	24.2	23.6	24.8
Sandia	28.3	*25.8*	27.5	29.2	31.4	30.0
Materials Production						
Lawrence Livermore	69.6	68.5	61.1	66.0	4.9	2.0
Los Alamos	32.7	35.8	23.2	26.5	13.1	12.4
Sandia	0.0	0.0	0.0	0.0	0.0	0.0
New Production Reactors						
Lawrence Livermore		1.0	0.0	0.0	0.2	0.3
Los Alarms		0.0	16.4	14.3	10.8	0.7
Sandia		0.0	7.7	4.3	7.3	4.0
Stockpile Support[a]						
Lawrence Livermore	6.9	6.0	0.0	0.0	0.0	0.0
Los Alamos	49.4	56.0	49.5	57.1	79.4	91.0
Sandia	117.0	118.9	118.0	122.8	143.3	133.0
Verification and Control						
Lawrence Livermore	19.1	24.1	25.5	20.8	22.8	50.3
Los Alamos	30.7	38.1	39.3	42.5	48.9	57.0
Sandia	37.1	44.4	39.6	43.3	47.7	65.7
Nuclear Safeguards and Security						
Lawrence Livermore	3.3	2.8	3.7	3.7	3.7	3.4
Los Alamos	14.5	15.7	17.8	16.3	16.2	9.4
Sandia	12.6	13.6	12.4	11.4	11.2	9.1
Intelligence						
Lawrence Livermore				8.4	8.0	8.2
Los Alamos				3.7	4.3	3.5
Sandia				2.0	2.1	2.1
Environmental Restoration and Waste Management (Defense)						
Lawrence Livermore	10.1	13.0	31.0	46.5	68.2	71.4
Los Alamos	12.1	14.1	52.4	88.0	128.5	195.2
Sandia	19.9	23.3	43.2	56.2	88.8	100.1
Program Direction						
Lawrence Livermore	0.7	1.0	2.4	0.6	3.0	9.7
Los Alamos	0.2	0.0	0.0	0.3	3.0	20.1
Sandra	0.0	0.0	0.0	0.2	5.0	3.0
Total Nuclear Weapons-related Activities[b]						
Lawrence Livermore	490.7	496.6	489.1	491.0	481.9	488.8
Los Alarms	454.1	478.3	505.9	540.6	625.9	687.2
Sandia	654.1	671.7	692.3	698.5	804.7	796.8

a Most nuclear weapons decommissioning activities are included under Stockpile Support.
b All atomic energy defense weapons activities are included. DOE has recently moved some activities formerly in Defense Programs to separate offices, but they are included here as weapons-related activities for consistency with former years.

SOURCE: Office of Technology Assessment, based on data from Lawrence Livermore National Laboratory, Los A amos National Laboratory, and Sandia National Laboratories.

Table 3-3-Summary of Nuclear Weapons-Related Activities and Total Funding at the DOE Weapons Laboratories, 1988-93 in Current Dollars and 1993 Dollars

	Nuclear weapons RD&T							
	Current year dollars (millions)				1993 dollars (millions)			
Year	Lawrence Liver more	Los Alamos	Sandia	Total	Lawrence Liver more	Los Alamos	Sandia	Total
1988	$ 314.9	$ 285.5	$ 439.2	$1,039.6	$ 379.9	$ 344.4	$ 529.8	$1,254.1
1989	315.6	288.7	445.7	1,050.0	364.8	333.7	515.2	1,213.7
1990	297.7	276.4	443.9	1,018.0	329.8	306.2	491.7	1,127.7
1991	267.8	267.7	429.1	964.6	283.7	283.6	454.6	1,021.9
1992	287.0	298.1	467.9	1,053.8	295.5	307.0	481.8	1,084.3
1993	253.5	273.1	449.8	976.4’	253.5	347.1	449.8	1,050.4[a]
	Total nuclear weapons-related activities							
	Current year dollars (millions)				1993 dollars (millions)			
Year	Lawrence Livermore	Los Alamos	Sandia	Total	Lawrence Liver more	Los Alamos	Sandia	Total
1988	$ 490.7	$ 454.1	$ 654.1	$1,598.9	$ 592.0	$ 547.8	$ 789.1	$1,928.9
1989	496.6	478.3	671.7	1,646.6	574,0	552.8	776.4	1,903.2
1990	489.1	505.9	692.3	1,687.3	541.8	560.4	766.8	1,869.0
1991	491.0	540.6	698.5	1,730.1	520.2	572.7	740.0	1,832.9
1992	481.9	625.9	804.7	1,912.5	496.2	644.5	828.6	1,969.3
1993	488.8	687.2	796.8	1,972.8	488.8	687.2	796.8	1,972.8
	Total funding (operating budgets only)							
	Current year dollars (millions)				1993 dollars (millions)			
Year	Lawrence Liver more	Los Alamos	Sandia	Total	Lawrence Liver more	Los Alamos	Sandia	Total
1988	$ 895.6	$ 884.4	$1,068.1	$2,848.1	$1,080.4	$1,064.5	$1,288.5	$3,433.4
1989	953.0	902.3	1,081.6	2,936.9	1,101,6	1,043.1	1,250.2	3,394.9
1990	983.5	926.0	1,110.6	3,020.1	1,089.4	1,025.7	1,230.2	3,345.3
1991	1,052.5	947.5	1,134.7	3,134.7	1,115,0	1,003.9	1,202.1	3,321.0
1992	1,022.6	1,010.9	1,276.6	3,310.1	1,053.0	1,041.0	1,314.6	3,408.6
1993	963.0	1,104.8	1,350,0	3,417.8	963.0	1,104.8	1,350.0	3,417.8

a Includes $82 million for technology commercialization.

SOURCE: OTA, basal on data from Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and Sandia National Laboratories.

nuclear and particle physics. An official at Lawrence Livermore describes it as a center of “applied science, ’ with nondefense work in fusion energy research, laser isotope separation, and environmental and biomedical research (e.g., mapping the human genome). In 1993, defense activities at Los Alamos were 71 percent of the total operating budget, down from 78 percent in 1987; Livermore’s share of defense activities was 67 percent, compared to 76 percent in 1988. Sandia, consistently more defense-oriented, went from 87 percent defense-related activities in 1989 to 78 percent in 1993.

These percentages are misleading, however, leaving an impression of more military activity than is the case. In FY 1993, Defense Programs and related nuclear defense funding of the three weapons labs amounted to about $2 billion; of this, about $1.1 billion was for weapons research, development and testing and other activities that are clearly military (see table 3-2). In addition, over $400 million went for non-proliferation responsibilities, safety and security of the stockpile, and decommissioning of excess weapons. Nuclear weapons funds also now pay substantial amounts for activities that are better described as dual use than defense. The largest of these is environmental restoration and waste management, which is mainly intended for cleaning up the nuclear and hazardous chemical detritus left by 50 years of nuclear weapons production but also has plenty of civilian applications.[17] Nuclear weapons funding for this purpose in the three labs was about $350 million in FY 1993. A smaller but growing activity funded by the nuclear weapons account is cooperative agreements with industry to develop dual-use technologies (discussed below); funding at the three weapons labs for this purpose was $84 million in 1993.[18]

The present is not the first time that DOE and its nuclear weapons labs have cut back on defense work. In the early 1970s, following the Vietnam War and coinciding with the Nixon-Kissinger policy of detente with what was then the Soviet Union, the labs went through a few years of declining budgets (in constant dollars). Sandia, the biggest and most defense-oriented, shrank the most (figures 3-4,3-5, and 3-6). In the later 1970s, the labs' budgets recovered, thanks in part to the nondefense energy research and applied energy programs that the Carter Administration strongly supported. By 1979-80, only about 50 percent of the Los Alamos budget was defense-related, 60 percent of Livermore's and 70 percent of Sandia's.

All this changed with the enormous military buildup of the 1980s. Already in the Carter administration, the amounts spent (in constant dollars) for defense projects in the weapons labs were rising from the low point of the Nixon-Ford years. After President Ronald Reagan took office, spending in the labs by DOE's Defense Programs and DoD took off; a good deal of the latter was for the Strategic Defense Initiative. Together, Defense Programs, related nuclear weapons offices, and DoD accounted for more than 100 percent of the huge rise in the weapons labs' budgets in the 1980s, as spending for energy programs declined.

Changing Missions

Over the years, the character and missions of the national labs have changed and diverged, reflecting in part the talents, interests, and traditions of the individual labs and their directors. The big changes, however, have come about in response to policy direction at the highest level, i.e., from the President and his Cabinet officers or from concerted efforts by Congress. Presidents Richard Nixon and Gerald Ford sharply cut back weapons work in the labs. President Jimmy Carter restored it to some degree and added a new mission of energy conservation and development of alternative energy sources. President Reagan largely undid the energy mission (and would have undone it more without the resistance of Congress) while pushing weapons work to heights unprecedented in peacetime. At the same time, through a series of laws and oversight, Congress energetically pushed the labs toward a new mission: transferring technology to private industry and working in partnership with industry to develop technologies with commercial promise. In the last year of the Bush Administration, the Secretary of Energy and other top officials joined in urging this new direction.

Even in the early postwar years, the national labs took different directions within the atomic energy complex and most became identified with a particular leading mission in the field. For Brookhaven and Lawrence Berkeley, it was scientific research; for Argonne, development of fission reactors for both defense and civilian uses; for INEL and (a bit later) Pacific Northwest, it

17 DOE also has a large separately funded nondefense environmental restoration and waste management R&D program.

18 These cooperative projects are mostly funded from the atomic weapons RD&T account.

was nuclear waste handling and materials production. Design of nuclear warheads was lodged in the rival Los Alamos and Livermore labs, and engineering of the weapons containing the warheads at Sandia.

Oak Ridge had a less distinct identity .19 Its Y-12 plant was the Manhattan Project center for producing weapons-grade uranium, but after World War H Oak Ridge lost out to other labs in the major activities of the AEC (e.g., physics research, reactor development, weapons design). By 1955, Oak Ridge's energetic and well-connected director, Alvin Weinberg, had begun to talk about diversified projects and sponsors for the projects other than AEC. In 1960, AEC and the congressional Joint Committee on Atomic Energy approved diversification, and Dr. Weinberg instituted seminars with senior members of the lab staff to search out national problems that fit the lab's abilities. The idea was to concentrate on large-scale, long-range problems of broad national interest that had little appeal to profitmaking institutions. Weinberg's vision was to create programs that formed a comprehensive whole, rather than a collection of disparate projects.

Oak Ridge did diversify, but the vision of a comprehensive whole did not materialize. The lab undertook programs successively in desalination of water, civil defense, large-scale biology and, eventually, environmental research. None, however, offered the sustained generous funding of AEC's nuclear energy projects or its hands-off management that left a great deal of discretion to the lab. In 1960, all of Oak Ridge's funding came from the AEC; by 1974, 15 percent came from other government agencies. But all the big initiatives Oak Ridge had launched in a grand plan for diversification eventually devolved to sets of relatively small projects.

Oak Ridge was the earliest but not the only national lab to look for other projects and other sponsors outside AEC.[20] Under the Nixon Administration, beginning in 1969, lab budgets got tighter; as the Vietnam War wound down and the Administration negotiated detente with the Soviet Union, funds for nuclear weapons research and design shrank substantially. For the first time since it was founded, Sandia laid off employees. Other labs looked for nonnuclear work. With a certain amount of prescience (the 'energy crisis' had not yet happened), some researchers at Lawrence Berkeley turned their efforts into renewable energy and energy conservation. Argonne began moving into nonnuclear fossil energy and environmental research.

Like Oak Ridge's much stronger push to diversify, these were lab-initiated efforts. Not until the energy crisis of 1973-74-the embargo by Mideast oil producers that created long lines at gas stations and the huge runup in oil prices resulting from cartel controls over oil production by the Organization of Petroleum Exporting Countries (OPEC)---was there high-level direction to the labs to alter their missions. Project Independence, decreed by President Nixon, was the beginning of a national effort to find ways other than OPEC oil to meet the Nation's energy needs. One result of this new emphasis was the creation of the Energy Research and Development Administration (ERDA) to oversee all the Federal Government's energy research programs. The AEC labs and several nonnuclear energy programs went to ERDA, and AEC's regulatory functions went to the new Nuclear Regulatory Commission.

19 Most of the material on the diversification efforts of Oak Ridge National Laboratory in the 1960s and early 1970s is drawn from Albert H. Teich and W. Henry Lambright, "The Redirection of a Large National Laboratory," *Minerva, vol. xiv, No. 4,* winter 1976-77.

20 Sources for experience of the national labs in the 1970s include Energy Research and Development Administration, *Report of the Field and Laboratory Utilization Study Group* (December 1975); U.S. Department of Energy, *Review of Roles and Functions of the Laboratories and Operations Office*, DESM 79-3 (August 1979); Energy Research Advisory Board to the U.S. Department of Energy, *The Department of Energy Multiprogram Laboratories, DOE/S-0015* (September 1982); U.S. Congress, Office of Technology Assessment, *National Laboratories---oversight and Legislation Issues,* background paper (1980); interviews with present and former lab personnel.

However, only after the Carter Administration took office in 1977 was there a strong sustained drive with the power of the President behind it for alternative energy supply and energy conservation. ERDA became the U.S. Department of Energy. And for the first time, substantial funding for applied energy R&D other than nuclear was open to the labs. Plenty of money was still available for R&D in nuclear power (e.g., for the breeder reactor, other forms of fission energy and, as a long shot, fusion), but new programs in solar energy, conservation, cleaner coal, and synthetic fuels from coal and shale got growing support. These new energy programs accounted for a rising share of the weapons labs' resources in the later 1970s, helped to swell their budgets, and contributed to the shift to a less military character in the weapons labs, especially Los Alamos.

With the military buildup of the 1980s, the weapons labs regained their overwhelmingly defense character and abandoned some of the energy programs they had begun under the Carter Administration. The energy labs too were affected by the powerful emphasis on defense in the Reagan years; Argonne and Oak Ridge both added fairly substantial DoD-funded programs. At the same time-perhaps surprisingly in view of the weight being given to defense-Congress led increasingly active efforts to promote the transfer of commercially promising technologies from the national labs to private industry. Technology transfer is a broad term that covers many kinds of activities, including spin-offs, that is, licensing to existing commercial firms technologies that the labs developed to meet their parent agencies' needs; startups, or helping new firms to license and commercialize lab technologies; letting firms use costly, specialized lab equipment or hire lab researchers as consultants; and-perhaps the most powerful form of technology transfer—collaborative projects in which the lab and a firm or consortium of firms team up to create new technology that meets industry needs.

From 1980 through 1989, Congress passed several major laws[21] that directed Federal agencies and the labs to transfer technologies to State and local governments and the private sector, where appropriate; mandated that every lab set up mechanisms for technology transfer, including creating an Office of Research and Technology Application and joining the Federal Laboratory Consortium for technology transfer; successively broadened the labs' authority to give private companies exclusive rights to technologies developed in the labs (thus encouraging the companies to put their own money into commercializing the technologies); and authorized the labs to sign formal cooperative research and development agreements (CRADAs) with industry. At first (in 1986), only government-operated labs got the CRADA authority; a 1989 law extended it to contractor-operated labs, which include nearly all the DOE labs.

Technology transfer has been an issue for the labs ever since their responsibilities were broadened beyond civilian and military uses of nuclear power. Relations between the AEC labs and the nascent nuclear power industry in the 1950s were necessarily close; the industry could hardly have existed without the labs. But from the time the labs undertook nonnuclear energy activities, they and their parent agency (first ERDA, then DOE) were concerned about getting their R&D results and new technologies out into the commercial energy world.[22]

21 Major laws promoting technology transfer include the Stevenson-Wydler Technology Innovation Act of 1980, the Patent and Trademark Amendments Act of 1980, the Bayh-Dole Patent Amendments of 1984, the Federal Technology Transfer Act of' 1986, the Omnibus Trade and Competitiveness Act of 1988, and the National Competitiveness Technology Transfer Act of 1989.

22 This concern got substantial attention in two reports on DOE labs and field offices in the 1970s: *Report of the Field and Laboratory Utilization Study Group* (December 1975), prepared by an independent study group that included members from universities, nonprofit research groups, and private companies, as well as from ERDA headquarters and the labs; and *DESM 79-3 Review of Roles and Functions of the Laboratories and Field Operations Offices* (August 1979), prepared by DOE and lab personnel.

In the 1980s, expectations about technology transfer took on a new character. Congressional interest in the issue centered increasingly on what lab technologies could do for American industry generally, rather than just feeding into the energy industry. Despite the rising and broadening expectations, however, and despite encouragement from the new laws, an executive order by President Reagan,[23] and congressional hearings, technology transfer from the national labs—indeed from most Federal labs—remained at very modest levels throughout the 1980s. In 1989, all the DOE labs, funded at about $5 billion, had issued 211 patents, concluded 54 license agreements, and received about $900,000 in royalties from outstanding licenses.[24] These measures do not capture all the technology transfer activities that were going on in the 1980s. Argonne and Oak Ridge, the two biggest of DOE's six multiprogram energy labs, both created institutions to help startup firms exploit lab technologies. Oak Ridge's Tennessee Innovation Center, formed in 1985, contributes equity capital to new fins, as well as providing various business services. Argonne's ARCH Development Corp., founded 1986, handles all the patents and licensing of Argonne's inventions, and has a venture capital fund that enables it to start up firms itself, if need be, to commercialize the lab's technologies. Sandia, the most energetic of the weapons labs in technology transfer during the 1980s, considered that its free consultations with 600 industry visitors per month—and even occasional house calls-were its most productive but hardest to measure form of transfer.[25] Nevertheless, on the whole, progress in commercializing the labs technologies was slow.[26]

As we shall see in the discussion below, the picture had changed markedly by 1992. Increasingly, the action in technology transfer was focused on cooperative lab/industry research, in which firms share the costs (often paying more than half) of projects to develop technologies of interest to both parties. Scores of firms responded enthusiastically to a pilot program for cooperative, industry-led projects in high temperature superconductivity, begun in late 1988 at three DOE labs, Argonne, Oak Ridge, and Los Alamos. By 1991-92, literally hundreds of firms were responding to calls for proposals to team up with the labs in collaborative R&D projects funded by DOE's Defense Programs.

Why the change? Several major factors played a part. First, the National Competitiveness Technology Transfer Act (NCTTA) of 1989 allowed the contractor-operated DOE labs, for the frost time, to sign CRADAs with industry. Although it

23 Executive Order 12591, Apr. 10, 1987, established guidelines for the Federal labs on transfer.

24 General Accounting offic, Program Evaluation and Methodology Division, *Diffusing Innovations: Implementing the Technology Transfer Act of 1986 (1991). This* record is sometimes compared with that of the Massachusetts Institute of Technology, which has one of the best-regarded technology licensing programs in the country. MIT (including Lincoln Laboratory, an FFRDC that is managed by MIT and does most of its work for the Air Force) had an annual research budget of about $800 million in the period 1990-92, had over 100 patents issued each of those years, concluded an average of 87 technology licensing agreements per year, and received income from these agreements ranging from $4 to $16 million a year. (Information provided by Christina Jansen, Technology Licensing Office, Massachusetts Institute of Technology, Aug. 27, 1992.) The comparison is not altogether a simple one, however. For example, in MIT's streamlined technology licensing process, firms are usually treated on "first-come, first-served" basis, As a private institution, MIT does not have the same obligation most government agencies undertake to give all potentially interested firms an equal chance at every license (though MIT considers that its system as a whole offers a fair opportunity to all).

25 For more details, see U.S. Congress, Office of Technology Assessment *Making* Things *Manufacturing*, OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, February 1990).

26 Several major reports in the 1980s focused on the performance of the DOE labs and other Federal labs in transferring technology to industry, generally concluding that the labs still had a way to go. In particular, see Energy Research Advisory Board to the U.S. Department of Energy, *Research and Technology Utilization* (Washington, DC: U.S. Department of Energy, August 1988) and U.S. General Accounting Office, *Diffusing Innovations: Implementing the Technology Transfer Act* 1986 (Washington, DC: U.S. General Accounting Office, 1991). The tone of the latter report was guardedly optimistic. It found that the major provisions of the 1986 act had not been fully implemented, but that some departments had made considerable progress, and it was reasonable to expect more progress in the next year or so.

was possible for the labs to undertake cooperative projects before, and some had done so, CRADAs have some significant advantages, including clear-cut legislative authority, the ability to handle patent rights more flexibly, and authority to protect information generated in the projects for as long as 5 years. Cooperative projects with the labs often have a good deal more appeal for industry than simply licensing existing technology, because much of what the labs have to offer is core technologies and capacities that need further development before they begin to be useful to commercial firms.

Second, by 1992, top officials of the Administration as well as Congress were actively pushing technology transfer from Federal R&D programs and labs. The Department of Energy claimed technology transfer as a ''formal, integrated mission' of all its labs, with the primary goal of "assisting U.S. based companies in the global race for competitive technologies. '[27] In February 1992, President George Bush launched a National Technology Initiative, with 15 conferences around the country at which 10 Federal agencies[28] invited industry to make commercial use of government-sponsored research.

Interest on the part of industry has been unprecedented-a third major factor. Partly, no doubt, this was because the power and prestige of the President and his Cabinet officers were now behind the program. It was also because many in U.S. industry had come to recognize that they needed the government as a partner in R&D, especially for high-risk, long-term, expensive projects. R&D spending by private industry, after climbing for many years, leveled off and even declined slightly in real terms after 1989. In the 1980s many firms went into deeper debt than ever before and that, plus a U.S. financial climate that is generally rather unfriendly to long-term investment,[29] made the prospect of sharing R&D risks with government attractive.

Fourth, there is a pot of money for cooperative R&D projects—at least for the DOE weapons labs and for Defense Programs in the energy labs—that was never before available. The NCTTA and subsequent legislation[30] encouraged the labs to devote program funds to cooperative projects with industry, insofar as practicable. But to give the CRADA process a jump start, Congress also dedicated $20 million of Defense programs' R&D funds in FY 1991 to cooperative projects with industry; in 1992 Congress raised the sum to $50 million and to $141 million in 1993. Although there was some dispute between DOE and Congress as to whether funds for technology transfer should be explicitly dedicated in this way, or whether all program funds should be regarded as available for the purpose, the amounts were becoming substantial enough to go at least part way toward meeting the keen new interest from industry.

Finally, the labs themselves now have a powerful motive for making technology transfer a central mission. During the 1980s, while Congress was urging this mission on the labs, it was at the same time providing steep rises in funding for both nuclear and nonnuclear defense

27 U.S. Department of Energy, ''The U.S. Department of Energy and Technology Transfer,' mimeo, n.d.

28 Participating agencies included the Departments of Commerce, Energy, Transportation% Defense, the Interior, Agriculture, and Health and Human Services as well as NASA, the Environmental Protection Agency, and the White House Office of Science and Technology Policy.

29 There is persuasive evidence that capital costs for investments in new equipment and technology (including tax provisions as well as interest rates) were higher in the United States than in Japan and Germany for a decade and a half through the late 1980s. Following actions by the Federal Reserve Bank, U.S. short-term interest rates dropped sharply in the recession and weak recovery of the early 1990s, but long term rates remained higher, and the expectation was that if deep Federal deficits persisted, they would lead to higher rates generally with business recovery. Moreover, the whole financial system in the United States, including the stock market and relations between firms and their banks, emphasizes and rewards high profits in the short run. For discussion, see Office of Technology Assessment *Making Things Better*, op. cit., footnote 26, ch. 3.

30 The Defense Authorization Act for Fiscal Years 1992 and 1993, Sec. xx.

work. Little wonder that the weapons labs, which saw their nuclear weapons and DoD funding swell by nearly 60 percent in the 1980s, should redouble their concentration on their historic defense mission, and that a new mission of working with industry on commercially promising technologies should be relatively neglected. The end of the Cold War and the dissolution of the Soviet Union has upended these priorities. Although old attitudes die hard and some in the labs still believe they will get the biggest part of a shrinking defense pie, the labs' leaders and many researchers are more realistic; they know their defense responsibilities must decline. In the new atmosphere, many in the labs are embracing the role of contributors to the economic security of the United States as well as its military security.

The Future of the Labs

The discussion so far has assumed, implicitly at least, that although the labs may change their emphasis, goals, and size, they will continue to exist in recognizable form. However, many people are asking more fundamental questions about the future of the labs. More than at any time since they were created, issues are coming to the fore as to what real national purposes the labs serve and what size and shape they need to assume to serve those goals effectively. A crucial question is whether they can make a significant contribution to advancing commercial technologies and thus help U.S. industries compete against the best in the world.

Some basic questions about the future of the labs were raised as long ago as 1983. Dr. George Keyworth, then Science Advisor to President Reagan, established a Federal Laboratory Review Panel, chaired by business leader David Packard,[31] to review the Federal laboratories and recommend actions to improve their use and performance. In a report to the White House Science Council,[32] the panel's top priority recommendation was that parent agencies should define clear, specific, and appropriate missions for the labs, and increase or reduce their size-to zero, if necessary-depending on mission requirements. Although the panel did not evaluate in detail the quality of work at the various labs, it criticized the alternative energy research projects at several multiprogram DOE labs as having departed from a clearly defined mission. The mission and quality of work at the weapons labs, on the other hand, were praised. These views were in tune with the times; the Reagan Administration had already sharply reduced the labs' research on alternative energy and was greatly expanding funds for weapons work. However, the panel took the discussion a step further, suggesting that some (unspecified) labs might be downsized or closed. "It would be better to reduce the size of a laboratory to meet the real needs of its legitimate missions than to maintain its size by filling in with unrelated research projects, ' said the panel, adding: "If necessary, a laboratory without a mission should be shut down."[33]

Nothing so drastic occurred. While the weapons labs grew throughout the 1980s, even the multiprogram energy labs more or less held their own (in constant dollar funding), although they did it by tilting to more weapons work. At the same time, another major recommendation of the Packard panel echoed earlier evaluations of the labs, and matched the rising congressional interest in more collaboration between the Federal labs and universities and industry. The panel said:

> [T]his country is increasingly challenged in its military and economic competitiveness. The national interest demands that the Federal laboratories collaborate with universities and industry to

31 Then Chief Executive officer of Hewlett-Packard.

32 *Report of the White House Science Council: Federal Laboratory Panel,* report to the Office Of Science and Technology Policy, Executive Office of the President (Washington, DC: May 1983).

33 Ibid., p. 4.

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ensure continued advances in scientific knowledge and its translation into useful technology.[34]

The end of the Cold War and the dissolution of the Soviet Union brought into sharper focus the question of the future of the DOE labs, especially the three big weapons labs. Three divergent points of view began to emerge. First, maintain and reinforce the labs' traditional focus on. nuclear and energy technologies. Second, give the weapons labs major new civilian missions, including both partnerships with industry and programs directed to public purposes (e.g., environmental protection). Third, drastically contract the whole DOE lab system, perhaps giving the job to a commission like the military base closing commission.

The first approach is essentially cautious and status quo, while the other two envision thoroughgoing changes, but in different directions. The view that the labs' mission should be broadened rests on the conviction that they have special assets to offer, available nowhere else: the ability to do large projects with a long-term payoff, using flexible, multidisciplinary teams that combine scientists and engineers. It also reflects concern over the ebbing of private R&D spending in the United States and hope that lab/industry partnerships can compensate to some degree. The contrary view is that the labs are an extravagance the Nation can ill afford; they can do little of interest to industry that cannot be done as well by universities or companies themselves, and that little costs too much. Some of the skeptics also hold the traditional view that government support for R&D should be limited to defense and basic science and should not extend to technologies with commercial potential. This idea is losing force, however. Support for government/industry cooperation in precommercial R&D has broadened in recent years and by 1992 included many in the Bush Administration as well as in Congress and, most significantly, in industry .35 The more relevant question is whether the labs are the right place, or one of the right places, for government/industry R&D partnerships.

An advisory task force appointed by Secretary of Energy James E. Watkins in November 1990 to consider the future of the DOE labs combined a status quo approach to the labs' missions with more radical suggestions to narrow the weapons labs' focus to nuclear defense only and downsize them accordingly. Watkins's charge to the Secretary of Energy Advisory Board Task Force on the Department of Energy National Laboratories was to define "a strategic vision for the National Laboratories . . . to guide [them] over the next 20 years. ''36 He asked the Task Force to give special emphasis to national defense, economic competitiveness, energy security, scientific and technological education, and environmental protection.

In its report of July 1992, the Task Force laid out a future in which the major missions for the DOE labs would continue to be energy and energy-related science and technology, nuclear science and technology for defense and civilian purposes, and the fundamental science and technology that underlie these. It also emphatically recommended a tight focus on nuclear defense for the three big weapons lab, with whatever reductions and consolidation are necessary in an era of overall reduction of the Nation's defense effort. It emphasized new lab responsibilities for environmental cleanup and waste management, at both the energy and the weapons labs. And it cautiously endorsed more cooperative work by the labs with industry. It suggested that a few flagship

34 Ibid., p. 11.

35 See the discussion of increasing support for government partnerships with industry in developing precompetitive commercial technologies in U.S. Congress, Office of Technology Assessment, *Competing Economies: America, Europe, and the Pacific Rim*, OTA-ITE-498 (Washington, DC: U.S. Government Printing Office, October 1991), pp. 62-63.

36 Secretary of Energy Advisory Board. op. cit., attachment, Memorandum for the Chairman and Executive Director, Secretary of Energy Advisory Board, from the Secretary of Energy, James D. Watkins, Nov. 9, 1990.

labs be designated as centers of excellence for technology partnerships with industry, selecting technologies consistent with their particular missions.

For the weapons labs, the Task Force called on DOE to develop a coherent new defense program, responsive to the changing nature of the nuclear threat and putting more emphasis on nonproliferation, verification, and arms control; restructuring of the weapons production complex; and environmental restoration and waste management. The Task Force underscored its view that the weapons labs must concentrate on nuclear defense and little else, recommending that nonnuclear defense work be limited so the labs would not depend on DoD to maintain their size and work forces. Somewhat contradictory, however, was the suggestion that Sandia—the largest of the weapons labs—be one of the several national labs designated as technology partnership centers of excellence, devoting as much as *20* percent of its R&D budget to cost-shared projects with industry.

For the multiprogram energy labs, the Task Force supported energy science and technology directed toward energy efficiency, assurance of future energy supplies—including renewed attention to civilian nuclear power—and understanding of the environmental effects of energy use. The Task Force further stated that each of the national laboratories must have its own clearly defined, specific missions to support DOE's over-arching missions, and should depart from its core mission only when a rigorous review shows that it is better qualified than other R&D performers to perform the research job at hand.

While supporting lab collaboration with appropriate private sector partners, the Task Force warned against overoptimism and premature expectations. It said the labs should build on their individual expertise and identify the industrial sectors they can work with best, rather than trying to satisfy all customers. For in-depth arrangements with industrial partners, long-term planning will be necessary.

The Chairman of the House Committee on Science, Space, and Technology, Rep. George E. Brown, Jr., of California, proposed a different approach.[37] Noting that the Nation no longer needs and cannot afford three nuclear weapons labs-'' all of which are trying desperately *to* retain as much of their defense activity as possible, while also diversifying feverishly toward civilian missions—Brown suggested making a different use of these labs. He offered a 3- to 5-year plan that would consolidate all nuclear defense and non-proliferation work at Los Alamos and concentrate verification activities at Sandia, while also making it a center of excellence for technology transfer. Lawrence Livermore would become a civilian National Critical Technologies Laboratory, building on the lab's strengths in materials science, computational science, fusion, environmental remediation, and biotechnology .38 Brown proposed a cessation of nuclear tests in 3 years, and a phased 4-year reduction of the nuclear weapons RDT&E budget from nearly $3 billion a year to about half that level. The money

[37] Letter to the Honorable James D. Watkins, Secretary, U.S. Department of Energy, from George E. Brown, Jr., Chairm an, U.S. House of Representatives, Committee on Science, Space, and Technology, Feb. 8, 1992.

[38] This proposal bore some resemblance t. a suggestion in a 1992 report from the National Academy of Sciences that looked at the whole Federal R&D establishment and its role in civilian technology. (Committee On Science, Engineering, and Public Policy, National Academy of Sciences and National Academy of Engineering, *The Government Role in Civilian Technology: Building* a New *Alliance* (Washington, DC: National Academy Press, 1992)). The report is sometimes called the Brown report, after Harold Brown, former U.S. Secretary of Defense, who chaired the Panel on the Government Role in Civilian Technology that prepared the report. The report concluded that only a few laboratories had the potential to contribute much to private sector commercialization, but it did single out the multipurpose DOE labs as having greater potential to transfer commercially relevant technology than others. It suggested that agencies with activities related to commercially relevant R&D should select one laboratory to focus on technology development and transfer.

saved could be directed toward civilian technology programs in the DOE lab system.

A proposal from a quarter that is less sanguine about the labs' ability to contribute to industry, but wants it given a fair chance, came from the private Council on Competitiveness.[39] The Council, made up of chief executives from business, labor, and universities, appointed an advisory committee led by Erich Bloch, former director of the National Science Foundation, to investigate the labs' potential. The Council's report called the labs a "major national resource" that should not be squandered, but warned against "holding up technology transfer from the labs to industry as the answer to our competitiveness problems. " The report confined itself to the prospects for useful partnerships between the labs and industry, and recommended several steps to make technology transfer work. It did not outline a broad future for the labs, but cautioned that industry/lab cooperation is not a justification for maintaining the labs' current staffing levels or programs, or a carte blanche for expansion into new activities, or a way to avoid the need for closing or consolidating some labs.

What the Council found was plenty of valuable basic technology in the labs, but plenty of barriers to its use by industry. "Clearly," said the report, "there is extensive overlap between industry needs and laboratory capabilities. ' But the Council found the pace of technology transfer, from the DOE labs in particular, has been disappointingly slow. Major barriers, it said, are too little funding for technology transfer, not enough attention to the mission of technology transfer in the lab system or rewards for its success, and too much bureaucratic interference from parent agencies (especially DOE) in lab-industry partnerships. Principal recommendations were: 1) authority to handle cooperative projects with industry should rest with the labs themselves-not with Congress, Federal agencies, or intermediaries; and 2) technology transfer does not require new funds but a redirection of existing funds-specifically, 10 percent of the labs' budgets should go to cooperative projects, with the share rising to 20 percent or even higher over the next few years. In addition, the Council recommended that the labs and industry should establish criteria for success now, apply the criteria after 3 to 5 years, and stop the program if it is not working.

The Council's report seems to blend two divergent, but not really contradictory, points of view: first, that the DOE labs do have valuable assets that industry could tap, but second, that they are expensive institutions, and the obstacles to fruitful partnerships are high. The upshot is a pragmatic approach: let the labs prove what they can do, but set a time limit for showing results.

Central to any real redirection of the DOE weapons labs is the issue of what missions they are supposed to carry out. Although the nuclear defense mission that occupied them in the past will not disappear, it will certainly diminish greatly and can no longer be central for all three of the biggest labs in the Federal system. Nor can it continue to be the preeminent source of technical strength in those labs as it has in the past. An informal poll by the Council on Competitiveness showed that industry rated advanced materials and processing, advanced computing, environmental technologies, and manufacturing processes, testing, and equipment as major technical areas in which they need assistance.[40] The labs specified these same areas as ones in which they have unique capabilities that could help

39 Council on Competitiveness, *Industry as a Customer* *Federal* Laboratories (Washington, DC: 1992). The Council confused with two other groups with similar names: the President's Council on Competitiveness, a government interagency committee that was made up of Cabinet members, was chaired by Vice-president Dan Quayle, but was abolished by President Bill Clinton; and the Competitiveness Policy Council, an independent advisory committee created by Congress and composed of Federal and State officials as well as private sector members.

40 Ibid., p. 10.

Box 3-A-Core Competencies of DOE Weapons Laboratories

Lawrence Livermore National Laboratory

Measurements and Diagnostics
- Sensors and detectors
- Data acquisition and analysis
- Imaging and signal processing

Computational Science and Engineering
- Solids, fluids, atomic structure
- Electronics, electromagnetic
- Scientific visualization
- Massively parallel processing

Lasers, Optics, Electro-optics
- High power/high radiance lasers
- High power semiconductor diode laser arrays
- X-ray sources, optics, and materials
- High power optical fiber transport

Manufacturing Engineering
- Precision engineering
- Computer modeling
- Computed tomography

Electronic Systems
- High density packaging
- Pulsed power
- High speed data transmission

Engineered Materials
- Ceramic-metallic composites
- Multi-layers
- Ultralightweight materials

Applied Physics and Chemistry
- Plasma, solid-state and atomic physics
- Chemical kinetics
- Magnetics and superconductivity
- Nuclear chemistry
- Linear accelerators

Atmospheric and Geosciences
- Seismology and imaging
- Geochemistry
- Transport modeling
- Global climate

Defense Sciences
- Nuclear measurements
- X-ray optics and diagnostics
- Energetic materials
- Conventional munitions

Bioscience
- Genomics
- Physical biology
- Analytical cytology

(continued on next page)

industry. Three out of four of these areas have contributed to and been supported by the nuclear weapons program for decades, and the fourth, environmental technologies, is now a prominent part of the program. Box 3-A shows in more detail the labs' own estimation of their core competencies, and possible civilian applications.

If the nuclear weapons program will not be the main source of technology advance in the labs in future years, what will be? Responsibilities for new public missions might be assigned to the labs. "Public missions" are usually defined as goals of national importance that benefit the public at large, but require heavy financial commitments and offer either no payoff or a highly uncertain payoff in the commercial marketplace, so that private industry is unlikely to tackle the goals alone. National defense clearly fits the definition. But Federal R&D has long been extended to other areas as well that lay claim to a public purpose, including agriculture, aeronautics, health, energy, and the exploration of space. Besides benefits to the public, research in most of these areas has contributed to commercial success for U.S. industries.

The list of public missions is expanding. The dawning realization over the last few years that many U.S. industries are in trouble, with foreign competitors passing them by, has raised economic competitiveness to the level of a new

Box 3-A-Continued

Los Alamos National Laboratory

Nuclear Technologies
- Nuclear weapons design
- Reactor design and safety analysis
- Nuclear medicine
- Nuclear measurements

High Performance Computing and Modeling
- Global environment (climate change, etc.)
- Computational test bed for industry
- Massively parallel processing
- High data rate communications
- Traffic modeling
- Visualization

Dynamic Experimentation and Diagnostics
- Arms control/verification/safeguards
- Global environment
- Neutron scattering
- Measurement of explosive phenomena
- Light detection and ranging (LIDAR) for atmospheric measurements

Systems Engineering and Rapid Prototyping
- Transportation systems
- Environmental and energy systems analysis
- Lasers manufacturing
- Accelerator systems

Advanced Materials and Processing
- Plutonium processing
- Manufacturing process analysis
- Materials modeling (materials by design)
- Polymers
- Ceramics
- Metallics
- Composites

Beam Technologies
- Accelerator transmutation of waste laser diagnostics
- Laser diagnostics
- Material characterization
- Photonics
- Photolithography

Theory and Complex Systems
- Human genome
- Traffic simulations
- Neural networks
- Non-linear phenomena

national goal. Many of the new missions now being proposed for the labs reflect a sense of urgency and public responsibility for shoring up technologies important to American industry. For example, the Department of Energy Laboratory Technology Partnership Act of 1992, a bill that passed the Senate in July 1992, directed DOE and the labs to establish partnerships for developing "technologies critical to national security and scientific and technical competitiveness."[41] Some of the areas specified in the bill were high performance computing, including hardware, software, and complex modeling programs; advanced manufacturing, including laser, robotics, microelectronics and optoelectronics technologies; and indeed any generic, precompetitive critical technology listed by the Department of Defense, the Secretary of Energy, or the biennial National Critical Technologies Report. Areas designated in the bill that fit a more traditional definition of public missions included renewed attention to energy conservation and energy supplies, transportation systems that reduce energy use and environmental damage, and, more broadly, health and the environment.

Several issues come up in connection with new missions for the labs. First, a mission broadly defined as "economic competitiveness" may be unworkable. Top officials at the labs fear that such an imprecise definition of their responsibil-

[41] Similar provisions are in S. 473, introduced in the 103d Congress.

Sandia National Laboratory

Engineered Materials and Processes
- Synthesis and processing of metals, ceramics, organics
- Characterization and analytical technique development
- Theory, simulation and modeling of materials and processes
- Melting, casting and joining metal alloys
- Chemical vapor deposition and plasma processing
- Ion beam processing and analysis

Computational Simulations and High Performance Computing
- Massively parallel computation
- High Performance scientific computing
- Quantum chemistry and electronic structure
- Computational hydrodynamics, mechanics, and dynamics
- Digital communications and networking
- Information surety
- Development and application of intelligent machines
- Signal processing

Microelectronics and Photonics
- Microsensors
- Optoelectronics and photonics
- X-ray lithography
- Reliability physics and engineering
- Radiation hardening technologies
- Advanced microelectronics and photonics packaging
- Advanced compound semiconductors

Physical Simulation and Engineering Sciences
- Fluid and thermal sciences
- Combustion science
- Geological sciences
- Experimental mechanics
- Solid and structural mechanics
- Aerodynamics
- Radiation transport and aboveground radiation testing
- Diagnostics and instrumentation development
- Nondestructive evaluation
- Environmental testing and engineering
- Research reactor engineering and experimentation

Pulsed Power
- Intense particle beam physics and technology
- High speed switching
- Intense x-ray physics
- Radiation effects simulation
- Plasma and electromagnetic theory and application

SOURCES: Lawrence Livermore National Laboratory, Livermore, CA; Los Alamos National Laboratory, @Alamos, NM; Sandia National Laboratories, Albuquerque, NM.

ity could lead the labs to scatter their efforts and become nothing but job shops for industry. A particular strength of the billion-dollar weapons labs is their depth and versatility, but even these labs need to focus on a limited number of technologies that fit their core competencies best.

This raises the related question of which labs should do what. The question applies not just to the DOE labs but to the whole diverse Federal laboratory system, in which dozens of labs (at the least) are capable of contributing to technologies with commercial promise. In such a system, some overlap in R&D is inevitable. In fact some overlap is useful, but some could be sheer waste. Certain strengths of the weapons labs are in areas covered by other agencies. For example, Livermore's work on genome sequencing could overlap with or complement the work of NIH. Sandia's work in specialty metals for jet engines might overlap with or complement some of the work of NASA's Lewis or Jet Propulsion Laboratories. The precision engineering developed at Livermore and the Y-12 weapons plant at Oak Ridge might overlap with or complement work at NIST's manufacturing laboratories.

A search for alternate public missions was the path trodden by Oak Ridge National Laboratory in the 1950s and 1960s, when its nuclear mission seemed to be drying up. As Oak Ridge discovered, some of the areas in which it claimed special prowess were already staked out by other agencies' labs. It was mainly for this reason that Oak Ridge's initiatives in large-scale biology eventually dwindled when there was a budget pinch, and returned to NIH. A serious long-term program to assign new public missions to the weapons labs would have to survey the talents, resources, and activities in the whole Federal laboratory system, to see where the missions-or various pieces of them-most properly belong.

Oak Ridge also discovered that it is hard for other public missions to command the same support as national defense. Even in a post-Cold War world, when Americans may be ready as never before to put their energies into nonmilitary national goals, it is possible that no single one, or even a combination of several, will get the level of funding that nuclear weapons received for 50 years. However, to keep the labs in the first rank of R&D institutions, able to draw excellent researchers and do outstanding scientific and technical work, the combination of missions would need to attract funding that is both reasonably generous and reliably sustained.

A different future and new missions for the weapons labs would raise other issues as well—for example, whether it makes sense for the labs to remain in the Department of Energy; still more important, whether there is need for an agency to give strategic direction to U.S. technology policy, of which the role of the labs is only apart. These issues are discussed further in chapter 2 of this report. A critical question is whether the labs, no matter how splendid their human abilities and excellent the technologies they have developed, are really capable of working productively with industry. Is their history and culture as elite military institutions so far from the practical industrial world that they cannot be useful for cooperative work on precompetitive, generic technologies? Is DOE management a crippling bureaucratic handicap? These questions are inescapable but probably cannot be answered without the passage of a few years. Only now, with the definitive end of the Cold War, have the labs become serious about finding work outside defense that is truly important to the Nation. Only now, with the recognition that the world is full of tough competitors, have hard-pressed U.S. companies become serious about finding government partners to share the risk of developing new technologies.