CHAPTER 7

Golden Anniversary: 1985–1995

As the golden anniversary of the marriage approached, the compact between the science establishment and the federal government remained intact and as felicitous as long-term compacts between the government and its citizens are likely to be. During those fifty years, the U.S. experience also helped to define science support in industrially developed nations everywhere. The essential feature adopted by the United States and many other nations was support of peer-reviewed proposals for basic research by individual scientists.

By 1995 the U.S. science agencies had matured in their role as intermediaries between the government—the Congress and the president—and scientists. Important similarities and differences in character among the individual agencies showed up more clearly than before. Just as individual men and women age differently, some more fortunate in their lives than others, some welcoming and flourishing under change and some resentful and unaccommodating, so did the individual science agencies. The science function of the DOE was submerged under other tasks, and change was not welcome. In contrast, NASA continued the transition from its manned space flights to a period emphasizing broadly based science and technology.

While continuing to serve as the universally acknowledged Mecca of biomedical research, the NIH was caught up in the general health care dilemma facing the nation. Finally, the NSF, like the NIH, emerged from a period of turmoil in which it successfully refuted accusations of incompetence and favoritism. The NSF consolidated its position as principal supporter of basic science and, without fanfare, extended support to developing areas of new science.

The Department of Energy endured undeserved backlash from Chernobyl, and problems of nuclear waste management and environmental cleanup of its own laboratories exacerbated its woes. Then with physicists' help, it bungled the Superconducting Super Collider (particle accelerator) project.

In October 1997 the DOE celebrated its twentieth birthday. During that twenty-year period, the United States had four presidents and eight secretaries of energy. The problems and events that the DOE faced involved mixtures of complex technical and political issues, some with straightforward solutions, some not.

In 1986 the nuclear power plant at Chernobyl in the Soviet Ukraine overheated and exploded, dispersing large amounts of radioactive material over all of eastern Europe and Scandinavia, and as far west as the nations on the Atlantic coast of Europe. The DOE reacted immediately to the meltdown, which was enormously more serious than the accident at Three Mile Island. It arranged to send reactor specialists from its own laboratories to help with containment of the still smoldering wreck and to safeguard the remaining reactors at the site. And it called on specialists in nuclear medicine to help with the treatment of severely irradiated plant workers and others affected who lived nearby.

The DOE had nothing to do with the miscalculations that produced the disaster at Chernobyl. The reactor was designed differently from U.S. reactors. Its design—including grossly inadequate safety controls and insufficient building containment of radioactive material in the case of a possible reactor accident—would never have left the drawing board in the United States, much less have been built. Furthermore, DOE scientists and engineers had demonstrated well before Chernobyl that nuclear reactor safety could be ensured by proper reactor design. Its Civilian Reactor Research and Development Program worked on the development of passively safe nuclear power plants and demonstrated that certain types of reactors, operating at full capacity, would automatically shut down when all cooling systems ceased to operate. The explanation for this automatic shutdown was that the natural laws of physics, not engineered safety systems, kept reactor core temperatures within safe limits and provided passive, as opposed to active, safety. In the cold war climate of fear of the time, this feature was not widely advertised. Nor were the critical differences between Russian power plants and U.S. power plant reactors made clear to the American public. As a consequence, little credit went to the DOE or to the expertise of its scientists and engineers for the accomplishments of its laboratories in the development of safe nuclear power.

A different aspect of nuclear power that also plagued the DOE was management of high-level nuclear waste from its own and privately owned nuclear reactors. The Nuclear Waste Policy Act of 1982 enjoined the DOE to site, design, construct, and operate the first U.S. geologic repository for permanent disposal of spent fuel and high-level waste from civilian nuclear reactors. Four years later, President Reagan selected three sites, all in western states, for study by the DOE; one of them would be recommended as a permanent site. Congress short-circuited this procedure with the Waste Policy Amendments Act of 1987 that designated the Yucca Mountain site in Nevada as the only candidate site to be considered. The governor of Nevada, Richard Bryan, and Nevadans in general strongly opposed that decision, on the grounds that Nevada had been the site for years of the federal government's underground nuclear weapons test facility and needed no further radioactive waste within its boundaries. Two years later, the next governor of Nevada, Robert Miller, also outraged by the decision to concentrate solely on the Yucca Mountain site, signed into law a bill that made the storage of high-level radioactive waste in Nevada illegal. So began a contest between the DOE and the state of Nevada in 1989, a case that went to the U.S. Supreme Court. The Supreme Court decision, as observed by a spokesman for Richard Bryan (by then a senator from Nevada) was "just one skirmish in what has been and will be a long battle."[1]

Two other waste storage battles occupied the DOE during the same period: the Monitored Retrievable Storage (MRS) site and the Waste Isolation Pilot Plant (WIPP). The MRS was mentioned in the Nuclear Waste Policy Act as an interim storage site in which regular monitoring was possible; when a permanent site became available, the waste material would be moved. The act required identification of a state or Native American tribe amenable to hosting an MRS facility. As of February 1992, the DOE had received seven applications for grants to study the prospects of an MRS location; however, no action of significance followed.

As for the WIPP, the DOE spent an average of $100 million for each of the seven years it took to construct a facility near Carlsbad, New Mexico, the region of the famous Carlsbad Caverns. Again, before radioactive material—mostly, spent fuel cells—could be deposited there, the issue landed in the courts. In this case, however, the DOE prevailed after twenty-five years of intensive on-site studies, protests, and lawsuits. In the spring of 1999, the $2 billion Waste Isolation Pilot Plant began receiving material for storage.

The DOE faced another serious technical problem. It needed to clean up the long-lived radioactive material scattered throughout the laboratories and isotope separation plants that had been the centers of uranium and plutonium production during WWII. During the war the standards for radiation safety were much looser. Once the harmful effects were better understood, radiation exposure limits were made far more stringent. Advances in nuclear medicine and case studies of bomb victims showed how the human body reacted to specific radioactive elements, such as the sensitivity of the thyroid gland to radioactive iodine and of the lungs to radioactive strontium. Those studies also led to stricter standards for external human body exposure to radioactivity. In short, radioactive cleanup was a technical problem that the DOE was nominally well equipped to handle.

In 1985 responsibility for DOE environmental, safety, and health programs was consolidated under a newly created assistant secretary. A year later, a special committee of the National Research Council conducted a survey of technical environmental safety at more than fifty DOE facilities. Among other findings, the committee discovered a surprising situation: the DOE lacked adequate technical understanding and capability to handle the problem. Equally serious was the conclusion that "weaknesses of management had led to a loose-knit system of largely self-regulated contractors."[2] John S. Herrington, secretary of energy under Ronald Reagan, promised action and established an independent oversight panel to propose corrective plans. The panel's study, reported in July 1989, after Herrington had left office, focused on seventeen sites and estimated expected cleanup and environmental compliance costs to be $66 billion through the year 2025; but a high estimate went to $110 billion by 2045. Senator John Glenn, former astronaut and chairman of the Governmental Affairs Committee, characterized the high estimate as likely to be the floor, not the ceiling.

The Bush administration named Admiral James D. Watkins to be secretary of energy in 1989. He left office three years later. He provided a retrospective of his tenure at the DOE, stating that his foremost accomplishment was implementation of "a new management culture that understands the need for compatibility between our defense mission and protection of the environment."[3] According to Watkins, the DOE had given first priority to bringing all facilities into environmental compliance. He admitted that at the end of the cold war in 1990, the DOE was not capable of producing new nuclear weapons. If it had been required to do so, it would have had to ask President Bush to override safety and environmental laws to resume production at facilities that would have been "safe enough, but not at a desirable level."[4]

During the first Clinton administration, the DOE, then under Secretary Hazel O'Leary, was spending $6 billion annually, fully one-third of its budget, on a still coalescing program of facilities cleanup. That program was described by Senator J. Bennett Johnston, chair of the Senate Energy Committee, as a "grand and glorious mess."[5] The new DOE assistant secretary for environmental management, Thomas P. Grumbly, acknowledged the lack of any concrete results. He explained "that everything we do is driven by compliance agreements."[6] These were essentially cleanup blueprints specifying enforceable milestones at each site, but at many sites the problems were "larger, more complex or simply different than we had originally expected."[7]

All this tested the DOE management. The results were mixed. Where nuclear reactor safety was concerned, the AEC and DOE had good records: no government-operated nuclear reactor had been a source of any trouble whatsoever. The many privately operated U.S. power reactors with reactor designs consistent with AEC specifications had good records except for the accident at Three Mile Island, which was caused by human error and, more important, did not result in any physical harm. On the other hand, the DOE record in waste management and environmental cleanup at its own facilities was dreadful.

Yet the solution of radioactive waste management—how and where to store spent fuel rods from the DOE's own and private power reactors—was essentially a technical one, and completely feasible. The DOE soon settled on several methods of packaging the radioactive material, for example, sealing it in thick-walled, initially molten glass cylinders encased in metal containers. The cylinders were subjected to stringent mechanical shock tests and seepage tests that would indicate even very slow oozing of the encased material through the glass and metal. The conclusion was that no measurable amount of radioactive material would leak from the container in less than ten thousand years, probably longer. Assuming that the cylinders would be stored in deep underground sites well engineered and carefully selected for geologic stability and deep water tables, the DOE technical staff believed that it had produced a technical solution for the waste management problem. A facility to test the method was planned under Yucca Mountain in the Nevada Weapons Test Site. The last of the necessary permits to build were obtained in March 1992.

Once again, however, the reaction of Nevadans and citizens of other western states was extremely negative. And the response of Congress to the issue was mixed and weak. The DOE did not exhibit the conviction of purpose or the continuity of leadership necessary to deal effectively with the stalemate. None of the eight secretaries of energy, whose average tenure was less than three years, was able to convince the public and Congress that, whatever the long-term future of nuclear power in the United States, the problem of spent fuel cell storage was serious—many reactors were in operation, and the problem would only become more serious if neglected—and that the DOE had sensible, tested solutions to the waste management problem that needed only to be implemented. Furthermore, most new secretaries tended to denigrate publicly the internal organization and lack of accomplishment of previous secretaries, and this reinforced congressional and public skepticism of any waste management plan offered by the DOE.

The cleanup of DOE facilities did not involve public or congressional approval, apart from its large cost in the department budget. It was strictly a technical problem, but a successful solution was not forthcoming.

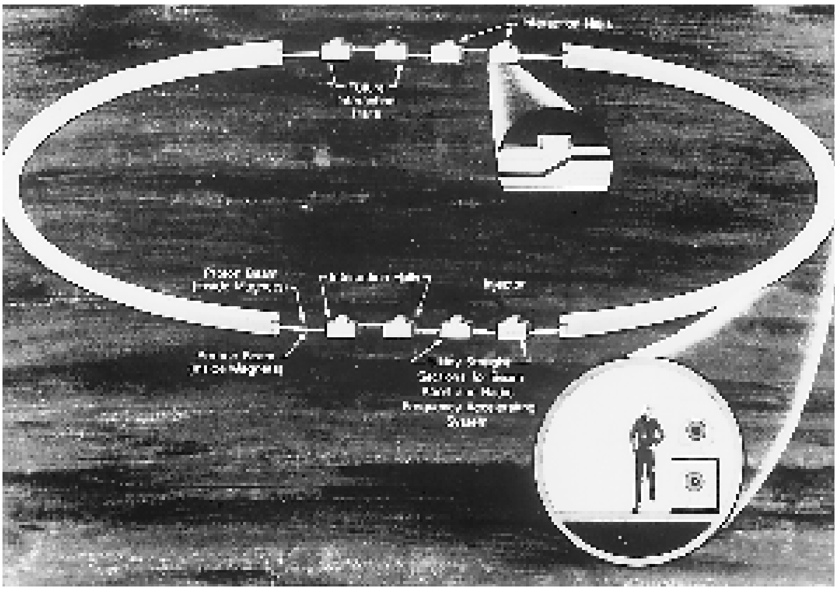
Perhaps the most telling failure of the DOE, however, aided and abetted by university scientists, involved a project to construct by far the largest, most energetic, and most expensive particle accelerator in the history of physics: the modestly named Superconducting Super Collider (SSC), designed to produce accelerated particles, subatomic in size but with energies rivaling any found in the particle spectrum of natural cosmic rays. The highest-energy cosmic rays, composed mostly of protons, are thought to originate in deep space and to be accelerated by the weak magnetic fields in space during the eons of travel time it takes to reach Earth. The SSC was intended to accelerate protons to energies comparable to those in cosmic rays by using a combination of very intense magnetic and electric fields.

The data acquired from experiments at lower-energy accelerators and the theories developed to explain the data strongly suggested that new phenomena would be present at SSC energies. It was claimed that experiments at SSC energies would revolutionize our understanding of the elementary particle world and perhaps also cast light on the origin of the universe.

Physicists had made similar claims ever since they had convinced the AEC—soon after WWII—to fund high energy physics (HEP) and the particle accelerators required for its study. With time, the need for accelerators of higher and higher energy led to the commitment by the AEC and its successors of larger sums for the construction and operation of new accelerator facilities. For example, the AEC paid for the highest-energy particle accelerator in the world and its associated facilities at a cost of $240 million in the early 1970s. That accelerator complex, located outside of Batavia, Illinois, and named Fermilab, was also funded annually by the AEC. It was managed, however, by a consortium of universities with interest in HEP. While Fermilab had a large staff of physicists and engineers, the accelerator was used primarily by university physicists whose proposals for experiments needed favorable peer review before they could be constructed and put in place. In addition, the university physicists' work was funded annually through AEC contracts—specified for HEP research—with their respective universities.

The reasons given to justify the large amount of funding were various. Some in Congress thought that national defense was the primary reason, some that U.S. stature in the international world of science was justification enough, and some that research in this far-out field was an investment in the unknown—recommended by many of the nation's most accomplished scientists—that the United States could ill afford not to make. Scientists in other fields had a variety of opposing opinions concerning the contributions of HEP to the national defense and the quality of American life. But negative views of high energy physics and its cost did not deter the university professors and students who were engaging in research in the subject. They saw themselves as seeking the "substance of substance," the elementary particles of which all matter is made: in a word, probing nature at its most fundamental level.

When the cold war was at its height, a congressional committee asked Robert R. Wilson, a former researcher at Los Alamos in WWII, professor at Cornell University, and director of Fermilab, to explain how high energy physics aided the defense of the United States. He turned the question on its head by responding that the freedom to pursue research in high energy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physics—the freedom to study at the farthest reach of the frontier of science—was one of the many freedoms that made the United States worth defending. It was that sense of mission that motivated high energy physicists and led them to propose the SSC.

The DOE encouraged the high energy physics community. In 1983 the High Energy Physics Advisory Panel (HEPAP) OF THE DOE and the director of the Office of Energy Research, Alvin W. Trivelpiece, recommended that it be assigned the highest priority. The project was expected to strain the federal research budget, but President Reagan's science adviser, George A. Keyworth II, and the secretary of energy, John S. Herrington, subsequently endorsed it. There was no disputing the potential scientific value of the SSC, but serious questions were raised concerning its impact on the funding of other areas of U.S. science. These divided the university science community.

President Reagan approved construction of the SSC in January 1987, when Secretary Herrington observed that it was equivalent "to putting a man on the Moon,"[8] a statement that did not endear the project to many scientists who were more skeptical of its importance. The total project cost was estimated at $4.4 billion over about ten years, based on a design study carried out by a multiuniversity team of accelerator experts in residence for several years at the University of California at Berkeley. The DOE proceeded to develop a site selection procedure, which, for such an expensive federal project, was typically a delicate business, usually making more enemies than friends. The SSC was no different in this respect. When the location choice finally settled on a site in Texas near Dallas, the enthusiasm of a number of political proponents of the project from other states waned. Nevertheless the project marched forward: the Universities Research Association (URA) was selected to manage construction of the accelerator and

FIGURE 7.1. *Opposite page top*: Department of Energy Secretary John S. Herrington (1985–1989) and Texas governor William Clements viewing an artist's conception of the Superconducting Super Collider (SSC) in 1988.

Source: T. R. Fehner and Jack M. Holl, *Department of Energy, 1977–1994: A Summary History* (Oak Ridge, Tenn.: Office of Scientific and Technical Information, 1995), p. 45.

Opposite page bottom: Schematic outline of the SSC showing the fifty-three-mile circumference tunnel and location of the related facilities.

Source: T. R. Fehner and Jack M. Holl, *Department of Energy, 1977–1994: A Summary History* (Oak Ridge, Tenn.: Office of Scientific and Technical Information, 1995), p. 45.

the new laboratory (the URA had successfully managed the construction and operation of a similar but smaller accelerator at Fermilab in Illinois). A project director was chosen, and the original design group was ready to go to work at the Texas site.

Progress on the conventional construction was made in the first few years. Strangely, the original design group was disbanded without explanation. By mid-1987, however, the cost estimate for the SSC had risen to $5.9 billion. Then, in January 1991, the DOE informed Congress that the new cost estimate was $8.25 billion, almost double the amount approved by President Reagan in 1987. Secretary O'Leary pledged in August 1993 that the cost would be held to $8.25 billion plus $2 billion in "stretch-out funding" to account for delays. One month later, the ante had risen to $9.94 billion plus stretch-out costs, according to a seventy-five-member committee headed by the DOE's procurement officer. In October 1993, in a last-minute effort to avert termination of the project by Congress, Secretary O'Leary informed the House that the cost of the project was tentatively estimated at less than $11 billion and would be held to that limit or new options for its fate would be presented by the DOE. Later in the fall of 1993 Congress terminated funding for the SSC project, leaving behind roughly five years of construction—a fifty-two-mile-circumference tunnel, laboratory buildings, and Texan farm and home land that had been bought by the state for the project. The dreams of the world high energy physics community focused on the SSC as the premier scientific instrument of the era were swiftly and thoroughly dashed. On the other hand, there was little mourning among scientists in other fields. They saw this outcome as a fitting response to the prideful attitude of the high energy physicists.

This had never happened during the fifty-year partnership of the physics community with the AEC, ERDA, and the DOE. A much smaller accelerator project had been terminated by the DOE almost two decades earlier, but the reason given for cancellation was inadequate progress on the superconducting magnets needed for the accelerator design. The demise of the highly advertised, high-priced SSC was a much different matter. It reduced the stature of the entire science community and the DOE throughout the government and widened the fissure between scientists and the DOE. An adequate account of the SSC has not yet been written, but it is sure to be a story full of ambition, intrigue, and human flaws.

A cursory explanation assigns culpability more or less equally to the high energy physicists involved and the DOE. Internal dissension among the physicists led to the dispersal of the original design group, an early sign of personality clashes and disputes at the director's level. Congress had been assured that 20 percent of the initial cost of the SSC would be contributed by foreign governments, but the necessary diplomatic and negotiating skills to acquire those funds were lacking, and the ever-increasing cost led to diminished enthusiasm abroad for the SSC. In the end, less than 3 percent of the original cost came from abroad.

As the estimated cost grew out of hand, both the physicists and the DOE exhibited rigidity in their behavior that was ill suited to a project of the magnitude of the SSC. The physicists did not propose feasible modifications of the original scope of the project, modifications that would still have yielded a valuable scientific instrument but at a much lower cost. They stubbornly insisted on all—no matter what the cost—or nothing. The DOE attempted to remedy the situation by taking control of the SSC project from the physicists and the URA management in all respects but name. A DOE contingent of several hundred people from its Washington headquarters was relocated at the SSC site to monitor commitments, expenditures, and construction progress. Soon, the DOE and the scientists grew contentious. Termination was inevitable.

On a completely different note, however, the DOE played an important, successful part in the origin of federal support for the human genome project. The DOE had for many years sponsored research in several of the laboratories it funded on the biological effects of radiation, especially genetic mutations. In 1983 the Life Sciences Division at the Los Alamos National Laboratory established a major data storage facility for genetic information. Known as Genbank, the facility obtained and stored DNA sequence data.

The director of the DOE Office of Health and Environment in Germantown, Maryland, was Charles DeLisi, formerly chief of mathematical biology at the NIH. Interested in how the data in Genbank might be used to study the genetic bases of human diseases, DeLisi speculated on the feasibility of acquiring a data bank containing the base-pair sequences of an entire human genome. At about that time, Robert Sinsheimer, a distinguished molecular biologist and chancellor of the Santa Cruz campus of the University of California, had the same idea. Independently, they organized workshops in Santa Cruz, in 1985, and Santa Fe, New Mexico, in 1986. Most of the participants were leaders in developing the methods and studies required to carry out the huge task presented by the human genome; in their view, the technical capability to do so was available.

Soon thereafter, enthusiasm for the human genome project and federal support of it began to mount, despite its size—enormous for biology—and cost—large for any scientific discipline. Charles DeLisi was in the forefront of the enthusiasts. Moreover, he spoke for the DOE and the $4.5 million allocated for the project in the DOE's fiscal 1987 appropriation. He advanced a plan for a five-year DOE program that made use of the technical strengths of the DOE laboratories. Toward the end of 1987 the secretary of energy ordered the establishment of human genome research centers at three of the DOE national laboratories: Los Alamos, Lawrence Livermore, and Lawrence Berkeley.

A number of biological and medical scientists questioned the fitness of the DOE—traditionally dominated by physical scientists—as the control center of the project. They were also distressed by the absence in the plan of the NIH, the principal federal agency concerned with the life sciences. These and other considerations brought about the support of James Wyngaarden, the director of the NIH, for a substantial NIH role in the human genome project. In December 1987 Congress appropriated approximately $17 million to the NIH and about $11 million to the DOE for human genome research in fiscal 1988.

So began the U.S. federally supported human genome project, appropriately shared between the two federal agencies with interests and talents vital to its success. The part played by the DOE, through DeLisi, in advancing the project in its early stage was salutary, forward-looking, and responsive to the needs of both the DOE and the science.

Nevertheless, the DOE as a whole has not been a successful agency. No secretary of energy has been able to organize it, to provide internal stability or solutions to the problems it has faced. Between 1977 and 1995 it sustained five major internal reorganizations at the hands of new secretaries of energy, each shifting or reversing the effect of an earlier reorganization. The DOE management of radioactive waste disposal and cleanup of its facilities has been at best inadequate. And DOE mismanagement of the ambitious scientific SSC project marked a low point in the history of the science establishment.

Although the magnitude of the research funds for which it is responsible is large—almost three times larger than the NSF—the Office of Energy Research of the DOE does not have the intellectual standing within the scientific community that the NSF has or, for that matter, that NASA has acquired in recent years. The DOE has been a study in inconsistency on the part of one administration after another, one Congress after another, and one energy secretary after another. All have contributed to making the DOE a catchall of energy issues and problems in technology without any ready solutions. Of the four major, civilian federal science agencies, the DOE has become the one most in need of substantial repair.

NASA recovered from the Challenger *disaster and concentrated on deploying many Earth-orbiting satellites.*

It took three years after the 1986 *Challenger* disaster before NASA and the space shuttle program recovered. That period of introspection and self-criticism affected all subsequent launches and space flights and brought about redesign of many shuttle components. In the interim, a number of unmanned space flights propelled by other launch vehicles were attempted. But several of these failed and added to NASA's sense of discouragement. In May 1986 a Delta rocket carrying a weather satellite was destroyed in flight after a steering failure. A year later, an Atlas-Centaur rocket for the navy's launch of a fleet satellite communications spacecraft was struck by lightning and broke up less than a minute after liftoff. A few months later, three rockets at the Wallops Island facility were ready when the launch pad was struck by lightning and all three shot off and crashed into the sea. And one month after that, yet another Atlas-Centaur rocket was destroyed by an industrial accident on its Cape Canaveral launch pad.

The space administration badly needed a centerpiece program for its own and public morale. In September 1988 the first post-*Challenger* shuttle flight took place successfully, and the shuttle program resumed without incident. In the seven years following, NASA placed forty-four satellites for industrial communications, thirteen weather observation satellites, and twenty-seven satellites devoted to the global positioning system (GPS) into Earth orbits. The communication satellites were an integral part of the revolution in information transferal that took place in the early 1990s, making the World Wide Web possible. The weather satellites extended and refined the weather database and its predictive precision, and the GPS satellites provided the coordinates of a point anywhere on Earth.

Another twenty-seven satellites were devoted exclusively to advanced scientific enquiry, of which eleven required the large cargo bay capacity of the space shuttle. That excursion into basic studies in astronomy, astrophysics, and cosmology brought NASA into far deeper and more extensive collaborations with university scientists than before. At the same time, the

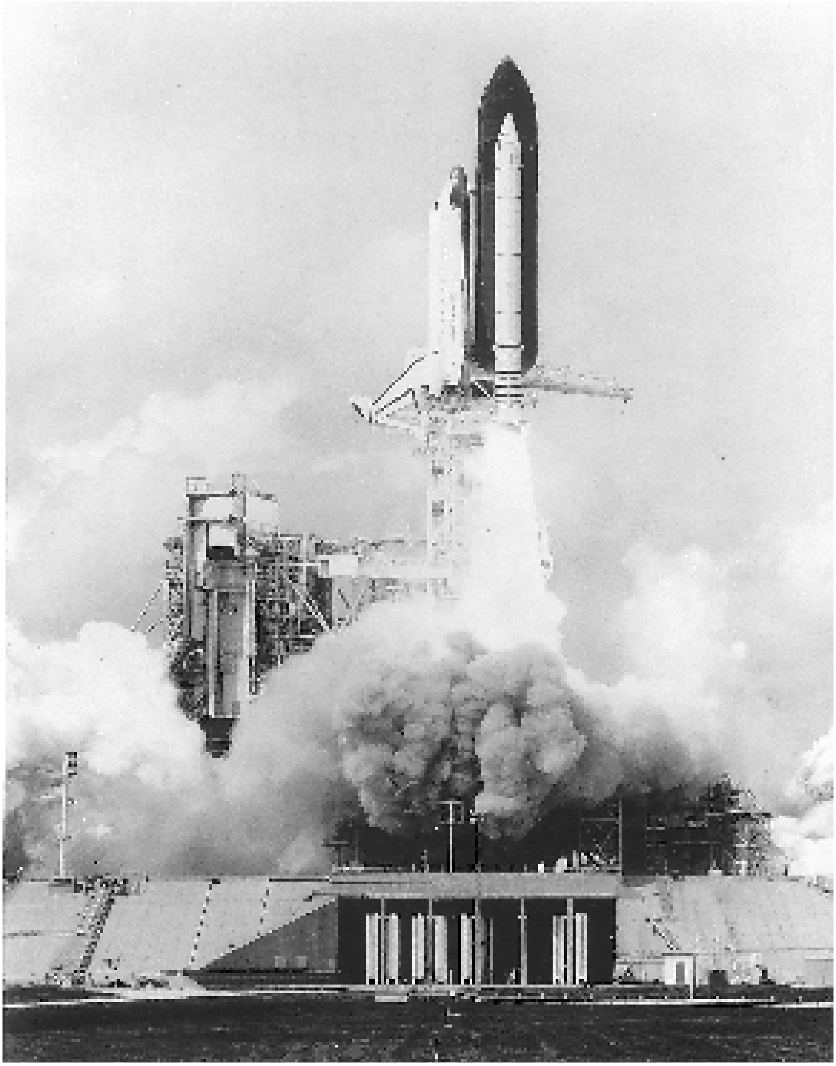


FIGURE 7.2. Launch of the space shuttle *Discovery* and its five-man crew on a four-day mission to deploy the Tracking and Data Relay Satellite. Crew members were Commander Rick Hauck, Pilot Richard Covey, and mission specialists Dave Hilmers, Mike Lounge, and George (Pinky) Nelson.

Source: Richard Mandel, *A Half Century of Peer Review (1946–1996)* (Alexandria, Va.: Division of Research Grants, National Institutes of Health, Logistic Applications, 1996), p. 146.

sophisticated science satellites launched by the shuttle opened new windows to the universe through which university scientists had never looked.

The most widely known of the science satellites is the Hubble space telescope (HST), launched in April 1990 and named for the astronomer Edwin Hubble, who first suggested in 1928 that the universe is expanding. The HST is best known for two reasons: the breathtakingly beautiful high-resolution color pictures of stellar bodies that it routinely obtains and sends back to Earth for display on the Web and the mistake in the initial preparation of the ninety-four-and-a-half-inch-diameter mirror, the heart of its optical system. Critics complained about the expensive mistake, but the public loved the drama of the 1993 shuttle flight repair job. The blurred images recorded before the mirror aberration was fixed helped to suggest a corrective procedure and to indicate the replacement components. The shuttle *Endeavour* delivered the components to the orbiting HST, and two *Endeavour* astronauts who had practiced on a model back on Earth refitted the mirror with almost no trouble. The success of the repair was quickly verified when scientists looked at a few images sent back to Earth before *Endeavour* returned home. This experience and others in which satellites, such as the Russian space station *Mir*, were repaired while in orbit foretold one aspect of NASA's future: a space station furnished by means of shuttle payloads. Ultimately, the space station would be the transfer point for establishment of a human colony for scientific and technological studies on the Moon.

The advantage of the HST over ground-based optical telescopes is that its spatial resolution is not limited by the Earth's thick, constantly changing atmosphere. Astronomers have dreamed of this since the beginning of modern astronomy. The HST sees objects seven times further away and more clearly than any Earth-bound optical telescope. It's so-called deep field survey has allowed astronomers to study the structure of galaxies that are closer to the edge of the visible universe, and in doing so the HST has filled fundamental gaps in our knowledge and corrected long-held errors. For example, the age of the universe has been revised downward in part because of HST observations and now seems to be little more than twice or at most three times the 4.6 billion year age of our solar system. This has profound implications for cosmology, the study of the origin of the universe.

Five years after the HST was placed in orbit, more than 60 percent of all U.S. astronomers and astrophysicists were using HST data in their research, data made available through the Space Telescope Science Institute (STSI)

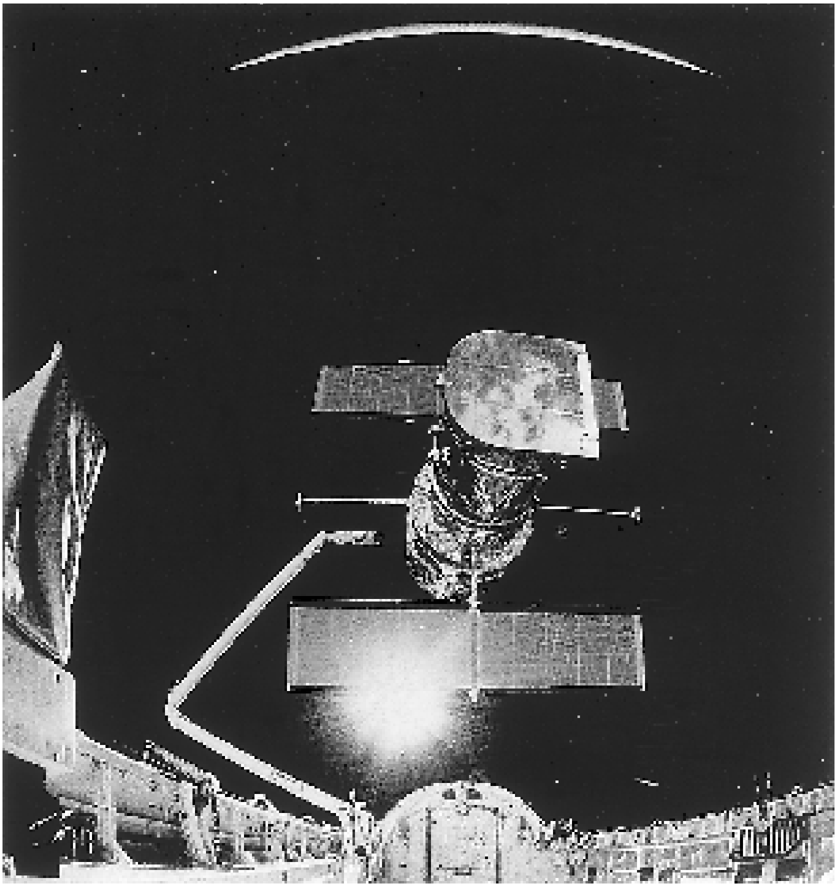


FIGURE 7.3. Photograph of the Hubble space telescope in orbit, just after being released from the space shuttle.

Source: Courtesy NASA.

located on the campus of the Johns Hopkins University, in Baltimore, Maryland. The space administration had put out a request to universities and national laboratories in the early 1980s for proposals to develop a ground-based institute to serve as headquarters for the analysis and dissemination of the data from the HST. Located near NASA's Goddard Space Flight Center, Johns Hopkins outbid the competition of other multimillion dollar proposals and won the opportunity to create the STSI.

Another satellite equipped for scientific observations was the Compton

Gamma-Ray Observatory (CGRO), launched on space shuttle *Atlantis* in April 1991 and named for Arthur H. Compton, a Nobel laureate for his pioneering X-ray studies. The CGRO carries (it is still in orbit) four scientific instruments that study the highest energy electromagnetic radiations observed in space: X-rays and gamma rays. Like the HST, the CGRO is an Earth satellite and has a planned mission duration of five to ten years. It can be reprogrammed from Earth to focus on selected stellar objects. At the end of 1995 the CGRO had observed more than fourteen hundred intense, short-lived gamma-ray bursts distributed over the entire sky. These bursts still have no completely adequate explanation and are consequently much studied. Of similar interest to astronomers and astrophysicists are the CGRO observations of especially powerful galaxies at the visible limit of the satellites. Many of these galaxies and clusters of galaxies have active nuclei—very intense emitting hot spots—at their centers. The active galactic nuclei (AGN), as they are called, are thought by most astronomers to be powered by extremely massive black holes at their cores. These attract mass from outside the black hole radii, converting the potential energy of the falling mass to kinetic energy that supplies the power of these most luminous of all known stellar bodies.

A third NASA science satellite, the cosmic background explorer (COBE), was launched earlier than the HST and CGRO, in November 1989, only a year after shuttle flights were resumed. According to the current theory of the origin of the universe, there occurred an explosion of extraordinary energy (the big bang, so-called) from which emerged the elementary particles that are the constituents of all matter and energy everywhere. Among the particles rushing away from the explosion—which account for the concept of the expanding universe—were particles of light (now called photons) that soon thereafter ceased to interact with other matter and energy as the distance separating them grew. In accord with relativity theory, the energy of the photons decreased as the universe expanded during the next ten to fifteen billion years. By now this sea of photons, which fills all space and is known as the cosmic background radiation (CBR), is radiation of very low energy or, equivalently, very low temperature. Initial observations of CBR in 1965 won a Nobel Prize for its discoverers. Early measurements by the COBE verified the existence of the CBR and further demonstrated that the temperature of the photon sea is consistent with the big bang theory.

The presence or absence of variations in the CBR temperature from point to point in space might reveal additional features of the big bang and the period immediately ensuing. These variations were what the COBE set out to measure; its success in doing so has given rise to a multitude of ground-based and balloon-flight experiments, as well as plans for a second, more sophisticated COBE satellite. The COBE data are a milestone in the development of a theory of the universe.

The HST, CGRO, and COBE science satellites have revolutionized the study of astronomy, astrophysics, and cosmology in universities throughout the world. They marked a change of emphasis within NASA from the manned-flight space agency of the 1960s and 1970s to the science and technology agency of the 1990s, a remarkable transition for any institution to make, much less a government agency. Today, NASA appears to have a bright future, both for the agency itself and for the university scientists whose research is intimately bound up with it.

Caught up in the national health care dilemma, the NIH fell further behind in funding approved proposals.

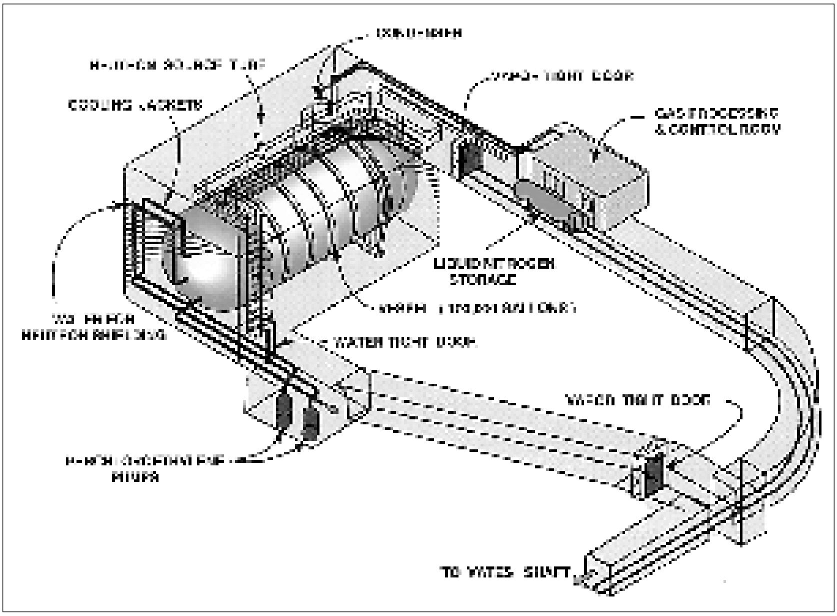
The NIH continued to struggle with its own success in the era of biomedical advances in molecular biology and gene splicing. The growth of funding in the 1980s did in fact help to sustain the promised annual rate of more than five thousand new and renewed investigator-initiated projects and ten

FIGURE 7.4. *Opposite page top*: Schematic outline of the radiochemical solar neutrino telescope, one mile (1600 meters) underground in the Homestake Gold Mine in Lead, South Dakota. The tank holds one hundred thousand gallons of perchlorethylene (a dry-cleaning fluid), which is both the target and the detector of the solar neutrinos. The auxiliary equipment is for flushing helium gas through the perchlorethylene to remove the radioactive argon atoms produced by the solar neutrinos interacting with it and for counting the individual argon atoms. This equipment began collecting data in 1967 and continues to do so today.

Source: Diagram courtesy of Raymond Davis Jr.

Opposite page bottom: Photograph of the very large array (VLA) of radio telescopes at the National Radio Astronomy Observatory in Socorro, New Mexico. The array contains twenty-seven telescopes, each twenty-five meters in diameter, located along the three legs of a Y, all of which can be pointed in the same direction. Only nine of the telescopes can be clearly seen here.

Source: Photograph courtesy of Douglas Johnson, 1981.



COOLING JACKETS
GAS PROCESSING
& CONTROL ROOM
LIQUID NITROGEN
STORAGE
WATER TIGHT DOOR
VAPOR TIGHT DOOR
TO WATER SHAFT

thousand trainees. During that period, the portion of the NIH budget devoted to basic research increased from 52 to 63 percent.

But the number of applications, the mass of paperwork, the number of peer review study sections, the growing demands of tutorials and amended applications, and, finally, the monitoring of project progress, imposed more of an administrative burden than the NIH could manage. Tutorials and amended applications had been established to help unsuccessful applicants, particularly those unfamiliar with the research application procedure. By 1990 only 22 percent of approved investigator-initiated projects could be funded, and the backlog of approved but unfunded applications rose to more than eleven thousand. As a consequence, the number of amended applications and reapplications proliferated and tended to crowd out new ones. Even for the best young investigators, the situation was forbidding. It was no wonder that the NIH award system in general and peer review in particular were again the subjects of serious reevaluation during the decade 1985–1995.

The NIH had grown in 1995 to seven institutes concerned with almost all of medical science: heart, lung, and blood; arthritis and metabolic diseases; mental health; general medical science; neurological diseases and blindness; cancer; and allergy and infectious diseases. Neither this growth nor the progress of medical practice and biomedical research could have been foreseen in the early days when the medical community was determined to keep the NIH separate from the other federal research agencies and the government itself. The virtually independent NIH prospered through successive administrations, however, and this situation prevailed throughout the first decades of the NIH. But as the cost to the government of medical care and the NIH began rising more and more rapidly, presidents from Nixon to Clinton looked for ways to bring health care and the NIH under better financial control. Counter to this, the success of biomedical research, largely sponsored by the NIH, demanded that funding for cutting-edge research be increased. The stalemate in health care legislation that subsequently developed is more familiar than the stalemate in attempts to solve the fiscal problem of the NIH. Both situations are similar, however, in that one administration after another has been convinced that future resources will not allow the cost of either medical practice or medical research to grow at their previous rates. The general problem was illustrated in miniature in the NIH as the rising number of applications for funding and their increased complexity and cost taxed the NIH to the limit of its capability.

Streamlining the application and award procedures, or modest increases of staff, or even modest funding increases were likely to be temporary stopgap measures in the face of the urgent demands of biomedical research. The fundamental problem before the NIH—generated by its remarkable success—would need to be addressed more generally to find a solution that could sustain reasonable, steady growth and stability.

The crisis of the award system within the NIH is especially relevant to the evolution of the science establishment. The difficulties encountered by the NIH award system are important in the continuing relationship of science and government because they raise a key question for both: at what level of funding does government say "enough" to a successful science agency that has provided the scientific basis for superior benefits to its citizens? The ongoing national debate on the general subject of health care has indicated that the question is only one aspect of government support of health care, from research laboratory to doctor's waiting room. In time, the question of "enough" will be asked of all federal science funding agencies as science expands and the allure of science continues to beckon many of the brightest and most dedicated in each new generation. For obvious reasons, the issue facing the NIH is simply the first to force the question.

The National Science Foundation remained constant to its primary function of funding basic science in diverse areas.

The NSF flirted once more with "the applied" and "the relevant" during the period from 1984 to 1990, when its director was the first to come from industry and the first to serve a full six-year term since 1969. Even so, the agency maintained its original emphasis on mathematics, science, and technology, areas that had always been the source of its strength. As a result, the NSF marched more or less sedately through the decade 1985–1995, expanding its core interests and branching carefully into new areas.

The NSF took over the funding of ground-based astronomy and low-temperature physics. It supported engineering and materials research in universities. It developed an extensive fleet of research vessels for oceanographic studies. It maintained the Antarctic research station and became a mainstay of atmospheric sciences research.

On average, about 11 percent of the roughly 135,000 science and engineering faculty in the United States applied to the NSF each year. In the ban-

Table 7.1 Science Advisers to the Presidents of the United States

ADVISER	PRESIDENT	DATES
Vannevar Bush	Roosevelt	1939–1951
Oliver Buckley	Truman	1951–1953
Lee A. Dubridge	Truman	1953–1955
Isadore I. Rabi	Truman	1955–1957
James R. Killian	Eisenhower	1957–1959
George B. Kistiakowsky	Eisenhower	1959–1961
Jerome Wiesner	Kennedy	1961–1963
Donald Hornig	Johnson	1964–1969
Lee A. Dubridge	Nixon	1969–1970
Edward E. David	Nixon	1971–1973
Guyford Stever	Nixon	1973–1974
Guyford Stever	Ford	1974–1977
Frank Press	Carter	1977–1981
George Keyworth	Reagan	1982–1987
William Graham	Reagan	1987–1989
D. Allan Bromley	Bush	1989–1993
John H. Gibbons	Clinton	1993–1999
Neal Lane	Clinton	1999–

ner fiscal year 1988, the NSF received over twenty-four thousand proposals of all kinds, which were evaluated by fifty-six thousand reviewers. The magnitude of the paperwork was enormous, well over two million pages in that year, but the NSF maintained its high efficiency by using such a large number of reviewers. The burden carried by an NSF reviewer was small compared with that carried by an NIH reviewer (the NIH's Division of Research Grants had roughly twenty-five hundred reviewers available at any time in 1987), which may have accounted for the ease with which the NSF was able to solicit reviews.

The NSF distributed annually close to $2 billion in support of basic science and technology. Nevertheless, the problem of making ends meet, of unwittingly promising more than it can deliver, is faced today by the NSF, just as it is by the NIH. The root cause is very much the same in both agencies: the demand for funds exceeds the supply by an amount that cannot be reduced by means that treat only the symptoms of the problem. The recurrent question before the government is deceptively simple: how much support is enough? Unfortunately, the answer is not nearly so simple; indeed, there are many questions to be considered before the question of "enough"

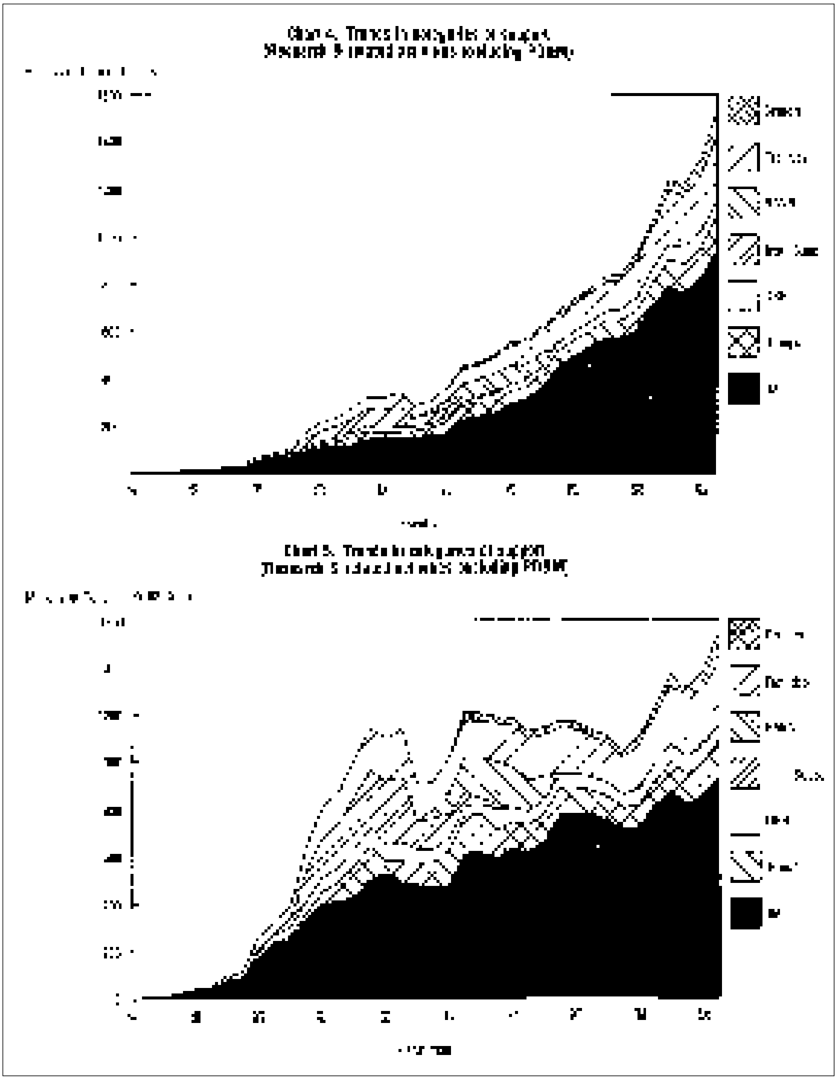


FIGURE 7.5. The NSF budget showing categories of support in research and related activities 1951–1987: RANN, research applied to national needs; Inst. Supp., institutional support; ORR, other research resources; Groups, group research; IIA, individual investigator awards; PD&M, program development and management. *Top*: current dollars; *bottom*; FY 1988 dollars.

Source: T. N. Cooley and Deh-I Hsiung, *Funding Trends and Balance of Activities: National Science Foundation, 1951–1988*, NSF 88-3 (Washington, D.C.: National Science Foundation, 1988), p. 7.

can even be addressed. For instance, considering the investments of time, energy, and taxpayer money that go into the education and training of a scientist, is it efficient to fund the research of only about 20 percent of them? Does that funding level indicate that there are too many scientists? Is it wise to send a message that discourages young people from acquiring an advanced university degree in science? And, if so, how should that be done? Finally, how large should the yearly investment in the science establishment be, relative to other government commitments and expenditures?

Even in the case of the NIH, where the research is without doubt directed toward national needs, the answers to those questions do not come easily. For the NSF, which is more diverse and less applied in much of the science it funds, the answers are harder to determine. Nevertheless, fifty years after the marriage of science and government, it is time to make a thoughtful effort to find better answers to those questions and to prepare the science establishment for the next half century.