40. In FY92 DARPA's budget of $1,586.3 million comprised: Research, $115.8 million; exploratory development, $744.4 million; advanced technology development, $657.6 million; and management and support, $68.5 million. The FY93 budget adds $473 million for dual-use technology and defense technology conversion to civil economic activity, all under a interagency program called the Technology Reinvestment Initiative.

41. DARPA has been criticized in the past, however, for failure to win adoption of the technologies it promotes into the weapons systems of the military services.

42. FY92 personnel: 142 civilians, 25 military, 16 IPAs, total of 183. But two-thirds of DARPA's expenditures are contracted by service and other agencies for DARPA, which minimizes DARPA's administrative burden.

43. ARPA, *Program Information Package for Defense Technology Conversion, Reinvestment, and Transition Assistance* (Washington, D.C.: Advanced Research Projects Agency, Department of Defense, March 10, 1993), p. 2-1.

44. Harvey Brooks, "University-Industry Cooperation as Industrial Strategy," in S. B. Lundstedt and Thomas H. Moss, eds., *Managing Innovation and Change* (Dordrecht, Netherlands: Kluwer Academic Publishers, 1989), chap. 4, pp. 35–46.

45. Wesley Cohen, Richard Florida, and W. Richard Goe, *University-Industry Research Centers in the United States,* Center for Economic Development, Carnegie Mellon University, A Report to the Ford Foundation, June 1992, to be published in book form in 1993.

46. NSF provides 54.9% of UIRC's aggregate support; Defense, 45.1%; Energy, 33.9%; NASA, 27.3%; and NIH, 26.7%. These percentages add to 187.9%. The centers were asked from what agencies they receive support. The data show that on average each center is supported by at least two agencies. The figures do not suggest that all agencies are investing in centers at comparable levels. NSF, for example, may support more than half of the centers, but with very modest grants.

47. Committee on Science Engineering and Public Policy, *The Government Role in Civilian Technology: Building a New Alliance* (Washington, D.C.: The National Academy Press, April 1992).

48. Dr. Lawrence Kushner, then Deputy Director of the National Bureau of Standards (now NIST), once described the Department of Commerce as the "only department of government with a hostile constituency" (private conversation with Lewis Branscomb, then Director of NBS).

49. See Alic, et al., *Beyond Spinoff,* pp. 400–401.

50. 820, Title III, subtitle D.

51. On September 14, 1992 a workshop on Federal Roles in Commercial Technology at the Kennedy School of Government, Harvard University, explored the subject of federal roles in commercial technology. There was little difference of opinion among the participants on desirable technology policies, but extensive differences over the likelihood of competent and politics-free execution.

4

National Laboratories: The Search for New Missions and New Structures

Lewis M. Branscomb

The end of the Cold War has left the DOE weapons labs scrambling to define new missions for themselves, yet they are all reaching for the same new missions. The Task Force . . . skirts a fundamental question that must be addressed: With the end of the Cold War, do we still need three nuclear weapons labs, each funded at approximately one billion dollars per year and each with employment of about 8,000 people? It seems to me . . . that the . . . answer is "no."

The Hon. George E. Brown, Jr., Letter to Hon. James D. Watkins, February 9, 1992.

The science and technology base of the Laboratories provides what I call the infrastructure for solving large problems of great complexity. It is this infrastructure that I propose to bring to bear on the question of the competitiveness of our industries and businesses. This should be done in partnership with business and universities. . . . Business can provide the market pull on the talents of the Laboratories that will assure their work is relevant.

The Hon. James D. Watkins, Letter to Hon. George E. Brown, Jr., February 18, 1992.

Over the past forty years the United States built a system of government-funded research and engineering laboratories that conducts thirteen percent of the nation's research and development, exceeding the total R&D performed in either Britain or France. With Cold War's end, and the shift of the nation's priorities toward economic competitiveness, many of these 700 laboratories are scrambling for new missions.

These laboratories are very diverse in purpose, institutional structure, and capability. Some, such as the National Institute for Standards and Technology (NIST), were established to help commercial industry and are well suited to expand their traditional roles. Others have demonstrated that collaboration with industry can stimulate economic growth. Fundamental scientific research at the National Institutes of Health (NIH), for example, has stimulated a fast-growing biotechnology industry. Most of the laboratories, however, are dedicated to defense, energy, or space-related federal missions and confront both tight budgets and shifting priorities that raise questions about their future roles.

This chapter deals with the roles these laboratories can play in the nation's new technological priorities. Through a series of statutes passed since the early 1980s, Congress has been encouraging all of the laboratories to transfer their technology to industry, as a means of addressing industry's competitiveness problems. The primary mechanism is the Cooperative Research and Development Agreement (CRADA), authorized by Congress in 1986.[1] This chapter describes the diverse types of government-funded laboratories from the perspective of their usefulness in contributing to the economy. We focus first on the Department of Energy's nuclear weapons laboratories, returning to NIST and NIH at the chapter's end.

We explore a number of questions about the effectiveness of technology transfer efforts from defense and nuclear weapons laboratories, about the appropriateness of using public funds to subsidize activities with commercial firms, and about the structure of the laboratories themselves. The valuable national asset these laboratories represent can be put to very good use if three conditions are met: the laboratories are given more authority for self-management; they focus their activities on a limited number of core areas of technical competence; and they avoid the inappropriate use of public funds. Even then, however, the laboratories could find themselves in difficulty if public expectations for their role in the domestic economy are not realistic.

The three nuclear weapons laboratories of the Department of Energy represent a particularly conspicuous example of the challenge of responding to policy change, both because of their great size and capability, and because of the dramatic reductions in the nuclear weapons work that may be required of them in the future. The nuclear weapons laboratories were structured to pursue government development goals that called for isolation in a secure

environment, rather than accessibility to commercial firms. Thus the federal government finds itself with an increasingly anachronistic national laboratory structure designed for Cold War development, facing a national demand to apply the laboratories to sustaining a highly diverse, market-driven, commercial industry. The laboratories are eager to respond in order to stabilize their futures, but they face a number of handicaps.

The Clinton administration proposes that the Department of Energy accelerate the technology transfer effort of its laboratories by authorizing the laboratories to spend up to ten percent of their appropriated funds on these activities.[2] Bills have been introduced into both the House and Senate to this effect. However, as we argued in Chapter 3, the government is not likely to be the primary source of commercially useful technology. Enhancing the competitiveness of private industry calls for a decentralized strategy that places more initiative in the hands of private industry, and focuses on better utilization of all existing technology, not limited to technologies developed in government-funded laboratories.

Expectations for increased contributions to the economy from government research spinoffs may have served to entrench Cold War institutional arrangements by broadening the constituency of the national laboratories.[3] By accepting the responsibilities inherent in the Federal Technology Transfer Act, the laboratories gave their Congressional delegations more powerful arguments against budget cuts and helped defuse the argument made by universities that they are more effective at technology transfer to industry by virtue of their educational activities.[4]

Thus the defense-related laboratories face, simultaneously, the threat of declining defense budgets and the call to transform their structures and cultures to adapt to new missions in industrial competitiveness, environmental technology, and other areas.

National and Other Federally Supported Laboratories: A Typology

Of FY 1992 federal expenditures of $70.4 billion spent on R&D, some $24,861 billion (over 30 percent of the total) is spent in the laboratories, and in their headquarters administration, which is entirely funded by federal agencies. For budgeting purposes, federally-funded R&D performers are divided into five groups (see Figure 4-1). Intramural laboratories are those owned and operated by government agencies.[5] They are staffed primarily by government employees, usually civil servants. Research contracted to profit-seeking businesses is reported in the table as "industry." The university category includes institutes and centers that are integrated into the life of a single university. Federally funded research and development centers (FFRDCs) are not-for-profit institutions operated for, but not by, government agencies to support the agencies' missions.[6] Contracts to operate FFRDCs may be held by universities, profit-seeking business firms, or not-for-profit corporations. Appendix 4-A shows the resources of FFRDCs by sponsoring agency and by the institutional form of the managing contractor. For example, the Los Alamos National Laboratory in New Mexico is operated for the Departments of Energy and Defense by the University of California; the Jet Propulsion Laboratory is operated for the National Aeronautics and Space Administration (NASA) by the California Institute of Technology.[7] The Oak Ridge National Laboratory is, by contrast, operated by Martin-Marietta Corporation, and the Savannah River Laboratory is operated by EG&G Corporation. Finally, some FFRDCs are contained within free-standing, not-for-profit corporations (such as MITRE Corporation and RAND Corporation). Still others, a number of which provide scientific facilities used by many universities and other laboratories, are operated by consortia of universities established for the purpose. Examples include the Brookhaven National Laboratory, operated for the Department of Energy by Associated Universities, Inc., and the Kitt Peak National Observatory, operated by the Associated Universities for Research in Astronomy.

Some eighteen of the FFRDC laboratories had R&D budgets of over $100 million in FY1990; the number is larger today. (Note that the total budgets of many of the labs, especially the weapons laboratories, are substantially higher because of work other than R&D.) These laboratories are listed in Appendix 4-B.

The Directly Operated Federal Laboratories

The total obligations for the directly operated, or intramural, federal laboratories in 1992 are estimated to be $17.645 billion,

Figure 4-1 Federal Obligations for R&D by performer, FY92 (estimated in $ millions)

Total	Intramural	Industry	Universities	FFRDC	Other
70,427	17,645	31,929	10,475	7,216	3,160

From National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1990, 1991, and 1992,* Volume XL, NSF 92-322 (Washington, D.C.: National Science Foundation, 1992), p. 51.

more than twice the $7.2 billion spent in FFRDCs. This figure includes the headquarters expense directly attributable to managing the laboratories. The federal agencies whose intramural (civil service) laboratories spent more than $100 million in FY 1992 are shown in Appendix 4-C.

Many of these laboratories have come under criticism over the years, because their missions are outdated, their effectiveness is compromised by bureaucratic government constraints, or they have been unable to attract the best scientific talent, most experienced management, or up-to-date equipment. The Department of Defense has embarked on an effort to identify ways of reducing its intramural R&D effort by up to 50 percent.

The first U.S. government laboratory was the U.S. Coast and Geodetic Survey, followed by the Geological Survey and the National Bureau of Standards (now NIST), all before the turn of the century. Other major civil service laboratories include the U.S. Public Health Service Laboratories (now NIH), the Naval Research Laboratory, the Langley, Ames, and Lewis Research Centers of NASA (the loci of much of the nation's aeronautical research work before World War II), and the Agricultural Research Service at Beltsville, Maryland, and elsewhere.

As government employees, researchers in intramural laboratories can perform technical work and make decisions as officers of the government. They can negotiate contracts for technology or equipment, make regulatory rulings, and take other official actions the contract personnel in an FFRDC cannot do. Most civil service scientists, however, only rarely act as agents of the government. They are reluctant to play any kind of regulatory role, preferring to devote themselves to research. Having taken an oath of office, civil servants are accountable to the president, Congress, and the public. Because the head count, mission scope, and funds for expenditure are specified by Congress annually, these institutions are under close political control. Their growth is unlikely to be rapid; their missions are stable to the point of inflexibility; their political freedom to act in their own interest is limited. The conventional wisdom that civil service laboratories are low in competence is an inaccurate generalization, however. Although there are examples enough to justify concern, particularly in the defense sector, government laboratories such as NIH, NIST, the U.S. Geological Survey, the Smithsonian Institution, and the Naval Research Laboratory have sustained world-class reputations for technical excellence and valued performance over many years. Their scientists have gathered Nobel Prizes and many other scientific honors. They pride themselves on their integrity and commitment to the public interest.

The intramural laboratories cannot be expanded rapidly or easily moved to new locations. They are very hard to shut down, since each has its own statutory existence, beholden to the committee of Congress responsible for its enabling statute. The best of these laboratories, such as NIST, NRL, and NIH, depend on decades-long traditions of high-quality work and have earned some special dispensations from government regulations concerning personnel matters. But most of them find it hard to shift the laboratory mission to new goals when the need arises, since their goals are usually defined in statutes. It is also difficult for most of them to compete with the contract laboratories in pay, flexibility of personnel management, capital facilities, and working conditions.

National Laboratories

The largest federally-financed research and development laboratories with the most diversified technical capabilities are called, informally, "national laboratories," although the designation "national laboratory" has no formal status. Most of the Department of Energy's multipurpose laboratories come to mind; a number of them, such as Los Alamos National Laboratory and Oak Ridge National Laboratory are in fact so named.[8] So, too, are some of the government's largest and best known intramural laboratories, such

as the National Institute for Standards and Technology (NIST) and the National Institutes of Health (NIH).

The government-owned, contractor-operated (GOCO) national laboratories (FFRDCs) evolved as a new institutional form during and after World War II. GOCOs were thought to have three advantages over civil service laboratories:

- Contract laboratories escape the strictures of civil-service pay schedules and government administrative regulations, and therefore should be more efficient and effective. This advantage has been realized in enough cases to validate the concept.
- A contract laboratory can be created through administrative action, if provision is made in the sponsoring agency's appropriation; it does not require establishment by statute. For the same reason, it should be easier to alter a laboratory's mission or even to close it down.
- The independence of the contract laboratory can be an advantage to its sponsoring agency, for it removes the performance of technical work one step from the focus of political pressures. Yet such a laboratory can fulfill most of the technical functions of its parent agency. Official decisions are made by the headquarters staff on advice from the contract laboratory.[9]

Throughout the growth of federal R&D activities after World War II, new R&D institutions were almost invariably created outside the civil service.[10] It has not been demonstrated, however, that the national laboratories are any easier to shrink, shut down, or redirect than are civil service laboratories. Vested interests in the laboratories' payroll and in subcontracts to the communities in which they are located are powerful political forces for stability in contract laboratory budgets and missions.

Department of Energy Weapons Laboratories

The Lawrence Livermore Laboratory in California, the Sandia Corporation, and Los Alamos National Laboratory in New Mexico conduct some $3 billion in R&D and related technical activities annually. Their primary mission is the National Defense Program of the Department of Energy: the design, development, and technical support for production, safekeeping, and ultimate destruction of nuclear weapons. Even with dramatic reductions in the U.S. nuclear weapons inventory under START treaties, there is still an important job for these three laboratories. Dismantling weapons, maintaining those that remain, assuring their security, retarding weapons proliferation, and cleaning up environmental problems at U.S. nuclear sites require the best technical effort DOE can muster. It is unclear, however, how much of the laboratories' current capability these tasks will require. Estimates of these defense needs range from one-third to one-half of the current $3 billion annual budget of the three laboratories.[11] A substantial reduction in laboratory budgets could be a serious blow to the communities around Albuquerque, New Mexico. Sandia and Los Alamos National Laboratories and their associated economic activity comprise the single largest source of income in the state. Anticipating a substantial reduction in support for the nuclear weapons development for which the laboratories were created, politicians are asking, "How can the vitality of these laboratories be sustained and their capabilities put to the best use?"

One possible answer lies in searching for large science projects, such as the project to map and sequence the human genome, which was initiated at Los Alamos, the DOE battery project, to be expanded into the Clean Car project, and in other civilian missions such as advanced transportation, for example the magnetically levitated train, or MAGLEV. Another answer lies in the acceleration of cooperative projects with industry to commercialize technologies in which the laboratories have experience, and in some cases patents.[12] In the summer of 1992, the Senate passed the "Department of Energy Laboratory Partnership Act of 1992," which would have authorized the expenditure of appropriated funds for use in technology transfer projects, had the House agreed.[13] The Clinton-Gore technology policy statement proposed that ten to twenty percent of DOE laboratory budgets be devoted to cooperative R&D with commercial firms.[14]

Senator Bennett Johnston, chair of the Committee on Energy and Natural Resources, introduced the "Department of Energy National Competitiveness Technology Partnership Act of 1993" (S. 473) to address this issue. His bill would confirm the ten-percent goal for all of the Energy Department's multi-purpose laboratories,

and would authorize the use of appropriated funds in industrial partnerships. The Senate bill sets out to reduce the time required for negotiating CRADA agreements, and broadens the missions of the laboratories to encompass most of the technical areas in which the laboratories have demonstrated competence. In short, the bill commits the Energy Department, through its laboratories, to a major role in the federal effort to make American industry more internationally competitive. In so doing it may be raising expectations well above what can reasonably be expected from efforts at technology transfer from federal laboratories.

Policy Issues

Authorizing public funding of commercial partnerships with national laboratories in the expectation that this will be effective in supporting competitiveness of American firms raises six questions that are addressed in this chapter:

- The new emphasis on federal support for the technological dimensions of private sector economic performance has resulted in calls for new activities in the area of civilian technology and information infrastructure development, and has cast doubt on the value—or the accessibility to industry—of much of the R&D created by institutions pursuing Cold War missions. How useful are the excess capabilities of national laboratories in support of this new federal role?
- Does the use of public funds in the performance of CRADAs constitute an unwarranted subsidy of selected firms? If so, are there policies that avoid the appearance of market distortion that would still support effective industry partnerships?
- Can the laboratories achieve the goal of having ten percent of their activity in CRADA partnerships without so fragmenting their technical activities that core competencies suffer? If so, does the Clinton-Gore strategy begin the transformation of the Department of Energy into an agency with a very broad technology charter, in effect, a "Department of Science and Technology"? And if not, can the laboratories find a small number of well-defined missions that justify avoiding drastic reductions in staff?

•Can the laboratories manage the new civilian missions well without increased delegation of authority from the agency headquarters? What restructuring of this complex of national laboratories might enhance their effectiveness in the new policy environment?

•Is a system of national laboratories in support of economic progress appropriate? If not, should some of the funds be shifted to universities, or to industry in the form of tax credits for R&D and other indirect incentives?

•What output measures of laboratory success will be used to evaluate their contribution to the economy? If the need is for very diverse research to create useful knowledge, techniques, tools, and standards for use in industry, the utility of this work may be hard to evaluate, especially in the near term. Is the number of CRADA agreements or the amount of counterpart private funds they attract a measure of merit for each of the laboratories?

The Evolution of Technology Transfer Policy

Americans have often criticized the structure of other nations' science and technology enterprises as overly centralized. The French CNRS (National Centers for Scientific Research) and the Australian Commonwealth Scientific Research Organization (CSIRO) are two examples of systems of national laboratories established to support non-military purposes. Both nations have taken major steps in recent years to try to integrate these laboratories more closely into the educational and industrial structure of the country. Americans have traditionally eschewed this pattern for research of economic value, preferring to focus on the universities, which transfer their technical knowledge to industry through training, consulting, and research collaboration. But the U.S. government has embraced the national laboratory system for managing weapons development and acquisition, support for manned space missions, and other federal missions in which the government is the customer for the technology. The national laboratories were primarily meant to support national security and to provide unique, shared facilities for other scientists, most of whom would be in universities.

Spinoff from Government Technology

As discussed in *Beyond Spinoff*, government policy during the Cold War was based on the assumption that spinoff from defense, space, and atomic energy research provided sufficient technological stimulus to keep America's commercial high-tech industry strong. The tacit assumption was that spinoff from work that was justified by federal missions was automatic and cost-free.[15] If so, the economy would benefit from federal expenditures on R&D without the government having to cross the line to industrial policy or find itself "picking winners" from among the available firms to benefit. The government could be blind to the processes through which this government-generated knowledge found its way into the sales catalogs of private firms.

The 1980 Stevenson-Wydler Innovation Act[16] and the federal Technology Transfer Act of 1986, which amended it, recognized implicitly that spinoff is not automatic. Congress charged the agencies to work at technology transfer by forming partnerships with private firms documented by CRADAs. With the Clinton technology policy and with S. 473, the second shoe has dropped; government now realizes that not only is spinoff not automatic, it is not cost-free either. If enacted, S. 473 would authorize the laboratories to spend any or all of their non-defense budgets on R&D to make CRADAs successful.

Obstacles to Effective Technology Transfer in DOE Laboratories

Recent experience has not been encouraging about the likelihood of deriving substantial economic benefits from the transfer of government-owned technologies.[17] Although the National Institutes of Health have moved swiftly to create a substantial number of CRADAs, particularly with rapidly growing, science-based biotechnology firms, the Department of Energy laboratories have faced four major inhibitions:

First, the Technology Transfer Act encouraged CRADAs but assumed that the agency's core mission gives rise to technology useful in meeting both DOE and commercial goals, and that it can be transferred "as is." Second, many firms are highly skeptical that the laboratories possess either the culture (sensitivity to cost and market requirements) or the experience (in process technology, design for manufacturability, and the like) necessary to make a contribution to commercial success. The DOE weapons laboratories grew up in a military arsenal culture, in which the complete life cycle of the products they design and build lies within their own control.

A third obstacle is that laboratory managers are subject to diverse and bureaucratic accountability; their programs are determined by multiple functional offices in DOE headquarters. This makes responsive decentralized decisions (so essential to commercial technology) difficult, and exacerbates the difficulty of negotiating CRADAs in a timely manner. Administrative complexities and reluctance to delegate decision authority to the laboratory management have made CRADA negotiation more tedious and time consuming that most firms will tolerate.

Finally, independent sources such as the White House Science Council have observed that the DOE laboratories are excessively micromanaged from DOE headquarters.[18] Experienced R&D firms identified long-term relationships of mutual trust as an essential element of a successful client-firm relationship. Fear of government inflexibility and intrusion are high among the concerns of firms contemplating CRADA relationships.[19] The effects of Congressional micromanagement are also evident at NIH. The NIH intramural research program (about 20 percent of its $6 billion research budget) is not subject to such severe budget pressure as the defense-related laboratories now anticipate, and collaborations between NIH scientists and bio-tech firms have been quite successful. NIH partnerships serve to support basic science goals by making biological materials available to NIH researchers, and new scientific ideas available to biotechnology firms. The very success of NIH CRADAs has led some members of Congress to urge that NIH use its influence on CRADA partners to persuade them to limit prices charged for drugs developed through partnership with government.[20] While this may be appropriate, the government's attempt to achieve social goals as a *quid pro quo* for CRADAs is almost certain to make them more difficult to negotiate.

When government spinoffs were considered automatic and free, no such demands could be made of firms exploiting government

research, once it was placed in the public domain. Once the government becomes a partner in product development, all manner of demands might be made relating not only to prices, but to other elements of social behavior. While firms remain free to "vote with their feet" by walking away from CRADAs with unreasonable demands in them, there is serious danger that Congress may believe its own rhetoric about the commercial value of government science and unintentionally damage the delicate relationship a laboratory needs to be able to negotiate with its industrial partner.

Senator Pete Domenici, co-sponsor of S. 473 with Senator Johnston, recognized the legitimacy of these concerns: "The Department of Energy Laboratories are a huge treasure and storehouse of knowledge and science. My dream is that they could be one of the lead institutions adding to America's ability to apply technology to the marketplace. But their record of traceable new products spun off is so small that one would almost think they are not charged with doing it."[21]

The difficulty of "spinning off" products from technical activities not undertaken for that purpose should not be surprising. Experienced industrial managers testify to the difficulty and risk of commercializing new scientific ideas from their own central R&D laboratories, when the laboratories are working hard at precisely this objective. Even within a single company, such as IBM or GE, moving new technology from corporate research to any of the firm's product development and production divisions requires carefully arranged incentive structures and the full-time attention of very experienced managers. Even then success is very chancy.

This observation does not imply that the laboratories are not supporting their parent agencies with distinction. Many—perhaps most—of them are engaged in supporting the setting of military requirements, developing new technologies to be procured for government use, and assisting procurement offices by monitoring and evaluating contractors. In the case of the nuclear weapons laboratories, they design, manufacture, install, maintain, and eventually dismantle their own products. There is very little need for the complex of intimate relationships with commercial firms that a mission of stimulating commercial innovation would entail.

The Slippery Slope to Mission Fragmentation

Will the pressure to support CRADA partners result in a fragmentation and dilution of the competencies necessary to support core missions? Dr. Robert M. White, president of the National Academy of Engineering, testifying on Senate bill S. 4, noted with reference to both ARPA and the DOE laboratories, "We seem to be heading in the direction of clouding agency roles rather than clarifying them. I'm not sure this will serve the purposes of coherence."[22]

The extraordinarily complex technical challenges of their weapons work, accompanied by generous budgets, have permitted the laboratories to acquire talent and experience in many important technologies, such as high-performance computing, exotic materials, seismic technology and geophysics, and sophisticated design engineering tools. Their mission in energy-related research has acquainted them with a range of transportation and power technologies. Each of these areas of technology touches on additional areas of industrial activity beyond those that have been a direct focus of federal agency interest. A number of them are also the purview of other departments of the government (for example, the Departments of Transportation, Space, and Interior). If the Congress, through legislation such as S. 473, is seen to press the laboratories to broaden their scope of work continuously, the laboratories may lose the technical focus that made them uniquely valuable in the first place.

The current sea-change in federal policy toward the national laboratories was anticipated ten years ago.[23] But concerns about the future of federally funded R&D laboratories have a substantially longer history. This history goes back at least to the "Bell Report," a study commissioned by President Kennedy and conducted for David Bell, director of the Office of Management and Budget, and aimed at establishing criteria for contracting out government work to national laboratories. The most recent study at the level of the Executive Office of the President was carried out in 1983 by the Federal Laboratory Review Panel, chaired by David Packard, for the White House Science Council.[24] Appendix C of the study lists 39 prior studies. In his transmittal letter to the chairman of the White House Science Council, David Packard summarized the panel's concerns:

The Panel's most important recommendations concern the missions and management of the laboratories. First, the parent agencies of the Federal laboratories must review and redefine the missions of these laboratories. At most multi-program laboratories, the research activities could be reduced in breadth, and reconcentrated on those areas most relevant to the missions and of demonstrated excellence. The size of a laboratory must be determined by its mission requirements and by the quality of the work.

Since this conclusion is shared in many previous studies,[25] one appreciates that the current questions about the changing priorities in the federal R&D agenda are being applied to a set of institutions, of which many have not been well focused on important missions even when priorities were not changing as rapidly as they are now. As Representative George Brown said when introducing the Department of Energy Laboratory Technology Act (DELTA) of 1993 (H.R. 1432) on March 23, 1993, "Technology transfer generally needs to be grounded in a mandated technology development effort aimed at satisfying a public mission." This bill takes a somewhat more cautious and disciplined approach than S. 473.

What Assets of DOE Labs Are Relevant to Economic Needs?

The national laboratories, and the Department of Energy laboratories in particular, possess some very important assets that once dispersed would take many years and billions of dollars to reassemble:

- The laboratories are staffed with smart people, more highly educated on average than those in industry. Laboratories like Sandia have a disproportionate number of doctorate engineers, physicists and chemists. Their government tasks have kept most of them at the "cutting edge" of the technologies they practice (although some of these technologies are rather specific to government missions).
- They work in excellent laboratories, better equipped than universities and most corporations. As noted above, many of these government facilities are shared with industry and academic users.
- These laboratories have developed a technical culture that bridges problem solving, technology development and basic research. Thus they can and do move new science into technology with great

facility. Unlike most universities, their engineers and scientists are accustomed to working together, creating technologies, not just research papers.

- The labs practice "technology fusion," by building new technologies from a variety of disciplines, a function that only the best companies (and few universities) are organized to perform.[26]
- They possess considerable analytical and theoretical capability, and are generally well equipped to engage in computer simulation and modelling.
- They are accustomed to work on long-term goals with higher technical risks than are common in all but very large companies with assured markets (such as the predivestiture AT&T).
- In many cases (especially where the work is not militarily sensitive) the laboratories not only have good links to university science, but provide a critical service to academic science by providing access to their unique instrumentation.
- The laboratories are highly motivated to exploit their "new mission in U.S. economic competitiveness" successfully.[27]

Policy Options for New Missions or Downsizing

Whatever changes Congress makes should be made with great care. Great laboratories are more—much more—than their budgets and buildings. The ability to accomplish great tasks depends on an ephemeral quality that might be called the laboratory's culture, spirit, or soul. In a 1983 Argonne Laboratory address I said:

> Laboratories do have souls that are expressed in their intellectual traditions, their style, their ambiance, their approach to life. I imagine the souls of human beings are intact from some indefinable early moment in life, but they do not become fully expressed until maturity. So it is with laboratories. The soul of a laboratory is a fragile thing. Long after it is withered due to either abuse or neglect, an institution—like the frog legs in the biology laboratory—continues to twitch its customary twitchings. Outsiders often can't tell the difference for a long time, but people in the laboratory can feel it in their bones.[28]

There is little doubt that America's research engine has a lot of horsepower. The problem, in part, is that the wagon of industrial

performance is not well coupled to the public sector part of the research engine; the engine, in turn, is spinning its wheels. How can more than $20 billion in national and federal laboratory R&D and another $20 billion in university R&D be coupled more effectively to the sources of employment and rising quality of life in America?

Given the size of the labs and the scale of their resources, it is very unlikely that any one policy solution to either the search for new missions or preparing for down-sizing will prove adequate or appropriate. Thus the following alternatives are likely to be used in combination.

Continue Current Policies

Make the Stevenson-Wydler approach work in the context of the labs as they are. Continuing on the current path requires no new legislation and leaves lab management free to identify their "dual use" technology and use CRADAs as a mechanism to move technology to private firms.[29] It also imposes no government expectations on the firms looking for cooperation opportunities. This most probable course of action in the near term may, however, also be the least desirable policy. The concept of the CRADA is a sound one if and only if the skills and activities of the national laboratory have a close match to those in the cooperating firms. This seems to be frequently the case in NIH, where the biotechnology industry is still in its science-driven early stage of maturity. How frequently it will be the case in the government's physical science and engineering laboratories is less clear.

Triage

Shrink the labs dramatically and transfer the resources to more effective institutions, using a political mechanism akin to the Defense Department's base closing commission. If one concludes that the public interest would be better served by a shift of resources from national laboratories to universities or to industry (or more likely to some mix of these), the national laboratory budgets are an attractive target. Defense industry executives have been expected to downsize their technical activities; they wonder why the very large national laboratories should be treated differently.

Expand Work Scope

Find new federal missions for the labs within the DOE core mission to nurture new energy technologies and promote more efficient use of energy or find more environmentally benign, energy expending technologies. If Congress interprets the DOE technical mission with sufficient breadth, no new legislation would be needed to authorize the laboratories once again to address such applications. Industrial consortia might be found to locate their joint activities at a national laboratory so that the transfers of technology back to the firms takes place within the staff of each firm. In short, the labs are designed for and experienced at working for a single customer with very deep pockets, a well-defined and stable requirement, and the ability to make all the decisions required to implement the technology developed in the labs. Under the right circumstances this customer could be a consortium of firms, perhaps with other government agencies participating.

Privatize

When the French Thomson company bought RCA, the RCA corporate laboratories were sold to a not-for-profit research organization headquartered in California, SRI International. Thomson then made a contract with SRI to buy back a substantial fraction of the laboratory's effort to support Thomson's development of high-tech television sets for the U.S. market. The rest of the laboratory offers its services for hire on the open market. One could imagine the DOE laboratories receiving authorization to perform "R&D for hire" and thus reducing their dependence on federal support as industry funding rises. Alternatively they could try to sell portions of the labs, with their people and facilities, to industry consortia. The unit costs of work at national laboratories are very high, however, and when added to the transaction costs to firms for buying research from government laboratories the economics of this alternative are unlikely to be attractive.

Reassign Parts of the Laboratories to Other Government Agencies

Parts of national laboratories might be transferred, with budgets intact, to another institutional setting where conditions for effectiveness might be better. One candidate is the Department of Transportation, which has no systems engineering capability on the scale of DOE; another is NIST, which does have a clear mission to address competitiveness issues. This approach would eliminate an intermediate layer of bureaucracy at DOE and would address the problem of a much more rapid buildup of technical resources behind civilian technology programs in Transportation or Commerce than would be possible any other way. The political feasibility of this idea is highly questionable, however, for it requires Congressional committees' willingness to transfer both money and "turf" from one committee to another, which is highly unlikely.

Legislate a New Mission in Support of Industrial Competitiveness

Creation of a new competitiveness mission for the laboratories may be the effect, if not the intent, of S. 473, discussed above. The laboratories would be chartered to respond to industry initiatives and to pursue development of industrially relevant technology, taking advantage of the laboratories' core competencies. This broader mission might look a lot like the broad charter to invest in commercial businesses suggested as the role for the Civilian Technology Corporation proposed by the Research Council's panel chaired by Harold Brown (see Chapter 3).[30]

Effective partnership with industry requires an industry voice in what work is done and how it is carried out. If the projects are developed from the initiatives of consortia of companies (such as the DOE battery project), there may be a useful role for the laboratories and little political objection. If the research is restricted to basic or pre-competitive research, or even to infrastructural or generic research, the benefits will flow indirectly to many users, but the laboratories may have a hard time justifying their huge budgets. If, on the other hand, the labs and their partners select projects with immediate commercial potential, then either competitors may object to what they see as an anti-competitive subsidy and market distortion, or economists and other policy makers may object to replacing the private investments, for which firms should have adequate incentive, with public funds.

Policy Constraints and Mission Opportunities

In government programs such as the Commerce ATP program, the government restricts the use of its funds to public-good technology: in that case defined as pre-competitive, generic technology. If the national laboratories do not have such a constraint, and may use their federal funds to share with partner firms the development of commercial products, the laboratory and its sponsoring agency may find themselves the center of a storm of criticism. This problem can be reduced or eliminated by insisting on full reimbursement through recaptured earnings, by offering the laboratory's R&D "for hire," or, perhaps, by exacting a *quid pro quo* in the form of some public benefit. But for reasons given above none of these alternatives are attractive.

Alternatively, policy guidelines can limit the perception that public funds are simply being diverted for private gain. These guidelines should not only reduce complaints of unfair, government-sponsored competition, but also reduce the level of political "earmarking." If CRADAs fail to produce any big winners, there will be few complaints. But given a few successes, serious political problems may arise when particular companies or individuals have reaped large financial rewards, unless it can be established that large spillover benefits or "positive externalities" have also resulted at the same time.

What policy guidelines could assure an appropriate role for the federally funded R&D? As discussed in Chapter 3, economists recognize that where there are demonstrable market failures it may be appropriate for government to compensate for underinvestment by private firms. A common kind of failure is a lack of appropriability of returns to an investing firm for technology which, when diffused throughout industry, provides social returns substantially in excess

of cost. Examples of those market failure situations are given in detail in Chapter 3. Those most frequently encountered are, in addition to technology for use by federal agencies in fulfillment of their missions (defense, space, public health, etc.):

- Basic research
- Pathbreaking technologies
- Infrastructural technologies
- High barriers to entry
- Strategic technologies
- Technologies for mixed public/private markets.

These options constitute valid missions for federal agencies and offer quite sufficient scope for the national laboratories. The Los Alamos National Laboratory defines the types of partnerships it undertakes in terms of the first three guidelines above.[31] The work of government biomedical scientists on pathbreaking technologies, for example, has created much of the basis for the biology-based new industry. According to a General Accounting Office (GAO) study, almost 95 percent of all royalty income ($33.9 million out of $35.8 million) received by government from the inventions of its scientists "was earned by employee inventions at five agencies - the Agricultural Research Service, the Alcohol, Drug Abuse and Mental Health Administration, the Centers for Disease Control, the Food and Drug Administration, and the NIH."[32]

Inappropriate Measures of Success

There is a serious danger that the ability to count CRADAs, patents, licenses, and other input data that may be interpreted as giving evidence of successful commercialization of laboratory technology. A Georgia Tech survey of 55 research-intensive U.S. companies found that firms value "access to unique technical resources, knowledge and expertise" more than "the immediate prospect of profit."[33] The 62 industrial division directors who had at least "moderate" levels of interaction with the laboratories had entered into 112 formal, collaborative R&D activities with one or more federal laboratories; 35 of these were CRADAs. The firms ranked technology licensing lowest among sources of value from interactions with the labs. Professor Roessner's conclusion: "There is a danger that too much emphasis will be placed on evidence of tangible economic payoffs (CRADAs, licenses) as measures of success, with insufficient recognition of the value to companies of access to state-of-the-art knowledge and equipment."[34]

The Congress and the administration should back off from setting quantitative goals for the number and size of partnerships with commercial firms, such as the ten to twenty percent of laboratory R&D proposed as the goal in the Clinton-Gore technology policy. All of the laboratories have major activities that are inappropriate for financial matching by private firms acting through CRADAs. The government requires that firms participating in CRADAs provide at least equal funding to that committed by the government laboratory. Thus if the weapons laboratories are devoting half of their activities to the National Defense Program and to basic research, the Clinton policy goal of ten to twenty percent devoted to CRADAs means twenty to forty percent of the remaining projects must be matched by industry. With some $6 billion in the budgets of the DOE general purpose laboratories, this could result in a search for $600 million to $1.2 billion of private industrial R&D funds, or about one percent of all private industrial R&D in the U.S. The bureaucratic interpretation of that goal is too likely to lead to measuring laboratory performance by counting CRADAs, to the detriment of the laboratories' coherence and competence and with little return to the economy. Instead a percentage of the budget, perhaps as much as ten percent, should be identified as an allowable expenditure for the laboratory's participation in CRADAs under laboratory director discretion. Preference should be given to CRADAs in which the initiative comes from industry. Experience with "pushing technology" from research laboratories to product development and production units shows how very difficult this is, even when the lab is part of the firm and a single technical executive is in charge of both units. Some very valuable partnerships may be formed when industry initiates the relationship. The laboratory managers must be given greater authority to negotiate CRADAs quickly, with a minimum of bureaucratic red tape and delay. The provisions on liability and intellectual property proposed in S. 473 could be very helpful in this respect. Laboratory directors should

have the authority to approve of CRADAs involving less than half a million of federal funding. The Department should create a "one size fits all" CRADA document, with pre-approved terms and conditions, so that all that is required for a contract is agreement between the parties on the scope of work and the time frame and resources to be committed.

The program as outlined in S 473 may serve to keep the people in the laboratories employed, but, as Congressman Brown notes, it may not be a stable mission, as discussed above. Today the laboratories are operated by contractors, but the contractor does not determine the mission of the laboratory, or control its size and scope of work; this is the responsibility of DOE headquarters staff. A declining level of nuclear weapons R&D, the national budget squeeze, and the difficulty of managing a laboratory struggling to support a wide variety of commercial firms with market interference may all combine to put pressure on the size of the laboratories. They can best adjust to these pressures if the laboratory managements have the authority to restructure the laboratory, diversify its clients, and even privatize or spin off parts of the laboratory to private ownership.

Institutional Innovations

The Congress and the Department should seriously consider incorporating each laboratory as a not-for-profit corporation with its own Board of Trustees, within which is embedded one or more FFRDCs for the DOE's work and that of other federal departments. The physical facilities could be leased to the new corporation for a nominal fee when used for government work; their managements should be allowed to capture and deploy both a management fee and Independent Research and Development (IR&D) and General & Administrative (G&A) funds. This would eliminate an unnecessary level of contract management and collocate responsibility and accountability.

In the longer term, the government will have to think hard about the structure and missions of not only the Department of Energy laboratories, but of NASA as well. Since the energy crisis of the 1970s the Department of Energy has searched for its proper role in its non-defense programs, but its culture bears still the imprint of the Atomic Energy Commission from which it evolved. In the 1970s the new missions in the quest for energy independence taught the Department some hard lessons about how new technologies that depend on commercialization for their value to society should—or should not—be jump-started by government agencies. Solar energy was an example of a path-breaking technology that was pushed into applications long before the technology base made it sufficiently economic. Oil shale development through partnerships showed how vulnerable to shifts in world prices a technology with huge entry costs can be. The Department of Energy must think through the institutional structures and policies through which the mission to make the United States more energy efficient with less environmental burden can be conducted. Ultimately a more decentralized R&D structure than now exhibited in the national laboratories will be needed, one in which industry initiative is given substantially more encouragement. A radical proposal for merging DOE, EPA, NOAA, and the Geological Survey is advanced in Chapter 9.

The National Institutes of Health, in contrast with the DOE weapons laboratories, appear to have been relatively successful with their joint projects with industry, having created 114 CRADAs by 1990, from a start of only ten in 1986. The immaturity of the biotechnology industry, which still draws its sustenance largely from very new science, may be in large measure responsible. A second reason may be that the NIH focus on basic science gave it natural channels for technology diffusion to clinical medicine and applied biology established within the professional research community. The Energy Department laboratories, on the other hand, grew up in a monopsonistic market for its technology: the nuclear weapons and nuclear power programs managed by the federal government itself. Two developments may be emerging that would make the NIH environment look more like the DOE laboratory environment today: the growth of a robust industry dependent on NIH technical support, and new pressures on NIH to take on significant tasks in the national strategy to reduce health care costs.

Similarly, at NIST, where technical interchange with commercial industry has been very close for many decades, the client set is quite diffuse and the channels of information flow are largely created by the professional applied research community: journals, workshop

Figure 4-2 Two Models of National Laboratory Mission and Structure

	Defense, Energy, NASA model	NIH, NIST model
Project structure	Large, interdisciplinary teams	Decentralized, diverse research program
Criteria for federal investment	Government-defined missions: e.g., environment, defense, transportation	Basic, infrastructural pathbreaking science
Mode of industry relationship	Large projects with industrial consortia	Many individual collaborations
Means for technology diffusion and transfer	Uses CRADAs and industrial consortia for technology transfer	Uses professional channels of technology diffusion

conferences, standards organizations, and guest workers from industry at the NIST laboratories. To retain this delicate balance between laboratory research at NIST and outreach to industry, it is important that the NIST laboratory not become administratively subordinate to the new and very rapidly growing new extramural missions given to NIST. ATP contracts with industry, manufacturing technology centers, and industrial extension services with the states should be assigned to a new agency co-located with NIST.

This line of argument suggests two possible models (see Figure 4-2) for a stable relationship between national laboratories and industry (whether in Energy, Commerce, or Health and Human Services): one diverse and decentralized, close to basic science, and using the traditional channels of technical interchange with industry, the other with a few clear, integrated missions conducted in direct collaboration with industrial consortia and justified by unambiguous Congressional mandate to pursue public goals (such as environment, health, safety, or transportation). Either of these models may be stable and effective, but scrambling their attributes could produce political, economic, or technical pathologies. However, common to both models is the necessity of a sufficiently clear and uncontroversial justification for expenditure of federal funds to help private firms make profits, so that the long-term relationships that are essential for CRADA success can be built and left undisturbed by the political turbulence that will always kick up the dust of the industrial policy debate.

Notes

1. The Federal Technology Transfer Act of 1986, Public Law 99-502.

2. William J. Clinton and Albert Gore Jr., *Technology for America's Economic Growth: A New Direction to Build Economic Strength* (Washington, D.C.: The White House, February 22, 1993). See also Clinton-Gore Campaign, *Technology: The Engine of Economic Growth: A National Technology Policy for America* (Little Rock, Arkansas: September 21, 1992).

3. The author is grateful to David Guston for pointing out the significance of these events to both NIH and DOE laboratories; the argument set out here is his.

4. Robert K. Carr, "Doing Technology Transfer in Federal Laboratories," *The Journal of Technology Transfer*, Spring–Summer 1992, pp. 8–28.

5. Government-owned, government-operated laboratories are sometimes known by the acronym GOGO, in contrast with government-owned, contractor-operated (GOCO) laboratories.

6. The definition of an FFRDC given by the NSF in its Science Resources Series is: an R&D performing organization substantially (more than 70 percent) or exclusively financed from federal sources, administered by a university, a private corporation, or a non-profit institution, enjoying a long-term relationship with its sponsoring agency (5 years or more), with its facilities federally owned or funded under federal contract, and its annual budget at least $500,000 per annum. The law governing FFRDCs is Part 35.017, of the Federal Acquisition Regulations, made effective 7 March 1990. Eight federal agencies sponsor 40 FFRDCs of three types: R&D laboratories, study and analysis centers, and systems engineering and integration support. See National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1990, 1991, and 1992.* Volume XL., NSF 92-322 (Washington, D.C.: National Science Foundation) 1992, p. 10.

7. An anomaly in the government's categorization is that the Applied Physics Laboratory, a large applied military research laboratory, is operated by Johns Hopkins University and is considered a part of the university for government accounting purposes.

8. The DOE laboratories are of two types: the weapons laboratories, including Livermore Research Laboratory, Los Alamos National Laboratory, and the Sandia Laboratory, and the multifunctional research laboratories, such as Fermilab, the Berkeley Radiation Lab, Argonne National Laboratory, Brookhaven National Laboratory, and Oak Ridge National Laboratory.

9. *Facing Toward Governments: Nongovernmental Organizations and Scientific and Technical Advice* (New York: Carnegie Commission on Science, Technology and Government, January, 1993).

10. The growth of NIH followed the pattern set by the Public Health Service by the addition of non-uniformed government scientists and physicians. However, eighty percent of NIH research funds are spent outside the huge laboratory complex in Bethesda, Maryland.

11. John Nuckolls, director of Livermore, stated that nuclear weapons research, as a percentage of Livermore Lab R&D, fell from 48% in 1988 to 36% in 1991; *Science*, November 22, 1991. The same article reported that Siegfried Hecker, director of the Los Alamos National Laboratory, said that weapons research employment has dropped by one-third in six years.

12. Incentives were established to encourage the formation of CRADAs in the 1986 Stevenson-Wydler amendments, called the Federal Technology Transfer Act of 1986 (Public Law 99-502).

13. S.B. 2566.

14. Clinton and Gore, *Technology for America's Economic Growth.*

15. John A. Alic, Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston: Harvard Business School Press, 1992), p. 9.

16. Public Law 96-480, October 26, 1980.

17. Alic, et al., *Beyond Spinoff*, chap. 3.

18. David Packard, panel chair, *Report of the White House Science Council: Federal Laboratory Review Panel* (Washington, D.C.: Office of Science and Technology Policy, Executive Office of the President, May 1983), p. 9. George E. Brown, Jr., Chairman of the Science, Space, and Technology Committee of the House of Representatives, noted in September 24, 1992, hearings, that the very diffuseness of mission of the laboratories encourages micromanagement.

19. Roger W. Werne, *U.S. Economic Competitiveness: A New Mission for the DOE Defense Programs' Laboratories*, UCRL-ID-112185 Rev. 1 (Livermore, Calif.: Lawrence Livermore Laboratory, November 1992), quoting Battelle, SRI International, Southwest Research Institute, and others he surveyed.

20. The Congress has applied pressure to the National Cancer Institute to extract commitments from CRADA partners such as Bristol-Myers-Squibb, developer of the anti-cancer drug Taxol, to limit its prices for the drug. The CRADA agreement in this case declares the government's "concern that there be a reasonable relationship between the pricing of Taxol, the public investment in Taxol research and development, and the health and safety needs of the public."

21. *Science*, May 13, 1988, p. 874.

22. Robert M. White, "The Emerging National Technology Strategy," Testimony to the Senate Commerce Committee hearing on S.4, March 25, 1993.

23. "A case can be made that a restructuring of the Federal research and development strategy, and its institutional underpinnings, is overdue. The driving force for this case is that in many people's minds, the major challenge facing American science and technology is economic rather than deriving from narrower Federal government missions such as space, defense, and energy." Lewis M. Branscomb, "National Laboratories in the Nineties," Director's Special Colloquium, October 12, 1983, published as an offprint by Argonne National Laboratories.

24. Packard, *Report of the White House Science Council: Federal Laboratory Review Panel.*

25. In the late 1960s the President's Science Advisory Committee (PSAC) asked Dr. Albert Hill of MIT to lead a panel to study the national laboratories and recommend ways to keep their missions up to date and improve their performance. He came back to the next meeting with a report consisting of a single transparency, on which appeared a matrix displaying a dozen prior studies of national laboratories and corresponding recommendations. The matrix was a forest of "x's," since every study had come to the same set of conclusions. His recommendation was, "Implement the recommendations of any of the prior studies." Most of the Packard report recommendations are repetitions of these earlier analyses.

26. Fumio Kodama, "Technology Fusion and The New R&D," *Harvard Business Review,* July–August 1992, pp. 70–78.

27. Werne, *U.S. Economic Competitiveness.*

28. Lewis M. Branscomb, address at Argonne National Laboratory, 1983, pp. 14–15.

29. Dr. William Happer, Director of the Office of Energy Research and Science Advisor to the Secretary of Energy, notes that in 1992 DOE doubled the number of CRADAs from 83 to over 200, representing $300 million in cooperative R&D, 60 percent of which is paid for by private industry. William Happer, testimony to the Committee on Science, Space and Technology, U.S. House of Representatives, September 24, 1992.

30. This interpretation has been contested by Dr. William Happer, DOE Director of Energy Research in the Bush Administration, both of the sponsoring Senators of S-473, and the directors of DOE laboratories. They note that the laboratories developed technical expertise in areas such as high performance computing, global climate change, nuclear medicine, advanced materials and manufacturing, transportation and space technologies. However, the pursuit of commercialization of any of these technologies in partnership with commercial manufacturers, and the laboratories' pursuits in support of a DOE mission in nuclear weapons development, are two quite different missions. If S. 473 authorizes public investment in any part of the technology required for commercial success, the goals of those projects will necessarily constitute a broadening of the DOE mission. See transcript, March 18, 1993, hearing before the Senate Committee on Energy and Natural Resources.

31. Kay V. Adams, presentation at the Fiftieth Anniversary symposium of the Los Alamos National Laboratory, April 16, 1993.

32. General Accounting Office, *Technology Transfer: Barriers limit royalty sharing's effectiveness* (Washington, D.C.: United States Government Printing Office [U.S. GPO], December 1992), pp. 33–35.

33. David Roessner, "Patterns of Industry Interaction with Federal Laboratories," to be published in *Research-Technology Management* (published by the Industrial Research Institute) and in the *Journal of Technology Transfer* in 1993. The work was carried out in cooperation with the Center for Innovation Management Studies, Lehigh University, the Industrial Research Institute, and the Department of Energy.

34. This conclusion is also confirmed in the survey of University-Industry Research Centers; see Wesley Cohen, Richard Florida, and W. Richard Goe, *University-Industry Research Centers in the United States,* Center for Economic Development, Carnegie-Mellon University, Report to the Ford Foundation, June 1992, to be published in book form in 1993.