# APPENDIX E
# REPORT OF THE TASK FORCE ON NUCLEAR ENERGY R&D: FISSION AND FUSION

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This appendix is the report of the Nuclear Task Force. The views presented here are those of the Task Force and not necessarily those of either the President's Committee of Advisors on Science and Technology (PCAST) or the PCAST Energy R&D Panel as a whole.

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| | |
|---|---|
| ABB-CE | ABB-Combustion Engineering |
| ABWR | Advanced Boiling Water Reactor |
| AEC | Atomic Energy Commission |
| AECL | Atomic Energy of Canada, Limited |
| ALWR | Advanced Light Water Reactor |
| APWR | Advanced Pressurized Water Reactor |
| BES | Office of Basic Energy Sciences (DOE) |
| BWR | Boiling Water Reactor |
| CANDU | Canadian Deuterium Uranium (reactor) |
| DOE | Department of Energy |
| DP | Office of Defense Programs (DOE) |
| DT | Deuterium-Tritium |
| EBR | Experimental Breeder Reactor |
| EDA | Engineering Design Activity |
| EIA | Energy Information Administration |
| EM | Office of Environmental Management (DOE) |
| EMSP | Environmental Management Science Program (DOE) |
| EPA | Environmental Protection Agency |
| EPRI | Electric Power Research Institute |
| ER | Office of Energy Research (DOE) |
| ERDA | Energy Research and Development Administration |
| FEAC | Fusion Energy Advisory Committee |
| FES | Fusion Energy Sciences |
| FESAC | Fusion Energy Sciences Advisory Committee |
| FOAKE | First-of-a-Kind Engineering |
| GA | General Atomics |
| GE | General Electric |
| GHG | Greenhouse Gas |
| GPRA | Government Performance and Results Act |
| HEU | Highly Enriched Uranium |
| HTGR | High-Temperature Gas Reactor |
| I&C | Instrumentation and Control |
| IAEA | International Atomic Energy Agency |
| ICF | Inertial Confinement Fusion |
| IEA | International Energy Agency |
| IFE | Inertial Fusion Energy |
| IFR | Integral Fast Reactor |
| INEEL | Idaho National Engineering and Environmental Laboratory |
| ITER | International Thermonuclear Experimental Reactor |
| JAERI | Japan Atomic Energy Research Institute |
| JET | Joint European Torus |
| LANL | Los Alamos National Laboratory |
| LMR | Liquid Metal Reactor |
| LWR | Light Water Reactor |
| MD | Office of Fissile Materials Disposition (DOE) |
| MIT | Massachusetts Institute of Technology |
| NE | Office of Nuclear Energy, Science and Technology (DOE) |
| NEA | Nuclear Energy Agency |
| NEI | Nuclear Energy Institute |

| | |
|---|---|
| NES | Nuclear Energy Security |

## LIST OF ABBREVIATIONS AND ACRONYMS (Continued)

| | |
|---|---|
| NGO | Nongovernmental Organization |
| NN | Office of Nonproliferation and National Security (DOE) |
| NPT | Nuclear Nonproliferation Treaty |
| NR | Office of Naval Reactors |
| NRC | Nuclear Regulatory Commission |
| NSF | National Science Foundation |
| NWDF | Nuclear Waste Disposal Fund |
| OCRWM | Office of Civilian Radioactive Waste Management (DOE) |
| OECD | Organization for Economic Cooperation and Development |
| OFES | Office of Fusion Energy Sciences (DOE) |
| PCAST | President's Committee of Advisors on Science and Technology |
| PRA | Probabilistic Risk Analysis |
| PWR | Pressurized Water Reactor |
| RW | Office of Civilian Radioactive Waste Management (DOE) |
| TFTR | Tokamak Fusion Test Reactor |
| TPX | Tokamak Physics Experiment |
| UN | United Nations |
| USAID | United States Agency for International Development |
| USPIRG | United States Public Interest Research Group |
| VVER | Soviet Pressurized Water Reactor |

## INTRODUCTION

This appendix presents the foundation for Chapter 5 (Nuclear Energy: Fission and Fusion) of the PCAST Energy R&D Report. The Nuclear Task Force met seven times for 12 days separately from the Energy R&D Panel. It heard from 90 invited representatives of industry, utilities, national laboratories, universities, the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), and nongovernmental organizations. These speakers included supporters and critics of both the programs and the basic technologies, and they came from Canada, the European Community, France, Germany, Japan, and the United States. In addition, the Task Force considered written contributions from several individuals and organizations. The primary concentration was on fission R&D programs, but substantial parts of two meetings were devoted to fusion R&D. A list of the meetings and information sources is provided at the end of this appendix.

## FISSION

The United States has been the recognized world leader in nuclear-energy-related activities since the end of World War II. At that time, the nation rapidly developed a program to use nuclear power for propulsion and then electricity generation, as well as testing and building a large number of nuclear weapons. Links in the public's mind between nuclear power and nuclear weapons and between nuclear power and radiation remain problems for the U.S. nuclear power industry today.

Besides the perceived links between nuclear power and nuclear weapons and the associated proliferation risks, nuclear power has several significant disadvantages: nuclear power is associated with radiation, something the public dreads;[1] the waste produced is hazardous for many centuries and, as a result, is a major environmental problem; and the public, when they do think about nuclear power, mistrusts the technology (or those who operate it) and is concerned about the potential for severe, even catastrophic, accidents.

However, nuclear power also has major advantages as an energy source:

- It is a reliable source of baseload electricity generation, currently providing 17 percent of the world's electricity;

- It does not produce greenhouse gases (GHG), sources of acidic precipitation, or particulates, and it does not cause smog;

- Its use decreases reliance on fossil fuels; and

- Its fuel supply is sufficient to last far into the twenty-first century for light water reactors (LWR), under all but the most nuclear-ambitious scenarios.

Nuclear power is used throughout the world. As of December 31, 1996, nuclear plants were operating in 30 countries, with 15 countries getting at least 30 percent of their electricity from nuclear power. In 1996 in countries of the Organization for Economic Cooperation and Development (OECD), nuclear power provided 77 percent of the electricity in France, 33 percent in Japan, 26 percent in the

[1] See, for example, several articles by Paul Slovic: P. Slovic, "Perceived Risk, Trust, and Democracy," *Risk Analysis*, Vol. 13, No. 6, 1993, pp. 675-682; P. Slovic, J. Flynn, and M. Laman, "Perceived Risk, Trust, and the Politics of Nuclear Waste," *Science*, vol. 254, 1991, pp. 1603-1607; P. Slovic, "Perception of Risk," *Science*, Vol. 236, 1987, pp. 280-285.

United Kingdom, and 22 percent in the United States. Worldwide, 442 nuclear power reactors were operating with a total capacity of 351 GW, and 36 more were under construction.[2]

[2]International Atomic Energy Agency, *Nuclear Power Reactors in the World*, Reference Data Series No. 2, April 1997 Edition, Vienna, 1997.

The United States has the largest number of operating nuclear reactors and the largest nuclear capacity in the world.[3] Reactor designs by Westinghouse and General Electric (GE) have served as the basis for the large nuclear power programs in France and Japan, the countries usually described as most "nuclear-friendly." U.S. technology continues to be used in overseas applications: the newest reactors in Japan are GE-designed advanced boiling water reactors (ABWR),[4] ABB-Combustion Engineering (ABB-CE) has sold its System 80+ design to South Korea, and Westinghouse is working with a Japanese utility on an advanced pressurized water reactor (APWR).

U.S. engineering schools have trained many of the people now in leadership positions in foreign nuclear programs, and the NRC's regulations have served as the basis for regulatory regimes around the world.

However, this position of world leadership is eroding. Although the United States gets more than 20 percent of its electricity from nuclear power, no new nuclear plant has been ordered in the United States for nearly 20 years. Owners are shutting down operating plants before the end of their licensed life, and more are likely to be closed as the utility system transitions to deregulation. Foreign manufacturers are competing for and winning new sales: Canada's Atomic Energy Canada, Limited (AECL), marketing the Canadian deuterium uranium reactor (CANDU); Framatome, marketing the improved French pressurized water reactor (PWR); and Russia, marketing the Soviet pressurized water reactor (VVER 1000), a large PWR with a Western-style containment. These vendors are likely to be joined soon by Japanese manufacturers. South Korea[5] and China are developing indigenous capability and eventually might market their designs in other countries.

Based on concerns about nuclear weapons proliferation, U.S. policies have opposed reprocessing and the development of breeder reactors. However, the strong U.S. opposition to these technologies (first forcefully stated in the Carter Administration, dropped during the Reagan and Bush Administrations, and now reiterated during the Clinton Administration) has been ineffective in stopping the active reprocessing industry in France and England, the desire by Russia to develop such an industry, or the Japanese program. Furthermore, the lack of strong breeder programs internationally is not due to U.S. influence but to the high cost of breeders, compared with LWRs, and the ample supply of low-cost uranium.

It is apparent that the decline of the nuclear power industry in the United States has eroded U.S. international nuclear-power leadership. The decline in the U.S. nuclear power industry resulted from many factors, including the following:

- 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.[6]

- Natural gas supplies have proven to be much larger than was earlier believed, resulting in high production and low prices. For the past decade, low prices and the steady improvement

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[3]The U.S. has 109 operating reactors with a capacity of 99 GW. The next two largest programs are those in France and Japan, with a combined total of 110 reactors with a capacity of 102 GW. "International Datafile," *IAEA Bulletin*, Vol. 39, No. 1, 1997, Vienna, p. 44.

[4]One was built by GE-Toshiba; the other by GE-Hitachi.

[5]South Korea's R&D program includes the following designs: the Korea Next Generation Reactor (KNGR), a 1300 megawatt evolutionary PWR; the Korea Advanced Liquid Metal Reactor, a 330 megawatt LMR module; and the Nuclear Cogeneration Integral Reactor, 330 megawatts, for seawater desalinization and small-scale electricity generation. *Nuclear News*, August 1997, p. 48.

[6]This led to a surplus in capacity and to the cancellation of 108 nuclear and 93 fossil fuel plants that were on order. Bertram Wolfe, "Why Environmentalists Should Promote Nuclear Energy," *Issues in Science & Technology*, Summer 1996, pp. 55-60.

in power plant efficiency of gas-fired combined-cycle plants have made gas the lowest cost and most rapidly implementable 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.[7]

- 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 all things nuclear — including concerns about proliferation, reactor safety, and radiation — has grown and outstripped generally ineffective efforts to address public concerns.[8]

For the United States to maintain a credible presence in the international nuclear arena and be able to motivate or influence other nations' nuclear energy choices — such as those related to fuel cycles — the United States must retain its technical competence and remain engaged in the world nuclear community. U.S. engagement is particularly important regarding policy issues and will require continuing active U.S. involvement in the International Atomic Energy Agency (IAEA) and in the Nuclear Energy Agency (NEA) of the OECD. The NEA has had major roles in organizing and managing programs of international cooperation. Continued U.S. participation will have high leverage and be extremely useful as nuclear policies throughout the world adjust to the demands of global emission controls.

### International

Nuclear power is an attractive and apparently cost-competitive source of electric power for some countries, particularly those in Asia. These countries will acquire and operate nuclear plants — with or without U.S. participation. In many countries other than the United States, the number of plants is expected to increase. With 341 GW in 1994 as the base, the Energy Information Administration (EIA) estimates that the total world capacity in 2015 will be between 316 and 434 GW,[9] with the lower number driven by an estimated reduction of 35 GW in the United States. All six scenarios[10] run for the World Energy Council, show net additions to nuclear generating capacity by 2020, with the capacity in that year ranging from 420 to 730 GW.[11] In all but one scenario, nuclear capacity continues to grow through 2050, reaching as much as 1900 GW.[12] In one scenario, nuclear capacity declines to 380 GW in 2050. This scenario includes a global regime to control the emission of GHGs and accelerates the use of renewables, which account in that scenario for 40 percent of the global energy consumption by 2050.[13]

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[7]A modified view is that of the former head of the GE nuclear division: "These extended construction times have been ascribed to an ever more complicated and inefficient regulatory system and to court delays resulting from suits brought by those opposed to nuclear power. Although these did indeed contribute to the delays, in my view the underlying cause was lack of need…I question whether NRC or the courts (or for that matter Congress) would have tolerated the delays if new electricity was truly needed." Wolfe, op. cit.

[8]A recent effort to understand the nuclear debate led the investigators to the following conclusion: "We knew the nuclear debate in the public arena to be confused and conflicted, with little sense of how to identify, rank, or prioritize issues. We found little evidence, however, that it was any less tangled, or better arranged, among the many experts we consulted and who came to our workshops." Gene I. Rochlin, et al., *A Cross-Disciplinary Inquiry Into Nuclear Power Futures for the United States*, draft report to the Alfred P. Sloan Foundation, 23 May 1997, p. 38.

[9]EIA, *International Energy Outlook 1996, with Projections to 2015*, DOE/EIA-0484(96), May 1996, p. 58.

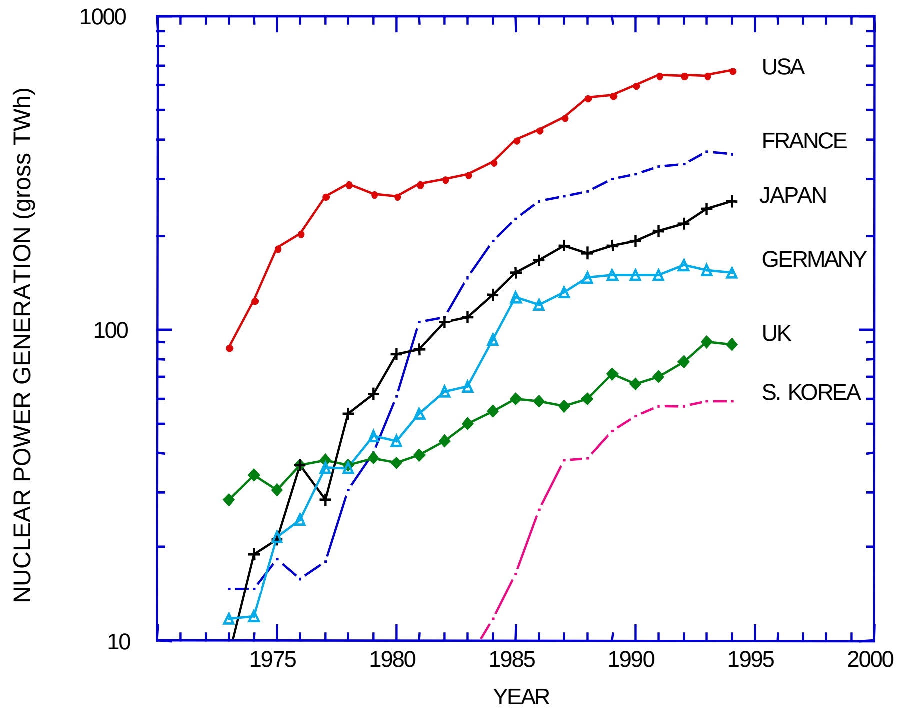
[10]World Energy Council and International Institute for Applied Systems Analysis, *Global Energy Perspectives to 2050 and Beyond*, Report 1995.

[11]Ibid., p. 61.

[12]Ibid., p. 62.

[13]Ibid., p. 52.

Nuclear programs remain strong in France and Japan and are growing in other parts of Asia. Figure E.1 shows the growth in nuclear power generation in selected countries since 1973.[14] France is still building nuclear plants. Japan has an annual Federal budget for nuclear energy of about $5 billion dollars,[15] of which about $3.1 billion was reported to be for R&D in 1995.[16] This large expenditure reflects the strong and growing nuclear program in Japan: as of June 1997, Japan had 60 boiling water reactor (BWR) and PWR plants operating, with one PWR and one BWR under construction. Four more BWRs are planned to be in operation by 2005. Japan also has an enrichment plant and a small reprocessing facility, with a larger reprocessing facility under construction.




*Source: D. Bodansky, Nuclear Energy: Principles, Practices and Prospects (AIP Press, 1996). Reprinted by permission of Springer-Verlag, New York.*

**Figure E.1: Growth of annual nuclear power generation in selected countries, 1973-1994.**

Although nuclear programs appear stronger in many other 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 operating and maintenance practices 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 into 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 transport of high-level waste to a storage facility at Gorleben.

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[14]Data from *Monthly Energy Review, September 1995*, DOE/EIA-0035 (95/09). Figure from David Bodansky, *Nuclear Energy: Principles, Practices and Prospects*, AIP Press, 1996, p. 15.
[15]Masaji Yoshikawa, President, Japan Atomic Energy Research Institute (JAERI), presentation to the Nuclear Task Force, Washington, D.C., 14 July 1997.
[16]International Energy Agency, *IEA Energy Technology R&D Statistics: 1974-1995*, OECD, 1997.

Among vendors, utilities, national laboratories, the NRC, nuclear power critics, and DOE, there is widespread consensus that no nuclear plant will be ordered in the United States within the next 10 or perhaps 20 years.[17] The principal reason is that nuclear power does not compete economically in U.S. markets, given the abundant supplies of low-cost natural gas.[18] Thus, U.S. vendors see their possible business growth in the export market, almost solely in Asia, where South Korea's program continues to grow, several countries appear to be possible customers for reactor sales, and China is seen by all vendors as the major untapped market. China's 5-year plan (to 2000) contains eight new reactors: two 600-MW Chinese-designed plants, two Russian VVERs, two French PWRs, and two CANDUs. China's next 5-year plan will call for 6600 MW in new nuclear capacity.[19] To participate in the Chinese market requires strong financial support by the vendor's government. As an example of the arrangements, China pays nothing for the CANDUs until the plants are complete. The Canadian government is advancing the required $3 billion,[20] with the expectation of being reimbursed once the plants begin operation.

Without a near-term domestic market for new nuclear power plants, the export of nuclear plants, equipment, and services is, by far, the most effective means of maintaining a viable commercial nuclear capability in the United States. There are two inexorably linked aspects to such a strategy. First, U.S. industry must remain competitive in these markets. Second, there is the need for U.S. government actions to ensure that the international playing field is level for U.S. industry.

This lesson is one the French, Japanese, and Canadians have all learned very well. Whereas U.S. nuclear equipment suppliers have aggressively pursued certain world markets, they have been barred from others by U.S. trade policies. In particular, the countries cited above are very actively involved in providing nuclear plants, equipment, and services to China's burgeoning electric power market, which has the potential to be the world's largest new market for nuclear power plants.[21]

To remain competitive in other Asian nations (e.g., South Korea and Japan), the U.S. government and industry should take several important steps. U.S. industry must maintain its nuclear energy technology "edge" over foreign competitors. If U.S. industry does not invest in the development of technological advancements to keep ahead of foreign competitors — and ahead of the markets in which U.S. industry is competing — then the United States could quickly lose its technology edge and be left behind. Keeping this edge is dependent, in part, on U.S. industry's ability to access all of the growing Asian market.

A related need is for U.S. industry to develop more efficient methods for designing and manufacturing nuclear plants (and the equipment that goes in them) to remain economically competitive, especially against relatively inexpensive Asian labor. Accelerated application of new U.S. technologies (especially computer technology) to nuclear plant design and manufacturing procedures is U.S. industry's best hope for maintaining economic competitiveness.

Finally, U.S. nuclear suppliers should continue to have access to favorable export financing terms from organizations such as the U.S. Export-Import Bank. Since suppliers from competing nations have

[17]Based on many presentations to the Nuclear Task Force.
[18]This opinion was given by many presenters, including Chauncey Starr, President Emeritus, EPRI, presentation to PCAST Nuclear Task Force, San Diego, CA., 27 June 1997.
[19]G. Kugler, Vice President, Commercial Operations, AECL, presentation to the PCAST Nuclear Task Force, San Diego, CA., 26 June 1997.
[20]This is the largest project the Canadian government has funded anywhere. Kugler, op. cit.
[21]The Chinese would prefer to purchase nuclear plants from the United States, if possible, because they recognize our technology to be the most advanced and safest technology available. Realizing that the nuclear-energy technologies offered by other industrialized nations actually originated in the United States, the Chinese would prefer to buy from the "teacher," rather than from the "students." However, the "students" are aggressively moving forward with advancements in nuclear technology on their own. Personal communication from Regis Matzie, Vice President, Engineering ABB-CE Nuclear Systems, July 1997.

access to relatively low-interest, government-backed loans, it is imperative that U.S. suppliers have similar access. It will do little good for U.S. suppliers to offer competitive prices for design and manufacturing services, if the overall costs to the buyer are not competitive because of higher financing costs. Such support, however, should be restricted to sales to countries that have signed the Nuclear Nonproliferation Treaty (NPT), in so far as this strategy does not contravene U.S. nonproliferation goals. It also would be useful for the government to pursue nonproliferation agreements aggressively with all trading partners.

**Issues in the United States**

The principal problems currently blocking nuclear power's acceptability and future in the United States are disposal of nuclear waste; cost of new plants, plant modifications, and upgrades, which are made more critical by utility deregulation; concerns about safety and proliferation; and how to keep current plants in operation. These problems define the context for nuclear fission R&D in the coming years.

**Nuclear Waste**

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. The United States actually is farther along than any other country[22] in that in 1987 Congress selected Yucca Mountain[23] in Nevada as the site. After Congress selected the site, the DOE program office, the Office of Civilian Radioactive Waste Management (RW, usually referred to as OCRWM), has concentrated on developing the information necessary to license that site. Currently, the DOE program is based on a schedule to apply for a license from the NRC in 2002.

OCRWM received $382 million in FY 1997 and DOE requested $380 million for FY 1998. Of the $380 million, $325 million is for Yucca Mountain site characterization; $10 million is for nuclear waste acceptance, storage, and transport; and $45 million is for program management.[24] 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 the weapons production sites. The commercial program is funded by the Nuclear Waste Disposal Fund (NWDF), which collects a fee of 1 mil/kWh on the generation of electricity from nuclear power plants.[25] In FY 1997, $200 million came from the appropriation for defense nuclear waste disposal and $182 million from the NWDF. The FY 1998 budget requested $190 million from each source, but Congress has reduced to $160 million the amount appropriated from the NWDF.

The magnitude of this effort can be gauged by its cost of more than $4 billion through 1996.[26] However, the "host" state continues to mount a major effort to halt the project, and Congress has become disenchanted with DOE's performance and cut back the allowed spending. The regulatory barriers to developing the site remain both uncertain and high. The Environmental Protection Agency (EPA) has not

[22]In France, a 1991 law requires the government to select a site in 2006. Remy Carle, Deputy General Manager, Electricité de France (retired) and President, World Association of Nuclear Operators, presentation to PCAST Nuclear Task Force, San Diego, CA., 27 June 1997.
[23]The 1987 Act directed the Secretary of Energy to stop examining all sites other than Yucca Mountain.
[24]FY 1998 DOE Budget Request to Congress, Summary Budget and Overview, pp. 140-144.
[25]In FY 1997, this fee brought in $649 million; it is expected to bring in $655 million in 1998 and about the same amount each year, then diminishing as reactors begin shutting down.
[26]Approximately twice this amount has been collected already from nuclear power utilities, i.e., from their ratepayers. The difference between what has gone to the Yucca Mountain effort and what has been collected was sent to the U.S. Treasury and therefore helped reduce the budget deficit.

yet published for comment the standards that must be met at Yucca Mountain, and, consequently, the NRC has not published the regulations that DOE must satisfy to get a license for the repository. The date for opening the repository continues to slip, from the original date of 1998 to the latest official date of 2010. It will take aggressive action, careful management, and resolution of the disputes with Nevada and Congress to keep the schedule from slipping into the 2015 to 2020 time frame, or beyond. The next major DOE step is to publish a viability assessment, due in September 1998.

At the same time, nuclear utilities are running out of room to store their spent fuel. A Federal law requires the DOE to dispose of this fuel beginning in 1998,[27] and a Federal court ruled in 1996, in a decision not appealed by the Administration, that DOE must do so. However, DOE has no place to put the spent fuel, but the Administration has promised to veto any legislation containing a provision to require constructing an interim storage facility until the decision is made to proceed with Yucca Mountain.[28] The issue is complicated by congressional insistence that such a facility be constructed adjacent to Yucca Mountain.

In the last 6 years, the Administration has not asked Congress to allow DOE to study an interim Federal storage site.[29] The Administration also has not put in place the process to be followed once the 1998 viability assessment for Yucca Mountain is received.[30] That assessment is unlikely to give a clear yes-no, but, more likely, will present the results of years of characterization, and let the readers draw conclusions about site suitability. **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.**

DOE also funds through its Office of Nuclear Energy, Science and Technology (NE) a program to develop electrometallurgical treatment of DOE spent fuels from EBR-II — the shutdown Experimental Breeder Reactor in Idaho. This program, labeled Nuclear Technology R&D in the NE budget, received $20 million in FY 1997. The FY 1998 budget requested $25 million. Congress reduced the amount to $12 million plus $8 million in termination costs. The results of this R&D are not expected to be applicable to treating commercial nuclear waste.

### Costs of Plant Construction and Operation and the Effects of Utility Deregulation

In the United States, nuclear plant operating licenses expire 40 years after issue, with one 20-year extension allowed, if approved by the NRC.[31] Figure E.2[32] shows the number of U.S. nuclear plants whose licenses will expire, by year. As can be seen, within the next few decades, many plant licenses will expire. However, the 40-year lifetime is not based on engineering analysis,[33] and life extension should be

[27]The 1982 Waste Policy Act included the following: "In return for the payment of fees established by this section, the Secretary, beginning not later than January 31, 1998, will dispose of the high-level radioactive waste or spent nuclear fuel involved..." (Section 302, Paragraph B).

[28]The House Commerce Subcommittee on Energy and Power recently approved a bill directing the DOE to construct an interim storage facility for HLW at Yucca Mountain by 2002. Congressional Representative Markey (D-MA) is reported to have said, regarding this bill, that the administration "has agreed to uphold its veto threat." *The Energy Daily*, 1 August 1997, p. 4.

[29]Presentation by Daniel Dreyfus, former director of DOE's Office of Civilian Radioactive Waste Management, to the PCAST Nuclear Task Force, 14 July 1997.

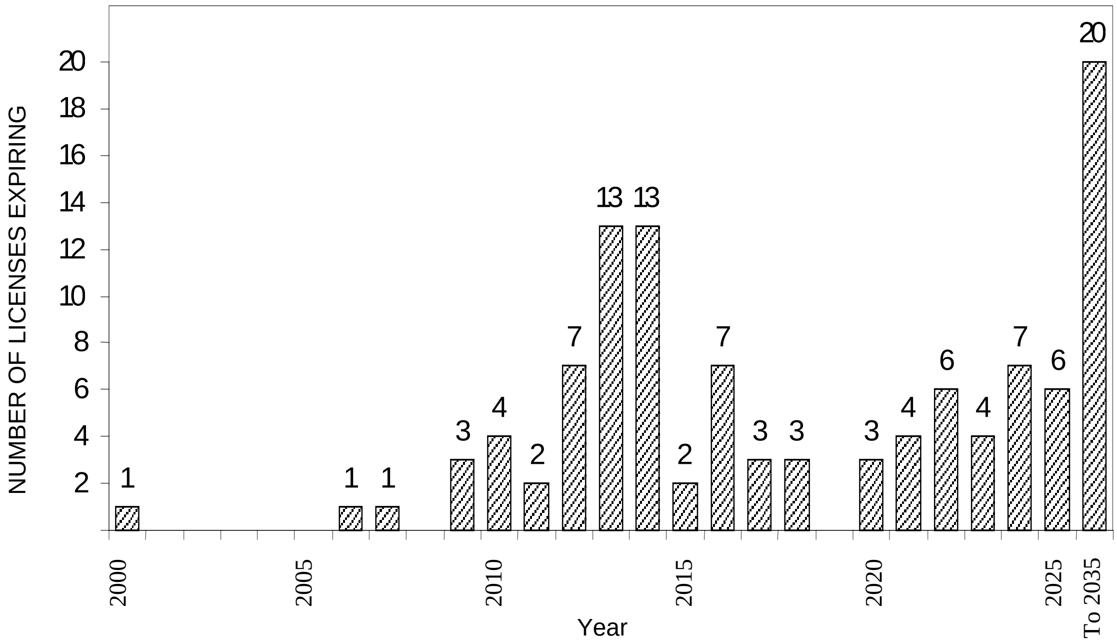
[30]Ibid.

[31]In many other countries, there is no predetermined limit on operating life. In France, plants are subject to an extensive outage review and an update of their safety analysis every 10 years: R. Carle, op. cit. In Japan, a periodic inspection is performed annually and a periodic safety review is performed every ten years: M. Yoshikawa, op. cit. In Germany, most companies plan on operating their plants more than 40 years: Dieter Brosche, Director, Head of Division Nuclear Power Plants, Bayernwerk AG, presentation to the Nuclear Task Force, San Diego, CA., 25 June 1997.

[32]NRC, *United States Nuclear Regulatory Commission Information Digest*, 1997 Edition, NUREG-1350, Vol. 9, p. 47, May 1997.

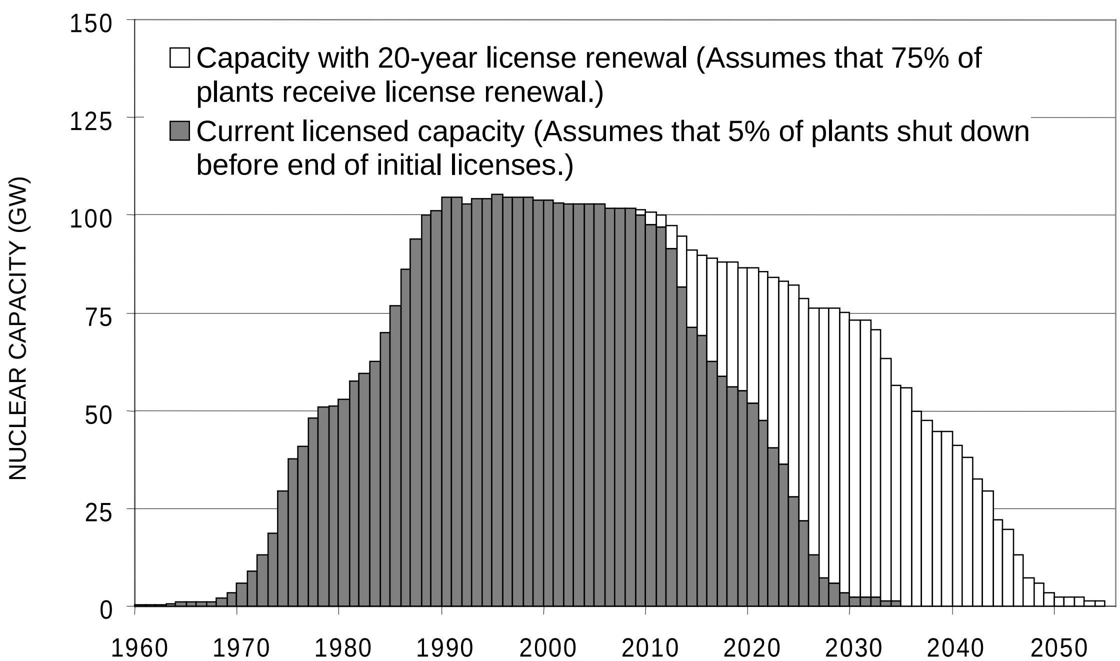
[33]It was set in the Atomic Energy Act.

possible for many plants. Figure E.3[34] shows the effect on U.S. nuclear generating capacity if 75 percent of the plants have their licenses extended.




*Source: Nuclear Regulatory Commission 1997 Information Digest. (Assumes licensees recover the time period between granting of construction permits and operating licenses).*

**Figure E.2: Number of U.S. commercial nuclear power reactor operating licenses, by year of expiration.**



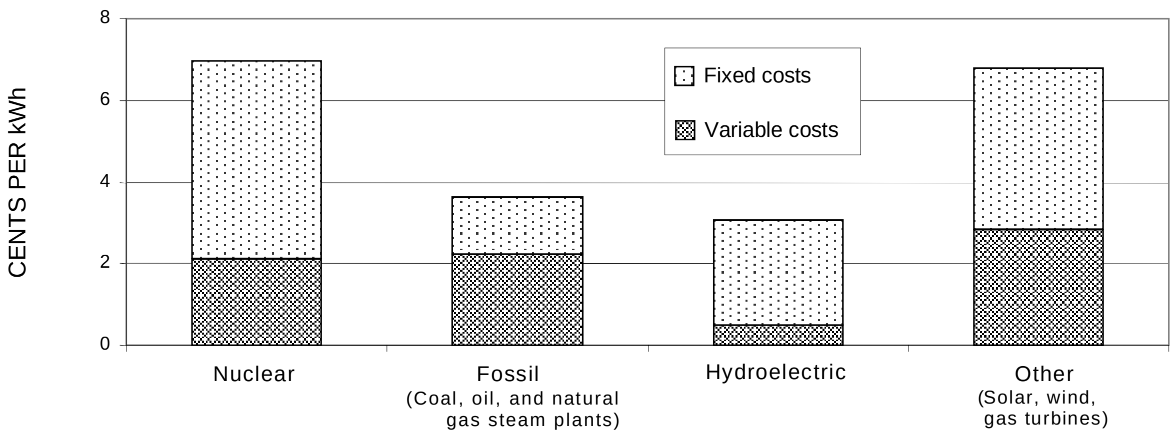

*Source: DOE Office of Nuclear Energy, Science and Technology.*

[34]DOE Office of Nuclear Energy, Science and Technology, “Nuclear Energy Security,” 15 June 1997, p. 2.

**Figure E.3: Projected U.S. nuclear generating capacity.**

Plants do age and, for some parts (steam generators being the most notable and expensive example), aging has been far more rapid than originally expected. Nevertheless, with good maintenance, and replacement of parts (such as steam generators), utilities have been expected to extend plant licenses. Two major obstacles have arisen for this scenario: utility deregulation and the NRC's untried relicensing procedures.

Deregulation of the electric utility industry is occurring more rapidly than most predictions. 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. Some nuclear plants are not cost competitive now, primarily due to the initial construction costs. Some are competitive: for one utility, its four nuclear plants are the cheapest electricity on its grid, and they are one-third as expensive as coal.[35] As Figure E.4[36] shows, nuclear power has low operating costs. Its high life-cycle costs are driven by the large capital costs associated with construction, usually because construction took, on average, over 10 years.[37]




*Data source: Richard H. Hilt, Measuring the Competition: Operating Cost Profiles for U.S. Investor-Owned Utilities – 1995, Utility Data Institute/McGraw-Hill, Washington, D.C., 1996.*

**Figure E.4: Cost of power generation.**

Nuclear plants that cannot compete economically will be closed. However, not all nuclear power will be noncompetitive. One financial analyst believes[38] "that there is proof that efficient, safe, well-operated nuclear plants are indeed viable, *profitable* assets" (emphasis in original). Economic competition will place different strains on nuclear plants than on fossil plants. A coal plant can be mothballed for a few hundred thousand dollars per year. The costs for a nuclear plant to shut down but still be able to be restarted are much higher, because a larger work force is needed on site, for example, to

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[35]Robert Saunders, Vice President for Nuclear Energy and Services, Virginia Power, presentation to the Nuclear Task Force, Washington, D.C., 19 May 1997. The two-unit Surry plant was the lowest cost U.S. nuclear plant, with variable production costs of 1.145 cents/kWh, and the two-unit North Anna plant was second at 1.265 cents/kWh. "U.S. Plants Continue to Improve," Utility Data Institute news release, 17 June 1997.

[36]Adapted from *New York Times*, 3 January 1997, p. C1.

[37]From 1980 through 1984, average construction time was 10.1 years for 17 plants, and from 1985 through 1989 it was 12.2 years, for 30 plants. National Research Council, *Nuclear Power, Technical and Institutional Options for the Future*, National Academy Press, 1992, p. 33.

[38]Judith B. Sack, "Faith, Hope, and Charity: A Wall Street Perspective on the Nuclear Industry," *International Investment Research*, 19 June 1997.

safeguard the spent and fresh fuel present. A nuclear plant that cannot be run will be shut down permanently.[39]

Many nuclear utilities have large capital investments, which they had planned to pay off over the 40-year life of the plants. If these plants close early, these utilities will have large "stranded costs"[40] including: (1) unrecovered capital costs, as much as $60 to $70 billion in total; and (2) decommissioning costs, which the Nuclear Energy Institute (NEI) estimates to be $40 to $45 billion, in total, of which only $8 to $9 billion has been collected so far.

States are now negotiating arrangements with utilities to write down these costs.[41] Such early write-downs either will make the nuclear plants more competitive on an add-in basis or allow them to be shut down soon.

One alternative being considered by some nuclear utilities is to sell the nuclear units. However, getting regulatory approval for license transfer may be quite lengthy. If a nuclear utility intends to continue to operate a nuclear plant, it will consider the probability and ease of successful relicensing. This consideration will come into play every time expensive repairs are seen to be necessary to continue current operation. If the owners are concerned the plant cannot be relicensed, it is unlikely that they will invest substantial funds to upgrade the plant for the few years remaining on the license.

Because no utility has yet to file for license renewal, the NRC's procedures for relicensing are untested and, therefore, uncertain. The NRC[42] is convinced that its procedures are not an obstacle, and it estimates that license renewal review will take 3 years. The NRC does not believe any plant will shut down rather than apply for license renewal, although it admits that the "industry is nervous." 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 NRC 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.[43] 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.[44]

While stating that relicensing will be feasible, one utility representative said that regulation is the biggest uncertainty for the future of nuclear power, which, at the moment, looks "grim."[45] A general industry picture is that regulations must be predictable, that the regulatory question is the big uncertainty for the future of nuclear power in this country, and that the regulatory process currently is "a wild card."[46]

Another facet of the U.S. regulatory system is that the NRC, by law, must recover all of its costs from licensees. Thus, a vendor wishing to get NRC approval for a new design must be able to fund the

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[39] E. Thomas Boulette, Senior Vice President, Nuclear, Boston Edison, presentation to the PCAST Nuclear Task Force, 19 May 1997.

[40] Linn Draper, CEO, American Electric Power, presentation at the Nuclear Energy Assembly, Washington, D.C., 30 May 1997.

[41] For example, the California Public Utilities Commission allowed Pacific Gas & Electric to charge higher rates for five years to recover $3.3 billion relating to the Diablo Canyon nuclear plants. However, starting in 2002, rates will be market-based. *Megawatt/Week*, 26 May 1997, p. 5.

[42] Marylee Slosson, Acting Director, Division of Reactor Program Management, NRC, presentation to the PCAST Nuclear Task Force, Washington, D.C., 19 May 1997.

[43] Boulette, op. cit.

[44] Charles Jackson, Manager Nuclear Safety and Licensing, Consolidated Edison, presentation to the PCAST Nuclear Task Force, Washington, D.C., 19 May 1997.

[45] Saunders, op. cit.

[46] W. E. Cummins, Project Manager AP600 First-of-a-Kind Engineering, Westinghouse, presentation to the PCAST Nuclear Task Force, San Diego, CA., 26 June 1997.

NRC staff reviewing the application, its own staff, and the facilities to develop the information to answer the NRC's questions. Westinghouse estimates that to design and obtain NRC certification for the AP600 design will cost altogether about $230 million. Of this amount, about $30 million will be paid to NRC. DOE provided about $83 million and $35 million came from the utilities. Westinghouse and its industrial partners put up the remainder.[47] For final Design Approval of GE's ABWR, DOE contributed $50 million, GE and its partners contributed $50 million, and the NRC was paid $15 to $18 million. To develop the design of the ABWR previously had cost $250 million, funded by GE along with Japanese utilities, vendors, and government, with GE providing about 10 percent.[48]

The licensing process is frequently criticized as the reason for the lengthy construction times in this country. Certainly some U.S. plants have taken many years to build, while others have been built in as little as 5 years. There are many reasons that some plants took longer to build than others, and protracted NRC proceedings is only one reason. The opposition to nuclear power in this country led to contested proceedings at nearly every step of the permitting process, whether it was a simple application before a town board for a transmission line to cross a street or a cooling-water discharge permit application before a regional office of the EPA.

Utility actions also contributed. At least one utility slowed construction activity because of its own financial limitations. In other cases, poor management of the construction process contributed to delays in completion. For whatever the reasons, lengthening licensing times significantly increased the costs of these already capital-intensive units. The high interest rates prevalent in the 1980s exacerbated the problem. The result has been that U.S. construction times, and, therefore, construction costs, have been much larger than those in other countries, where U.S.-designed plants have been built in much shorter times. GE's ABWR recently was built in Japan in less than 5 years; ABB-CE's plants are being built in South Korea in 5 years or less.[49] Other designs also have been built in short times; the last CANDU built in South Korea took less than 5 years to get into operation.[50] Figure E.5 shows that the average construction time for power reactors in the United States more than doubled between 1961 and 1990, while in Japan it remained reasonably constant and under 5 years.[51]

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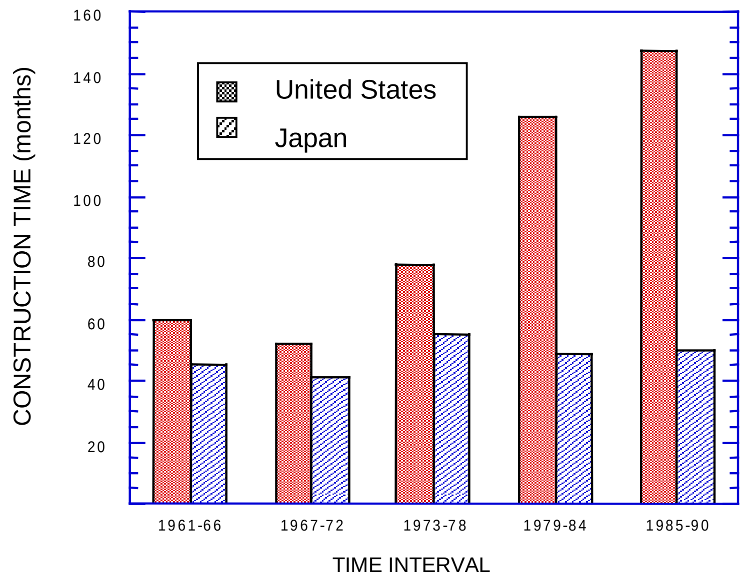
[47]Ibid.

[48]Steven A. Hucik, General Manager, Nuclear Plant Projects, General Electric, presentation to the PCAST Nuclear Task Force, San Diego, CA., 26 June 1997. Phone conversation: John Redding, GE, 23 September 1997.

[49]IAEA, *Nuclear Power Reactors in the World*, op. cit. [ref #2].

[50]Kugler, op. cit.

[51]Data from U.S. Council for Energy Awareness, *Advanced Design Nuclear Power Plants: Competitive, Economical Electricity, An Analysis of the Costs of Electricity from Coal, Gas, and Nuclear Power Plants,* 1992; Figure from David Bodansky, op. cit., p. 309.




*Source: D. Bodansky, Nuclear Energy: Principles, Practices and Prospects (AIP Press, 1996). Reprinted by permission of Springer-Verlag, New York.*

**Figure E.5: Construction time for reactors in the United States and Japan, 1961-1990.**

For nuclear power to be cost competitive, operating costs must be kept low. For new nuclear plants to be even considered, the capital costs must be significantly lower than recent averages, which means, in particular, cutting construction times by at least 50 percent, to no more than 5 years. The main DOE effort in nuclear energy for several years has been on engineering to complete work on three Advanced Light Water Reactor (ALWR) designs so they could get NRC approval. In this effort, the DOE worked with the Electric Power Research Institute (EPRI), the Advanced Reactor Corporation, and the vendors. This R&D focus was based on the belief that there would be an order for a new nuclear plant in the United States within the next 7 to 10 years, [52] which is not likely. The ALWR designs are intended to be easier to build and cheaper to operate, based on greatly reduced amounts of piping, valves, pumps, and cables. Probabilistic risk analysis (PRA) also indicated that these reactors would be safer to operate. One design, the Westinghouse AP600, is of a class labeled "passively safe," since it does not require active systems, such as pumps, to operate to cool the reactor in case of an accident.

NRC design certification was achieved in 1997 for two of the designs, the ABB-CE System 80+ and GE's ABWR. The AP600 is expected to receive Design Certification by 2000.[53] DOE funded approximately $240 million of the design certification program; industry furnished $360 million. In addition, DOE and industry jointly funded First-of-a-Kind Engineering (FOAKE) for the ABWR and AP600 designs. Industry paid about $170 million of the $270 million total. The FY 1997 budget included $34 million for the ALWR program, its last year at congressional direction.

Nuclear Regulatory Commission. The NRC has been subject to criticism from many sides throughout its existence. Sometimes the environmental community has criticized the agency for being too close to the industry or for making the hearing process so legalistic that ordinary citizens could not participate. Other times, industry has criticized the agency for not focusing on real safety issues and for getting bogged down in regulations and overly legalistic processes: "[t]he key problem is that the licensing

[52]Terry Lash, NE Director, presentation to the PCAST Nuclear Task Force, Washington, D.C., 7 May 1997.

[53]"Design Certification Rulemaking [for the Westinghouse AP600] is expected to occur in the FY 1998 through FY 2000 time frame." Letter from Marylee Slosson, Acting Director, NRC Division of Reactor Program Management, to Beverly Hartline, 21 July 1997.

system in this country is so inefficient that it takes a dozen to 20 years, and exorbitant costs to build a plant here...Under present circumstances, no sensible person or organization would propose to initiate a new nuclear power project in this country."[54]

> *During the rapid growth of nuclear power in the late 1960's, cost was not a primary concern of either the government or industry...Since cost was not a major concern, the U.S. established many safety regulations or standards which may, at times, have contributed little to safety, and sometimes even had an adverse effect, but increased cost substantially...*[55]

It is not only the industry that has suggested it is time to examine how the NRC functions. Recently, an NRC Commissioner said:

> *…the present regulatory system, although adequate from the viewpoint of protecting workers and the public from actual radiological risks, is not satisfactory nor does it serve the industry well, the NRC, or most importantly, the American public. Licensees see the present framework as intrusive; the NRC has to work with its gaps and inconsistencies; and the American public ultimately has to bear the burden of cumbersome and costly activities. The reality is that the system has grown too much, uncertainties have remained in the process and new ones have been added. We are applying 30-, 25-, 20-, 15-year-old regulations, inspections and assessment modules to a complex and changed industry.*[56]

In the report accompanying the FY 1998 Energy and Water Development Appropriations bill, the Senate Appropriations Committee wrote that it "encourages the NRC to continue to give special attention to replacing unnecessary prescriptive requirements and guidance with performance-based requirements and guidance," and that the committee "believes that a performance-based regulatory approach can substantially improve the regulatory process and result in a more effective and efficient use of both the NRC and licensee resources."[57]

An example of the difficulty the NRC has been having in developing a regulatory approach to new technology is that of instrumentation and control (I&C). A recent National Research Council report described the current NRC research program in this area as "a disjointed collection of studies lacking an underlying strategy and in some specific cases pursuing topics of questionable worth."[58] An earlier report noted that "advisory committees, including the Advisory Committee on Reactor Safeguards and the Nuclear Safety Research Review Committee, have expressed concern that the NRC may be lagging behind in its understanding of digital I&C systems..."[59]

To avoid becoming a non-safety-related obstacle to continued operation of U.S. nuclear power plants, the NRC will have to adjust to the demands of a deregulated utility environment. One step would be to implement risk- and performance-based regulation, a goal advocated by the agency's leaders but not

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[54]Letter to John Ahearne from Bertram Wolfe, former head of GE Nuclear, 29 May 1997.

[55]Letter to John Ahearne from C. K. Chou, Deputy Associate Director, Fission Energy & Systems Safety Program, Lawrence Livermore National Laboratory, 20 June 1997.

[56]Commissioner Nils J. Diaz, "Nuclear Power and the 21st Century: Establishing a Regulatory Framework for a Mature Industry," speech given at the Nuclear Energy Assembly, Washington, D.C., 30 May 1997.

[57]As quoted in *National Radioactive Waste Management Exchange*, 25 July 1997, p. 6.

[58]National Research Council, *Digital Instrumentation and Control Systems in Nuclear Power Plants, Safety and Reliability Issues (Final Report)*, National Academy Press, 1997, p. 20.

[59]National Research Council, *Digital Instrumentation and Control Systems in Nuclear Power Plants, Safety and Reliability Issues*, National Academy Press, 1995, p. 2.

yet implemented at the staff levels. Further, **it would be beneficial for the Congress to reexamine the role, functioning, and funding of the NRC, to ensure the effectiveness of that agency and its relicensing process in the evolving deregulated utility environment.** The goal is to ensure safe operation of plants in a manner adapted to the needs of utility deregulation, so that the NRC does not become a constraint or impose a cost burden, beyond what is necessary for safety.

**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 the United States, the 1979 accident at Three Mile Island, although it did not release any significant amount of radiation, 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 few nuclear power accidents in the United States and none leading to radiation-related, off-site health effects. In 1992, a National Research Council study that reviewed nuclear power in the United States concluded as follows:

- *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 improved.*

- *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.*[60]

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 Nuclear Energy Security (NES) initiative contained $9 million for R&D on operating-reactor safety. NE has also supported R&D on the high-temperature gas reactor (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. The United States Agency for International Development (USAID) 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. Only $35 million was appropriated.

**Proliferation**

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[60] National Research Council, *Nuclear Power: Technical and Institutional Options for the Future*, National Academy Press, 1992, p. 69.

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

The link between nuclear-power programs and nuclear-weapons development has been debated for nearly a half-century, without a consensus emerging. Defenders of nuclear power argue that no country with nuclear weapons developed these by using a nuclear-power program. Opponents argue that reactor-grade plutonium, found in spent fuel, is usable in nuclear weapons. Furthermore, breeder programs, in particular those associated with recycling operations, make separated plutonium more accessible.

Without taking sides on these arguments, the Task Force observes that:

- Los Alamos weapons designer Carson Mark noted many years ago that a nuclear power program trains people in the handling of radioactive materials and in the use of appropriate instrumentation, both of which are essential for a weapons program.

- The proliferation issue must be addressed directly if proliferation-related objections to nuclear power are to be treated substantively.

In discussions with vendors, national laboratories, and others, the Task Force did not find 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.[61] Other suggestions for protecting against proliferation are not new:

- An improved international control regime, led by the IAEA. While there seems to be increased international support for the IAEA, it remains an agency with limited enforcement powers. The outgoing Director General, Hans Blix, often said that the principal role of the IAEA is to provide assurance that countries are complying with the NPT and to rely on the international community for action, such as imposing sanctions, if the IAEA concludes a country has violated the NPT.

- The "containment-in-a-pellet" approach of the HTGR, such as sponsored by General Atomics (GA). The ceramic triple coating makes reprocessing more difficult, with no technology currently developed to do so (but no incentive either). A weak point is that the fuel (at about 19.8 percent enrichment) is just marginally below highly enriched uranium (HEU). The HTGR has not been supported by the utility community on the grounds that it is untried and, at least in the past, projected to be not cost competitive. The current GA concept eliminates steam generators and uses hot helium to drive the turbines (Brayton cycle). GA estimates substantially increased efficiency and lower costs with this conceptual design.[62] The coated pellet also provides a substantial safety feature against severe accidents.

- The IFR. This program was based on a liquid metal reactor (LMR) and electrometallurgical reprocessing, with the spent fuel recycled in the same facility after reprocessing. Thus, it was

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[61]Alvin Radkowsky, who was Admiral Rickover's chief scientist, has proposed a design which he writes "is completely nonproliferative for all practical purposes." He estimates that the nuclear yield from plutonium in his fuel would be one-half to one-third less than that from plutonium in PWR fuel and would have a high probability of a fizzle yield. A. Radkowsky and A. Galperin, "The Nonproliferative Light Water Reactor, A New Approach to BWR Core Technology," submitted to *Nuclear News*. Radkowsky reports that an improved design, RTF (Radkowsky Thorium Fuel), can be used in standard LWRs with little plant modification. Fax from Alvin Radkowsky to John Ahearne, 5 August 1997, and *Science and Global Security*, Vol. 6, pp. 265-290, 1997.

[62]Presentations by Linden Blue and Walter Simon of GA to the Nuclear Task Force, San Diego, CA., 26 June 1997.

planned to operate as a closed cycle. The IFR R&D program, at Argonne National Laboratory, was canceled by this Administration on the grounds that breeders and nuclear fuel recycling are major proliferation risks.

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 $4 million in FY 1997, and DOE requested the same amount in FY 1998. No funds were appropriated.

A related issue has developed around the proposed U.S. program to address the growing amount of plutonium from dismantled nuclear weapons in Russia and the United States. The program, announced last December, includes manufacturing reactor fuel (mixed uranium and plutonium, MOX) and using it in commercial reactors. Some members of the U.S. nonproliferation community have mounted a strong campaign to oppose this approach. While perhaps not directly a part of an energy R&D discussion, the issue will be a part of any debate on the Administration's nuclear energy policy. The Task Force supports the use of MOX as the preferred method to remove excess weapons plutonium from ready access. The MOX program does not involve reprocessing, does not use commercial reactors to make nuclear weapons material but uses them to destroy nuclear weapons material, and is the program that can lead to joint U.S.-Russian weapons plutonium reduction.

**Operating Reactors**

A recent study concluded: "Unless there is an unforeseen change in the institutional, economic, social, and political environment for nuclear power in the United States, nuclear power will gradually be phased out early in the next century as plants retire. However, there does not seem to be any sound basis for forecasting which plants, or how many, will retire when their licenses expire, which will retire 'early' due to economic and social pressures, and which will extend their operating time through license renewals."[63]

Extending the operation of nuclear plants will make it easier to meet GHG emission goals. Therefore, in the near term, it may be in the national interest to keep safe nuclear plants operating as long as possible. Government action may be required to do so, if the economics of the deregulated electric-utility industry lead owners to choose premature shutdown of their nuclear plants, in favor of replacement by fossil plants. Programs to retain currently operating plants will have immediate benefits to U.S. GHG emissions, thereby providing time for improved nuclear and other low- or no-carbon electric generation technologies to be developed.

DOE has a responsibility for protecting the nation's energy supply. Although nuclear power is a mature technology, providing over 20 percent of the electricity in the United States, 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 in 1996 at the Marble Hill reactor. 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 its FY 1998 NES initiative, DOE requested $39.8 million, which included $8.5 million for advanced controls and technology, $8.5 million for extended fuel burnup, and $9 million to address component safety. Congress zeroed the NES program. Whereas the program was sound, in principle, in trying to maintain the nuclear option, it appeared to provide inappropriate support for a mature industry.[64]

Several areas need work to improve plant operations. Much will be done by the industry. Some will need support from the Federal government. For example, U.S. commercial plants have little in the way of digital I&C systems. Among the problems that have prevented the introduction of such systems are the cost and the difficulty of introducing control-system changes into an operating plant,[65] the need to retrain operators, and the difficulties NRC has had in developing a regulatory regime for digital I&C. After several years of joint NRC-industry efforts to decide how to introduce digital I&C safely into nuclear power plants, the NRC requested the National Research Council to conduct a study. The National Research Council was asked to define the important safety and reliability issues associated with digital I&C and to identify criteria for review and acceptance of this technology in both retrofitted reactors and new reactors of advanced design. In its final report, the National Research Council wrote that "there is substantial further work to be done,"[66] concluding that "the regulatory response to the development and implementation of digital I&C upgrades in nuclear plants has proceeded in a manner that resulted in some degree of confusion and uncertainty within the licensee community…This

[63]Rochlin, op. cit., p. 38.

[64]United States Public Interest Research Group (USPIRG) described this program as "a 'new' nuclear boondoggle," demonstrating that "DOE has no commitment to cutting the nuclear pork from its budget." Testimony of Anna Aurilio before the House Science Subcommittee on Energy and Environment, 9 April 1997.

[65]Several possible approaches for less costly and simpler improvements have been proposed, including wireless sensors. Personal communication from Professor Robert Uhrig, University of Tennessee, 1997.

[66]National Research Council, *Digital Instrumentation and Control Systems in Nuclear Power Plants, Safety and Reliability Issues (Final Report)*, National Academy Press, 1997, p. 3.

uncertainty and the resultant incremental cost has been a major contributor to the reluctance on the part of utilities in proceeding with digital upgrades."[67] The Council recommended further work on the issues because "digital I&C systems offer powerful capabilities that can, however, affect nuclear power plant safety..."[68]

## Funding for Fission Energy R&D

Funding for nuclear energy research in the United States comes from the Federal government and industry. Federal funding originally was provided through the Atomic Energy Commission (AEC). In 1975, the AEC was split into the NRC and the Energy Research and Development Administration (ERDA). In 1977, ERDA was combined with several other parts of the Federal government to form DOE.

DOE national laboratories are among the primary performers of R&D in nuclear-energy-related fields, whether that research is sponsored by DOE programs, NRC, 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 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 I&C, nuclear fuels, and computational models and analysis tools.[69] Some DOE national laboratories also invest "discretionary funds"[70] 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 between the DOE program offices sponsoring the work.

### Department of Energy

At least eight DOE program offices support R&D applicable or related to nuclear energy: NE, OCRWM, Defense Programs (DP), the Office of Nonproliferation and National Security (NN), the Office of Naval Reactors (NR), the Office of Fissile Materials Disposition (MD), Environmental Management (EM), and the Office of Energy Research (ER). In the case of ER, some basic research on materials and chemistry is 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 OCRWM — the specific levels of investment that are relevant to nuclear power. Thus, the Task Force 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.

Not all NE R&D funding addresses issues associated with nuclear power. Over many years, DOE and its predecessor agencies have funded research in and produced radioisotopes for use in industry, research, and medicine. As an example of the importance of radioisotopes in medicine, at least half of

[67] Ibid., p. 17.
[68] Ibid., p. 22.
[69] Some examples sponsored by DP and EM at DOE's defense laboratories are summarized by E. A. Arthur, ed., "Technology Development Examples Applicable to Nuclear Energy, and Fuel Cycle Improvement," Los Alamos National Laboratory, LA-UR-97-2989, July 1997.
[70] 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.

cancer patients receive radiation therapy and one-third of hospital patients use radioisotopes in some way.[71] Other nuclear energy funding has supported R&D on space-power systems; development of lower enriched uranium cores for research reactors to replace proliferation-sensitive highly enriched fuel; and, more recently, assistance to improve the safety of nuclear reactors in the former Soviet Union. But, over the years, most of the funding has supported R&D for large-scale commercial nuclear power.

Furthermore, it is widely believed that support for nuclear energy has dominated Federal energy R&D. This is true for most years since 1985, as seen in Figure E.6.[72] But when funding is disaggregated into fusion and specific types of fission technologies, the facts do not support three frequently stated misconceptions concerning Federal support for nuclear power R&D.

- Misconception: ***Federal funding for nuclear energy has been dominated by funding for LWRs, the type of reactor used for all currently operating U.S. commercial nuclear plants.*** Figure E.7[73] shows that more than half of the fission R&D funding supported development of the liquid metal project — the breeder reactor. From 1948 through 1997, in as-spent dollars, Federal R&D funding amounted to $6.8 billion for the LMR and $7.5 billion for all breeder R&D. From 1958 through 1997, $2.0 billion was invested in LWR R&D. Thus, breeder R&D received over 70 percent of the funding for R&D targeting three types of reactors — LWRs, breeders, and HTGR.[74] Figure E.8 shows that fusion research funding was comparable to that for the LMR from 1979 to 1984.

- Misconception: ***Federal funding for nuclear power R&D continued to grow until reduced by the Clinton Administration***. Figure E.9 shows that funding had already dropped significantly in 1985 with the termination of the Clinch River Breeder reactor project, stabilized in 1987, and has fallen further in the current Administration.

- Misconception: ***The Federal government has not supported development of the HTGR.*** Actually, from 1966 through 1995, Federal funding for the HTGR amounted to $730 million (as-spent dollars), and from 1979 through 1986, annual funding for the HTGR exceeded that for the LWR. Over the years GA has invested a comparable amount ($740 million) in HTGR development and continues to work on the concept.[75]

Figure E.10[76] shows the allocation of funding in the proposed FY 1998 DOE energy resources R&D budget request. Of the total, nuclear energy research comprises 3.3 percent ($46 million), which consists of a $6 million university program and the $40 million nuclear energy R&D initiative, NES. The university program includes fellowships for students and fuel for university research reactors.

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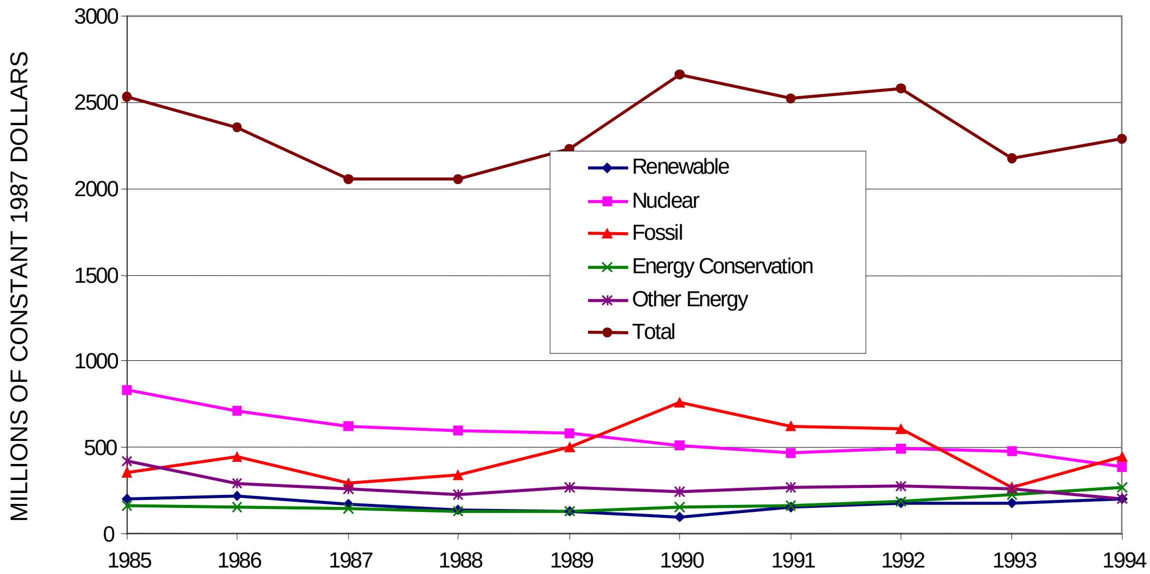
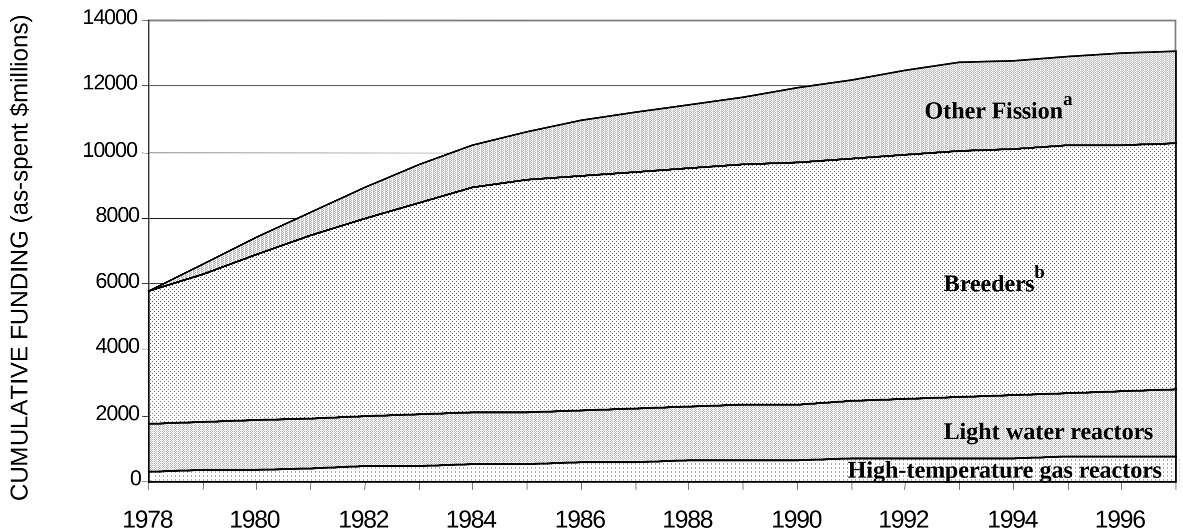
[71]Secretary of Energy Advisory Board, *Energy R&D: Shaping our Nation's Future in a Competitive World*, June 1995, usually referred to as the "Yergin Report," p. 34.
[72]J. J. Dooley, "Trends in US Private -Sector Energy R&D Funding 1985-1994," PNNL-11295, September 1996, p. A-8.
[73]Figures E.7 to E.11 are in as-spent dollars, not 1997 constant dollars as in the main report.
[74]DOE, Office of Nuclear Energy, Science and Technology; communication to the Nuclear Task Force, July 1997.
[75]Fax from Linden Blue, GA Vice Chairman, to John Ahearne/Beverly Hartline, 21 July 1997.
[76]Presented to the PCAST Energy R&D Panel by C. Kyle Simpson, Senior Policy Advisor, Office of the Secretary, 27 March 1997.




*Source: J. J. Dooley, Trends in US Private-Sector Energy R&D Funding 1985-1994, Pacific Northwest National Laboratory, PNNL-11295, Washington, D.C., September, 1996.*

**Figure E.6: Federal support for energy R&D 1985-1994.**

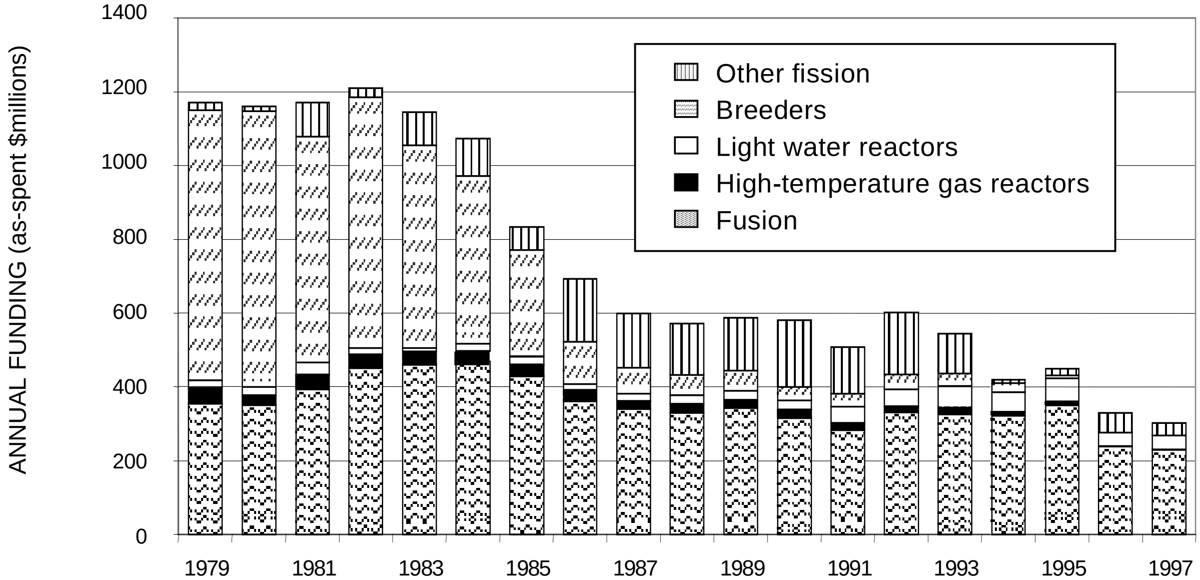



*Source: DOE Chief Financial Officer and Office of Nuclear Energy, Science and Technology.*

**Figure E.7: Cumulative DOE funding for R&D on fission power technologies.**

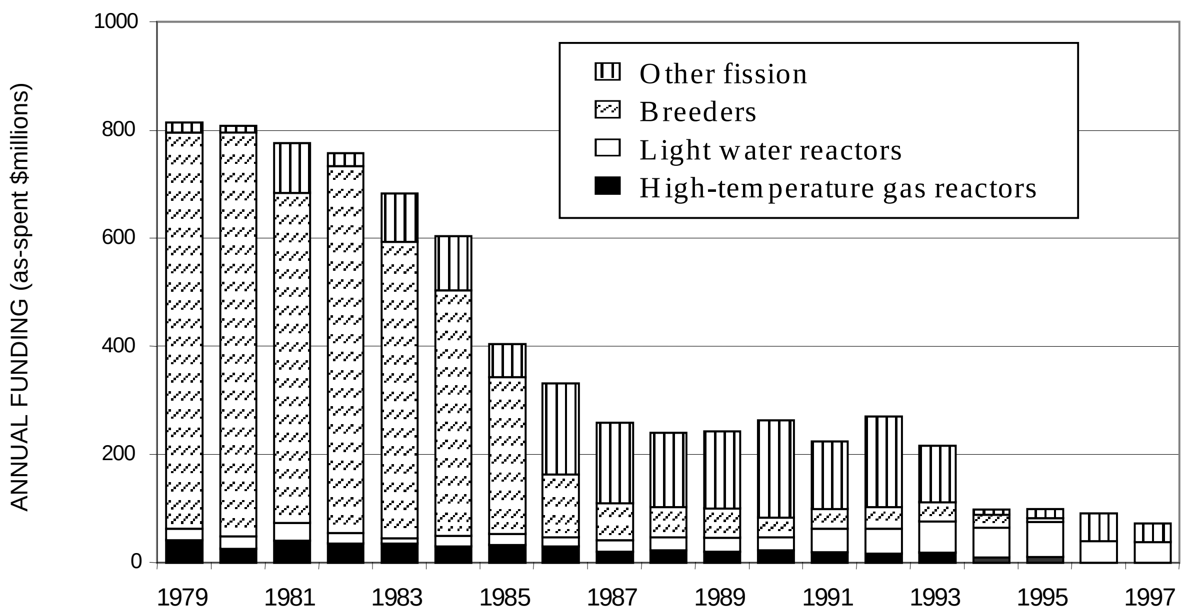
[a]Funding before 1979 not included.

[b]Before 1979 includes only liquid metal.



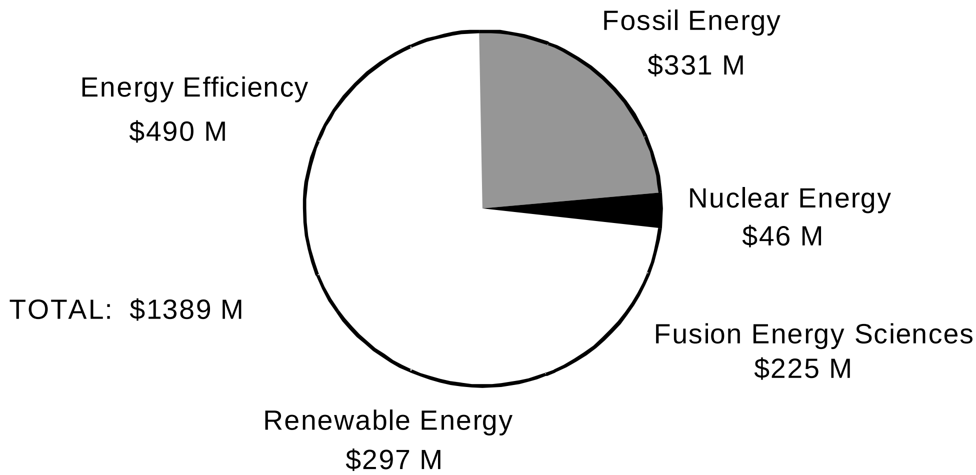

*Source: Fission: DOE Chief Financial Officer and Office of Nuclear Energy, Science and Technology.*
*Fusion: DOE Energy Resources Board.*

**Figure E.8: Funding history for fission power R&D and fusion R&D, in as-spent dollars.**




*Source: DOE Chief Financial Officer and Office of Nuclear Energy, Science and Technology.*

**Figure E.9: Funding history for fission power R&D, in as-spent dollars.**




*Source: DOE FY 1998 Congressional Budget Request.*

**Figure E.10: DOE budget request for FY 1998 energy resources research, development, and demonstration.**

Nuclear power is a mature industry and, therefore, it can be argued, does not qualify for Federal assistance of any kind, including Federal R&D support. These arguments are used by fiscal conservatives to strike nuclear energy funding from the DOE budget, while those opposed to nuclear power on other grounds, such as concerns about environmental effects, safety, nuclear waste, or proliferation, also favor eliminating nuclear energy support, including R&D. DOE's proposal of the NES program to continue R&D on nuclear power beyond FY 1997 — the last year of ALWR R&D — thus was not approved by Congress.[77] The NES program element addressing extended-fuel burnup, however, could be seen as having support from the Yergin Committee.[78]

The FY 1998 budget request for NE is much larger than $46 million (see Table E.1), totaling $382 million split between Energy Supply and Atomic Energy Defense Activities.[79] Beyond nuclear power R&D, the NE budget proposal includes funding for advanced radioisotope power systems for spacecraft, cleanup, termination of some facilities, and landlord functions, as well as $2 million for fusion irradiation experiments at the Advanced Test Reactor in Idaho. One major DOE effort requested altogether about $56 million to improve the safety of reactors in the former Soviet Union. There is also a $25-million program to develop electrometallurgical technology for possible handling of spent DOE fuel. In its action on the FY 1998 Energy and Water Bill, Congress transferred the $2 million for fusion experiments to the ER fusion budget, reduced the $56 million request to $35 million, and cut the electrometallurgical technology program to $12 million plus $8 million for termination.

[77]In the FY 1998 Energy and Water appropriations bill, Congress provided no funds for NES.

[78]The "Yergin Report" used "More Efficient Nuclear Fuels" as an example of a successful program that was "[t]oo risky and expensive for industry..." but is now used throughout the industry. "Yergin Report," p. 36. The 1998 Nuclear Energy Security program proposed to study going further than the current extended burnup.

[79]*DOE FY 1998 Congressional Budget Request*, DOE/CR-0041, 1997.

**Table E.1: R&D Investments of DOE's Office of Nuclear Energy**

| | FY 1997 Actual $ Millions | FY 1998 President's Request $ Millions |
|---|---|---|
| Waste[a] | 20 | 25 |
| Cost/New Reactor Concepts | 34 | - |
| Safety[b] | - | 15 |
| Nonproliferation | - | - |
| Operating Reactors | 4 | 25 |
| Education | 4 | 6 |
| Total NE Fission R&D | 62 | 71[c] |
| Subtotal: Energy Resources R&D | 42 | 46 |
| Other NE Activities[d] | 265 | 311 |
| Total NE Appropriation | 327 | 382 |
| Subtotal: Energy Supply R&D | 278 | 301 |
| Subtotal: Atomic Energy Defense Activities[e] | 49 | 81 |

[a]Electrometallurgical technology for treating DOE nuclear waste. Not applicable to commercial nuclear power, not included in "Energy Resources" budget.
[b]Elements of other programs also address safety concerns.
[c]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.
[d]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.
[e]Not including Naval Reactors Program.

Naval Reactors. The FY 1997 DOE budget provided $666 million for the Naval Nuclear Propulsion Program, commonly called NR, to support the fleet of nuclear ships and submarines in the U.S. Navy. NR, a joint program of DOE and the Department of the Navy, is responsible for all aspects of naval nuclear propulsion. This responsibility includes research, development, design, acquisition, installation, inspection, testing, refueling, operating practices and procedures, maintenance, logistics, and ultimate disposal of naval nuclear-propulsion plants and any related special-maintenance service facilities. The program also is responsible for selecting and training the enlisted and officer personnel who operate shipboard and prototype naval nuclear propulsion plants.[80] The program has two dedicated DOE laboratories, Bettis and Knolls, with a combined staff of about 5,750. The program focus is on the 120-plus operating reactors in submarines and surface ships. These shipboard reactors are designed for conditions and objectives quite different than commercial power plants.

Over the years, NR has contributed substantially to the knowledge base for the general nuclear power community. NR developed and operated the first commercial nuclear power station — the Shippingport Atomic Power Station. Through this project, the program developed the uranium dioxide-zircaloy tube fuel system that is in use in the majority of commercial reactors today. Handbooks were published on many topics, including the metallurgy of zirconium, corrosion in water-cooled reactors, and neutron absorbers. Computer codes on such topics as heat transfer, Monte Carlo analysis, and shielding

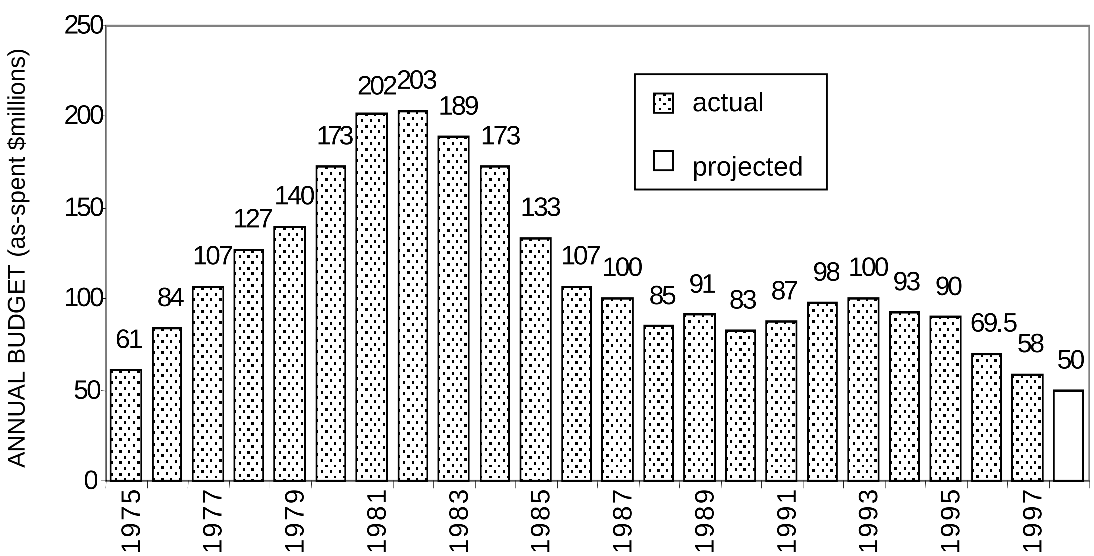
[80]Funds to support the training of Navy officers and enlisted personnel come from the Navy.

have been made available to industry. The program performs some research at universities, national laboratories, and at commercial facilities. Current work of particular interest to the commercial power plant industry and to the NRC includes brittle-fracture test analysis, development of reactor-vessel annealing techniques, and steam-generator technology. In addition, NR is providing $2.3 million to the Idaho National Engineering and Environmental Laboratory (INEEL) to upgrade TELAP5 and $2.2 million to Los Alamos National Laboratory (LANL) for TRACP. Both of these computer codes are owned by the government and routinely available to commercial industry. NR's knowledge base of material properties, disciplined operation, and improved I&C make contributions to the commercial nuclear-power industry. The program trains about 2000 enlisted personnel and 400 officers per year, many of whom find employment in the commercial nuclear-power industry after they leave the Navy. For FY 1998, DOE requested $626 million for NR, to develop new naval reactor plants and to ensure continued safe operation of those on board Navy ships and submarines. Congress has appropriated $656 million.

**Nuclear Regulatory Commission Research**

The NRC sponsors research primarily to verify experimental data from and analysis performed by licensees, although the program also tries to anticipate future issues. Specific technical topics include fire resistance of cable coatings, thermal hydraulics, structural performance, behavior of reactor vessels under pressurized thermal shock, PRA, severe accident analysis, control systems, and human-factors research. In addition, NRC develops and maintains computer codes to simulate operational conditions and accident scenarios. To accomplish this R&D agenda, NRC issues contracts for specific R&D tasks to performers — primarily DOE laboratories — who are independent of the nuclear industry organizations being regulated. In FY 1997, NRC's budget for R&D contracts was about $58 million, and the request for FY 1998 is $50 million. Funds expended by the NRC are collected from fees paid by licensees.

NRC's research budget peaked following the Three Mile Island accident, and has dropped substantially since the mid-1980s, as shown in Figure E.11.[81] The figure is in as-spent dollars, masking the decline in value due to inflation.




*Source: NRC Office of Research.*

[81]Included in letter from Marylee Slosson, Acting Director, NRC Division of Reactor Program Management to Beverly Hartline, 14 August 1997.

**Figure E.11: NRC research budget (contract support).**

### Summary of Federal Investment in Fission Energy

Table E.2 summarizes the Federal investments in FY 1997 for fission energy-related activities sponsored by NE, NR, OCRWM, and NRC (contract research only), along with the budgets requested and enacted for FY 1998. The activities in this table are sorted according to their focus on waste, safety, proliferation, new reactor concepts, operating reactors, education, naval reactors, and other. Only a small portion of the investment funds R&D directly applicable to commercial nuclear power, which was the focus of the Task Force's attention.

**Table E.2: Federal Investments Related to Fission Energy (Millions of As-Spent Dollars)**

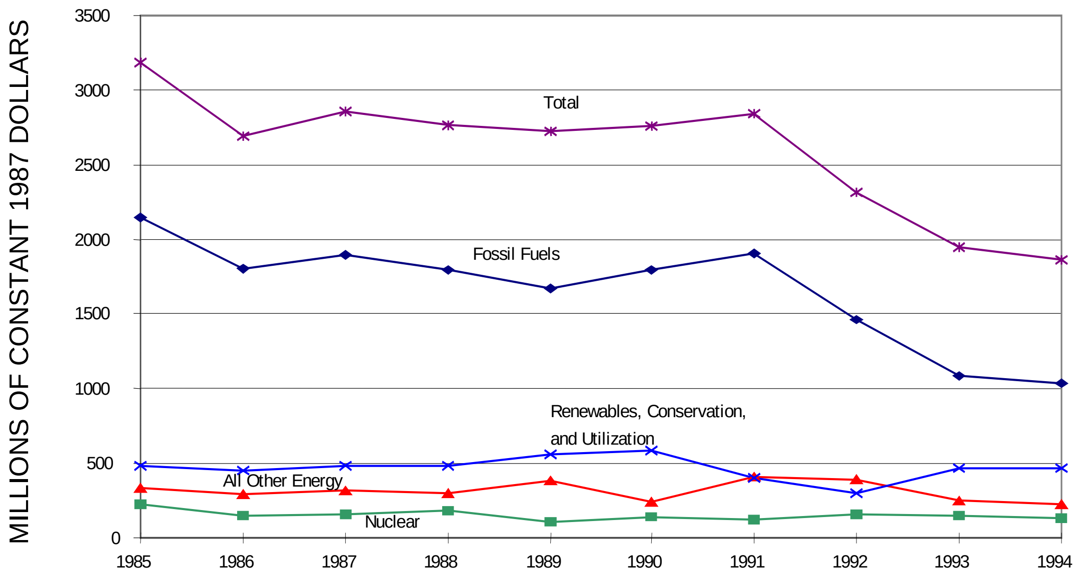
| Federal Program by Nuclear Energy Topic[a] | FY 1997 Actual | FY 1998 Request | FY 1998 Congressional Action |
|---|---|---|---|
| **Nuclear Waste** | | | |
| Nuclear Technology (Electromet. Tech.)[b] | 20 | 25[c] | 12[d] |
| OCRWM: Yucca Mountain Characterization | 325 | 325 | 350 |
| OCRWM: Waste Acceptance, Storage, Transport | 10 | 10 | Incl. Above |
| OCRWM: Program Management Center | 47 | 45 | Incl. Above |
| **Nuclear Reactor Safety** | | | |
| International Nuclear Safety[c] | 45 | 50 | 35 |
| Chernobyl Shutdown[c] | - | 2 | 0 |
| International Collaboration on Safety[b] | - | 6[e] | 0 |
| Key Component Safety[b] | - | 9[e] | 0 |
| **Proliferation:**[f] Nuclear Security[c] | 4 | 4 | 0 |
| **New Reactor Designs:**[b] Advanced Light Water Reactors | 34 | - | - |
| **Operating Commercial Power Reactors** [b] | | | |
| Light Water Reactors | 4 | 4[e] | 0 |
| Advanced Controls, Sensors, Instrumentation | - | 8.5[e] | 0 |
| High Efficiency Fuel | - | 8.5[e] | 0 |
| Risk Management | - | 4[e] | 0 |
| NRC: Confirmatory and Anticipatory R&D | 58 | 50 | [i] |
| **Education:**[b] University Programs (including reactor fuel) | 4 | 6 | 7 |
| **NR: Naval Reactors**[c,g] | | | |
| Naval Reactor Program | 647 | 606 | 636 |
| Naval Reactor Program Direction | 19 | 20 | 20 |
| **Other NE**[h] | | | |
| Program Direction and Landlord Activities | 29 | 29 | 38 |
| Advanced Radioisotope Power Systems | 37 | 47 | 41 |
| Termination Costs | 79 | 76 | 77 |
| Isotope Support | 13 | 22 | 16 |
| Uranium Programs | 59 | 79 | 65 |

[a]Programs of DOE-NE, except where indicated.
[b]All R&D.
[c]Funded through the Atomic Energy Defense Activities portion of DOE's budget.
[d]Plus $8 million for termination costs, included below.
[e]Nuclear Energy Security Initiative.
[f]Not including NN, MD, or Arms Control and Disarmament Agency, which together invest over $700 million per year in

nonproliferation, including some R&D. The Panel did not study these programs.
[g]All R&D, most of which ensures the viability and improves the performance of the 120-plus operating naval reactor plants.
[h]Hot standby operation of Fast Flux Test Reactor at Hanford may be transferred to NE at about $30 million per year.
[i]Not a line item in the Energy and Water Bill.

### Industry Investment in Fission Energy R&D

Vendors and nuclear utilities have funded substantial R&D on nuclear energy systems, much of it through EPRI, the research arm of the utility industry. From its founding in 1973 through 1997, EPRI's funding for nuclear energy amounted to $1.7 billion, about 21 percent of its total funding.[82] EPRI and DOE have examined what should be done to support nuclear power. EPRI has proposed that DOE's nuclear energy R&D budget for FY 1998 should be $60 to $70 million and then remain steady at $60 million per year. EPRI also wrote to DOE that industry would provide about twice this amount.[83] Figure E.12[84] indicates that industry funding for nuclear energy R&D has been less than that for other fuels from 1985 to 1994.




*Source: J. J. Dooley, Trends in US Private-Sector Energy R&D Funding 1985-1994, Pacific Northwest National Laboratory, PNNL-11295, Washington, D.C., September, 1996.*

**Figure E.12: U.S. private sector energy R&D by fuel type.**

Each manufacturer of nuclear power plants has invested substantial funds over the years to develop the particular designs it markets. However, individual vendors were reluctant to provide specific R&D funding information, although some was obtained:

- Westinghouse and its industrial partners have spent $215 million through the first half of 1997 on developing the AP600 – the small "passively-safe" PWR — and DOE has contributed $133 million. In addition to this funding, "Westinghouse Nuclear Energy R&D is between 1 and 2

[82]Data included in letter from Robin Jones, EPRI Vice President for Nuclear Power, to Beverly Hartline, OSTP, 25 July 1997.
[83]Letter from Kurt Yeager, EPRI President, to Deputy Secretary Charles Curtis, 13 December 1996. Letter from Kurt Yeager, EPRI President, to Secretary Peña, 3 July 1997; EPRI, "Nuclear Energy R&D: Strategic Plan in Support of National Nuclear Energy Needs," Vol. I, June 1997.
[84]J. J. Dooley, "Trends in US Private -Sector Energy R&D Funding 1985-1994," PNNL-11295, September 1996, p. 4.

percent of sales."[85] These sales for the last 3 years have been about $1.3 billion per year. Westinghouse expects to spend an additional $30 million to complete the NRC design certification process for the AP600.

[85]Letter from W. E. Cummins, Project Manager, Nuclear Products Division, Westinghouse, to Beverly Hartline, 5 August 1997.

- The development and design certification process of the GE ABWR cost about $460 million, of which about $225 million came from Japanese industry, $130 million from GE and its partners, $85 million from DOE, and $20 million from U.S. utilities.[86]

- ABB-Combustion Engineering declined to provide information on its funding of nuclear R&D, "due to company policy," but did indicate that nuclear orders received totaled $0.5 billion in 1995 and $1.3 billion in 1996.[87]

- From 1957 through 1996, GA invested $740 million in the development of the HTGR.[88]

- For R&D, AECL annually gets about $100 million (US) from the Canadian government and about $30 million (US) from utilities. The amount is spent about equally on near-term R&D priorities set by the utilities and on long-term projects.[89]

- British Nuclear Fuels Limited (BNFL) spends about $100 million per year on R&D, derived from nuclear fuel and services revenue of about $2 billion per year.[90]

**Potential Contributions**

Nuclear power has been implemented in several countries, e.g., France and Japan, to reduce dependence on imported fuels: "The nuclear sector represents more than 30 percent of the electricity production of the European Union, and consequently contributes to lower external energy dependency."[91] Plentiful coal and natural gas make this factor less important in the United States, and it is likely to remain so unless U.S. transportation systems (especially cars) evolve to run predominantly on electricity requiring central-station generation.

A rising concern about how to reduce GHG emissions, particularly $CO_2$, is a major reason for Federal support of nuclear power. Nuclear power is a major factor that has restrained the growth in emissions. Since 1973, were U.S. nuclear plants to have been coal plants, to produce the same amount of electricity would have led to emitting approximately 2 billion metric tons of carbon. This amount is about 90 percent of the carbon emissions avoided by the U.S. electricity sector since 1973.[92] Operating the existing nuclear plants through their current license period would help constrain U.S. carbon emissions substantially below what they would be if the plants closed were replaced by fossil generation.

The 1992 United Nations Conference on Environment and Development resulted in a commitment by the participating countries to work to reduce emissions of GHGs.[93] In December 1997, national delegates to a conference in Kyoto, Japan will attempt to develop a treaty that would bind signatory nations to reduction targets. This issue was raised at the Denver summit by the new British Prime Minister and again by him at the United Nations (U.N.) conference in June of this year. As a non-GHG emitter, nuclear power could play a major role in helping countries to meet such goals, especially in the United States, which emits more GHGs than any other nation.

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[86]Gary Vine, EPRI, and John Redding, GE, personal communication, September 1997.
[87]Fax from George A. Davis, ABB-CE Project Office to Beverly Hartline, 28 July 1997.
[88]Fax from Linden Blue, GA Vice Chairman, to John Ahearne/Beverly Hartline, 21 July 1997.
[89]Kugler, op. cit.
[90]Marilyn F. Meigs, Vice President, Fuel Cycle and Materials Processing, BNFL, presentation to the PCAST Nuclear Task Force, San Diego, CA., 25 June 1997.
[91]European Commission, *An Overall View of Energy Policy and Actions*, COM(97), Brussels, Draft of 21 April 1997, p. 10.
[92]DOE-NE, "Nuclear Energy Security," op. cit., p. 3.
[93]The U.N. Framework Convention on Climate Change.

The effect on GHG emissions of a large-scale switch from fossil fuel plants to nuclear power has been shown dramatically by France (Figure E.13), where "the rapid introduction of nuclear energy since the mid-1970s has led to higher rates of decarbonization of primary energy..."[94] In Europe, "use of nuclear energy is already avoiding the emission of some 700 million tonnes of $CO_2$ annually, compared to a situation where the same electricity would have been produced using a mix of fossil fuels."[95] (This amount corresponds to about 190 million tons of carbon.) This impact also can be seen in work done by the Japanese government to examine approaches to reducing future $CO_2$ emissions. In scenario runs, reducing Japanese carbon emissions to 1990 levels by 2030 required an additional 50,000 MW of nuclear power.[96]

The United States has about 100 GW of nuclear power generation capacity. Assuming a 80 percent availability factor, Brookhaven National Laboratory estimated that the annual amount of carbon emissions from 100 GW of nuclear would be "insignificant;" from 100 GW of coal steam, 180 million metric tons (MtC); and from 100 GW of gas combined cycle, 70 MtC.[97] Using the 1996 average capacity factor of 74.9 percent for U.S. nuclear plants reduces these equivalent emissions to 168 MtC for coal-fired plants and to 66 MtC for gas.

The EIA has estimated the effect on U.S. carbon emissions of various nuclear scenarios. 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 MtC are emitted annually above that in the reference case. In the high-nuclear case, 29 MtC less is emitted annually than in the reference case.[98]

The Administration has run several models to examine the economics of stabilizing carbon emissions at 1990 levels.[99] Using permit trading, these models predict stabilization at prices in 2010 ranging from $81 to $145 per ton of carbon (1995 dollars). By 2020, the models predict prices between $106 and $130 per ton (1995 dollars). "A permit price of $100 per ton is the equivalent of a price increase of 26 cents per gallon of refined petroleum product, $1.49 per thousand cubic feet of natural gas, $52.52 per ton of coal, and 2 cents per kW of electricity produced." The models predict drops in the use of coal by as much as 50 percent by 2010, compared with 1990, and 75 percent by 2020. Nuclear power appears not to be considered in these model runs.

Figure E.14[100] shows one set of model runs indicating the effect of emission controls upon U.S. nuclear capacity. In the base case, a moratorium on advanced reactors is assumed. In the nuclear cases, introduction of an ALWR is allowed. The nuclear option is the lowest carbon emitter and is the preferred option to meet the carbon constraint. However, license extension is not considered in these cases and might be preferred over introduction of the ALWR.[101]

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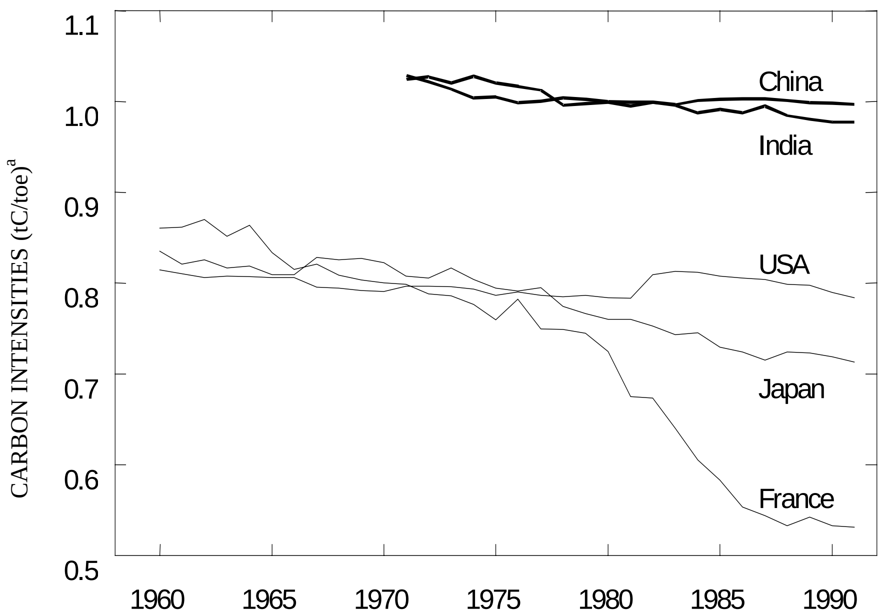
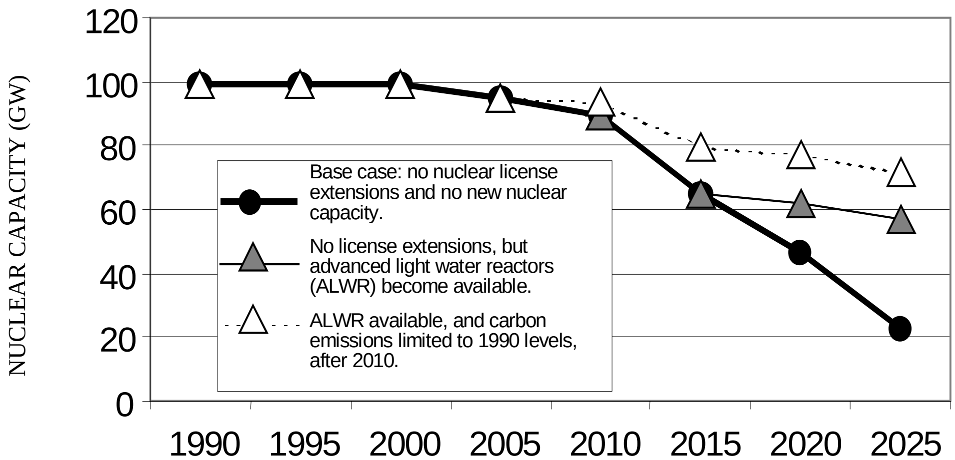
[94]Nebojsa Nakicenovic, "Freeing Energy from Carbon," *Daedalus*, *125(3)*, pp. 95-112, 1996.
[95]European Commission, *Communication from the Commission on the Nuclear Industries in the European Union*, Brussels, 25.09.1996, COM(96) 339 final, p. 13.
[96]Yoshikawa, op. cit.
[97]Letter to John Ahearne from Robert A. Bari, Chairman, Department of Advanced Technology, Brookhaven National Laboratory, 23 July 1997.
[98]EIA, *Annual Energy Outlook 1997, With Projections to 2015*, DOE/EIA-0383(97), December 1996, p. 52.
[99]Interagency Analytical Team, "Economic Effects of Global Change Policies," June 1997, pp. 8-9, 15.
[100]A. Reisman, J. Jo, J. Lee, and U. Rohatgi, "MARKAL-MACRO: Capabilities, Global Climate Change, and the Nuclear Option," Brookhaven National Laboratory, 7 July 1997, submitted to the PCAST Nuclear Task Force.
[101]U. Rohatgi, email to John Ahearne, 19 August 1997.




*Source: Nakicenovic (1996).*

**Figure E.13: Carbon intensities of primary energy expressed in tons of carbon (tC) per ton of oil equivalent energy (toe).**
[a]The zero of the carbon intensity axis is suppressed.




*Source: Brookhaven National Laboratory, Department of Advanced Technology.*

**Figure E.14: MARKAL-MACRO economic model projections of U.S. nuclear generating capacity.**

As the United States formulates its position on carbon-emissions goals and other aspects of possible international agreements that might emerge from the Kyoto conference in December 1997, it is important for U.S. policy makers to be fully informed about the pros and cons, costs and benefits, and feasibility and impact of various strategies to reduce carbon emissions while maintaining a strong economy and securing the health and safety of people and ecosystems. Consequently, several analyses have been underway this year, and their reports are being released.

Two examples that have been released recently were prepared, respectively, by a collaboration of five DOE laboratories and by five nongovernmental organizations (NGO).[102] Both studies give little attention to nuclear power as part of the future national and global energy mix. The Five-NGO Report limits its attention to United States. The Five-Lab Report assumes that nuclear power's present disadvantages will preclude it from being economically or politically viable in the future, not just in the United States but worldwide. This assumption contradicts information provided by numerous sources to the PCAST Energy R&D 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.

The Five-Lab Report was sponsored by the DOE Office of Energy Efficiency and Renewable Energy and released on September 25, 1997. It "quantifies the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States."[103] This report focuses especially on energy-efficient and renewable-energy technologies and does not include much coverage of fission energy.

The Five-Lab Report bases its analysis of the contribution nuclear power can make to U.S. carbon emissions in 2010 on an estimate from EIA.[104] EIA projected that, for a "high nuclear case" in which U.S. nuclear generation capacity in 2010 is about the same as it is today, annual U.S. carbon emissions would be 12 MtC lower than in a reference case, in which plants close at the end of their current licenses and only 89 MW of nuclear capacity would remain in operation. The Five-Lab Report's authors acknowledge that, "An effort to maintain the viability of this [nuclear] capacity could result in a very large contribution to carbon reductions over the next quarter century."[105] However, in projecting the contributions of nuclear power to carbon-emission reduction, the authors conclude, "it will not be economical or politically feasible to extend the operation of nuclear power plants with licenses that expire by the year 2010." Thus, they report that a reduction in the "range of 4 to 7 MtC would appear to be a more realistic forecast,"[106] which assumes license extensions for 35 to 65 percent of plants with licenses expiring prior to 2010.

The Five-NGO Study also dismisses nuclear energy as a significant factor in the future energy portfolio of the United States.[107] This study's stated purpose is to provide "an independent analysis of policies that can reduce U.S. greenhouse gas emissions over the coming decades in order to help inform policy makers and the public in evaluating the wide variety of proposals that are on the table." The "study

[102]This discussion is included because of the importance attributed by press coverage to the reports (see, e.g. *Energy Daily*, 26 September 1997 and *Washington Post*, 26 September 1997, p. A1). Government reports have a greater responsibility for objectivity than do those from industry or NGOs. National Research Council, *Improving Risk Communication*, Washington, D.C., National Academy Press, 1989, pp. 129, 169.

[103]DOE, Office of Energy Efficiency and Renewable Energy, *Scenarios of U.S. Carbon Reductions, Potential Impact of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond*, 1997, p. 1-1. This report is known as "The Five-Lab Report."

[104]"Annual Energy Outlook," op. cit.

[105]"The Five-Lab Report," op. cit., p. 7.30.

[106]Ibid.

[107]Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Tellus Institute and Union of Concerned Scientists, *Energy Innovations: A Prosperous Path to a Clean Environment*, June 1997, p. ii. This report is known as "The Five-NGO Report."

analyzes a balanced national strategy…" in which its recommended path, "the Innovation Path," pursues "a measured but progressive phase out of both coal and nuclear power by 2030."[108]

If the fission energy R&D recommendations of the PCAST Energy R&D Panel 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 to maintain nuclear power's significant, no-carbon contributions to the energy supply in the U.S. and 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 for encouraging 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 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.

## Policy Viewpoints

With all the attention focused on climate change, and with the increasing visibility of the White House on this issue of global importance, the Task Force attempted to see how fission energy was being factored into the public statements and policy viewpoints being expressed.

### The White House

On 26 June, President Clinton spoke at the U.N. environmental conference.[109] Some of his points are specifically germane to the role of nuclear power:

> *The science is clear and compelling: We humans are changing the global climate.*
>
> *...to reduce greenhouse gases and grow the economy, we must invest more in the technologies of the future.*
>
> *We must create new technologies...that will both curtail pollution and support continued economic growth.*
>
> *Many of the technologies that will help us to meet the new air quality standards in America can also help address climate change.*

[108]Ibid., p. xii.
[109]From transcript on *The New York Times* web site.

These words could be interpreted as a basis for supporting nuclear power. However, the speech, like other statements on climate change from the White House and the State Department, does not mention nuclear power.[110]

The President recently said, "I am convinced that when the nations of [the] world meet in Kyoto, Japan, in December on this issue, the United States has got to be committed to realistic and binding limits on our emissions of greenhouse gases."[111] The impending Kyoto meeting may be leading to a rethinking of the role of nuclear power. In a speech in July to a climate change workshop, the Assistant to the President for Science and Technology, Dr. John H. Gibbons, said:

> *We have the opportunity to lead the world in developing and deploying clean technologies for cost-effective reductions in greenhouse gas emissions. After a decade of languishing budgets, our Administration is just beginning to return the energy efficiency and renewable energy R&D programs in the Department of Energy to viable levels. But this has been a struggle every step of the way. Congress needs to join us in supporting these efforts, such as efficiency, low carbon fuels (or carbon sequestration), and renewables, instead of slowing us down. The extent of the long-term imperative for nuclear energy, despite its knotty problems, will likely be defined by this research.*[112]

Many commenters to the PCAST Energy R&D Panel and Nuclear Task Force, including a range of Administration officials, add that U.S. nuclear power policy must take into account three points:

1. The United States needs to keep a global context in looking at our policy regarding nuclear power.

2. The United States cannot afford to walk away from nuclear power now, when we have about 20 percent of our electrical generation coming from nuclear plants, and when we have no real idea of what our energy mix and the world's mix will be in the future.

3. The United States needs to maintain nuclear energy as an option, and, depending on the outcome of R&D on the various renewables approaches, nuclear energy may go from an option to a necessity.

**The Department of Energy**

Although the DOE is the sponsor of nuclear-power R&D programs within the Federal government, the upper echelons of this agency have not been supportive of nuclear power under the current Administration. There are, however, a few indications that this may be shifting. In congressional testimony this year, Secretary Peña said:

> *Nuclear energy currently provides about 22 percent of U.S. electricity generation and will provide a significant portion of U.S. electrical production for many years to come.*

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[110]One of the latest examples is in a report referenced in 15 July 1997 testimony to the House Commerce Committee by Council of Economic Advisors Chair, Janet Yellin. The report, by the Administration's Interagency Analytic Team, is on *Economic Effects of Global Change Policies*, June 1997. The report identifies that "reduction in energy-related greenhouse emissions in the 2010 time frame will require a combination of three types of energy system changes: increased end-use efficiency, reduced end-use activity, or fuel-switching towards an increased share of low- and no-carbon fuels in the energy mix...[F]uel switching favors low- and no-carbon fuels, such as natural gas and renewable energy, relative to coal." p. 14. Nuclear power is not discussed.
[111]Office of the Press Secretary, The White House, Opening Remarks by the President and the Vice President at Discussion on Climate Change, 24 July 1997.
[112]Keynote presentation to Regional Climate Change Workshop, Seattle, WA., 14 July 1997, p. 7.

*Nuclear power plants in the U.S. make a significant contribution to lowering the emission of gases associated with global climate change. Whether or not new nuclear power plants are built in the U.S. in the foreseeable future, the U.S. has a strong interest in maximizing the value of its investment in its 109 nuclear power plants in 20 states. The Department's Nuclear Energy R&D program focuses on issues relating to the viability of this energy source in the future.*[113]

Furthermore, in statements quoted in the press, Secretary Peña has indicated that nuclear energy will be a part of the energy portfolio supported by DOE.[114] A more detailed picture of DOE's current thinking can be seen by examining a report required by congressional legislation. The Government Performance and Results Act (GPRA) requires Federal agencies to prepare a strategic plan that identifies the agency's goals and objectives and serves as the basis for setting specific performance goals. The DOE recently submitted the "U.S. Department of Energy Strategic Plan."[115] This plan includes the following statements:

*The Department of Energy...enhances the nation's energy security by...maintaining the U.S. nuclear option...*[116]

*By resolving nuclear waste disposal issues and developing advanced nuclear technology, DOE will remove some concerns and may open the door to renewed consideration of nuclear energy as an additional option for addressing air quality and greenhouse gas emissions.*[117]

The plan gives a strategic goal for each DOE "business line," followed by objectives to support the goal and strategies for each objective.

The strategic goal under the Energy Resources "business line" is that "[t]he Department of Energy and its partners promote secure, competitive, and environmentally responsible energy systems that serve the needs of the public." Objective 2 under this strategic goal is to "[e]nsure that a competitive electricity generation industry is in place that can deliver adequate and affordable supplies with reduced environmental impact." Strategies 7 and 8 pertain to the nuclear option:

*Improve nuclear plant reliability and availability to increase the capacity factor of existing nuclear power plants from the 1996 average of 76 percent to 85 percent by 2010.*

*Maintain a viable nuclear option for future, carbon-free baseload electricity through cooperative technical developmental activities with U.S. electric industry that would facilitate a U.S. order of an advanced nuclear plant by 2010.*[118]

Objective 4 is to "[s]upport U.S. energy, environmental, and economic interests in global markets." Strategy 2 under this objective is to "[c]ooperate with foreign governments and international institutions to develop open energy markets, and [to] facilitate the adoption and export of clean, safe, and

[113]Testimony before the House Committee on Science, 14 May 1997.
[114]*Inside Energy/with Federal Lands*, 29 September 1997, p. 7. This article quotes from a 16 September 1997 letter Secretary Peña sent to Senator Craig.
[115]DOE, *U.S. Department of Energy Strategic Plan: Providing America with Energy Security, National Security, Environmental Quality, Science Leadership*, DOE/PO-0053, September 1997.
[116]Ibid., inside front cover.
[117]Ibid., p. 11.
[118]Ibid., p. 15.

efficient energy technologies and energy services." One of the steps indicated to implement this strategy is "[b]y the end of FY 1998, support implementation of U.S. Government agreements with Asian-Pacific countries that open enhanced market opportunities for U.S. nuclear industrial suppliers, enabling them to exchange information and export U.S. light-water reactor technology and services, contributing to a four-fold increase in U.S. nuclear-related exports (from $1.2 billion in 1997) to $4.8 billion by 2005."[119]

The strategic plan also supports efforts to improve international nuclear safety, to provide radioisotope power systems for NASA, and to develop and supply isotopes for industry, research, and medical applications.

The Strategic Goal under the environmental quality business line is to "[a]ggressively clean up the environmental legacy of nuclear weapons and civilian nuclear research and development programs, minimize future waste generation, safely manage nuclear materials, and permanently dispose of the Nation's radioactive wastes."[120] Objective 5 is to "[d]ispose of high level radioactive waste and spent nuclear fuel in accordance with the Nuclear Waste Policy Act as amended." Strategy 1 is to "[c]omplete the scientific and technical analyses of the Yucca Mountain site, and if it is determined to be suitable for a geologic repository, obtain a license from the Nuclear Regulatory Commission." The five steps under this strategy address what to do if the site is suitable. They do not include what to do if the site is not suitable. Strategy 2 is to "[m]aintain the capability to rapidly respond to potential statutory direction that may include transportation of spent nuclear fuel and high level waste to a designated interim storage facility."[121] There is no indication that the DOE intends to develop an interim site unless congressionally directed to do so; however, even that would not be enough, unless the Administration were to support the bill or Congress were to override the President's veto.

The Strategic Goal for the science and technology business line is to "[d]eliver the scientific understanding and technological innovations that are critical to the success of DOE's mission and the Nation's science base." Objective 1 is to "[d]evelop the science that underlies DOE's long-term mission."[122] One of the steps to implement that strategy is to "[c]omplete evaluation of the readiness to proceed with International Thermonuclear Experimental Reactor construction with other parties in FY 2000."[123]

The plan lists "factors external to DOE's full control that can influence our desired outcomes." These include:

> *Without legislative relief, restructuring the electric utility retail market could adversely impact industry's investment in longer-term research, development, and demonstration of renewables and advanced lower-emission fossil fuel and advanced nuclear power technologies.*[124]
>
> *By 2015, 60 percent of the existing coal-fueled and 40 percent of the nuclear-powered electric generating plants will be 40 years old. It is not clear how long these plants can operate due to regulatory and economic issues.*[125]

[119]Ibid., p. 16.
[120]Ibid., p. 25.
[121]Ibid., pp. 27-28.
[122]Ibid., p. 30.
[123]Ibid., p. 32.
[124]Ibid., p. 44.
[125]Ibid.

The last two points highlight that the plan lacks any support for relicensing of existing nuclear plants. A 16 June Working Draft was supportive of relicensing. In that earlier draft, under the Energy Resources business line, Objective 1 was to "[i]ncrease the security, flexibility, and reliability of the U.S. energy system."[126] Strategy 4 was to "[e]nhance diversity of the domestic energy portfolio." One of the implementing steps, called Success Measures in this draft, was to "[d]evelop and demonstrate technologies that will support the first license renewal of an existing nuclear power plant by 2005, and the technologies and infrastructure that can support construction of advanced light water reactor plants."[127]

Objective 2 was to "[i]ncrease energy productivity and energy efficiency, and reduce environmental impact of the U.S. energy system." For this objective, Strategy 4 was to "[i]mprove the efficiency and reduce the environmental impact of electric power generating systems."[128] An implementing step for this strategy was to "[d]evelop technologies by 2005 to enable industry to achieve 20-year nuclear power plant license renewals of up to 75 percent of the 109 existing plants over the next 25 years."[129] These DOE goals would be consistent with the need to retain the current plants, if possible. The disappearance of these goals relating to relicensing weakens the support for nuclear power in the strategic plan, reinforcing the impression that the DOE leadership does not support that technology.

Maintaining a concern for relicensing would be consistent with a goal to reduce GHG emissions and with retaining the nuclear option. Another DOE action to indicate support for retaining the nuclear option would be to reverse the action in this Administration to downgrade the senior nuclear position in DOE from an Assistant Secretary to a Director, an action described by congressional staff as sending "a firm message to Congress."

### The Congress

Congress has zeroed the nuclear reactor R&D initiative (NES) in the FY 1998 budget request for NE. This action could be interpreted as reflecting an unfavorable attitude by Congress toward nuclear power. However, based on statements made on the floor of the Senate[130] and on congressional letters to DOE and the State Department,[131] this congressional action may be more a rejection of the specific programs proposed in the DOE budget than opposition to funding of nuclear-power R&D per se.

## What R&D Should Be Funded

The "Yergin Report" reiterated a position taken over many administrations:

> *The Federal Government should not fund R&D that the private sector can and should do on its own. Federal support for R&D is most strongly justified when the R&D serves national interests not adequately addressed by market action alone.*[132]

The Task Force heard views from many sources on what should be in a Federal nuclear-energy

[126] DOE, *U.S. Department of Energy Strategic Plan: Providing America with Energy Security, National Security, Environmental Quality, Science Leadership*, Working Draft, 16 June 1997, p. 10.
[127] Ibid., p. 11.
[128] Ibid., p. 12.
[129] Ibid., p. 13.
[130] Statements by Senators Craig, Murkowski, Kyl, and Kempthorne, Senate Congressional Record, 15 July 1997, S7479.
[131] Letter from Senator Murkowski to Daniel Reifsnyder, OES/OGC, U.S. Department of State, 15 May 1997; letter to Secretary Peña from Senators Craig, Murkowski, Kempthorne, Domenici, Kyl, and Durbin, 30 July 1997; letter from Senator Domenici to Secretary Peña, 9 August 1997.
[132] "Yergin Report," op. cit., p. ix.

R&D program. A good summary was provided by a group from MIT.[133] They wrote that the highest priority goals should be to:

- Develop a new generation of technology options.
- Allow the current fleet of reactors and the planned repository to operate safely.
- Maintain technological manpower.
- Seek better understanding of sustained fusion.
- Establish clear and objective measures of economic, environmental, and resource availability factors for the energy options.

Another set of recommendations comes from the American Physical Society:

> *A balanced energy policy, however, also requires that the Department of Energy have strong programs to keep the nuclear energy option open, through: (a) the continued development of nuclear reactors which can be built, operated, and eventually decommissioned in a manner which is simple, safe, environmentally sound, and cost-effective; (b) the development and implementation of programs for the safe disposal of spent fuels and radioactive wastes; and (c) the development of an effective public education program to allow a more informed debate on the strengths and weaknesses of nuclear power. The American Physical Society is deeply concerned that progress in these areas is inadequate.*[134]

To reach emission reduction goals will require halting the increase in carbon emissions and then switching to lower- or no-carbon producing sources of electricity, as well as other actions. These objectives impact on the Federal actions regarding nuclear power in both the near and long term. In the near term, the national interest may require government action to prevent the economics of a deregulated industry from forcing premature shutdown of nuclear plants, which would most likely be replaced by fossil plants. In the long term, the government should take steps to ensure that the current problems with nuclear power are addressed so that nuclear power can become an accepted part of the energy mix, as well as a hedge in case renewables and efficiency do not achieve the performance levels and market share necessary to meet emission-reduction targets.

A major step toward retaining the current fleet of nuclear reactors and benefiting from its carbon-free operation would be for the government to put in place a carbon (or $CO_2$) credit. Similar to the $SO_2$ credit now the basis for trading emissions permits, a carbon credit would provide a technology-neutral incentive to keep low (or zero) carbon emitting plants running. This credit would be an advantage for some nuclear plants. If these plants are close to being economic now, a carbon credit would permit their owners to keep them in operation. For plants far from being economic, a carbon credit probably would not suffice to retain them in the operating fleet.

**Near-Term R&D**

Industry will fund research with short-term payoff. There is no need for the Federal government to be involved. Such topics include major component reliability, operations and maintenance (O&M) cost

[133]Letter to John Ahearne from M. S. Kazimi, N. E. Todreas, et al., 13 June 1997.
[134]Resolution adopted by the American Physical Society Council, November 1993.

control technology, chemistry and radiation control, fuel reliability, and safety and reliability assessment.[135] 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 makes nuclear power plants noncompetitive in many cases. To protect its shareholders, it is in the interest of the utility to do whatever is necessary to get rid of the capital burden, including shutting down the nuclear unit. The national interest may be to keep the plants running despite the economics faced by their owners.

[135] EPRI, "Nuclear Energy R&D," op. cit., pp. 10-11.

Because industry has the responsibility for plant operation, relicensing, and life extension, industry should be responsible for any associated R&D. However, **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 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 NRC requirements.**

In addition, **DOE should 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. The program should be funded at $10 million per year, matched by industry.**

**Long-Term R&D**

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 PCAST Energy R&D 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).[136] This program was established by Congress "...to develop a program that takes advantage of laboratory and university expertise. This funding ['at least $50,000,000'] is to be used to stimulate the required basic research, development and demonstration efforts to seek new and innovative cleanup methods..."[137] 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 previously been 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.**

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[136]For a description of the program, including the selection process for grants, see National Research Council, *Building An Effective Environmental Management Science Program: Final Assessment*, National Academy Press, 1997.
[137]Conference report accompanying HR 1905 (Energy and Water Development Appropriation Bill, enrolled as PL 104-46, 1995).

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. It also 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. This budget would support a sufficient number of competitively selected investigators, students, productive R&D groups, and specialized facilities at universities, national laboratories, and industry to promote synergies and revitalize the human resource base. This effort would build a base of university research, keep core groups at several national laboratories, and maintain selected research facilities, such as hot cells. This investment is quite small compared with the investment in the nuclear-power industry or the amount spent on national security. Retaining a major energy option that may be required to address global warming is definitely a national security issue.

### Fission Energy R&D Funding Recommendations

Table E.3 summarizes the Panel's funding recommendations for fission energy R&D.

**Table E.3: Recommended DOE Funding for Fission 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 |
| Total: Fission Energy R&D | 42 | 46[b] | 66 | 86 | 101 | 116 | 119 |

[a]Includes student fellowships and fuel support for university reactors.
[b]Congress appropriated $7 million for education and no funding for reactor concepts or operating-reactor R&D.

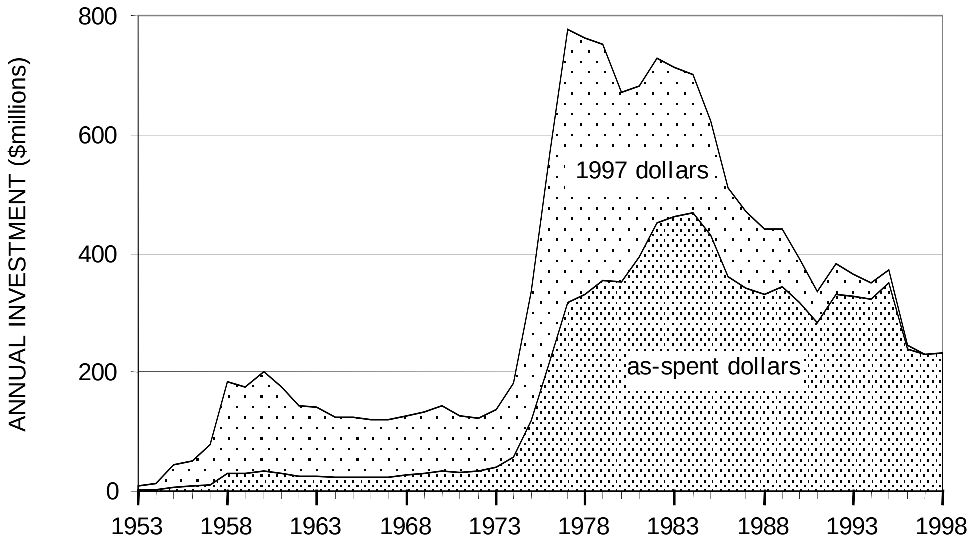
## FUSION

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, combine to form heavier atoms. The objective of DOE's Office of Fusion Energy Sciences (OFES) is to develop the scientific and technological basis for fusion as a long-term energy option for the United States and the world.

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 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 ER.

The fusion program is strongly centered in basic research and makes a valuable national contribution by supporting the important field of plasma science in addition to fusion's future energy applications.[138]

Figure E.15 shows the history of DOE investment in fusion since 1953. 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 off somewhat about 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. Now most of the funds allocated for fusion energy science support basic research on the physics of high-temperature plasmas, which are central in fusion research, important to the astrophysical sciences, and intrinsic to the field of basic plasma science.




*Source: DOE Energy Resources Board.*

**Figure E.15: History of DOE fusion R&D funding.**

Because fusion is a global energy solution, much of the R&D effort is internationalized. In 1997, 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 important participant in the global fusion-energy R&D effort.

**Fusion R&D Portfolio**

In total, the United States, through DOE and its predecessors, has invested $8.2 billion (as-spent dollars, $14.7 billion in 1997 dollars) in fusion science and technology through FY 1997 (Figure E.15). Results and techniques from fusion science have had a fundamental and pervasive impact for many other scientific fields and have made substantial contributions to industry and manufacturing. Since 1970, the fusion power achieved in experiments has increased from less than 0.1 W to 12 MW. Recent experiments have reached 50 percent of the breakeven threshold — the point at which the amount of fusion power

[138]The Task Force asked DOE how much of the fusion program supports basic science, how much supports the energy goal, and how much is dual purpose. DOE responded that most of the work sponsored by OFES serves both purposes. The Task Force concludes that without a rigorous review, it is not possible to clearly separate the categories, and even such a review might not lead to such a separation.

produced exceeds the power used to heat and confine the plasma.[139]

The nation's fusion 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).[140] The current study examined the fusion energy sciences program to understand changes that have occurred since the 1995 review and to determine whether the organizing principles recommended by PCAST-95 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."[141]

PCAST-95 recommended annual funding of $320 million for a budget-constrained internationally integrated U.S. fusion R&D program designed around a strategy centered on three key priorities:

- A strong domestic core program in plasma science and fusion technology;
- A collaboratively funded international fusion experiment focused on the key next-step scientific issue of ignition and moderately sustained burn; and
- An international program to develop practical low-activation materials for fusion energy systems.

The first of these priorities is key to the support of plasma physics as a scientific discipline and, in this sense, is more akin to DOE's support of other scientific fields, such as high-energy and nuclear physics or basic energy sciences. PCAST-95 recommended, within the $320-million budget, a somewhat enhanced U.S. core program above the level of $180 million. This level of support for plasma physics is about 8 percent of ER's annual research budget of about $2.5 billion.

In FY 1996, Congress reduced the fusion budget and directed DOE to restructure its fusion program. DOE charged its Fusion Energy Advisory Committee (FEAC) with examining the program and providing input for a strategic plan. DOE asked FEAC to be as consistent as possible with the principles recommended by PCAST-95 and to take into account the guidance provided by Congress. FEAC presented its findings and recommendations in a report prepared in January 1996.[142] FEAC's primary recommendation was that the mission of the U.S. fusion R&D program be modified to be consistent with both the most recent programmatic guidance and the level of resources provided by Congress. The reformulated mission is to "advance plasma science, fusion science and fusion technology — the knowledge base needed for an economically and environmentally attractive fusion energy source."[143]

FEAC also recommended three policy goals to serve this mission: (1) "advance plasma science in pursuit of national science and technology goals;" (2) "develop fusion science, fusion technology, and plasma confinement innovations as the central theme of the domestic program;" and (3) "pursue fusion energy science and technology as a partner in the international effort."[144] These goals are consistent with

[139]Experimental results from JET, September 1997.
[140]The President's Committee of Advisors on Science and Technology (PCAST), *The U.S. Program of Fusion Energy Research and Development: Report of the Fusion Review Panel*, July 1995 (PCAST-95).
[141]Ibid., p. 1.
[142]DOE Fusion Energy Advisory Committee, *A Restructured Fusion Energy Sciences Program*, 27 January 1996.
[143]Ibid., p. 3.
[144]Ibid., p. 4. As a result of the increased focus on basic science, FEAC was renamed the Fusion Energy Sciences Advisory

the PCAST-95 recommendations.

FEAC recommended a budget of at least $250 million per year. That level of funding has not materialized; the FY 1997 fusion budget is $232 million, of which $7 million is for support of the National Energy Research Supercomputing Center. The FY 1998 request is $225 million in ER plus $2 million requested through NE for work at the Advanced Test Reactor in Idaho on fusion irradiation experiments.[145]

FEAC also concluded that the most cost-effective way for the United States to maintain a strong research effort in burning plasma physics was through continued participation in the Engineering Design Activity (EDA) of the International Thermonuclear Experimental Reactor (ITER) and the international ITER process. ITER is the international effort to design and then construct an experimental fusion device having, at its heart, an ignited or nearly ignited plasma operating for pulses of 1,000 seconds or longer in a technological environment consistent with the ultimate needs of a fusion-energy-generating plant.

In the view of the PCAST Energy R&D Panel, the R&D program sponsored by OFES has been restructured over the past 2 years in a manner consistent with the priorities proposed by PCAST-95, to the degree that this was feasible given the lower budget. The program's organizing principles are sound and are in alignment with the recommendations of both PCAST-95 and FEAC.

The R&D portfolio of OFES emphasizes basic plasma science, high-temperature plasma physics, basic fusion-related technology, and work in support of the long-term objective of practical fusion energy. The PCAST Energy R&D Panel finds this portfolio appropriate, given both the budget and the current state of development of fusion as an energy option. With this mix of R&D activities and decades of international effort, the U.S. program can contribute to the knowledge base needed for fusion to become a viable and practical energy source in the second half of the next century.

However, the current funding level is too low to support a fully balanced program: it is approximately $20 million below the minimum FEAC recommended and $90 million less than the level PCAST-95 recommended. The budget allows no significant U.S. activity relating to the third PCAST-95 priority, namely, participation in an international program to develop practical low-activation materials; it has required reducing U.S. contributions to the design of ITER; it has resulted in the early shutdown of the largest U.S. fusion experiment[146]; and it has precluded initiation of the next major domestic plasma science and fusion experiment, the Tokamak Physics Experiment (TPX). The low funding has also limited the resources available to explore and develop alternative fusion concepts.

The Panel reiterates the PCAST-95 conclusion: "[f]unding for fusion 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. This funding also sustains an important field of scientific research — plasma science — in which the United States is the world leader and which has generated a panoply of insights and techniques widely applicable in other fields of science and in industry."[147]

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

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Committee (FESAC).
[145]Congress appropriated $232 million for OFES, including the $2 million originally requested for NE.
[146]The Tokamak Fusion Test Reactor (TFTR) at Princeton Plasma Physics Laboratory.
[147]PCAST-95, op. cit., p. 45.

### 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 internationally. ITER will complete its 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.

The objectives of ITER are to demonstrate controlled ignition and extended burn of a fusion plasma, to demonstrate steady-state operation, and to demonstrate the technologies essential for a fusion power system. A recent comprehensive review[148] stated that "the achievement of ITER's mission will be a major milestone in the development of a safe, economic, and sustainable energy source for the future."

U.S. participation in the ITER EDA has been an integral and cost-effective component of the domestic fusion science and engineering program, especially in light of the reduced funding level relative to that recommended by PCAST-95. 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 PCAST Energy R&D 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. In this post-EDA period, the United States should continue to participate in the international design activities and should concentrate on the specific types of ITER-related science and engineering efforts that also have high domestic value. 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.

The U.S. should also consider, as part of its overall ITER-related activity, participating in international steps toward a burning plasma experiment and the energy goal. In this connection, **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**. This effort would be fully consistent with the priority stressed by PCAST-95 and FEAC that the United States should engage in international collaboration focused on the key next-step scientific issue of ignition and moderately sustained burn. At the same time, it would be desirable to make additional resources available for alternative-concepts research, consistent with the restructuring of the fusion 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

[148] Fusion Energy Sciences Advisory Committee to the U.S. Department of Energy, *Review of the International Thermonuclear Experimental Reactor (ITER) Detailed Design Report*, April 1997.

estimated by the ITER project team to be $11.4 billion (in 1997 dollars, adjusted to be consistent with DOE's cost-estimating methodologies). A substantial share is expected to be borne by the host party.

The Panel 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 party states its intention to offer a site for ITER in the next year or two, the United States 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.[149]

**Inertial Fusion Energy**

The PCAST Energy R&D 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, inertial confinement fusion (ICF) — 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 in FY 1998 is allocated for laser-based ICF in support of DOE's stewardship of the nuclear weapons stockpile.[150] The technology approach favored for energy production would use an accelerator to produce intense beams of ions that compress and heat a tiny volume of fusion fuel so rapidly that fusion reactions occur before the target expands.

DOE's program to develop an accelerator that can drive inertial fusion for energy generation is called inertial fusion energy (IFE), and it was moved from ER's Office of Basic Energy Sciences (BES) to OFES after a review in 1990.[151] The aim of that transfer was to place the IFE effort under more programmatically appropriate management. The match is still not perfect, because the primary intellectual connections of this activity are with the ICF program in DP and the accelerator-dominated high-energy and nuclear physics programs in ER. However, IFE shares the long-term objective of producing energy from fusion with the magnetic confinement approaches that dominate the R&D portfolio of OFES.

The support ultimately needed to develop IFE — in particular, the heavy-ion accelerator needed to drive the fusion reaction — 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.**

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[149]A subpanel of FESAC was charged with making recommendations to DOE on specific priorities for the ITER transition period. Chaired by Hermann Grunder, this FESAC subpanel worked in parallel with the PCAST study and issued its interim report in late October 1997.

[150]This amount includes $198 million to continue construction of the National Ignition Facility, estimated by DOE to cost about $1.2 billion.

[151]DOE Energy Research Advisory Board, *Fusion Policy Advisory Committee (FPAC), Report of the Technical Panel on Magnetic Fusion*, DOE S-0081, September 1990.

**Fusion R&D Funding Recommendation**

**The PCAST Energy R&D Panel confirms the conclusions of 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 E.4.** In a letter to the President in December 1996, PCAST urged restoration of fusion R&D funding to the level recommended by PCAST-95.

**Table E.4: Recommended DOE Funding for Fusion Energy R&D[a] (Millions of As-Spent Dollars)**

| | FY 1997 Actual | FY 1998 Request | FY 1999 | FY 2000 | FY 2001 | FY 2002 | FY 2003 |
|---|---|---|---|---|---|---|---|
| Fusion Irradiation at ATR (NE) | 1 | 2 | 0[b] | 0[b] | 0[b] | 0[b] | 0[b] |
| Fusion Energy Sciences (ER) | 232 | 225[c] | 250 | 270 | 290 | 320 | 328 |

[a] The Panel did not review and makes no recommendation on funding for the ICF program in DP.
[b] Funding for fusion irradiation at ATR is included in the recommendation for Fusion Energy Sciences.
[c] Congress appropriated $232 million for ER, including funds for the fusion irradiation activity requested through NE.

## CRITICAL VIEWS

The Nuclear Task Force sought input from supporters and critics of both commercial nuclear power and the DOE fusion program. Although the overall conclusions of the Task Force probably would not satisfy the critics, some of the points they made about nuclear waste, plant safety, economics, proliferation, the appropriate Federal role, and the difficulties of developing practical fusion, were influential in reaching the final recommendations. The issues raised by the critics are summarized very briefly below. They should be considered when developing R&D policies and programs to address the problems underlying the concerns raised by the public and some of the technical community about nuclear fission and fusion.

### Fission

One critic said that commercial nuclear power is a mature industry, whose problems are economic and therefore not within the purview of Federal R&D policy. In his view, the government should not continue to subsidize power-plant development, including funding R&D to extend the life of existing reactors. He recommended that U.S. nuclear power policy have as its primary objective the elimination of nuclear weapons and their proliferation. Following such a policy, the Administration should strongly oppose the plutonium-based, closed-fuel-cycle programs of the European Community, Japan, and Russia.[152]

The Union of Concerned Scientists' representative stated that "Federal support for nuclear energy is harmful to U.S. domestic policy when it comes at the expense of accelerating the role of renewable energy

[152] Thomas B. Cochran, National Resources Defense Council, presentation to the PCAST Nuclear Task Force, Washington, D.C., 14 July 1997.

sources." He also said that "since the United States is a leader in energy technology, U.S. support for nuclear energy has a negative effect on development of energy options in other countries." He did note that nuclear power falls behind the majority of energy technologies that can be used to address global warming and that nuclear power's problems in the United States could be solved because they are due to bad management, particularly in lack of standardization and ineffective quality control assurance programs.[153]

The representative from Public Citizen said that "age-related degradation of major reactor components and a competitive electricity market make it unlikely that any nuclear reactor ever will...[operate] for the 40 year term of its license." Believing that "most, if not all of the problems experienced by nuclear power have been self inflicted," he said that "it has been the nuclear industry's inability to effectively manage the construction and operation of its reactors that has solidified public opposition to nuclear power in the United States." He said that "nuclear power has no role to play in combating greenhouse emissions," and that "nothing should be done to prevent the demise of nuclear power." Because of the long-lived nature of high-level radioactive waste, he opposed the concept of a repository. Noting that these wastes must be monitored and retrievable in perpetuity, he supported new thinking on long-term solutions.[154]

In congressional testimony, a representative of the United States Public Interest Research Group (USPIRG) said: "We are now burdened with the yet-to-be-solved problem of addressing the highly radioactive, nuclear wastes which result from nuclear fission, and aging reactors present an increasing safety concern. The nuclear energy industry has fed long enough at the federal trough. Nuclear fission is uneconomic, unsafe and generates lethal waste. Let us look beyond the almost religious fanaticism of the handful of nuclear power promoters who ignore economic realities. Nuclear power is a failed technology, it belongs in the past."[155]

Another presenter said that nuclear power should not be supported as a major element to address international GHG emissions because "it will be too little, it will be too late, it will be too costly, and there are far better ways to use the money to reduce greenhouse gas emissions." [156] He has written: "In order to ensure that nuclear reactors are not vulnerable to catastrophic accidents, new designs would need to be developed...Such an effort to ensure reactor safety and regain public confidence would take decades, if it can be accomplished at all. However, carbon dioxide emissions must be reduced in the same period."[157]

**Fusion**

Fusion critics either oppose the current program's focus on tokamaks and ITER or the large funding going into fusion at the expense, in their view, of other energy sources, such as fission or renewables.

An EPRI president emeritus wrote that "...some of us...are convinced that the fusion power plant concept should not be included as an option in the strategies proposed to realistically meet our future national energy needs...The policy damage that has already occurred by the perception of fusion as being 'almost-at-hand'…has been the diversion of attention and support from continuous improvement of

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[153]Presentation by David A. Lochbaum, Nuclear Safety Engineer, Union of Concerned Scientists, to PCAST Nuclear Task Force, Washington, D.C., 14 July 1997.

[154]James P. Riccio, staff attorney of Public Citizen, presentation to PCAST Nuclear Task Force, Washington, D.C., 28 July 1997.

[155]Testimony of Anna Aurilio before the House Science Committee, Subcommittee of Energy and Environment, 9 April 1997.

[156]Arjun Makhijani, Institute for Energy and Environmental Research, presentation to the PCAST Nuclear Task Force, Washington, D.C., 28 July 1997.

[157]Arjun Makhijani and Scott Saleska, "The Nuclear Power Deception: U.S. Nuclear Mythology from Electricity 'Too Cheap to Meter' to 'Inherently Safe' Reactors," Institute for Energy and Environmental Research, April 1996, p. 9.

nonfossil energy sources."[158] In a presentation to the Task Force,[159] he emphasized that the absence of a materials test facility is a major handicap to progress in the ITER program. With regard to fusion's eventual utility, he argued that with present concepts, the cost of a fusion plant will be a multiple of that of a fission plant, making it unlikely to be a financially practical choice.

A recent article noted that "…DT tokamaks, as we understand or envision them today, simply do not offer a workable approach to commercial fusion power." The authors favor continued funding of fusion R&D and concluded that "...the present annual budget of somewhat more than $200 million/year would be required to develop fusion — the ultimate power source for modern civilization."[160]

USPIRG recommended that Congress do the following: "Terminate existing tokamak reactors, cancel planned spheromak, move fusion from the DOE R&D budget to Basic Science, [and] begin phase out of participation from the ITER project unless the emphasis is switched to basic research."[161]

Following the Task Force meeting at which he was invited to speak, an MIT professor with many years of experience in fusion research, wrote in opposition to the ITER approach: "...to reach burn regimes and ignition, with considerably higher probabilities than ITER, meaningful smaller scale experiments can be envisioned and proposed…The ITER concept has major problems of consistency, both in its physics basis and the relevant technological solutions…The large number of identified problems of the ITER concept are by themselves sufficient to give a combined probability that is quite low for results that are commensurate with the costs and times involved in this enterprise." [162]

**EDUCATION**

Nuclear engineering and sciences are complex disciplines with a substantial body of knowledge, algorithms, and techniques requiring both broad and specialized expertise. Nuclear expertise remains essential to the nation for fission-power-plant operation and regulation, nuclear safety, nuclear waste management, national security, fusion R&D, and growing applications in high-technology industry and medicine.

Today, however, enrollments in nuclear fields are declining, the academic offerings at both undergraduate and graduate levels are thinning, and — in the case of nuclear engineering — degree programs are being terminated or merged into other departments at many universities throughout the United States.[163] Today, there are 34 operating university research reactors, down from 76 in 1975, and 35 nuclear engineering departments or programs in universities with their principal discipline being nuclear engineering or radiation science and technology,[164] down from 50 in 1975. There are only 17 programs that grant a B.S. degree in nuclear engineering and that have not announced any plans for being phased out or converted to options under other degree programs. The undergraduate enrollment in these programs is declining at a rate of about 10 percent per year, and the number of graduate students supported by research grants declined about 16 percent from 1992 to 1995. As faculty retire, they are not being replaced. 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 a program for

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[158] Letter from Chauncey Starr to John Ahearne, 8 May 1997.

[159] Chauncey Starr, President Emeritus, EPRI, presentation to the PCAST Nuclear Task Force, San Diego, CA., 27 June 1997.

[160] Robert L. Hirsch, et al., "Fusion Research With A Future," *Issues in Science and Technology*, Summer 1997, pp. 60-64.

[161] Aurilio, op. cit.

[162] Letter to John Ahearne from Professor Bruno Coppi, 21 July 1997.

[163] Most of the data following are from G. A. Emmert, et al., *Department of Energy-Industry Nuclear Power Engineering Education Matching Grant Program, Status Report: 1992-1996*, March 1997.

[164] Nuclear Engineering Department Heads Organization and National Organization of Test, Research, and Training Reactors, "Infrastructure Goals of the Nuclear Engineering/Radiation Sciences and Technology and University Research Reactor Community," 8 January 1997.

undergraduates.[165] Thus, formerly strong university groups are becoming subcritical in size and expertise, thereby compromising the quality of education provided.

Given the U.S. need — justified for reasons of national security and global stability alone — to maintain international leadership in matters nuclear, this trend is alarming. The importance to human health, the environment, and national prosperity of maintaining an exemplary record in nuclear safety, of solving the problem of nuclear waste disposal, of cleaning up radioactively contaminated sites, and of developing advanced nuclear-based technologies for medicine, manufacturing, and other commercial uses argues against phasing out nuclear education. In addition, the nation would benefit from a higher level of nuclear awareness and knowledge among the general population.

Nuclear materials and energy are growing in importance and value to society through an increasing range of applications. They are central to problems, solutions, and decisions faced by the nation. Little to no exposure to nuclear knowledge and issues is provided prior to college, and many colleges and universities offer no specialized course work and only very limited general education in these areas. Increasingly, specialized nuclear education and training must be provided by employers. Despite such efforts, there is typically a noticeable difference between degreed nuclear professionals educated thoroughly in nuclear and related disciplines and trained to advance the state of the art and those who learn the specific techniques and knowledge narrowly required by their jobs. Although presentations to the Task Force by both utilities and vendors indicated they were not having difficulty hiring new technical people, one senior person, a member of a review team for a major nuclear plant for several years, said that he has seen a clear decline in the strength of the staff. As experienced, degreed nuclear professionals retire from industry, utilities, and laboratories, their wisdom and expertise are lost to the work force.

Nonmarket forces have distorted the appeal of nuclear-related majors, and the decline in the numbers of degree recipients and degree opportunities is poorly serving the current and future needs of the United States in science, technology, energy, and national security. Important challenges and unknowns can be found in nuclear fields, and their exploration can yield substantial benefits in numerous areas. However, the antinuclear posture in the United States makes these fields unattractive and diminishes the resources available to university groups for the kinds of research that attract and educate bright students. Fast-moving fields, with faculty engaged in visible and exciting efforts to explore the unknown, advance the state of the art, or pursue an important career, draw bright students in large numbers. It further helps when many of these students are able to continue their studies by winning fellowships or receiving paid research assistantships supported by faculty research grants or contracts. Universities expect faculty to obtain such resources to enhance the research and intellectual activity on campus and to contribute to the institution's prestige.

In the science and engineering departments of universities, this level of scholarship is essential to the survival of the degree program. Yet, for nuclear engineering and plasma physics, R&D resources have been increasingly scarce. In FY 1997, as a result of recommendations made by the National Research Council[166] and endorsed by FEAC,[167] DOE and the National Science Foundation (NSF) together launched a new initiative to make available $4 million per year for competitive peer-reviewed proposals from university faculty to do research in plasma science and engineering, along with $1 million per year for a grant program targeting young investigators. The outpouring of quality proposals (240 requesting eight times the available funding) was overwhelming and demonstrated the untapped reservoir of creative ideas in the university plasma science and engineering community. A comparable rush of good ideas would

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[165]National Research Council, *Plasma Science: From Fundamental Research to Technological Applications*, Washington, D.C., National Academy Press, 1995.
[166]Ibid.
[167]DOE, FEAC, op. cit.

probably emerge in response to the PCAST Energy R&D Panel's proposed Nuclear Energy Research Initiative.

A recent report[168] on nuclear engineering concluded: "[u]nless the decline in both nuclear engineering enrollments and departments is stemmed within the next 5 to 10 years, both government and industry will experience difficulties in hiring sufficient numbers of well-trained entry-level nuclear engineers to meet their needs. At that time, the rate of decline in enrollments coupled with the rate at which nuclear engineers leave the field due to retirements, career changes, etc. is expected to significantly exceed the reduction in the nuclear engineering work force due to government and industry downsizing."

The NSF is traditionally the Federal agency supporting science and engineering education. However, NSF has discouraged applications for research and education from nuclear engineering faculty, citing DOE as the appropriate Federal agency for such proposals.[169] Congress provided funding from FY 1990 through FY 1995 for these areas, although DOE did not include budget requests for these areas until FY 1995. DOE received $4 million in FY 1997 for this effort and requested $6 million for FY 1998. Congress appropriated $7 million, which included supplying fuel for university research reactors.

With the limited funds available for traditional nuclear engineering research, there have been few exciting advances. Nuclear engineering faculty have had to diversify into other areas to obtain grant funding and attract students. This diversification has resulted in significant contributions to environmental science, bionuclear engineering, and radiological physics, among other fields. At the same time, the core of the field is depleted, and the knowledge base for solving the nation's and world's nuclear-related problems and for developing future nuclear technologies is stagnating. The United States cannot maintain international leadership by continuing along this path.

## OVERALL FINDINGS AND RECOMMENDATIONS

The following material summarizes the results of the Nuclear Task Force's deliberations. As mentioned at the beginning of this appendix, these findings and recommendations represent a consensus of the Task Force, though they have not necessarily been endorsed by the full PCAST Energy R&D Panel.

### Findings

1. Nuclear power is a major source of electricity generation; does not produce any GHGs, sources of acidic precipitation, or particulates; does not cause smog; and decreases reliance on fossil fuels.

2. There is widespread belief in the nuclear power industry that the Administration is not serious about resolving the commercial spent-fuel-storage problem in a timely fashion, although it has the responsibility and the funds.

3. Because of proliferation concerns, U.S. government policies have not supported the export of U.S. nuclear technology in all possible markets.

4. There is widespread belief that the United States should remain a part of the world nuclear community, particularly regarding consideration of policy issues. One step would be continued membership in the OECD's Nuclear Energy Agency.

[168]Emmert, op. cit., p. 33.
[169]Nuclear Engineering Department Heads Organization, et al., op. cit.

5. Many DOE offices fund nuclear-power-related R&D programs. However, there is no, or at best little, coordination between these offices: Nuclear Energy (NE), Civilian Radioactive Waste Management (OCRWM), Defense Programs (DP), Energy Research (ER), Environmental Management (EM), Materials Disposition (MD), Naval Reactors (NR), and Nonproliferation and National Security (NN).

6. Since its formation, DOE has not funded research to create and develop new ideas for proliferation-resistant fuel cycles.

7. There are many basic and applied research problems regarding nuclear waste management, improved manufacturing productivity for nuclear plants, and nonproliferation.

8. Although the national laboratories have substantial expertise in areas relating to nuclear power, this expertise is declining because of reduced budgets, leading to lack of work. In addition, this expertise is not linked to industry. At the same time, too many laboratories are attempting to remain involved in nuclear energy activities, with the result that there no longer exists, or will shortly cease to exist, a critical mass in many laboratories in each of the areas of interest.

9. Electricity 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 loss of operating reactors primarily will be offset by using gas turbines or coal plants, increasing the use of fossil fuel with its associated emissions.

10. The NRC has exerted a strong influence on the U.S. nuclear power industry. This influence has had noteworthy benefits, for example, the requirement for containments and safety systems and the development of internationally recognized standards. More recently, NRC's influence is viewed by industry as having developed negative elements: an excessive emphasis on paperwork, resistance to implementation of a regulatory regime based on risk and performance, and practices that are increasingly poorly connected with the needs and realities of an industry in transition to utility deregulation.

11. Currently, in the United States, nuclear power costs too much for new nuclear plants to be competitive. Even considering the shortest construction times, leading to lower capital costs, new nuclear power still cannot compete against gas turbines and will not unless the cost of gas rises significantly. However, it may not be necessary to bring the cost of nuclear power down to the current cost of combined-cycle natural gas generation, because concerns about GHG emissions may lead to actions that drive up the cost of all fossil fuel generation.

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

13. An overwhelming consensus is that no nuclear plant will be built in the United States in the next 10 or perhaps even 20 years.

14. 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.

15. The market for new nuclear plants in the next decade is in Asia: Japan, Korea, Taiwan, China, and perhaps Indonesia and India.

16. Because capital costs are a larger part of the total life-cycle costs of nuclear plants than for other types of generation, the time to build a nuclear plant is extremely important. Current designs can be built in less than 5 years (recent experience in Japan and South Korea).

17. U.S. nuclear power vendors, through their technologies and commercial offerings, will contribute substantially to the stabilization and reduction of $CO_2$ globally. Under current policies, this contribution is not likely to occur in the United States and, in time, will not be dependent on U.S. technological leadership.

18. At universities, nuclear engineering departments are financially stressed and are being absorbed into other engineering departments. If not resolved, this trend will probably result, in the long term, in a reduction in the availability of new ideas and of graduates who have the deep understanding that leads to insight. To date, however, the supply of personnel has not been a problem for vendors, utilities, or national laboratories.

19. This review confirms the conclusion of PCAST-95: "U.S. funding for research and development (R&D) on fusion energy is a valuable investment in the energy future of this country and the world, as well as sustaining a field of scientific research — plasma physics — that is important in its own right and has been highly productive of insights and techniques applicable in other fields of science and industry."[170]

20. Over the past 2 years, the DOE Fusion Energy Sciences program has been restructured. The new organizing principles are sound and are consistent with the recommendations of both PCAST-95 and FEAC.

21. Participation by the United States in the International Thermonuclear Experimental Reactor (ITER) Engineering Design Activity (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-95. 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.

22. It would be helpful to all parties involved if, over the next year or two, at least one of the parties in the ITER program expressed its intention to offer a specific site for ITER construction by the end of the 3-year period.

23. A more modestly priced ITER, focused on the key next-step scientific issue of ignition and moderately sustained burn, might make it easier for all parties to come to agreement. It might be useful if the parties to the ITER program were to consider further reductions in the cost of the ITER machine, although significant cost reduction might mean that only a subset of ITER's current mission could be fulfilled.

24. There is inadequate coordination between Defense Programs (DP) and Energy Research (ER) regarding their inertial confinement fusion programs.

25. Given the importance of nuclear engineering and plasma science to many areas of national interest and industrial application, it is important to revitalize educational programs in these areas and to help them to attract high-caliber students.

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[170]PCAST-95, op. cit.

**Recommendations**

1. **The Administration should implement a campaign to explain to the public the importance of energy to our economy and quality of life.**

2. **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.**

3. **DOE should improve coordination and integration between all the DOE program offices sponsoring R&D applicable to fission energy. These program offices include Nuclear Energy (NE), Civilian Radioactive Waste Management (OCRWM), Defense Programs (DP), Energy Research (ER), Environmental Management (EM), Materials Disposition (MD), Naval Reactors (NR), and Nonproliferation and National Security (NN).**

4. **Anticipating that the 1998 viability assessment for Yucca Mountain 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.**

5. **To strengthen the national laboratories' fission energy R&D programs and their management, DOE should consolidate these programs at fewer national laboratories and encourage stronger links with industry.**

6. **Congress should reexamine the role, functioning, and funding of the NRC to ensure the effectiveness of that agency and its relicensing process in the evolving deregulated utility environment.**

7. **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, for all countries that have signed the Nuclear Nonproliferation Treaty (NPT), insofar as this strategy does not contravene U.S. nonproliferation goals. It also would be useful for the government to pursue nonproliferation agreements aggressively with all trading partners.**

8. **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 the International Atomic Energy Agency (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.**

9. **If the United States were to implement a carbon-emissions policy that would require existing plants to operate longer than their owners would choose to in a deregulated electric-power market, DOE should monitor operations and relicensing and be prepared to fund 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 NRC requirements.**

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

11. **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 (as-spent dollars). This program would provide funding for investigator-initiated ideas that address the issues confront-ing nuclear energy. Projects proposed by universities, national laboratories, and in-dustry 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 relevance to DOE's missions.**

12. **The Federal government should continue to emphasize fusion research, recognizing the enormous energy potential, the half-century horizon,[171] and the substantial basic science component of the program. The PCAST Energy R&D Panel confirms the conclusions of 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 FEAC ($250 million) and be increased to $320 million over 3 years.**

13. **The U.S. fusion 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.**

14. **If the parties agree to move forward on ITER construction, the United States should be prepared to determine, with stakeholder input, what the level and nature of its involvement should be.**

15. **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.**

[171] "Since it is expected that fusion energy would not enter the marketplace for commercial electricity generation until the middle or later half of the next century, significant market penetration is not expected until the 22nd century." N. Anne Davies, Director of the DOE Office of Fusion Energy Sciences, "Input to PCAST R&D Panel Portfolio Analysis," 26 August 1997, p. 5.

16. **The Panel recommends closer communication and collaboration between DP and ER to establish an effective funding and decision-making process for inertial fusion energy (IFE), which leverages the substantial ongoing DP investment in the coming years.**

17. **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.**

## LIST OF MEETINGS AND SOURCES

### Presentations May 7-8, 1997, Washington, D.C.

Terry Lash, Director, Office of Nuclear Energy, Science and Technology (NE), DOE
Dennis Harrison, Program Director, Office of Engineering and Technology Development, NE, DOE
John Herczeg, Technical Director, NE, DOE
Trevor Cook, Program Director, Office of Engineering and Technology Development, NE, DOE
Earl Wahlquist, Deputy Associate Director, Office of Engineering and Technology Development, NE, DOE
Dean Eastman, Director, Argonne National Laboratory (ANL)
David J. Hill, Director, International Nuclear Safety Center, ANL
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William Guyton, Jr., Vice President and General Manager, Applied Engineering and Development Laboratory, Idaho National Engineering and Environmental Laboratory (INEEL)
Phillip MacDonald, Consulting Engineer, Advanced Nuclear Energy Products, INEEL
James Lake, Director, Advanced Nuclear Energy Products, INEEL
Robert Schock, Deputy Associate Director, Energy Program, Lawrence Livermore National Laboratory (LLNL)
Tom Isaacs, Office of Policy, Planning and Special Studies, LLNL
C.K. Chou, Deputy Associate Director, Fission Energy and Systems Safety Program, LLNL

### Presentations May 19, 1997, Washington, D.C.

Marylee Slosson, Acting Director, Division of Reactor Program Management, Office of Nuclear Reactor Regulation, Nuclear Regulatory Commission (NRC)
David Morrison, Director, Office of Nuclear Regulatory Research, Division of Reactor Program Management, Office of Nuclear Regulatory Research, NRC
Margaret Federline, Deputy Director, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, NRC
David B. Matthews, Chief, Generic Issues and Environmental Projects Branch, Division of Reactor Program Management, Office of Nuclear Reactor Regulation, NRC
Richard L. Wagner, Jr., Project Leader, Nuclear Futures, Los Alamos National Laboratory (LANL)
Paul T. Cunningham, Program Director, Nuclear Materials and Stockpile Management, LANL
Edward D. Arthur, Senior Science Advisor, Nuclear Materials and Stockpile Management, LANL
Bill Shipp, Associate Laboratory Director, Environmental Technology Division, Pacific Northwest National Laboratory (PNNL)
Alvin R. Ankrum, Senior Program Manager, Energy Technology Department, PNNL
E. Thomas Boulette, Senior Vice President, Nuclear, Boston Edison
Robert Saunders, Vice President for Nuclear Engineering and Services, Virginia Power
Charles Jackson, Manager, Nuclear Safety and Licensing, Consolidated Edison

**Presentations May 20, 1997 (Focus On Fusion), Washington, D.C.**

Martha Krebs, Director, Office of Energy Research, DOE
Anne Davies, Director, Office of Fusion Energy Sciences, DOE
Michael L. Knotek, ANL, Chairman of FEAC's 1996 Strategic Planning Committee
David Baldwin, Senior Vice President, Fusion Group, General Atomics (GA)
Thomas Simonen, Vice President, GA
Stewart Prager, Professor, Department of Physics, University of Wisconsin
Ian Hutchinson, Professor, Department of Nuclear Engineering, Massachusetts Institute of Technology (MIT)
Bruno Coppi, Professor, Department of Physics, MIT
John Schmidt, Interim Director (now Head, Advanced Projects), Princeton Plasma Physics Laboratory (PPPL)
Robert J. Goldston, Associate Director for Research (now Laboratory Director), PPPL
Charles Baker, University of California San Diego, and Director, ITER Home Team
Michael Mauel, Columbia University and President of the University Fusion Association

**Presentations June 24-28, 1997, San Diego, California**

Gary Kugler, Vice President, Commercial Operations, Atomic Energy of Canada, Ltd.
Marilyn Meigs, Vice President, Fuel Cycle and Materials Processing, British Nuclear Fuels, Ltd.
Patrice Laget, Counselor, Science, Technology and Education, European Commission
Dieter Brosche, Director, Head of Division of Nuclear Power Plans, Bayernwerk AG, Germany
W. Edward Cummins, Project Manager, AP600 FOAKE, Westinghouse
Steven Hucik, General Manager, Nuclear Plant Projects, General Electric
Regis Matzie, Vice President, Engineering, ABB-Combustion Engineering Nuclear Systems
Linden Blue, Vice-Chairman, GA
Walter Simon, Senior Vice President, GA
Robert Bari, Chairman, Department of Advanced Technology, Brookhaven National Laboratory
E. Michael Campbell, Associate Director for Laser Programs, LLNL
Roger Bangerter, Program Head, Fusion Energy Research, Lawrence Berkeley National Laboratory
Chauncey Starr, President Emeritus, Electric Power Research Institute
Remy Carle, Electricité de France (retired), and President, World Association of Nuclear Power Operators
William Kastenberg, Chairman, Department of Nuclear Engineering, University of California Berkeley; also representing university nuclear engineering departments
Stephen Dean, President, Fusion Power Associates
William Ellis, Vice President and General Manager, Advanced Technology Center, Raytheon Engineers and Construction, and Chairman, U.S. ITER Industry Council
John Davis, Manager, High Energy Systems, New Aircraft and Missile Products, McDonnell-Douglas

**Presentations July 14, 1997, Washington, D.C.**

Masaji Yoshikawa, Director, Japan Atomic Energy Research Institute
Robert Aymar, Director, International Thermonuclear Experimental Reactor, Joint Central Design Team
Daniel Dreyfus, Smithsonian Museums, formerly Director of the Office of Civilian Radioactive Waste Management, DOE
Robin Jones, Vice President, Nuclear Systems, Electric Power Research Institute

David Lochbaum, Nuclear Safety Engineer, Union of Concerned Scientists
Thomas B. Cochran, Senior Scientist, Natural Resources Defense Council

**Presentations July 28, 1997, Washington, D.C.**

James Riccio, Staff Attorney, Public Citizen Critical Mass Energy Project
Arjun Makhijani, President, Institute for Energy Analysis and Environmental Research
Joseph Colvin, President and Chief Executive Officer, Nuclear Energy Institute
Marvin Fertel, Vice President of Nuclear Infrastructure Support and International Programs, Nuclear Energy Institute
Angelina S. Howard, Senior Vice President, Industry Communications, Nuclear Energy Institute
Ronald L. Simard, Senior Director, Suppliers and International Programs, Nuclear Energy Institute
Donald W. Miller, Past President, American Nuclear Society
Stanley Hatcher, President, American Nuclear Society
Edward L. Quinn, Vice President, American Nuclear Society
Bertram Wolfe, Past President, American Nuclear Society

**Presentations July 28, 1998 (Focus On DOE Basic Energy Sciences Program), Washington, D.C.**

Martha Krebs, Director, Office of Energy Research, DOE
Patricia Dehmer, Director, Office of Basic Energy Sciences (BES), DOE
Iran Thomas, Deputy Associate Director, BES, DOE
Robert Marianelli, Director, Chemical Sciences Division, BES, DOE

**Discussions July 28-29, 1997, Washington, D.C.**

Alex Flint, Minority Staff Director, Senate Appropriations Committee, Energy and Water Subcommittee
Robert Simon, Staff, Senator Jeff Bingaman
Harlan Watson, House Science Committee, Subcommittee on Energy
Beth Robinson, House Science Committee, Subcommittee on Energy
David Garman, Staff, Senate Committee on Energy and Natural Resources
Victor Rezendes, Director, Energy Resources and Science Division, General Accounting Office (GAO)
Robin Nazzaro, Assistant Director, Energy Resources and Science Division, GAO
Gary Boss, Assistant Director, Energy Resources and Science Division, GAO

**Presentations August 15, 1997 (Classified; J.F. Ahearne Only), Arlington, Virginia**

Admiral Frank Bowman, Director, Office of Naval Reactors, DOE
Carl Schmitt, Deputy Director, Office of Naval Reactors, DOE

**Task Force Working Meetings In Addition To The Above**

March 27, 1997, Washington, D.C.
July 29, 1997, Washington, D.C.
August 14, 1997, Chicago, Illinois

**Written Contributions Received From Individuals Not Listed Above**

Mohamed Abdou, Professor of Nuclear Engineering, University of California Los Angeles
H. Kenneth Davis, consultant, San Rafael, California, formerly Deputy Secretary of Energy
Robert D. Gadsby, Director, MOX Project, Atomic Energy of Canada Limited
Robert M. George, Uranium Sales Program, NE, DOE
Francis Perkins, International Thermonuclear Experimental Reactor, San Diego, California
Miklos Porkolab, Professor and Director, Plasma Science and Fusion Center, MIT
Alvin Radkowsky, Tel-Aviv University, Israel, formerly Admiral Rickover's chief scientist
Theodore Rockwell, MPR Associates, Chevy Chase, Maryland
A. David Rossin, nuclear safety consultant, Los Altos Hills, California, formerly Assistant Secretary for DOE-NE
John Sheffield, Fusion Energy Division, ORNL; Chairman, Fusion Energy Sciences Advisory Committee
Alan Waltar, President, Eagle Alliance
Gary S. Was, Nuclear Engineering Department, University of Michigan, Nuclear Engineering Department Heads Organization

**Letter from Georgia Tech Engineering Faculty**

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