CHAPTER 5
NUCLEAR ENERGY: FISSION AND FUSION

Many of the technologies that will help us to meet the new air quality standards in America can also help to address climate change.

President Bill Clinton[1]

Two distinct processes involving the nuclei of atoms can be harnessed, in principle, for energy production: fission—the splitting of a nucleus—and fusion—the joining together of two nuclei. For any given mass or volume of fuel, nuclear processes generate more energy than can be produced through any other fuel-based approach. Another attractive feature of these energy-producing reactions is that they do not produce greenhouse gases (GHG) or other forms of air pollution directly. In the case of nuclear fission—a mature though controversial energy technology—electricity is generated from the energy released when heavy nuclei break apart. In the case of nuclear fusion, much work remains in the quest to sustain the fusion reactions and then to design and build practical fusion power plants. Fusion's fuel is abundant, namely, light atoms such as the isotopes of hydrogen, and essentially limitless. The most optimistic timetable for fusion development is half a century, because of the extraordinary scientific and engineering challenges involved, but fusion's benefits are so globally attractive that fusion R&D is an important component of today's energy R&D portfolio internationally.

Fission power currently provides about 17 percent of the world's electric power. As of December 1996, 442 nuclear power reactors were operating in 30 countries, and 36 more plants were under construction. If fossil plants were used to produce the amount of electricity generated by these nuclear plants, more than an additional 300 million metric tons of carbon would be emitted each year.

Worldwide, 15 countries obtain at least 30 percent of their electricity from nuclear fission power. In 1996, among countries of the Organization for Economic Cooperation and Development (OECD), nuclear power[2] provided 77 percent of the electricity in France, 33 percent in Japan, 26 percent in the United Kingdom, and 20 percent in the United States. The United States has the largest number of operating nuclear reactors (109) and the largest nuclear capacity (about 100,000 MW) of any nation. Nuclear fission power is a widely used technology with the potential for further growth, particularly in Asia.

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[1] President Bill Clinton, Address to the United Nations Environmental Conference, 26 June 1997.

[2] Fission energy has a vocabulary that is well established in both technical and popular communication: It has adopted "nuclear" as its own. In this report, "nuclear power," "nuclear plants," and other uses of the word "nuclear," when applied to existing energy generation capability, refer to nuclear fission only. As nuclear fusion has not achieved that state of development, there should be no confusion.

However, several problems cloud fission's potential as an acceptable power source today and into the future: disposal of radioactive waste; concern about nuclear weapons proliferation; concern about safe operation of plants; and noncompetitive economics. Nuclear waste remains radioactive and hazardous for many centuries, and no nation has developed a satisfactory long-term solution for disposal. There are concerns that nuclear power could provide terrorists and rogue nations with technical expertise and a source of materials to make a bomb. Accidents at nuclear plants have the potential to unleash vast amounts of radiation, such as occurred at Chernobyl in 1986. In the coming era of a fully deregulated electric power industry, decisions on whether to build or continue to operate plants will be driven by economics.

Given the projected growth in global energy demand as developing nations industrialize, and the need to stabilize and then reduce GHG emissions, it is important to establish fission energy as an acceptable and viable option, if at all possible, and to develop the capability to harness fusion. Therefore, R&D is needed to solve the problems associated with nuclear-waste storage and disposal, proliferation, operational safety, and plant economics, as well as to gain the scientific and engineering knowledge needed to harness fusion. It may not be necessary to reduce the cost to the current level for natural gas-fired combined-cycle generation, because concerns about GHG emissions may lead to actions that raise the cost of electricity generated from fossil fuels.

This chapter of the report discusses the context, R&D portfolio, and policy issues associated with both fission and fusion energy, and it makes recommendations regarding R&D priorities for these technologies. Appendix E provides additional information about the R&D portfolio and issues, the international situation in nuclear energy, and the views of critics. Because fission and fusion are at very different points in development and involve different types of R&D and policy issues, the discussions are separated rather than integrated. Moreover, the U.S. fusion energy research program has received three major reviews since 1990, the most comprehensive being the 1995 study by the Panel on the U.S. Program of Fusion Energy Research and Development (PCAST-95).[3] The current Panel used this previous PCAST study as a baseline. The Panel focused on understanding changes that have occurred since the 1995 review and on determining whether the organizing principles recommended by PCAST-95 remain appropriate. Thus, the coverage of fusion is considerably briefer than that of fission.

CONTEXT

The contexts for fission and fusion energy and related R&D are examined separately below.

Context for Fission Energy and Related R&D

Since World War II, the United States has been the international leader in all nuclear energy matters. U.S. engineering programs have trained many of the people now in key positions in foreign nuclear programs, U.S. Nuclear Regulatory Commission (USNRC) regulations have provided the foundation for regulatory regimes in other nations, and American industry's reactor designs have served as the basis for the large fission power programs in France and Japan—the countries usually described as most "nuclear friendly." U.S. technology continues to be used in overseas applications in cooperative design and development efforts with the countries involved: The newest reactors in Japan are advanced boiling-water reactors (ABWRs) designed by General Electric (GE); Combustion Engineering has sold its

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[3] PCAST (1995).

System 80+ design to South Korea; and Westinghouse is working with a Japanese utility on an advanced pressurized-water reactor (APWR).

World leadership in nuclear technologies and the underlying science is vital to the United States from the perspectives of national security, international influence, and global stability. However, U.S. leadership is eroding for several reasons. No new fission power plant has been ordered in the United States since 1978. Utilities have shut down operating plants before the end of their licenses, and more plants are likely to be closed as the electric utility system becomes deregulated. The outlook is that no new nuclear plant will be built in the United States in the next 10—or perhaps even 20—years. This situation depresses R&D investments, slows progress and innovation, and affects the career choices of bright young people, who choose other specialties, thereby impoverishing U.S. human resources in nuclear fields.

Even as nuclear power diminishes in importance in the United States, other nations are building nuclear power capability. Therefore, the near- to mid-term outlook for fission energy is brighter globally than it is in the United States. Nations with rapidly increasing electricity demand are attracted by the independence from oil imports for electricity generation, the lack of emissions of GHGs and other atmospheric pollution, and the capability to provide reliable base-load power. Moreover, in many other countries, fossil fuel costs are substantially higher than they are in the United States.

Nuclear power programs remain strong in France and Japan and are growing in other parts of Asia. Figure 5.1 shows the growth in nuclear power generation in selected countries since 1973.[4] France is still building nuclear plants, and Japan has an annual Federal budget for nuclear energy of about $5 billion dollars, of which about $3.1 billion was for R&D in 1995.[5] This large expenditure reflects the strong nuclear program in Japan: As of June 1997, Japan had 60 boiling-water-reactor (BWR) and pressurized-water-reactor (PWR) power plants operating, with 1 PWR and 1 BWR under construction. Four more BWRs are planned to be in operation by 2005. Japan also has an enrichment plant and a reprocessing facility, with a larger reprocessing facility under construction.

Despite its apparent success in many countries, nuclear power is not supported uniformly by any means. In Canada, Ontario Hydro recently shut down half of its reactors after an external review harshly criticized the poor operational practices and maintenance of the utility. When, if ever, these reactors will be restarted is uncertain at this time. In Japan, a series of spills and other accidents at nuclear plants and a storage facility have increased public opposition to nuclear power, especially since utility officials were slow to inform local officials and the government of the problems. In France, although public opposition was muted in the 1980s, it resurfaced during the Chernobyl accident and when the French government attempted to examine sites for a permanent high-level waste repository. Finally, in Germany, state governments have opposed operation of some nuclear plants, and tens of thousands of protesters attempted to block the transport of high-level waste to a storage facility at Gorleben.

The current market for new nuclear reactors is primarily in Asia, where developing economies are buying and installing diversified electric generation capacity. Foreign manufacturers are competing for and winning many of these sales: Atomic Energy of Canada Limited, marketing the heavy-water-moderated, natural-uranium-fueled CANDU reactor; Framatome selling the improved French PWR; and Russia, marketing the VVER 1000, a large PWR with a western-style containment. These vendors are likely to be joined soon by Japanese and possibly South Korean manufacturers.

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4 Bodansky (1996)
5 IEA (1997).

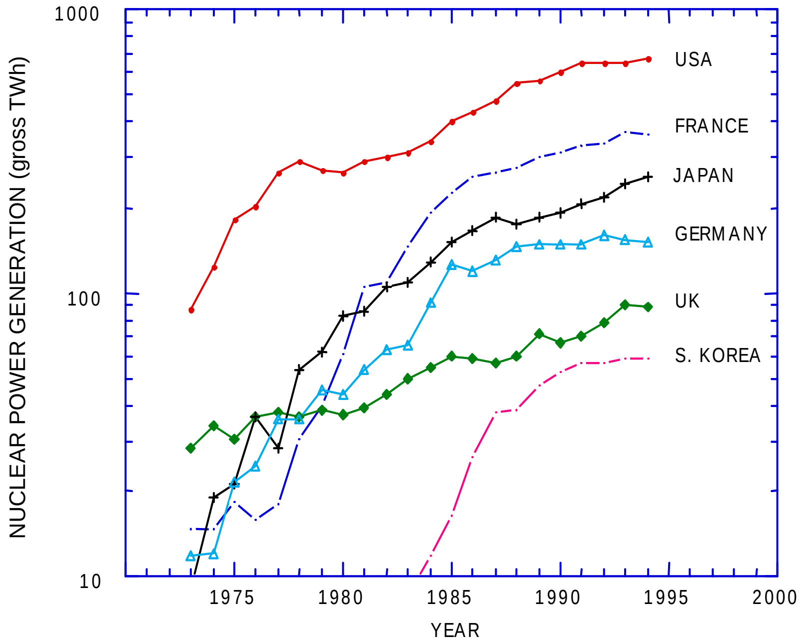

Figure 5.1: Growth of annual nuclear power generation in selected countries, 1973-1994.
Source: Bodansky (1996). Reprinted by permission of Springer-Verlag, New York.

To reduce GHG emissions and ensure that the United States has the capacity to achieve internationally agreed-to targets, it is important to pursue R&D that will help determine whether nuclear fission can become a stabilized and later an expanding contributor to this goal. As background, the Panel sought to understand the reasons why nuclear energy declined in the United States and to identify any obstacles amenable to R&D that are preventing nuclear energy from becoming a genuinely attractive and publicly acceptable source of electricity.

The decline of nuclear power in the United States resulted from many factors:

- Electricity consumption in the United States declined from an annual growth rate of 7+ percent in the 1950s and 1960s to an average annual growth rate of 1.5 to 2 percent in the last 20 years. Fewer power plants of any kind were needed.

- Natural gas supplies have proven to be much larger than was earlier believed, resulting in high production and highly competitive prices. For the past decade, competitive prices and the steady improvement in power plant efficiency of gas-fired combined-cycle plants have made gas the lowest cost and most rapidlyimplementable electricity generation option.

- The cost of nuclear plant construction in the United States escalated at a rate higher than the rate of inflation. Some cost increases can be attributed to weak management within the nuclear industry and others to regulatory and permitting delays.

- Nuclear waste disposition, which many claim is not a technical problem, nonetheless continues to be unresolved, with a schedule that is receding into the future.

- Public opposition to nuclear power—including concerns about proliferation, reactor safety, and radiation—has grown and outstripped generally ineffective efforts to address public concerns.

These factors, in combination with the upcoming deregulation of electric utilities, may lead to premature shutdown of operating nuclear plants in the United States. Forward-looking R&D can and should address many of these issues, specifically nuclear waste, cost, reactor safety, proliferation, and operating reactors. If successful, this R&D would help make fission power an acceptable option for providing electricity in the coming century. The Federal government's role is to ensure that long-term problems with nuclear power are addressed so that nuclear can become, if possible, a realistic and acceptable energy option, as well as a hedge in case renewables and efficiency cannot reach the performance levels and market share necessary to meet emission reduction targets.

Context for Fusion Energy and Related R&D

Fusion energy R&D started in the United States, Great Britain, and the Soviet Union in 1951 as a spin-off of work on the hydrogen bomb. These efforts, overwhelmingly sponsored by governments because of the very long time horizon needed to achieve practical application, gave birth to a new and important scientific field—plasma physics. In DOE, the program in fusion energy sciences is managed by the Office of Energy Research (ER), which is the department's basic research organization. The fusion program is strongly centered in basic research and makes a valuable national contribution by supporting plasma science in addition to fusion's future energy applications.

During the energy crisis of the 1970s to mid-1980s, U.S. investments in fusion R&D peaked at a buying power above $700 million per year (1997 dollars), and the program pursued the advertised goal of making fusion energy practical by the turn of the century. However, the funding declined by 50 percent over several years, leveling in 1990. In FY 1996, recognizing that Federal spending needed to be reduced, Congress cut the fusion R&D budget by an additional one-third and directed DOE to restructure its program. Because fusion is a global energy solution, much of the R&D effort is internationalized. Currently, U.S. investments in fusion R&D are about 15 percent of the world total, with both the European Union and Japan mounting substantially larger programs. Today, the objective of the U.S. fusion program is to help develop the scientific and technological basis for fusion as a long-term energy option for the United States and the world.

EVALUATION OF THE R&D PORTFOLIO

This section summarizes the current R&D portfolio and the Panel's findings and recommendations for nuclear fission and fusion R&D.

Fission R&D Portfolio

Historically, the development of fission power and other peaceful uses of the atom complemented the nuclear weapons mission as a primary effort of DOE and its predecessor agencies. Funding for nuclear energy led Federal energy R&D for most years in the 1970s and 1980s. Included in the amounts was funding for such non-reactor topics as radioisotope thermoelectric generators for spacecraft, production of radioisotopes, and nuclear-waste efforts prior to DOE's establishing the Office of Civilian Radioactive Waste Management (RW). The reactor-related funding totaled $11.3 billion (in constant 1997 dollars) from 1979 to 1997, of which $7.1 billion was for the controversial and now terminated breeder reactor R&D program, which included the demonstration project at Clinch River. In the same period, $640 million was spent for R&D on the high-temperature gas reactor (HTGR). The total funding for light-water reactor (LWR) development during these years was $770 million. Figure 5.2 shows the funding history since 1979 of nuclear energy—both fission and fusion—in constant 1997 dollars.[6]

Significant amounts of fission energy R&D are performed or sponsored by DOE, the USNRC, and industry. DOE has had a very broad R&D charter in this area, whereas the USNRC focuses on confirmatory and anticipatory research directly applicable to its regulations or its oversight of licensees. The USNRC issued about $56 million in R&D contracts in FY 1997 and plans for about $50 million in FY 1998. In addition, the Arms Control and Disarmament Agency is involved in nuclear nonproliferation activities, not studied by the Panel. Much of industry's R&D on nuclear power is sponsored through the Electric Power Research Institute (EPRI), the research arm of the utility industry, which has since its founding in 1973 invested $2.4 billion (constant 1997 dollars; $1.7 billion in as-spent dollars), primarily on near-term issues to improve plant safety, reduce operating costs, and increase plant reliability. During 1997, EPRI funded about $90 million in nuclear energy R&D. However, industry funding for nuclear energy R&D was disproportionately less than it spent on other fuels in the period from 1985 to 1994,[7] even when compared with its share of the electricity supply. In addition, nuclear suppliers and manufacturers invested in R&D related to the products and services they offer, but it was not possible for the Panel to determine the total amount.

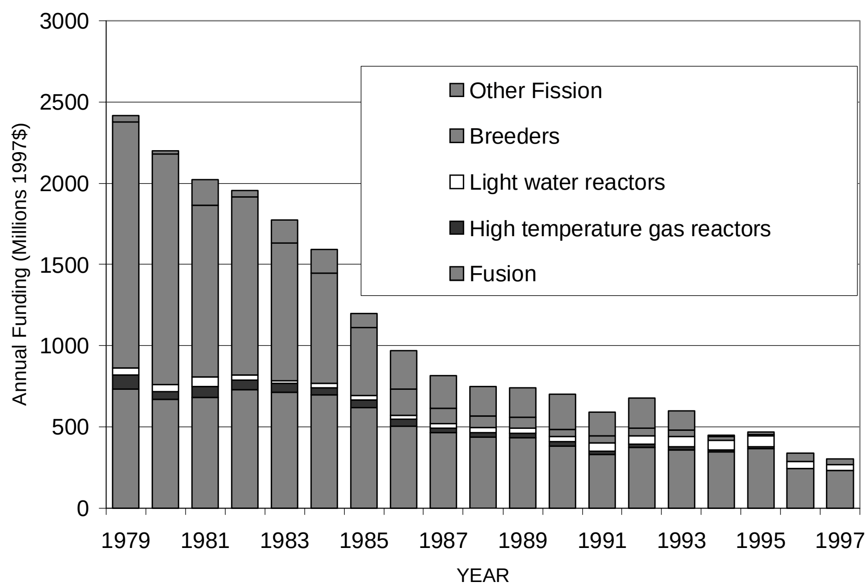

Figure 5.2: Funding history for fission power R&D and fusion energy. Source: DOE Energy Resources Board and Office of Nuclear Engineering, Science and Technology.

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[6] DOE-NE informed the Panel that prior to FY 1979, it spent a total of about $4 billion on breeder R&D, $1.4 billion on LWR R&D, and $300 million on HTGR R&D. These figures are in as-spent dollars and would increase significantly if converted to constant 1997 dollars, since the multiplier for 1978 is 2.2, and for 1948 it is 6.5.

[7] Dooley (1996).

At least eight DOE program offices support R&D applicable or related to nuclear energy: the Office of Nuclear Energy, Science and Technology (NE), Defense Programs (DP), the Office of Nonproliferation and National Security (NN), RW, the Office of Naval Reactors (NR), the Office of Fissile Materials Disposition (MD), and Environmental Management (EM). Some basic research on materials and chemistry sponsored by ER is also applicable to nuclear power issues. Taken together, efforts funded by these DOE programs contribute to the knowledge and technology base underlying fission energy, as well as to their primary mission areas. However, it is very hard to identify—other than for NE, NR, and RW—the specific levels of investment that are relevant to nuclear power. Thus, the Panel limits its budget summary to these three programs, and its portfolio analysis to NE, which funds all the R&D addressing improvements in nuclear-energy technology.

DOE's summary of its FY 1998 energy resources budget request showed nuclear energy R&D as 3.3 percent ($46 million) of the total energy R&D investment portfolio. This amount includes a $6 million university support program (including fuel for university research reactors) and a new $40 million initiative, called Nuclear Energy Security (NES). Congress has provided no funding for NES, which would have sponsored R&D to support relicensing the existing nuclear plants, to minimize spent nuclear fuel, and to address other issues. Previously, NE's focus in nuclear energy R&D has been on a joint program with industry on design certification of advanced light-water reactors (ALWRs), supported by DOE at a level of $34 million in FY 1997, the terminal year of the program.

DOE's FY 1998 Congressional Budget Request[8] reports NE's direct appropriation as $327 million in FY 1997, and it requests $382 million for FY 1998. These resources are split between Energy Supply and Atomic Energy Defense activities. In addition to R&D focused on nuclear power, this budget funds such efforts as the development of advanced radioisotope power systems for spacecraft, cleanup, termination and landlord costs, and international nuclear safety—focused especially on reactors in the former Soviet Union. In addition, NE manages in excess of $200 million of work funded by others (for example EM, ER, DP, NR, NASA, DOD, and U.S. AID), primarily for facilities operation and international efforts. Within the NE budget, the R&D component totals about $62 million (FY 1997) and $71 million (President's budget request for FY 1998), as shown in Table 5.1. Some of this R&D does not address nuclear power issues, as it supports electrometallurgical technology development ($20 million in FY 1997 and $25 million in FY 1998).

NR's budget is about $680 million per year to support the U.S. Navy's fleet of nuclear ships and submarines. Current work of potential relevance to commercial nuclear power includes brittle-fracture test analysis, development of reactor-vessel annealing techniques, steam generator technology, and support for advanced computer codes.

RW's program for high-level-radioactive-waste management receives about $380 million per year. The primary activity supported is the characterization of the Yucca Mountain Site, including the preparation of a viability assessment.

DOE national laboratories are among the primary performers of R&D in nuclear-energy-related fields, whether that research is sponsored by DOE programs, the USNRC, other Federal agencies, or industry. The laboratories bring to bear long-standing core competencies and specialized infrastructure for nuclear R&D, including hot cells, research reactors, and test facilities. At several of these laboratories, groups and individuals perform for various sponsors nuclear-related energy, materials, policy, and

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[8] DOE (1997a).

technology R&D, some of which is directly relevant to issues applicable to commercial nuclear power. These issues include, for example, materials degradation in a radiation environment, component and systems reliability, advanced design and manufacturing, digital instrumentation and controls, nuclear fuels, and computational models and analysis tools.[9] Some DOE national laboratories also invest "discretionary funds"[10] in R&D applicable to nuclear power. Unfortunately, there is no centralized compilation of such laboratory activities and capabilities to guide technology integration and utilization across disciplines, technologies, and sponsors. Likewise, asset utilization planning and R&D strategies, spanning the various DOE offices responsible for relevant nuclear-related research, do not always exist. Coordination, integration, and interdisciplinary synergism occur to a much greater extent within one laboratory, or a small group of laboratories, than among the DOE program offices sponsoring the work.

Key obstacles to nuclear power's acceptability are nuclear waste disposal, cost, reactor safety, and potential for weapons proliferation. The R&D portfolio analysis is organized around these issues, independent of funding source or performer; it concludes with a discussion of R&D needed to keep the existing fleet of commercial reactors operating; and it includes comments on NE's preliminary FY 1999 R&D plans. These plans were shared with the Panel, with the understanding that they provide a snapshot of the program's outyear thinking, but do not necessarily reflect what will be in the President's FY 1999 budget request.

Table 5.1: R&D Investments ofDOE's Office of Nuclear Energy

	FY 1997 Actual $ Millions	FY 1998 President's request $ Millions	FY 1999 Plan $ Millions[a]
Waste[b]	20	25	21
Cost/New Reactor Concepts	34	-	11
Safety[c]	-	15	-
Nonproliferation	-	-	9
Operating Reactors	4	25	27
Education	4	6	10
Total NE Fission R&D	62	71[d]	78
Other NE Activities[e]	265	311	?
Total NE Appropriation	327	382	?
Subtotal: Energy Supply R&D	278	301	?
Subtotal: Atomic Energy Defense[f]	49	81	?

[a] Preliminary NE plans as of September 18, 1997.
[b] Electrometallurgical technology for treating DOE nuclear waste. Not applicable to commercial nuclear power.
[c] Elements of other programs also address safety concerns.
[d] The $40 million sum allocated to safety and operating reactors comprises the NE initiative called Nuclear Energy Security, which has been zeroed in the FY 1998 Energy and Water Appropriations bill.
[e] Not R&D, not related to nuclear power, and not reviewed by the Panel. Includes development of advanced radioisotope power systems for spacecraft, cleanup, termination and landlord costs, and international nuclear safety.
[f] Not including Naval Reactors Program.

[9] Some examples sponsored by DP and EM at DOE's defense laboratories are summarized by Arthur (1997).
[10] DOE laboratory directors are allowed to allocate not more than 6 percent of the laboratory's budget to laboratory-directed R&D projects of the laboratory's choosing.

Nuclear Waste

So far no country has solved the problem of how to dispose of highly radioactive and long-lived nuclear waste—the fission products from plant operations. The United States, like many countries, has committed to using a geologic repository for permanent disposal. RW manages the DOE program for developing such a repository, which is planned to provide for permanent geological disposal of the waste. Since 1987, when Congress selected Yucca Mountain, Nevada, as the site, RW has concentrated on developing the information necessary to license that site. Currently, the DOE program is based on applying for a license from the USNRC in 2002. The next major step is to complete the viability assessment of Yucca Mountain, due in 1998.

The program received $382 million in FY 1997, and DOE requested $380 million for FY 1998. The program is funded from two sources because the repository is designed both for spent fuel from commercial power reactors and for defense wastes resulting from nuclear weapons production and cleaning up weapons production sites. The commercial program is funded by the Nuclear Waste Disposal Fund, which collects a fee of 1 mil per kWh on the generation of electricity from nuclear power plants.[11] In FY 1997, $200 million came from the appropriation for defense nuclear waste disposal and $182 million from the Nuclear Waste Disposal Fund. The FY 1998 budget requests $190 million from each source; Congress reduced by $30 million the amount appropriated from the Nuclear Waste Fund.

DOE also funds a program to develop electrometallurgical methods for treating DOE's own spent nuclear fuels. This program, labeled Nuclear Technology R&D in the NE budget, received $20 million in FY 1997. The FY 1998 budget requests $25 million. The results of this R&D are not expected to be relevant to treating commercial nuclear waste.

NE shared with the Panel its new proposal to start a program on spent-fuel minimization in FY 1999. This program originally was included in the FY 1998 NES request, and has as its goal to double the burnup of reactor fuel. Current reactor fuel is licensed for 60,000 MW-days per metric ton of heavy metal. If successful, the R&D would lead to a significant reduction in the amount of spent fuel generated for a fixed number of MW-days of reactor operation. The current plan is to ask for $10.5 million in FY 1999, increasing to $20 million per year through 2003, with the total program estimated to cost $190 million through 2010. Improving the burnup would have no direct impact on GHG emissions,[12] would require thorough testing to demonstrate no degradation in safety, might reduce the risk of proliferation because of the decreased amount of spent fuel, and could slightly lower operating costs. DOE's main rationale for the program is to reduce the Federal government's waste-disposal costs. Because this R&D, if successful, would be primarily an economic benefit to industry**,** the Panel recommends that industry would be the appropriate sponsor.

Cost

For nuclear power to be cost-competitive, operating costs must be kept low. Because capital costs are a larger part of the total life-cycle costs of nuclear plants than they are of most other types of generation, the time to build a nuclear plant is also extremely important. For new nuclear plants to be even

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[11] In FY 1997, this fee brought in $649 million; it is expected to bring in $655 million in FY 1998 and about the same amount each year until reactors begin shutting down. Not all of these funds are used for the RW program: The majority is sent to the U.S. Treasury.

[12] An indirect impact would occur if the results of this R&D improved the economics of nuclear plants sufficiently to keep them in operation or encourage new nuclear plant construction, thereby reducing the need for electricity generation from fossil fuels.

considered, the capital costs must be significantly lower than the recent averages, which means, in particular, cutting construction times by at least 50 percent, to less than 5 years, as has been achieved in other countries. Current U.S. designs can be built in less than 5 years, as proved by recent experience in Japan and South Korea. There are many reasons that some plants took longer to build than others, and protracted USNRC licensing proceedings is only one. Increasing opposition to nuclear power in this country led to contested proceedings at nearly every step of the permitting process. Poor management of the construction process contributed to delays in completion, and at least one utility slowed construction activity because of its financial limitations.

In the United States, nuclear plant construction costs have been much too high for any operator to consider a nuclear plant as a viable option for new generation. The industry and DOE have worked together since FY 1986 to develop ALWR designs that would be easier to build and cheaper to operate, based on greatly reducing the amount of piping, valves, pumps, and cables required. Probabilistic risk analysis (PRA) also indicated these reactors would be safer to operate. One design, Westinghouse's AP600, is of a class labeled "passively safe," not requiring active systems, such as pumps, to cool down the reactor in case of an accident.

The goal of the ALWR program has been to complete engineering on three ALWR designs, so that they could be certified by the USNRC. In this program, DOE worked with EPRI, the Advanced Reactor Corporation, and the vendors. DOE funded approximately $240 million of the design certification program; industry funded $360 million. In addition, DOE and industry jointly funded First-of-a-Kind Engineering (FOAKE) for GE's ABWR design and for the AP600. DOE's share was $100 million, and industry's was $170 million. The FY 1997 budget included $34 million for the last year of this program. USNRC design certification was achieved in 1997 for two of the three designs: Combustion Engineering's System 80+ and the ABWR. The AP600 is expected to receive design certification in 1999.

In its preliminary R&D plan, NE is proposing to establish a grant-making nuclear institute funded at about $11.5 million per year to address a variety of issues. NE's thinking about this institute is in a formative stage. The Panel commends NE for recognizing the importance of reaching out to the research community to tap its ideas, but the Panel believes that the recommendation for a new initiative, described later in this chapter, has a greater probability of producing useful results.

Safety

An operating nuclear reactor has a large amount of radioactive material in its core and sufficient stored energy to disperse that material over a wide area, as catastrophically demonstrated by the Chernobyl accident in 1986. In the United States, although the 1979 accident at Three Mile Island did not release any significant amount of radiation, it greatly alarmed the local population and reinforced fears of dangers associated with nuclear power. Concerns about safety remain an obstacle to the acceptability of nuclear power.

However, there have been no nuclear power accidents in the United States leading to radiation-related, off-site health effects. A National Research Council review of nuclear power in the United States concluded:

- *The risk to the health of the public from the operation of current reactors in the United States is very small. In this fundamental sense, current reactors are safe.*

- *A significant segment of the public has a different perception, and also believes that the level of safety can and should be increased.*

- *As a result of operating experience, improved operator and maintenance training programs, safety research, better inspections, and productive use of PRA, safety is continually improved. In many cases these improvements are closely linked to improvements in simplicity, reliability, and economy.* [13]

DOE does not have an R&D program specifically focused on domestic power-reactor safety. However, safety issues and features have been addressed within other NE R&D programs, most recently the R&D program on ALWRs. The FY 1998 NES initiative contained $9 million for R&D on operating-reactor safety. NE has also supported R&D on the HTGR and the integral fast reactor (IFR). Proponents of these reactor concepts argue that they would be much less susceptible to severe accidents than current LWRs. In its preliminary planning for FY 1999, NE has incorporated safety-related R&D into its proposals dealing with fuel, sensors and instrumentation, and operating reactors.

With respect to power-reactor safety internationally, the DOE has an ongoing program addressing the safety of operating reactors in the former Soviet Union. This program was funded at $45 million in FY 1997. U.S. AID provided $27 million for work on Chernobyl starting in FY 1997 and an additional $35 million for other assistance to Ukraine. DOE requested $50 million in FY 1998 for international nuclear safety, plus $6 million within NES for international collaboration on safety R&D.

Proliferation

There is a concern, particularly in the United States, that the further expansion of nuclear power will increase significantly the risk of proliferation of nuclear weapons.

In discussions with vendors and others, the Panel has not found any new developed concepts for a more "proliferation-resistant" reactor. There are many suggestions for new approaches, including increasing the burnup of existing fuels, accelerator-based systems, and thorium systems, such as the seed-and-blanket design worked on for many years by Alvin Radkowsky. Other suggestions for protecting against proliferation are not new, but could be explored:

- An improved international control regime, led by the International Atomic Energy Agency (IAEA).

- The "containment-in-a-pellet" fuel used in the HTGR, such as sponsored by General Atomics (GA). Nonproliferation attributes of this fuel include high burnup and greater difficulty in reprocessing than fuel fromLWRs.

- The IFR, a breeder reactor design in which the fuel is reprocessed on site and reused, allowing security to be maintained at one site.

The Panel agrees that the United States should continue to give the IAEA strong support. The HTGR concept is continuing to be developed without U.S. government funding under a joint program involving GA and the Russian Ministry of Atomic Energy, with additional support from Japan and France.

[13] NRC (1992), p. 69.

The breeder reactor has been concluded to be uneconomic by the United States and, more recently, by France. Based on this conclusion, coupled with the continued proliferation concerns about the breeder, the Panel does not support any further work on the IFR.

DOE has not had a program explicitly focused on reducing the proliferation risks of nuclear power, although under the “Nuclear Security” line in the NE budget is a small program to assist in the conversion of Russian production reactor cores so that these reactors no longer will be plutonium producers, and to improve spent-fuel management practices in the former Soviet Union. This program received $3.5 million in FY 1997, and DOE requested $4 million in FY 1998.

NE is planning an initiative for FY 1999 to develop advanced proliferation-resistant reactor systems. It would explore such concepts as small reactors (50-MW scale) with lifetime cores to eliminate on-site refueling. In addition, NE is proposing a new focus on advanced proliferation-resistant fuels. Initial plans are to ask for $9 million in FY 1999 for these two programs.

Operating Reactors

Industry is funding research with short-time payoff, such as R&D on major component reliability, technologies to reduce operating and maintenance costs, chemistry and radiation control, fuel reliability, and safety and reliability assessment. However, as utilities prepare for deregulation, they are attempting to shed higher cost generation, especially nuclear plants. Although operating costs for nuclear plants are often competitive with those for gas and coal, the potential for future high capital-improvement costs make nuclear power plants, in many cases, noncompetitive for their current owners. Many of these cases involve newer, larger plants. The national interest may be to keep the plants running despite the economics faced by their owners. DOE should monitor the status of nuclear units and be prepared to share the cost of R&D that might be required to make continued operation of the nuclear units economic. Examples of such research are better and more cost-effective methods to repair steam generators, to determine the condition of steam generator tubing, and to install improved instrumentation and control systems economically.

DOE has a responsibility for protecting the nation’s energy supply. Although nuclear power is a mature technology, DOE has cooperated with industry to fund R&D to address problems that might shut down operating reactors prematurely. For example, under a joint industry/DOE program, a full-scale annealing demonstration was conducted at the Marble Hill reactor in 1996. This technique may be necessary to extend the life of some reactors. In FY 1997, the NE program included $4 million for addressing problems with operating reactors. In FY 1998, the proposed NES initiative requested $25 million for advanced instrumentation and controls technology, extended fuel burnup, and other topics. Although sound, in principle, in trying to maintain the nuclear option, the program appeared to provide inappropriate support for a mature industry. As a result, Congress zeroed it out.

Extending the operation of nuclear plants will make it easier to meet GHG emission goals. Depending on how the economics of electric-utility deregulation unfolds, government action may be required to keep reactors operating. Efforts to retain currently operating plants can reduce GHG emissions during the coming years, thereby providing time for improved nuclear and other low- or no-carbon electric generation technologies to be developed.

In its preliminary planning, NE is considering an $18 million R&D program to develop advanced digital instrumentation and control systems, to optimize thermal and electrical efficiency, and to expand international cooperation on nuclear power. The funding would be matched by industry. The Panel agrees with the basic concept of addressing problems that may prevent continued operation of nuclear plants. **The**

Panel recommends that DOE work with its laboratories and the utility industry to develop the specifics of an R&D program to address the problems that may prevent continued operation of current plants, and to fund such a program at $10 million per year, to be matched by industry.

Fission R&D Program Recommendations

Nuclear energy R&D sponsored by the DOE has been managed in the traditional style of directed research, where the program office defines the R&D topics, milestones, scope and approach. In light of the maturity of the nuclear industry and the nature of the R&D issues, this program-management style is no longer suitable. To overcome the diverse obstacles blocking fission's acceptability, the Panel believes that it is time for a fundamental change in management approach. The purpose of the change is to create an R&D program that encourages and fosters innovation and new ideas. The most fertile source of such ideas is the R&D community at large, and DOE's management challenge is to tap into it.

Fortunately, DOE already has a program following this model: the Environmental Management Science Program (EMSP). This program has attracted numerous researchers from universities, laboratories, and industry who bring new approaches and ideas to solve the problems associated with cleaning up weapons production sites. Many of these researchers had not been previously involved in R&D relevant to the DOE's environmental cleanup problems.

DOE should establish an R&D program—the Nuclear Energy Research Initiative—funded initially at $50 million per year (comparable in concept and size to its EMSP) and increasing to $100 million per year by FY 2002, to provide funding for investigator-initiated ideas to address the issues confronting nuclear energy. Projects proposed by universities, national laboratories, and industry would be selected competitively, and partnerships would be encouraged. Topics would include, but not be limited to, the following: proliferation-resistant reactors or fuel cycles; new reactor designs with higher efficiency, lower cost, and improved safety to compete in the global market; low-power units for use in developing countries; and new techniques for on-site and surface storage and for permanent disposal of nuclear waste. In defining the program, it is important not to be too specific and to allow the prospective performers maximum latitude to propose potentially promising studies or projects. Funds should be awarded after a two-stage evaluation: first a peer review to judge scientific and technical quality, and second—only for those proposals judged to be of the highest merit—a review to assess the relevance to the missions of DOE.

The availability of such funding, managed as described, would help reverse the decline of nuclear energy R&D programs at both universities and national laboratories. An initial effort of $50 million would stimulate innovative research proposals addressing the difficult problems—waste, safety, proliferation, and cost—whose solution would help make nuclear power attractive. The Federal role is to stimulate innovation and to invest in R&D whose results would have impact in the 10- to 20-year time frame. The budget should increase over 3 years to a steady-state level of $100 million. This budget would support a sufficient number of competitively selected investigators, students, and specialized facilities at universities, national laboratories, and industry to generate the needed new ideas and maintain an adequate human resource base.

If the United States were to implement a carbon-emissions policy that would require existing plants to operate longer than their owners would choose in a deregulated electric-power market, DOE should monitor operations and relicensing and be prepared to fund the R&D necessary to maintain operations. Such efforts might include R&D to reduce the cost of replacing major components, such as steam generators, or to reduce the cost of plant upgrades to meet USNRC requirements.

Fusion R&D Portfolio

Nuclear fusion—the fundamental energy source of the stars—is an energy-generating process in which the nuclei of light atoms, such as hydrogen and its isotopes, fuse. The objective of DOE's fusion energy sciences program is to develop the scientific and technological basis for fusion as a long-term energy option for the United States and the world. The fusion R&D program is strongly centered in basic research and supports the important field of plasma science.

In total, the United States, through DOE and its predecessors, has invested $14.7 billion (1997 dollars; $8.2 billion in as-spent dollars) in fusion science and technology through FY 1997. Figure 5.2 shows the funding history since 1979 in 1997 dollars. Results and techniques from fusion plasma science have had fundamental and pervasive impact for many other scientific fields, and they have made substantial contributions to industry and manufacturing. Since 1970, fusion power achieved in experiments has increased from less than 0.1 watt to 12 megawatts. Recent experiments are approaching the breakeven threshold, where the amount of fusion power produced exceeds the power used to heat and confine the plasma.

The nation's fusion energy research program has received three major reviews since 1990, the most comprehensive being the 1995 study by the PCAST Panel on the U.S. Program of Fusion Energy Research and Development (PCAST-95).[14] The current study examined the fusion energy sciences program with a focus on understanding changes that have occurred since the 1995 review and to determine whether the organizing principles recommended by PCAST remain appropriate.

PCAST-95 concluded that "funding for fusion energy R&D by the Federal government is an important investment in the development of an attractive and possibly essential new energy source for this country and the world in the middle of the next century and beyond. ... U.S. funding has been crucial to a productive, equitable, and durable international collaboration in fusion science and technology that represents the best hope for timely commercialization of fusion energy at affordable cost."[15] PCAST-95 recommended an annual budget of $320 million.

In FY 1996, Congress reduced the fusion budget by about one-third and directed DOE to restructure its fusion energy program. DOE based the restructuring on the advice of its Fusion Energy Sciences Advisory Committee (FESAC-96),[16] which formulated a new mission: "To advance plasma science, fusion science and fusion technology—the knowledge base needed for an economically and environmentally attractive fusion energy source." FESAC also recommended three policy goals: (1) to advance plasma science in pursuit of national science and technology goals; (2) to develop fusion science, fusion technology, and plasma confinement innovations as the central theme of the domestic program; and (3) to pursue fusion energy science and technology as a partner in an international effort. At this point, Europe, Russia, and Japan collectively are investing about five times the U.S. level in fusion science and technology, making the United States a significantly smaller financial party but still an intellectually significant participant in the global fusion energy R&D effort.

DOE's fusion energy sciences (FES) program has been restructured over the past 2 years in a manner consistent with the PCAST-95 principles, to the degree that this was feasible given the lower

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[14] PCAST (1995).
[15] PCAST (1995, p. 1).
[16] FESAC (1996).

budget, though with considerable sacrifice of worthwhile efforts. The FY 1997 fusion budget is $230 million in ER plus $1 million funded through NE for work at the Advanced Test Reactor in Idaho on fusion irradiation experiments. The FY 1998 request is $225 million in ER plus $2 million in NE. In the view of the Panel, this funding level is too low. It allows no significant U.S. activity relating to the third PCAST priority, namely, participation in an international program to develop practical low-activation materials; it has required a reduced level of funding for the design of the International Thermonuclear Experimental Reactor (ITER); it has resulted in the early shutdown of the largest U.S. fusion experiment, TFTR; and it has precluded initiation of the next major U.S. plasma science and fusion experiment, the Tokamak Physics Experiment. The low funding level also has limited the resources available to conduct research on alternative fusion concepts.

Two particular topics warrant additional comment at this time: ITER and the pursuit of innovative paths to a fusion energy system, specifically inertial fusion energy (IFE).

International Thermonuclear Experimental Reactor

International implementation of a burning plasma experiment is a centerpiece of the U.S. domestic fusion R&D program and is of global importance, both scientifically and in the pursuit of fusion energy. ITER is a well-developed concept to accomplish this technical goal, along with other goals that have been agreed to internationally. ITER will complete its Engineering Design Activity (EDA) phase in July 1998, culminating a worldwide effort to conceive and design an experimental device to advance the development of fusion power and fusion science. The decision on whether to proceed to construction of ITER will be made internationally and it should be made with U.S. participation.

U.S. participation in the ITER EDA has been an integral and cost-effective component of our domestic fusion science and engineering program, especially in light of the reduced funding level relative to that recommended by PCAST. Such participation leverages U.S. access to activities, experiences, and data generated as part of the overall ITER program at a moderate portion of the overall cost.

The ITER program now plans a 3-year post-EDA phase. During this phase, activities will focus on testing prototypes built during the EDA; on making the design site- and country-specific for realistic locations being considered in Japan, Europe, and possibly elsewhere; on resolving licensing issues; and on pursuing value engineering and design modifications that would reduce cost without compromising performance goals.

The Panel judges that the proposed 3-year transition between the completion of the ITER EDA phase and the international decision to construct is reasonable, and that the ITER effort merits continued U.S. involvement. The parties to ITER need to address targeted issues during this period. Furthermore, DOE should act to reincorporate into the core fusion R&D program the basic fusion technology research activities now funded within the ITER allocation. In addition, **the U.S. program should establish significant collaborations with both the JET program in Europe and the JT-60 program in Japan; such collaborations would provide experience in experiments that are prototypes for a burning plasma machine, such as ITER, and that can explore driven burning plasma discharges**. It would be desirable to make funds available to expand alternative-concepts research, consistent with the restructuring of the FES program initiated in FY 1996.

It would also be helpful to all parties in the ITER enterprise, if at least one of the parties would express, within the next year or two, its intention to offer a specific site for ITER construction by the end of the 3-year period. Clearly, one major hurdle to ITER construction is its total project cost, most recently estimated by the ITER project team to be $11.4 billion (in 1997 dollars, consistent with DOE's cost-estimating methodologies). A substantial share is expected to be borne by the host party.

The Panel also recognizes that any significant cost reduction would mean that only a subset of ITER's present mission might be fulfilled. Yet, a more modestly priced ITER focused on the key next-step scientific issue of burning plasma physics may make it easier for all parties to come to agreement. The Panel respects the desires of all parties, understands that the parties must resolve this issue together, and urges them to do so and to examine the prospects for a reduced-cost device. If, however, any of the parties states its intention to offer a site for ITER in the next year or two, the U.S. should be prepared to continue and to maximize its participation in ITER. In particular**, at the time the parties agree to move forward on ITER construction (now scheduled for 3 years from now), the United States should be prepared to determine, with stakeholder input, what the level and nature of its involvement should be.**

If no party offers to host ITER in the next 3 years, it is nonetheless vital to continue without delay the international pursuit of fusion energy via a more modestly scaled and priced device aimed at a mutually agreed set of scientific objectives. A modified experiment is better than no next international step toward practical fusion. In any case, the United States should continue to participate as a partner and leader in the evolving international program.

Inertial Fusion Energy

The Panel endorses DOE's new emphasis on diverse scientific and technological approaches to the fusion energy goal. The science focus and the growing program of R&D on innovative concepts are essential elements of the restructured program and are consistent with the recommendations of PCAST-95. In this context, IFE—in which ion or laser beams rather than magnetic fields are used both to confine and to heat the plasma—represents one alternative line of research. Through DP, more than $400 million per year is invested in inertial confinement fusion in support of DOE's stewardship of the nuclear weapons stockpile. The support ultimately needed by the IFE heavy-ion accelerator program will almost certainly require collaborative funding by several DOE offices, most notably DP and ER. **The Panel recommends closer communication and collaboration between DP and ER to establish an effective funding and decision-making process for IFE, which leverages the substantial ongoing DP investment in the coming years.**

Fusion R&D Funding Recommendation

The Panel confirms the conclusions in PCAST-95, which recommended annual funding of $320 million and a budget-constrained strategy built around three key priorities: (1) a strong domestic core program in plasma science and fusion technology; (2) a collaboratively funded international fusion experiment focused on the key next-step scientific issue of ignition and moderately sustained burn; and (3) participation in an international program to develop practical low-activation materials for fusion energy systems. The Panel recommends that, in FY 1999, the fusion R&D program be funded at the minimum level recommended by FESAC-96 ($250 million) and be increased to $320 million over 3 years, as shown in Table 5.2. In a letter to the President in December 1996, PCAST urged restoration of fusion R&D funding to the level recommended by PCAST-95.

Summary of Funding Recommendations

Table 5.2 summarizes the funding recommendations for both fission energy and fusion R&D.

Table 5.2: Recommended DOE Investments in Fission and Fusion Energy R&D
Millions of As-Spent Dollars

Program Element	FY 1997 Actual	FY 1998 Request	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
ALWR & Reactor Concepts	34	15	0	0	0	0	0
Nuclear Energy Research Initiative	0	0	50	70	85	100	103
Operating Reactor R&D	4	25	10	10	10	10	10
Education[a]	4	6	6	6	6	6	6
Subtotal: Fission Energy R&D	42	46[b]	66	86	101	116	119
Electrometallur-gical Technology	20	25	[c]	[c]	[c]	[c]	[c]
Total: Fission R&D	62	71	66[c]	86[c]	101[c]	116[c]	119[c]
Other NE Activities[d]	265	311	?	?	?	?	?
Total NE Appropriations	327	382	?	?	?	?	?
Fusion Energy Sciences	232	225	250	270	290	320	328

[a] Includes student fellowships and fuel support for university reactors.
[b] Congress appropriated $7 million for education and no funds for reactor concepts or operating reactor R&D.
[c] The Panel neither reviewed nor makes recommendations on electrometallurgical technology, which is conducted for a purpose other than nuclear energy. Its funding would add to the fission R&D total.
[d] Not R&D. The Panel makes no recommendations on these programs.

POLICY ISSUES

There are eight policy issues that will determine the future of fission as a viable energy option in the near- and long-term: the global policy context, deregulation of the electric power industry, the license renewal process, radioactive waste management, R&D program management, human resource development, export policy, and Administration acknowledgment of nuclear power as a no-carbon energy technology.

Global Policy Context

Nuclear power is a global issue: Major power plant accidents have global consequences, and the proliferation potential of nuclear weapons has major ramifications for global stability and security. Therefore, **to be able to motivate or influence other nations' nuclear energy choices, such as those related to fuel cycles, regulation, and nuclear safeguards, the United States must maintain a credible presence as a leader in the international nuclear arena. The United States must retain its technical competence, its human resource base, and its engagement in the world nuclear community, particularly regarding positions on policy issues. This will require continuing active involvement in IAEA and in OECD's Nuclear Energy Agency (NEA). Continued U.S. participation in NEA will be extremely useful as nuclear policies adjust to the demands of global emission controls.**

Deregulation of the Electric Power Industry

Continued operation of and license extension for current U.S. nuclear plants would help in meeting GHG and other emission reduction goals in the near term. With the approach of deregulation in the electric utility sector, economic considerations by plant owners are likely to lead to early shutdown of those plants that are not cost-competitive at today's U.S. oil and gas prices. Deregulation is occurring more rapidly than many people had originally thought. In a competitive market, where customers can buy power from the least-cost provider, nuclear plants generally will be at a disadvantage for their current owners. Nuclear power has low operating costs, but high life-cycle costs, because of the large capital costs associated with construction, major component replacement, and upgrade. Owners may shut down plants rather than face the possibility of having to incur future capital costs to replace major components, such as steam generators, and/or to make older plants meet current, more stringent standards. An additional problem faced by nuclear plant operators is that, although a coal plant can be mothballed for a few hundred thousand dollars per year, the staffing levels required to ensure fuel safety and plant security make not running a nuclear plant far more expensive. If a nuclear plant is not going to run for a while, the utility will shut it down permanently.

Deregulation probably will reduce the number of operating nuclear power plants over the next 5 to 15 years and will significantly lengthen the time before new orders for nuclear power plants might be placed. The resulting loss of electric generation capacity on this time scale primarily will be made up by using gas turbines or coal plants, increasing the use of fossil fuels with their associated emissions. Deregulation is also an important new context for nuclear safety regulation and the operation of the USNRC.

License Renewal Process

In the United States, nuclear plant operating licenses are issued for 40 years. By 2017, 57 plant licenses will expire. Life extension should be possible for many plants, with the effect shown in Figure 5.3, but will require license renewal by the USNRC. Because no utility has yet to file for license renewal, the USNRC's procedures for relicensing are untested and therefore uncertain. The USNRC is convinced that its procedures are not an obstacle, it estimates that license renewal review will take 3 years, and it does not believe any plant will shut down rather than apply for license renewal. From a utility perspective, however, the regulatory process is a major problem: It is convoluted, complex, and in a high state of flux. The utility industry believes the USNRC will try to use license renewal to require them to upgrade all plants to a common standard, whether or not this is necessary for safe operation. The forward uncertainty of the related capital costs may lead many utility owners to shut down their nuclear plants prematurely, because they do not see a clear path to amortization of incremental capital costs over a defined and certain future time period. A typical utility position is that the company is planning to extend its plant license, but definitely will not be the first to apply.

It would be beneficial to reexamine the role, functioning, and funding of the USNRC, to ensure the effectiveness of that agency and its relicensing process in the evolving deregulated utility environment.

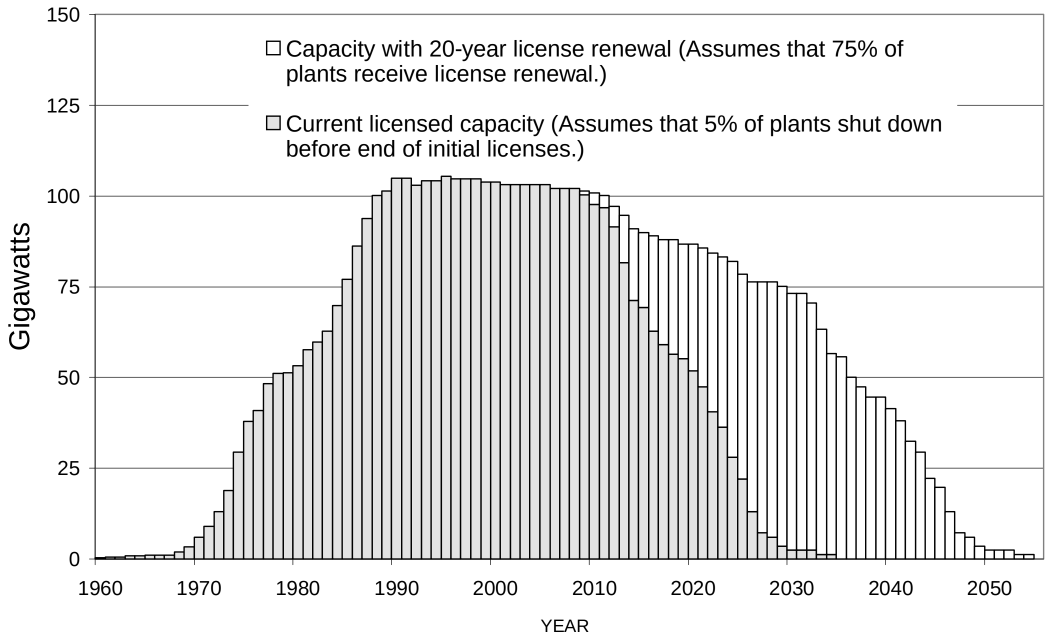

Figure 5.3: Projected U.S. nuclear generating capacity. Source: DOE Office of Nuclear Energy, Science and Technology.

Radioactive Waste Management

DOE's nuclear waste program is predicated on licensing the Yucca Mountain site, and DOE will produce a viability assessment in 1998. **Anticipating that the Yucca Mountain viability assessment will not provide an unambiguous answer, the Administration should establish now a decision process that incorporates that assessment and leads to a definitive course of action for nuclear-waste disposal**. Adequate funds are available in the RW budget to begin addressing possible alternatives to Yucca Mountain as well as to plan for an interim storage facility if one is needed. Such action could remove a growing obstacle to continued operation of current plants, as nuclear utilities are running out of capacity to store their spent fuel.

A Federal law requires DOE to take spent nuclear fuel beginning in 1998, and a Federal court ruled, in a decision not appealed by the Administration, that DOE must do so. However, DOE has no place to put the waste, and the Administration has opposed constructing an interim storage facility until the decision is made to go ahead with Yucca Mountain, promising to veto any legislation containing such a provision. The Administration clearly has both the responsibility and the funds to solve this problem.

R&D Program Management

Several DOE programs sponsor nuclear-power-related R&D, and several DOE national laboratories are trying to maintain nuclear-energy R&D programs, even as the total R&D funding available has declined substantially from what it was at the peak of the program. **DOE should improve coordination and integration between all the DOE program offices sponsoring R&D applicable to fission energy. These program offices include NE, NR, DP, EM, RW, NN, MD, and ER.**

Several of DOE's major national laboratories have large, capable staffs, unique laboratory facilities, and substantial expertise in areas relating to nuclear power. Too many of the laboratories are attempting to remain involved in nuclear energy, even in the face of reduced budgets. As a consequence, there no longer exists, or will shortly cease to exist, a critical mass in many laboratories in each of the areas of interest. **To strengthen the national laboratories' fission energy R&D programs and their management, DOE should consolidate those programs at fewer national laboratories and encourage stronger links with industry.**

Human Resource Development

In areas relating to both fission and fusion energy, the higher education system is shrinking. Currently, there are 35 nuclear engineering departments or programs, down from 50 in 1975. There are 34 operating university research reactors, down from 76 in 1975. In 1992, of 40 departments that had awarded 86 percent of the doctorates in plasma physics from 1987 to 1991, only 25 still had a plasma science program, including ones for undergraduates. **Given the importance of nuclear engineering and plasma science to many areas of national interest and industrial application, it is important to revitalize these educational programs and help them to attract high-caliber students.** NE proposed to fund its university program at $6 million in FY 1998.[17] It offers fellowships to students and provides fuel support and funding for operational upgrades for the university reactors. This university program should continue at about the present level. The merit-based, competitive Nuclear Energy Research Initiative recommended by this Panel also will help provide the opportunities and resources needed for the best programs to thrive and attract good students.

Export Policy

Without a near-term domestic market for new nuclear power plants, the export of nuclear plants, equipment, and services is the most effective means of maintaining a viable U.S. commercial nuclear capability. Not surprisingly, U.S. vendors see their business growth in the export market, almost solely in Asia, where Japan already has a large program, South Korea's and Taiwan's continue to grow, and China is seen by all vendors as the major untapped market. For U.S. vendors to be effective in the growing Asian markets requires a strategy with two inexorably linked aspects. First, U.S. industry must provide competitive products. Second, U.S. government actions are needed to ensure that the international playing field is level for U.S. industry.

It is up to U.S. industry to ensure its products are competitive in the marketplace. In the case of nuclear reactor technology, to remain economically competitive, especially against relatively inexpensive Asian labor, industry must develop more efficient methods for designing and manufacturing nuclear plants (and the equipment that goes in them). For example, accelerated application of new U.S. technologies

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[17] Congress appropriated $7 million.

(especially computer technology) to nuclear plant design, component manufacturing, and efficient operation will be one important element of a competitive strategy for U.S. industry.

U.S. vendors can be competitive in the active new markets for nuclear power overseas (mainly in Asia) by offering the designs and technologies developed and USNRC-certified through the recently completed ALWR effort sponsored jointly by industry and DOE. Seeing the market potential, industry willingly bore most of the costs of this R&D, FOAKE, and design-certification program. Success in the international market will allow the United States and its nuclear industry to: (1) capture the economic return on the R&D investment by selling several units of these new standardized designs; (2) introduce the technology and start to bring down unit costs; (3) keep vendors' internal R&D programs viable; and (4) develop techniques to shorten manufacturing and construction times.

The Administration's export policy should support the nuclear industry in the same fashion it supports other U.S. industries. For example, the Administration should support access for U.S. nuclear suppliers to competitive export financing, such as from the Export-Import Bank, to all countries that have signed the Nuclear Nonproliferation Treaty, insofar as this strategy does not contravene U.S. nonproliferation goals. It would also be useful for the government to pursue non-proliferation agreements aggressively with all trading partners.

Administration Acknowledgment of Nuclear Power as a No-Carbon Energy Technology

To reach a goal of reducing GHG emissions in the most cost-effective way will require halting the increase in carbon emissions and then switching to sources of electricity that produce no or low carbon emissions, as well as other actions. **It is important for the Administration to acknowledge nuclear power as an energy option that could contribute substantially to meeting national and international emissions goals, if the concerns surrounding it are resolved.** Such acknowledgment is necessary to dispel the widespread belief that the Administration is hostile to nuclear power, a belief that reinforces those in and outside the government who are opposed to nuclear power, both current and future.

POTENTIAL CONTRIBUTIONS

As a non-GHG emitter, nuclear power can play a major role in allowing countries to meet emission goals. This is the case in France, where the switch to nuclear power led to a dramatic reduction in polluting emissions, as seen in Figure 5.4. The Japanese government has examined approaches to reducing GHG emissions. In scenario runs, reducing carbon emissions to 1990 levels by 2030 required an additional 50 large nuclear plants.

Nuclear power is a major factor in restraining the growth in emissions, and it will be more difficult for the United States to meet emission goals without nuclear power. Since 1973, the generation of electricity by U.S. nuclear plants has resulted in approximately 2 billion metric tons less carbon emissions than if the same amount of electricity had been produced by coal plants.

The United States has about 100 GW of nuclear generating capacity. Assuming a 75 percent capacity factor, Brookhaven National Laboratory estimated that the annual amount of carbon emissions from 100 GW of nuclear power plants would be "insignificant"; from 100 GW of coal-steam plants would be 168 million metric tons (MMtC); and from 100 GW of combined-cycle gas plants would be 66 MMtC.[18]

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[18] The average U.S. capacity factor in 1996 was 74.9 percent. Brookhaven's estimates are based on a capacity factor of 80 percent; these figures are adjusted to correspond to 75 percent.

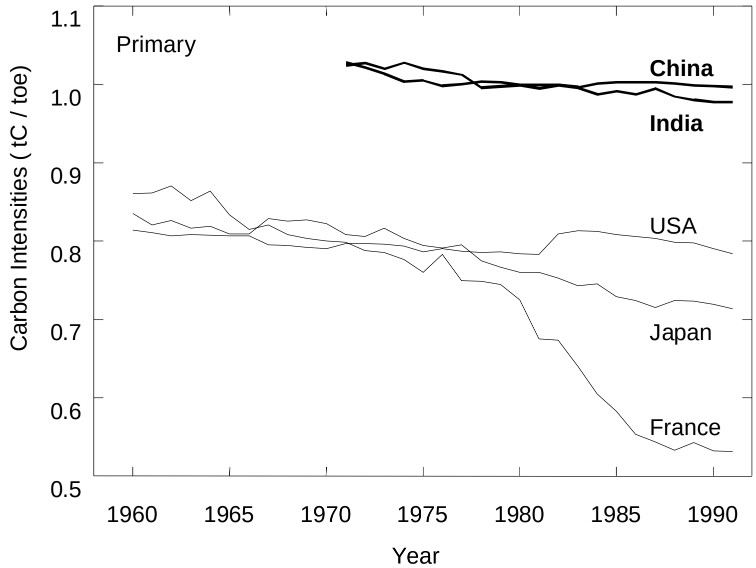

Figure 5.4: Carbon intensities of primary energy expressed in tons of carbon per ton of oil equivalent energy. Note that the zero of the carbon-intensity axis is suppressed. Source: Nakicenovic (1996).

The Energy Information Administration has estimated the effect of various nuclear scenarios on U.S. carbon emissions. The reference case assumes most units operate until the end of their 40-year licenses. A low nuclear case assumes units are retired 10 years before license expiration, and a high nuclear case assumes 10 years of additional operation beyond the current licenses. Retired capacity is assumed to be replaced primarily by coal-fired units (37 percent of the capacity) and combined-cycle gas units (47 percent of the capacity). In the low nuclear case, through 2015, 43 million metric tons of carbon are emitted per year above that in the reference case. In the high nuclear case, 29 million metric tons less are emitted per year than in the reference case.

Analyses of scenarios projecting future economic growth, energy consumption, energy intensity, carbon emissions, and the potential for energy-efficient and low- or no-carbon technologies often are simplistic in their assumptions about nuclear power as part of the future national and global energy mix. A common assumption is that nuclear power's present disadvantages will preclude it from being economically or politically viable in the future, both in the United States and internationally.[19] This assumption contradicts information provided by numerous sources to the Panel regarding the future of nuclear power, particularly in Asia. Those sources indicated that the collective electric generation capacity of nuclear plants outside the United States was likely to be stable or to rise. Moreover, the future of nuclear power worldwide depends on future global agreements on carbon emissions, national strategies implemented to comply with those agreements, and the extent to which the current difficulties associated with nuclear power can be overcome through R&D.

[19] See, for example DOE (1997b), pp. 7-29.

If the R&D recommendations in this chapter are implemented, and if the R&D successfully helps resolve the issues of nuclear-waste disposal, plant safety, proliferation potential, and economics, then there will be a firm basis for maintaining nuclear power's significant, no-carbon contributions to the energy supply of the United States and the world in the near term. Moreover, the obstacles to including fission energy as an expanding component of the global and national energy portfolio later in the twenty-first century will be substantially reduced. Any mechanism that encourages market success of low- and no-carbon energy sources would benefit nuclear power, as well as natural gas, efficiency, and renewables.

Clearly, global implementation of energy-supply technologies that lower carbon emissions significantly will require new investments on a large scale. Furthermore, a substantial amount of capital is currently tied up in power plants, buildings, and transportation systems that are not energy efficient or carbon avoiding, but are providing functional service or producing income. It would be very costly to replace or to write off such assets on an accelerated timescale and, simultaneously, to provide capital to introduce new renewable, energy-efficient, and low-GHG technologies for stationary as well as transportation power systems. Maximizing the life of the existing nuclear plants is potentially a cost-effective route to provide considerable amounts of carbon-free energy in the near- to mid-term. A phased and orderly plan would accomplish emissions-reduction goals by introducing new low- or no-GHG technologies and capacity while replacing the highest carbon emitters first.

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