1 of 2

World Nuclear Capacity and Fuel Cycle Requirements 1993

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MASTER

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Preface

Section 205(a)(2) of the Department of Energy Organization Act of 1977 (Public Law 95-91) requires the Administrator of the Energy Information Administration (EIA) to carry out a central, comprehensive, and unified energy data information program that will collect, evaluate, assemble, analyze, and disseminate data and information relevant to energy resources, reserves, production, demand, technology, and related economic and statistical information.

As part of the EIA program to provide energy information, this analysis report presents the current status and projections of nuclear capacity, generation, and fuel cycle requirements for all countries in the world using nuclear power to generate electricity for commercial use. Long-term projections of U.S. nuclear capacity, generation, fuel cycle requirements, and spent fuel discharges for three different scenarios through 2030 are provided in support of the Department of Energy's activities pertaining to the Nuclear Waste Policy Act of 1982 (as amended in 1987). The projections of uranium requirements also support the Energy Information Administration's annual report, *Domestic Uranium Mining and Milling Industry: Viability Assessment*, and are provided to the Organization for Economic Cooperation and Development (OECD) for preparation of the Nuclear Energy Agency/OECD report, *Summary of*

Nuclear Power and Fuel Cycle Data in OECD Member Countries. Long-term nuclear capacity projections used for the Lower and Upper Reference case scenarios were obtained from the Office of Integrated Analysis and Forecasting, Energy Information Administration. Most of these projections were developed using the World Integrated Nuclear Evaluation System (WINES) model. The model is documented in *Model Documentation of the World Integrated Nuclear Evaluation System*, Volumes I, II, and III (DOE/EI-M049). The International Nuclear Model (INM), used for calculating the electricity generation values and fuel cycle requirements in this report, is documented in *International Nuclear Model*, Volumes I, II, and III (DOE/EI-19656) and the International Nuclear Model Personal Computer Model Documentation.

The legislation that created the EIA vested the organization with an element of statutory independence. The EIA does not take positions on policy questions. Its responsibility is to provide timely, high-quality information and to perform objective, credible analyses in support of deliberations by both public and private decisionmakers. Accordingly, this report does not purport to represent the policy positions of the U.S. Department of Energy or the Administration.

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Executive Summary

U.S. Highlights

The most important national event affecting the U.S. nuclear industry in 1992 was the passage of the Energy Policy Act of 1992 (EPACT), Public Law 102-486. Seven of EPACT's 30 Titles contain provisions related to nuclear power and/or uranium. In particular, Title XXVIII, "Nuclear Plant Licensing," provides a new licensing procedure for U.S. nuclear power plants, based on "off-the-shelf" reactor designs that will be approved and certified by the U.S. Nuclear Regulatory Commission (NRC). The NRC is currently in the process of certifying four new reactor designs. The new licensing procedure, which is intended to provide a more predictable process for applicants (i.e., utilities) planning nuclear power construction projects, has the potential to reduce the financial risks associated with nuclear construction, thus making the nuclear option more favorable.

Another significant development for the U.S. nuclear industry in 1992 was the fact that the overall average capacity factor for U.S. commercial power reactors reached an all-time high of 70.9 percent, up slightly from the previous record of 70.2 percent set in 1991. This was the third consecutive year in which capacity factors reached record levels in the United States. The continuing improvement in plant performance contributed to a record level of electricity generation for U.S. commercial nuclear power in 1992—a total of 618.8 net terawatt-hours (Twh). The United States generated 19.8 percent of its electricity from nuclear plants in 1992. This percentage refers to utility and nonutility generation.

Status of Nuclear Power Throughout the World

At the end of 1992 there were 424 commercial nuclear reactors operating in 28 countries throughout the world, with a capacity of 329.2 net gigawatts electricity (GWe).¹ This was a net increase of three units and 3.1 GWe from 1991. Nuclear-generated electricity increased

by a modest 1.2 percent from the 1991 total of 1998.7 net terawatt-hours.

The nations with the most nuclear capacity as of yearend 1992 were the United States (99.0 GWe), France (57.7 GWe), and Japan (34.2 GWe), followed by the Commonwealth of Independent States (C.I.S.) (30.9 GWe), Germany (22.5 GWe), Canada (14.6 GWe), and the United Kingdom (11.9 GWe). Combined, these countries accounted for 82 percent of worldwide nuclear capacity.

Of countries with at least 5 GWe of nuclear capacity, France produced the largest share of electricity generation with nuclear power, nearly 73 percent. Five other countries with 5 GWe or more of nuclear capacity produced 30 percent or more of their electricity from nuclear power. In addition, it is expected that the percentage of total electricity generated by Japanese nuclear plants will also increase to 30 percent or more in the near future because of the aggressive nuclear power program in Japan.

Ninety-seven units totaling 83.8 GWe of capacity were under construction or in the planning stages in foreign countries in 1992. Of the 97 units, 55 of them were less than 26 percent complete. Japan had 23 units under construction or in the planning stage with a capacity of 23.9 GWe. Six of the 23 units were more than 75 percent complete. Japan's nuclear construction program is by far the largest in the world. Three other countries (France, India, and South Korea) have a total of 24 units under construction or planned, with a combined capacity of 20.8 GWe. At the end of 1992, the United States had 8 units in the construction pipeline that were ordered before 1978, but 5 of those units are classified by the U.S. Nuclear Regulatory Commission as "indefinitely deferred."

Six nuclear units were connected to the electric grids in their respective countries and three units were shut down in 1992. In India two units (Narora 2 and Kakrapar 1) began generating electricity. The addition of these two units brings India's total nuclear capacity to

¹Four of these units are Bilibino 1-4 located in Russia, with a total capacity of 44 MWe. They are used primarily for district heating rather than electricity generation. Therefore, they are not included in the electricity generating statistics and projections contained in this report.

1.8 GWe. In France one unit (Penly 2) began operation, and in Canada one unit (Darlington 3) was connected to the grid, bringing Canada's total operable nuclear capacity to 14.6 GWe. Japan also connected two units to the grid, Ohi 4, a 1,127-MWe PWR and Kashiwazaki Kariha-3, a 1,067 MWe BWR. The retired units were San Onofre 1 and Yankee Rowe in the United States and Saint Laurent A2 located in Loir-et-Cher, France. In addition, the Trojan nuclear plant in the United States was shutdown in November 1992 because of equipment problems. It was announced in January 1993 that it would shutdown permanently.

World Nuclear Capacity Projections

Worldwide, nuclear capacity is projected to increase from 329.2 GWe in 1992 to between 350.9 and 426.8 GWe by 2010, representing a growth rate between 0.4 and 1.5 percent. As seen in the Lower Reference case projections, however, the future of nuclear power is projected to be much stronger in some countries.² In the Far East, nuclear power capacity is projected to grow from 46.6 GWe to 68.8 GWe by 2010 in the Lower Reference case, representing a 2.2-percent annual growth rate (Figure ES1). Japan and South Korea, which

Figure ES1. 1992 World Nuclear Capacity and Projected Capacity for 2010

Note: GWe = Gigawatts-electric

Source: 1992 Nuclear Capacity: Appendices D, F; Table 10. Projections: Energy Information Administration, World Integrated Nuclear Evaluation System file WINES.OUT, April 1993. Information used in developing the projections for the countries of Eastern Europe, the People's Republic of China, Cuba, and North Korea was obtained from the International Atomic Energy Agency's March 1993 Consultancy on Nuclear Capacity Forecasting.

²Two scenarios, a Lower and Upper Reference case, are developed for foreign countries through the year 2010, based on different assumptions about economic growth and energy demand. The Lower case is cited more frequently in the text because it represents a more cautious projection of nuclear power throughout the world. This is justified because of the high uncertainty of the expansion of nuclear power in many countries. Details of the assumptions are presented in Appendix B of this report.

have aggressive nuclear power expansion programs account for most of this increase. Nuclear power capacity in Western Europe is projected to decline in the Lower Reference case from 121.0 GWe in 1992 to 107.5 GWe by 2010. The countries accounting for this decline are Belgium, Sweden, and the United Kingdom. France is the only country in Western Europe that is projected to increase its nuclear power capacity from 57.7 GWe to 62.1 GWe in the Lower Reference case, with an annual growth rate of 0.4 percent. U.S. nuclear power capacity is projected to grow modestly over the same period, from 99.0 GWe to 102.4 GWe in the Lower Reference case. All the projected growth in U.S. capacity comes from completion of reactors currently in the construction pipeline.

World Demand for Uranium and Enrichment Services

Worldwide average uranium requirements for 1993 through 1995 are projected to range between 139.8 and 146.6 million pounds U_3O_8 per year for the Lower and Upper Reference cases. By the years 2006 through 2010, annual uranium requirements will grow to a range of between 148.8 and 180.3 million pounds per year. The Lower Reference case projects a relatively stable level of annual uranium requirements through 2010, with an annual growth rate of only 0.4 percent, compared with a 1.2-percent annual growth rate in the Upper Reference case. The overall increase in annual uranium requirements reflects the projected worldwide increase in nuclear capacity through 2010, and the expected increase in capacity factors from an average of 71 percent to a worldwide average of about 75 percent by 2010.

Cumulative uranium requirements through 2010 are projected to be between 2.6 and 2.9 billion pounds U_3O_8 . In the Lower Reference case, reactors in Western

Europe account for 32 percent of cumulative requirements through 2010, the United States accounts for 30 percent, and the Far East accounts for 18 percent. The projected uranium requirements in both the Upper and Lower Reference cases are more than the Western World's (excluding the C.I.S., the Peoples Republic of China, and Eastern European countries) Reasonably Assured Resources recoverable at a forward cost of approximately \$20 per pound U_3O_8 . These resources are estimated at 2.3 billion pounds U_3O_8 .³

For the near-term years 1993 through 1995, average enrichment service requirements are projected to be in the range of 28.0 to 28.7 million separative work units (SWU) per year worldwide, growing to approximately 30 to 31 million SWU by 1996 in both scenarios. For the years 2006 through 2010, annual SWU requirements are projected to range between 32.7 and 39.0 million. For 1993 through 1995 in the Lower Reference case, Western Europe accounts for 35 percent of annual enrichment requirements, the United States 31 percent, and the Far East 17 percent. Enrichment capacity at the end of 1992 was 46.1 million SWU. The United States accounts for 42 percent of world enrichment capacity (this is not to be interpreted as percent of world enrichment sales), and Eurodif in France accounts for 23 percent of world capacity. Clearly, with capacity far in excess of annual requirements, the enrichment services market is highly competitive.

Average annual spent fuel discharges worldwide are 10.1 thousand metric tons of initial heavy metal (MTIHM) for 1993 through 1995, and this level remains about the same through 2010. Cumulative spent fuel discharges from 1993 through 2010 are projected to be between 177.7 and 190.1 MTIHM. In the Lower Reference case, Western Europe accounts for 30 percent of the total spent fuel discharges, the United States 20 percent, Canada 19 percent and the Far East 13 percent.

³Energy Resources International, Inc., *1993 Nuclear Fuel Cycle and Price Report* (Washington, DC, April 1993), p. 4-51.

1. Introduction

Worldwide, the nuclear power industry showed little change over the past year. Nuclear power accounted for about 22 percent of total electricity generation worldwide in 1992. Through 2010, nuclear capacity and annual uranium and enrichment requirements are projected to have moderate growth.

This report presents the status of nuclear power at the end of 1992 in the United States and in other countries with nuclear power programs. The report also contains projections of nuclear capacity, generation, nuclear fuel requirements, and spent fuel discharges. These projections are provided annually to the Organization for Economic Cooperation and Development and the International Atomic Energy Agency. The U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) also uses the projections of capacity, generation, and spent fuel discharges in the United States for estimating nuclear waste fund revenues, planning construction of a permanent waste repository, and providing spent fuel projections in an Annual Report to Congress. Projections of uranium requirements are also used in the report *Domestic Uranium Mining and Milling Industry: Viability Assessment*.¹

Chapter 2 of this report discusses commercial nuclear power in the United States. Important events that occurred in the U.S. nuclear power industry in 1992 and the early months of 1993 are discussed, followed by a detailed presentation of nuclear capacity, generation, and fuel requirement projections through the year 2030. The fuel requirements referred to in all chapters are based on an estimate of reactor demand—that is, the actual amount of uranium and enrichment services necessary to fuel and operate the nuclear reactors. Three scenarios, representing different nuclear capacity projections, are presented for the United States. A No New Orders case, which represents a no growth scenario, assumes that there will be no new orders for construction of commercial reactors in the United States, and that reactors will retire on the dates specified in their operating licenses. A Lower Reference case and an Upper Reference case represent two different nuclear capacity growth scenarios.

Two sensitivity cases are also developed. These two cases examine the effect on capacity, uranium requirements, and spent fuel discharges of changing the reactor retirement assumptions in the No New Orders case.

Capacity projections through 2010 are developed by reviewing schedules for reactors under construction and making a judgment as to when these reactors will come on-line. The Upper and Lower Reference cases assume that 50 percent of the existing reactors will extend their operating licenses for an additional 20 years. The No New Orders case does not make this assumption.

Chapter 3 presents similar information for nuclear power programs in foreign countries. Two scenarios, a Lower and Upper Reference case, are developed for foreign countries through the year 2010. Analyses of reactor construction schedules and retirements, similar to the U.S. projections, are conducted for each country, followed by a WINES model projection, as deemed appropriate.

Chapter 4 presents more detailed information about each foreign country's nuclear power program. The status of each country's program is highlighted, and important events affecting the future of nuclear power in the country are evaluated.

Chapter 5 contains a detailed analysis of nuclear reactor performance in the United States, and a brief comparison of U.S. performance to reactors in other countries. Reactor performance, as measured by reactor capacity factors, is an important element affecting the cost of operation and possibly the future of nuclear power.

Chapter 6 contains a comparison of EIA's projections to those of other organizations involved in the evaluation, analysis and reporting of information in the nuclear and uranium industries.

Appendix A gives a brief description of nuclear power technology and the nuclear fuel cycle. Appendix B

¹Energy Information Administration, *Domestic Uranium Mining and Milling Industry 1992: Viability Assessment*, DOE/EIA-0477(92) (Washington, DC, December 1993).

describes the input assumptions for the projections of installed nuclear capacity. Appendix C explains the methodology and fuel cycle plans used in projecting fuel cycle requirements and spent fuel discharges. Appendices D, E, F, and G are listings of reactors that are operable or in the construction pipeline. Appendix

H contains annual capacity, generation, spent fuel, and fuel burnup projections for reactors in the United States. Appendix I lists the nuclear fuel cycle facilities that convert, enrich, and fabricate fuel for use in nuclear units. Appendix J shows projected uranium requirements in metric tons of uranium.

2. U.S. Nuclear Power Capacity and Fuel Cycle Requirements

This chapter discusses the overall status of nuclear power in the United States and important events associated with particular reactors. This is followed by projections of nuclear capacity and generation, fuel requirements, and spent fuel discharges through 2030.

The most important national event affecting the U.S. nuclear industry in 1992 was the passage of the Energy Policy Act of 1992 (EPACT). The Act includes 30 Titles, seven of which contain provisions related to nuclear power and/or uranium. The implications of this Act for the nuclear industry are far reaching and varied.

Under the new licensing procedure outlined in the EPACT, the applicant (i.e., an entity that seeks to build a new reactor), will use off-the-shelf reactor designs that will have been approved and certified by the U.S. Nuclear Regulatory Commission (NRC). The NRC is in the process of certifying four new reactor designs. After reviewing the application and holding one or more public hearings, the NRC may issue a combined construction and operating license. Because the applicant is using an NRC-certified design, safety issues related to the design will have been resolved, and the main concern will be the quality of construction of the reactor. Before authorizing power operation, the NRC will perform comprehensive testing and acceptance procedures on the reactor. Codified in part 52 of Title 10, Code of Federal Regulations, the new licensing process is in place and ready to be used when certification of the new designs is completed. This new licensing procedure is said to be a more predictable process with less uncertainty, and less financial risk to the applicant.²

Four new designs for light water reactors are being evaluated by the NRC for certification. The certification of these reactor designs is a cooperative effort funded by the Department of Energy and private industry. There are two evolutionary designs, General Electric

Nuclear Energy's Advanced Boiling Water Reactor (ABWR), and Asea Brown Boveri-Combustion Engineering, Inc.'s System 80+ which are improved versions of the large plants that these companies built in the past. The plants may appear similar to the old designs, but they incorporate advances in technology, simpler safety systems and have improved control systems. Final Design Approval is scheduled for May 1994 for the ABWR and August 1994 for the System 80+. Two passive safety designs are General Electric's Simplified Boiling Water Reactor (SBWR), and Westinghouse's Advanced Pressurized Water reactor (AP600). The passive reactors rely on gravity-activated systems and natural circulation, eliminating an extensive array of pipes, motorized pumps, and valves. Final Design Approval is scheduled for May 1996 for the SBWR and January 1996 for the AP600. The ABWR review is affecting the other evolutionary and advanced LWR reviews because the ABWR design is serving as the lead plant for resolving certain first-of-a-kind issues (inspections, tests, analysis, and other acceptance criteria).³

In addition to the new licensing procedure, EPACT calls for the Department of Energy to provide technical and financial assistance for the first-of-a-kind engineering design of *standardized* commercial nuclear power plants. Two designs were selected recently by the Department of Energy for the program: General Electric's ABWR and Westinghouse's AP600.⁴ Standardization of reactor designs will help make construction costs and schedules more reliable and predictable.

It was announced in the latter part of 1992 that Section 2124 of the EPACT, which called for the development of preliminary engineering designs for no more than two prototype advanced nuclear reactor technologies other than light-water reactors, would not be funded or implemented under current plans.

²Energy Information Administration, personal conversations with NRC officials, May 5, 1993.

³Nuclear Regulatory Commission, *Policy Issue (Information) Integrated Review Schedules for the Evolutionary and Advanced Light Water Reactor Projects*, April 14, 1993.

⁴Energy Information Administration, personal conversations with officials from the Department of Energy's Office of LWR Safety & Technology.

Status as of December 31, 1992

As of December 31, 1992, the list of operable nuclear power plants in the United States included 109 nuclear units with a total net capacity of 99.0 gigawatts-electric (GWe) (Table 1). This is a decrease of two units with a combined capacity of 603 net MWe from the end of 1991.⁵ Yankee Rowe, owned by Yankee Atomic Electric Company, and San Onofre 1, owned jointly by Southern California Edison and San Diego Gas and Electric were permanently shut down during 1992.⁶ At the end of 1992, eight units remained in the construction pipeline, five of which are classified by the NRC as indefinitely deferred. As in 1991, construction continued on three units. No new nuclear generating units received low- or full-power licenses in the United States in 1991 or 1992.

Table 1. Status of U.S. Nuclear Units as of December 31, 1992

Status	Number of Units	Net Summer Capability (GWe) ^a
Operable^b		
In Commercial Operation	109	99.0
In Power Ascension	0	0
Total	109	99.0
In Construction Pipeline		
In Low-Power Testing	0	0
Under Construction ^c	3	3.5
Indefinitely Deferred ^d	5	6.1
Total	8	9.6
Total	117	108.6

^aGWe = gigawatts-electric.

^bOperable units are those that have been issued a full-power license by the Nuclear Regulatory Commission. Retired units are not included.

^cIncludes Comanche Peak 2, Watts Bar 1, and Watts Bar 2.

^dIncludes Bellefonte 1 and 2, Perry 2, WNP1 and WNP3.

Note: Total capacity may not equal sum of components due to independent rounding.

Sources: **Capacity Data**—Energy Information Administration, Form EIA-860, "Annual Electric Generator Report" (1992). **Status Data**—Energy Information Administration, *Monthly Energy Review*, April 1993, DOE/EIA-0035(93/04) April 1993.

U.S. nuclear units achieved a record electricity generation—producing 618.8 net terawatt-hours in 1992. Utilities generated 22.1 percent of their electricity from nuclear plants in 1992, compared with 21.7 percent in 1991—an increase of about 2 percent. Seven of the 10 regions in the United States generated more than 20 percent of their electricity from nuclear power plants, led by New England (45.5 percent) and New York/New Jersey (31.9 percent) (Table 2).

In 1992, the capacity factor for nuclear plants again reached an all-time high—70.9 percent, up slightly from the record set in 1991 of 70.2 percent. This was the third consecutive year that capacity factors reached record levels. One of the main reasons for the improvement is the relatively high performance level of reactors that came on-line in the mid- to late 1980's, all of which are large units. A detailed discussion of nuclear capacity factors is presented in Chapter 5.

On February 2, 1993, the NRC granted approval to start low-power testing of Texas Utility Generating Company's Comanche Peak 2, a 1,150-megawatt-electric (MWe) PWR located about 40 miles southwest of Fort Worth, Texas. Low-power testing was completed in March.⁷ The NRC approved full-power operations on April 6, 1993. Commercial operation is expected during the summer of 1993. Comanche Peak 2 is the first unit to come on-line since 1990 when two units, Comanche Peak 1 and Seabrook, received their full-power licenses. The Comanche Peak plant with a combined capacity of 2,300 MWe, could supply the power needs of a city the size of Dallas.

Licensing of Comanche Peak 2 follows many years of dispute over the plant's safety. Construction on the unit was halted in 1985 to concentrate resources on the completion of Comanche Peak 1. Texas Utility Generating Company undertook a massive quality assurance rework program to satisfy NRC and other party concerns that had been the impetus for extensive NRC licensing board hearings. When construction resumed on Unit 2 after this delay, however, it faced few of the obstacles or roadblocks that hindered the construction of Unit 1.

⁵Energy Information Administration, *World Nuclear Capacity and Fuel Cycle Requirements 1992*, DOE/EIA-0436(92) (Washington, DC, December 1992), p. 78.

⁶Trojan nuclear plant was shutdown in November 1992 because of equipment problems. It was announced in January 1993 that it will be shutdown permanently.

⁷Primary sources of information concerning the status of nuclear power units in the United States include "Reuters News Service," July 1992 through June 1993; "Nucleonics Week," July 1992 through June 1993.

Table 2. U.S. Nuclear Capacity and Generation as of December 31, 1992, by Federal Region

Federal Region	Capacity (net MWe) ^a	Actual 1992 Generation (net TWh) ^b	Percent Share ^c
I New England	6,393	38,473,922	45.5
II New York/New Jersey	8,684	45,750,029	31.9
III Middle Atlantic	13,700	94,131,019	28.2
IV South Atlantic	26,850	164,627,376	25.6
V Midwest	21,650	129,770,091	24.7
VI Southwest	7,332	46,177,573	11.4
VII Central	4,053	28,728,245	20.5
VIII North Central	0	0	0.0
IX West	8,120	60,853,042	28.0
X Northwest	2,204	10,264,966	7.6
Total	98,985	618,776,263	22.1

^aMWe = Megawatt-electric.

^bTWh, Terawatthours. One TWh is equivalent to one billion kilowatthours.

^cNuclear-generated electricity as a percentage of utility-generated electricity. Non-utility generated electricity is not included.

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

A more recent issue involving Comanche Peak 2 concerned the adequacy of Thermo-Lag 330, a material used to shield cables so that a fire breaking out in one system with safe-shutdown responsibility would not impair an independent safe-shutdown system. Comanche Peak 2 uses this material extensively. Texas Utility launched an ambitious last-minute and ultimately successful testing program to qualify the modified Thermo-Lag installations used in Unit 2. NRC staff approved the fire barrier modifications for Unit 2 despite objections from other organizations.

Northern States Power Co.'s (NSP) Monticello, put its license renewal application to the NRC on "indefinite deferral." NSP decided to postpone its life extension efforts for various reasons, including NRC's requirement for more documentation of reactor components, lack of resolution of the spent fuel disposal problem, and the continuing increase in operating and maintenance (O&M) costs. NSP wants to make certain that it can keep O&M costs under control; otherwise, the increase in costs will negate any potential savings incurred by renewing the license. Whether NSP will continue its life extension activity is unknown. The Monticello unit is scheduled for retirement in 2010.

The Tennessee Valley Authority (TVA) informed the NRC in May 1993 that it intends to resume work on the 1,212-MWe Bellefonte 1 unit. The Bellefonte nuclear power plant, located about 7 miles from Scottsboro, Alabama, has two units, both of which have been indefinitely deferred. The TVA board of directors

announced plans early in 1993 to complete Unit 1, now 80 percent complete. In addition to the two Bellefonte units, TVA has two units under construction at the Watts Bar nuclear power plant located near Spring City, Tennessee, and three operable units at the Browns Ferry nuclear power plant near Decatur, Alabama. Watts Bar 1 is 86 percent complete, and is scheduled to come on-line between 1994 and 1995. Watts Bar 2 is 70 percent complete and scheduled to start in 1996.

In November 1992, the 1,104-MWe Trojan nuclear plant shut down because it was uneconomic to repair the plant's steam generators. Portland General Electric Co. (PGE), the owner of Trojan, decided in January 1993 to shutdown the plant permanently. This is 19 years before the scheduled operating license expiration date of 2011. To complete the retirement process, the company must submit to the NRC a final decommissioning plan for the plant by January 1995. Before the unexpected closing of the plant in January 1993, PGE had decided as a cost-saving measure to close the plant in 1996 rather than operate it until its license expiration date. Through the integrated-resource-plan process, PGE and the Oregon Public Utility Commission established that it would be more economical to phase out the plant rather than invest an estimated \$200 million to replace the steam generators. It is interesting to note that PGE is suing Westinghouse, the manufacturer of PGE's reactor, over the company's steam generator, charging that the generators were faulty and eventually caused PGE to close the Trojan nuclear plant prematurely. Steam generator corrosion and cracking

problems in PWRs have caused and continue to cause serious problems in the industry. At least nine other utilities have filed similar suits against Westinghouse, although PGE is the only one to have closed its plant because of problems associated with steam generators. A more detailed discussion of this issue is presented in Chapter 5.

U.S. Nuclear Power Outlook

Nuclear power faces many obstacles for it to remain a significant source for commercial electricity in the future. Among these obstacles are public image issues concerning safety, waste disposal, and high construction and operating costs. These problems coupled with a decline in the rate of growth of electricity demand, suggest that nuclear power may not be a favorable option for utility planners in the future.⁸

Proponents of the nuclear option suggest that nuclear power should be included in our future energy mix because of its benefits. They contend that nuclear power reduces our dependence on foreign oil, and the carbon emissions associated with fossil fuels. Currently, many utilities are promoting energy efficiency and conservation, but they face many uncertainties about programs to manage growth in electricity demand. Also, the effectiveness of energy efficiency and conservation programs is uncertain.⁹

For nuclear power to remain a viable option, significant changes by both industry and government will be required. Reactor costs in relation to alternatives and the recovery of capital and operating charges through rates that are charged for the electricity produced are among the most important factors affecting the future of nuclear power.¹⁰ Before construction begins, better methods for managing the design and construction of new plants must be developed by government and industry in order to ensure that State regulatory authorities will allow capital costs to be recovered. A consistently high level of demonstrated utility management practice is essential to help improve the public's attitude about nuclear power. Reactor standardization is important for ensuring the highest level of safety, realizing potential economic benefits, and allowing standardized approaches to plant modification, main-

tenance, operation, and training.¹¹ Selection of a permanent repository for high-level waste and the development of a monitored retrieval storage facility to accept the waste until the permanent repository is completed is important and will eliminate a major concern by utilities considering new plant orders.

Case Definitions for U.S. Nuclear Power Projections

Three scenarios for future nuclear power capacity are presented in this report: Upper Reference, Lower Reference, and No New Orders. These scenarios present a range of nuclear capacity projections which vary as a result of differing assumptions about the operating lives of existing nuclear units as well as newly ordered units. These cases should not be interpreted as exhausting the range of possible nuclear supply futures.

Upper Reference: This is a demand-driven capacity growth case, in which it is assumed that a limited number of introductory units will begin operating between 2003 and 2010, thus providing assurance of technical advantages and economic competitiveness of nuclear power. After 2010, the projection assumes economic and electrical demand growth rates which approximate those of the High Macroeconomic Growth Case of the *Annual Energy Outlook 1993*,¹² extended beyond 2010. The operating licenses for 50 percent of all existing units are renewed for 20 years.

Lower Reference: In this scenario, one newly-ordered unit begins operating in 2003, and capacity resulting from additional new orders is projected for the period after 2010. The Lower Reference case assumes lower economic and electrical demand growth rates than those in the Upper Reference case. These assumptions are consistent with the Reference case of the AEO93. The operating licenses for 50 percent of all existing units are renewed for 20 years.

No New Orders: This scenario, which represents a no growth case, assumes that no new orders and no new construction of commercial reactors will occur in the United States before 2040. Under this scenario, reactors will retire according to the dates specified in their operating licenses.

⁸John F. Ahearne, "The Future of Nuclear Power," *American Scientist*, Volume 81, January-February 1993, pp. 24-35.

⁹C.T. Carley, Mississippi State University, "Nation must rethink nuclear power," *The Commercial Appeal*, June 6, 1993.

¹⁰National Research Council, *NUCLEAR POWER Technical and Institutional Options for the Future*, National Academy Press, Washington, D.C. 1992, pp. 1-14.

¹¹*Ibid.*

¹²Energy Information Administration, *Annual Energy Outlook 1993* DOE/EIA-0383(93), (Washington, DC, January 1993).

Assumptions for U.S. Nuclear Power Projections

Estimates of first operation dates for nuclear units actively under construction reflect historical construction performance, regulatory or financial constraints, and regional electricity demand considerations. As of December 31, 1992, eight nuclear units with a total capacity of 9.6 GWe, remain in the U.S. construction pipeline. A listing of these units, their capacities, and estimated operable dates is presented in Appendix E. Five of these units—Bellefonte 1 and 2, WNP 1 and 3, and Perry 2—are in an indefinitely deferred status. Estimates of operable dates for these units are uncertain; consequently, differing assumptions are made for the cases concerning when, and if, these units will be completed. Comanche Peak 2 received a full-power license in April 1993, and therefore is included in the capacity projections starting in 1993. The remaining units—Watts Bar 1 and 2—are actively under construction and will come on-line between 1994 and the end of 1996, depending on the scenario.

Through the projection period, capacity factors for existing reactors will remain at the level of operation achieved over the past 3 years. New units coming on-line in the three cases will operate at an average capacity factor of 75 percent.

The Upper and Lower Reference cases assume that nuclear units for which no license renewals are sought will operate for 40 years from the date of issuance of their operating licenses. Prior to 1982, nuclear operating licenses were issued for 40 years, beginning with the issuance of a construction permit. However, an electric utility may petition the NRC for a redefinition of the operating license in order to recover construction time. The Upper and Lower Reference cases assume that all these licenses will be redefined. The No New Orders case assumes no redefinition of the operating license beyond petitions already granted. It is important to note that there is little difference in U.S. aggregate nuclear capacity resulting from using or not using the license redefinition assumption. Later in this chapter, a sensitivity case will show the difference in projected capacity resulting from a change in this assumption.

In addition to the assumptions for developing projections of nuclear capacity under the three supply scenarios, the following assumptions are used for projecting uranium concentrate and enrichment service requirements.

- The enrichment tails assay remains at 0.3 percent in 1993 through 2000, and then decreases by 0.01 percentage point annually to a level of 0.25 percent in 2006 and for the remainder of the projection period. The spot price of uranium is projected to increase slightly from the present through 2005; therefore, a slight decrease in the tails assay is warranted. The tails assay is stabilized at 0.25 for the remainder of the projection period due to the lack of any long term uranium price projections, and the uncertainty of the prices of uranium that far in the future.¹³
- Design burnup increases from 33,000 megawattdays thermal per metric ton of uranium (MWDt/MTu) in 1993 to 43,000 MWDt/MTu in 2007 and beyond for BWRs; 42,000 MWDt/MTu in 1993 to 55,000 MWDt/MTu in 2005 and beyond for PWRs. Appendix C shows specific design burnup assumptions by year and other important assumptions about reactor fuel plans.

These assumptions apply to all three U.S. nuclear supply scenarios. Specific fuel plans for BWR's and PWR's in the United States are also presented in Appendix C. Fuel plans determine the reactor fuel requirements over the projection period. They consist of estimates of the quantity of fuel loaded into the reactor for each cycle, the length of the cycle (expressed in full power days), and the average enrichment level of uranium loaded into the reactor. The fuel plans—developed separately for BWR's and PWR's—are a statistical representation of a typical reactor in the group. In other words, fuel plans represent an average of the historical operating characteristics of the reactors in the group.

Projections of Nuclear Capacity

Nuclear capacity in the United States has grown from 60.0 GWe in 1982 to 99.0 GWe by the end of 1992—at an annual growth rate of 5 percent. Most of this growth occurred between 1982 and 1989, when nuclear units ordered in the late 1970's were completed. The three nuclear capacity scenarios in this report project similar nuclear capacities through 2005, with slight variations as a result of different assumptions about when or if reactors in the construction pipeline will start. After 2005 the three scenarios begin to diverge, and the projections of nuclear capacity vary widely by 2030 (Figure 1). The Upper Reference case capacity is projected to reach 167.8 GWe in 2030; the Lower Reference case is

¹³Energy Information Administration, *Domestic Uranium Mining and Milling Industry: 1991 Viability Assessment*, (DOE/EIA-0477) (Washington, DC, December 1992), p. 71.

Figure 1. Domestic Nuclear Capacity, 1982-2030

Note: GWe = Gigawatts-electric.

Source: •Historical Capacity Data—Energy Information Administration, *Monthly Energy Review*, April 1992, DOE/EIA-0035(92/04) (Washington, DC, April 1992). •Capacity projections—Upper and Lower Reference Case—Projections through 2010 are from the Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383(93) with an adjustment for the retirement of Trojan in 1993, instead of 1996. •Post 2010 Projections are from the World Integrated Evaluation System, file WINES.OUT, April 1993. •Capacity Projections for the No New Orders Case—Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93. OUTPUT, June 1993.

less optimistic, projecting 118.8 GWe; and the No New Orders case shows capacity declining to 4.7 GWe due to retirements by 2030.

While installed capacity is not expected to increase very much over the next decade, it is also not expected to decrease. By 1995 nuclear capacity in the United States is projected to reach 100.2 net GWe (Table 3). This will be achieved by the addition of Comanche Peak 2, which received its full-power license in April 1993, followed by the operation of Watts Bar 1. Watts Bar 2 is pro-

jected to come on-line in 1996, bringing capacity to 101.4 GWe in 1996. All three cases project the same capacity from 1996 through 1999. In the Upper Reference case, Bellefonte 1 is projected to come on-line in 2000, bringing the total capacity to 102.6 net GWe. The No New Orders and Lower Reference cases project that Bellefonte 1 will come on-line in 2001.

By 2005, the three scenarios show different estimates of nuclear capacity attributable to differences in startup schedules for reactors in the construction pipeline and retirement dates for operable reactors. In the Upper and Lower Reference cases, Washington Public Power Supply System's WNP 1 unit comes on-line in 2002 and 2005, respectively. The Upper Reference case projects the startup of Bellefonte 2 in 2002. The Lower Reference case projects no startup for Bellefonte 2 in the forecasted period. The No New Orders case, representing a less optimistic projection, assumes that Bellefonte 2 and WNP 1 will not come on-line in the projection period. All three scenarios assume that Washington Public Power Supply System's WNP 3 unit and Cleveland Electric Illuminating Company's Perry 2 unit, which are indefinitely deferred, will not come on-line during the projection period.

By 2010, the capacity projections for the No New Orders case are substantially lower than those for the Upper and Lower Reference cases. The No New Orders case assumes that reactors retire according to license expiration dates, whereas the Upper and Lower Reference cases assume that the operating lives for 50 percent of the reactors will be extended by 20 years.

The No New Orders scenario approximates the path of U.S. nuclear capacity under the status quo. In actuality, however, some reactors may receive life extensions, and others (generally first-generation reactors) may be retired before their operating licenses expire. (San Onofre 1, Yankee Rowe, and Trojan are examples of early retirement.) Additional research on the potential for early retirements is needed before they can be included in capacity projection assumptions. However, two "sensitivity cases" based on life extension assumptions are described later in this chapter.

Assuming that reactors retire according to their current license expiration dates, 20 units, representing 14.1 GWe of capacity, are scheduled to be retired between 2002 and 2010, and by 2015 that total rises to 52 reactors with a capacity of 40.0 GWe (Figure 2). This implies that over the next decade utilities will have to make important decisions regarding life extension of existing plants or obtaining replacement power should they choose to retire the nuclear unit.

Table 3. U.S. Operable Nuclear Capacity and Generation at Year End 1992 and Projections for Selected Years, 1995-2030

Year	Capacity (net GWe) ^a			Generation (net TWh) ^a		
	No New Orders Case	Lower Reference Case	Upper Reference Case	No New Orders Case	Lower Reference Case	Upper Reference Case
1992 ^b	99.0	99.0	99.0	619	619	619
1995	100.2	100.2	100.2	611	615	615
2000	101.4	101.4	102.6	626	626	632
2005	101.9	104.4	105.6	630	641	654
2010	88.5	102.4	104.8	558	637	651
2015	63.7	108.0	124.0	397	659	745
2020	49.0	112.8	139.8	317	711	873
2025	24.4	115.8	153.8	168	743	977
2030	4.7	118.8	167.8	33	768	1,075

^aTWh = Terawatt-hours. One TWh is equivalent to one billion kilowatt-hours. GWe = gigawatt-electric.

^bActual data.

Note: Capacity values are based on net summer capability.

Source: **Capacity for the Upper and Lower Reference Cases**—Projections through 2010 are from the Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383(93), with an adjustment for the retirement of Trojan in 1993 instead of 1996. Post 2010 projections are from the World Integrated Evaluation System, file WINES.OUT, April 1993. **Capacity projections for the No New Orders Case**—Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993. **Generation**—Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June, 1993.

Projections of Uranium Concentrate Requirements

Through the remainder of this decade, average U.S. annual uranium requirements are expected to range from 44.1 to 46.0 million pounds U₃O₈ per year (Table 4 and Figure 3). Uranium requirements are defined as the amount of uranium needed to fuel reactors, assuming that capacity factors remain at their current high level of 70.9 percent. Changes in capacity factors will change the uranium requirements proportionally. For example, a 1-percent increase in the projected capacity factor will increase the uranium requirements by 1 percent. If the trend in capacity factors continues to increase as it has over the past 5 years, uranium requirements can be expected to increase as well.

Projected uranium requirements are based on the year the U₃O₈ would be delivered to the conversion plant (approximately 15 months before it is needed in the reactor) and, therefore, depend on reactors that will be operating in 1994 or later. After 2005, the uranium requirements begin to diverge, coinciding with the divergence in the nuclear capacity projections for the three scenarios. Average uranium requirements con-

tinue to decrease under the No New Orders scenario, and by the 2026 through 2030 period they fall to 3.1 million pounds U₃O₈ per year. Under this scenario, the uranium industry in the United States will be virtually nonexistent, as far as domestic sales are concerned.

Uranium concentrate production in the United States has ranged from 13.8 to 8.0 million pounds per year from 1986 through 1991.¹⁴ Assuming that average production remains about the same, it appears that most of the uranium requirements in the United States will be satisfied from sources other than domestic production. As a source of uranium, imports have ranged from 14.4 to 26.6 million pounds per year from 1986 through 1991, representing a substantial portion of the uranium deliveries to U.S. utilities. Utilities also maintain sizeable inventories of uranium, totaling 97.6 million pounds in 1991, so that some of the uranium requirements can be met from the inventories.

It is interesting to note that uranium reserves in the United States as of 1991 total 304 million pounds U₃O₈ at a forward-cost of \$30 per pound.¹⁵ These reserves could almost cover total uranium requirements through 2000 which are projected to be 359 million pounds U₃O₈.

¹⁴Energy Information Administration, *Uranium Industry Annual 1991*, DOE/EIA-0478(91) (Washington, DC, October 1992), p. 14.

¹⁵*Ibid.*, p. 29.

Figure 2. Nuclear Reactor Capacity Scheduled for Retirement in the United States, 2000-2030

Note: Based on operating license expiration date.
Source: Nuclear Regulatory Commission, *Information Digest*, 1992 Edition, Nureg-1350, Volume 4, March 1992.

(Table 5 and Figure 4). However for these reserves to be fully exploited, the price of uranium will have to increase. In 1991, the average delivered price of uranium was \$13.66 per pound U_3O_8 , which is significantly below the cost of mining the reserves.

Potential uranium resources (undiscovered resources classified as Estimated Additional Resources) are estimated at 2.2 billion pounds U_3O_8 at a forward-cost of \$30 per pound. These resources could be used to meet total uranium requirements in the United States through 2030, which are projected to range from 1.1 to 2.1 billion pounds U_3O_8 . Here again the market price of uranium will have to increase substantially to make it profitable to fully exploit these resources.

Another source of uranium will be from the purchase by the United States of Highly Enriched Uranium (HEU) from Russia. The U.S. has entered into an agreement to purchase 500 metric tons of HEU from Russia over the next twenty years. This material is to be converted to low enriched uranium suitable for fueling light-water reactors. This quantity is estimated to be the equivalent of 323 million pounds U_3O_8 . The impact of this purchase on the U.S. uranium market is highly uncertain, but it has the potential of being a significant source of uranium in the future. A more detailed analysis of the U.S. uranium market can be found in EIA's *Domestic Uranium Mining and Milling Industry: 1991 Viability Assessment*.¹⁶

Table 4. Projected Average Annual Natural Uranium Requirements for U.S. Nuclear Power Plants, 1993-2030 (Million Pounds U_3O_8)

Year	No New Orders Case	Lower Reference Case	Upper Reference Case
1993-1995	44.6	44.1	44.1
1996-2000	45.1	45.2	46.0
2001-2005	43.7	44.4	44.9
2006-2010	36.9	43.5	45.9
2011-2015	28.2	45.8	53.2
2016-2020	20.5	48.2	60.5
2021-2025	12.4	51.5	68.2
2026-2030	3.1	51.0	71.8

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

¹⁶Energy Information Administration, *Domestic Uranium Mining and Milling Industry: 1991 Viability Assessment*, (DOE/EIA-0477) (Washington, DC, December 1992).

Figure 3. Projected U.S. Average Annual Uranium Requirements, 1993-2030

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Table 5. Projected Cumulative Natural Uranium Requirements for U.S. Nuclear Power Plants, Selected Years from 1993

(Million Pounds U₃O₈)

Year	No New Orders Case	Lower Reference Case	Upper Reference Case
1995	133.7	132.4	132.4
2000	359.1	358.4	362.2
2005	577.6	580.4	586.6
2010	762.2	798.1	816.0
2015	903.2	1,027.2	1,082.2
2020	1,005.7	1,268.4	1,384.6
2025	1,067.9	1,525.9	1,725.4
2030	1,083.6	1,781.1	2,084.3

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Figure 4. Projected U.S. Cumulative Uranium Requirements, 1993-2030

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Uranium Enrichment Service Requirements

Average U.S. enrichment service requirements through 1995 are projected at 8.8 million separative work units (SWU) per year in all three scenarios (Table 6 and Figure 5). Through 2010, the projections range between 8.8 and 10.7 SWU per year. After 2010, the No New Orders case shows a sharp decline in enrichment requirements, reaching a low of 0.8 SWU per year in 2026 through 2030. The Lower and Upper Reference projections range between 12.8 and 17.7 SWU per year for 2020 through 2030.

¹⁷Effective July 1, 1993, the uranium enrichment function of the U.S. Department of Energy was transferred to a government owned corporation, the United States Enrichment Corporation. This transfer was established in the Energy Policy Act of 1992. Powers of the corporation, organizational structure, and other aspects can be found in the Act.

¹⁸Energy Information Administration, *Uranium Industry Annual 1991*, DOE/EIA-0478(91) (Washington, DC, October 1992).

¹⁹*Ibid.*

²⁰Energy Information Administration, *Spent Nuclear Fuel Discharge from U.S. Reactors 1991*, Service Report, SR/CNEAF/93-01, (Washington, DC, February 1993), p. 21.

To meet enrichment requirements (in effect, demand for enriched uranium product), utilities obtain enrichment services from the United States Enrichment Corporation and from foreign enrichment suppliers.¹⁷ In 1991, U.S. utilities shipped 38 million pounds of U₃O₈ equivalent to enrichment suppliers: 33.9 million pounds to the Department of Energy and 4.1 million to foreign suppliers.¹⁸ Assuming that this uranium was enriched to 3.4 percent using a tails assay of 0.3 percent, this converts to approximately 9 million SWU used by utilities in 1991. Utilities can also use enriched uranium from inventory. At the end of 1991, utilities had 26.2 million pounds U₃O₈ equivalent of enriched uranium in inventory.¹⁹ The HEU entering the market through the purchase agreement with Russia, as noted above, will also have an impact on the SWU market. The 500 metric tons of HEU has the potential to displace the production of an estimated 70 million SWU over the next 20 years.

Spent Fuel Discharges

From 1987 through 1991, an average of 1.9 thousand metric tons of initial heavy metal (MTIHM) of fuel were permanently discharged from U.S. reactors each year.²⁰ This level of discharge is expected to continue, with average spent fuel discharges for 1993 through 2010 ranging from 1.9 to 2.1 MTIHM per year (Table 7 and Figure 6). Little difference exists between the three scenarios through 2010 because the projected capacity for the three scenarios is similar. After 2010, the projections diverge, with the No New Orders case declining to an average of 0.5 MTIHM per year for 2026 through 2030, compared with 2.9 MTIHM in the Upper Reference case. Total discharges of spent fuel by U.S. utilities equal 25.9 MTIHM through the end of 1992. Total discharges are projected to increase to between 84.5 to 112.1 MTIHM by 2030 (Table 8 and Figure 7).

One of the more significant issues in the nuclear industry these days is the question of what to do with the spent fuel. A central spent fuel repository is being planned by the Department of Energy, but a site has not yet been approved. One potential repository site, Yucca mountain, is now being characterized. Characterization activities include preparing access roads and a pad complex and acquiring equipment for tunnel

Table 6. Projected Average Annual Uranium Enrichment Service Requirements for U.S. Nuclear Power Plants, 1993-2030
(Million Separative Work Units)

Year	No New Orders Case	Lower Reference Case	Upper Reference Case
1993-1995	8.8	8.8	8.8
1996-2000	9.7	9.7	9.9
2001-2005	9.9	10.1	10.2
2006-2010	8.8	10.2	10.7
2011-2015	7.2	11.2	12.7
2016-2020	5.4	11.8	14.6
2021-2025	3.2	12.4	16.3
2026-2030	0.8	12.8	17.7

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Figure 5. Projected U.S. Average Annual Uranium Enrichment Service Requirements, 1993-2030

Source: Table 6.

Table 7. Projected Average Annual Spent Fuel Discharges from U.S. Nuclear Power Plants, 1993-2030
(Thousand Metric Tons of Initial Heavy Metal)

Year	No New Orders Case	Lower Reference Case	Upper Reference Case
1993-1995	2.1	2.1	2.1
1996-2000	2.0	2.0	2.0
2001-2005	1.9	1.9	2.0
2006-2010	2.0	1.9	1.9
2011-2015	1.8	2.1	2.2
2016-2020	1.1	1.9	2.3
2021-2025	1.1	2.1	2.6
2026-2030	0.5	2.2	2.9

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Figure 6. Projected U.S. Average Nuclear Spent Fuel Discharges, 1993-2030

Source: Table 7.

Table 8. Projected Cumulative Spent Fuel Discharges From U.S. Nuclear Power Plants, Selected years from 1957
(Thousand Metric Tons of Initial Heavy Metal)

Year	No New Orders Case	Lower Reference Case	Upper Reference Case
1992 ^a	25.9	25.9	25.9
1995	32.3	32.3	32.3
2000	42.3	42.3	42.3
2005	51.9	51.9	52.1
2010	61.9	61.5	61.7
2015	71.0	72.1	73.0
2020	76.7	81.5	84.2
2025	82.1	92.1	97.4
2030	84.5	103.2	112.1

^aData collected on Form RW-859, "Nuclear Fuel Data" (1992), indicate that 25.9 thousand metric tons of initial heavy metal are in storage as of December 31, 1992. The 25.9 thousand metric tons of initial heavy metal in storage do not include irradiated nuclear fuel that was reprocessed by the U.S. Government or that will be reinserted in future cycles of the nuclear reactors.

Note: Total spent fuel discharges include all discharges since 1957 that were not reprocessed by the U.S. Government and are not scheduled for reinsertion (1957 was the inception of commercial nuclear power in the United States).

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

boring. These activities are being performed to support seismic evaluation and other geological studies to determine the adequacy of the site for storing radioactive waste.

The Department of Energy is also committed to temporarily storing spent fuel until the final storage site is completed, and to begin accepting waste in 1998 into a Monitored Retrievable Storage (MRS) facility. Procedures required for developing the MRS include identifying and selecting a volunteer host site, or identifying a Federal site suitable for interim storage. A third option is to allow participation by potential applicants from the private sector, such as businesses, utility firms, and individuals.²¹

Currently utilities are storing their discharged fuel on site in spent fuel storage pools (a borated water-filled pool in which assemblies may be stored). Assuming that the volume of spent fuel discharges is consistent with the No New Orders case, the overflow of spent fuel is projected to be about 2.7 thousand MTIHM by 2000, increasing to 11.7 MTIHM by 2010 and 26.2 MTIHM by 2030 (Figure 8). Hence, the need for the permanent repository becomes more urgent in the future. In the interim, some utilities may consider expanding their storage pool or developing independent spent fuel storage installations in which the spent fuel is stored above ground in dry casks.

Sensitivity Analysis

Projections of uranium and enrichment requirements and spent fuel discharges depend upon assumptions about fuel management variables and the operating characteristics of individual reactors. This section presents a discussion of the differences in capacity, uranium requirements, and spent fuel discharges when the assumption of the operating life of reactors in the No New Orders scenario is changed. Using the No New Orders case as the "base case," a comparison is made with the two sensitivity cases.

The first case assumes that the operating life of the reactor began at the time the reactor received its full-power license. The difference from the base case is that, for some reactors, the 40-year life was counted from the time construction began. The second sensitivity case assumes that the operating life of 30 percent of the currently operable U.S. reactors will be extended by an additional 20 years. Both of these cases are reasonable in that a redefinition of the 40-year life is fairly easy to achieve, and life extension is a viable on-going program, even though no utility has actually implemented a life extension at this time.

There is little difference in projected uranium requirements and spent fuel discharges between the base case and the 40-year life case (Table 9); total uranium

²¹Paper presented by Lake Barrett, acting Director, Office of Civilian Radioactive Waste Management, U.S. DOE at the U.S. Council for Energy Awareness (USCEA) Fuel Cycle Seminar, March 22, 1993, Dallas, Texas.

Figure 7. U.S. Cumulative Nuclear Spent Fuel Discharges, 1970-2030

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

requirements from 1993 through 2030 are 1.08 billion pounds and 1.09 billion pounds, respectively, and the difference between spent fuel discharges is also minimal. The 30 percent life extension case projects total uranium requirements of 1.23 billion pounds from 1993 through 2030, or about 13 percent higher than the

Figure 8. Projections of Utility Spent Fuel Overflow Through 2030

Note: The volume of spent fuel discharges used to estimate overflow are from the No New Orders case.

Source: International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June, 1993 and Form RW-985, "Nuclear Fuel Data" (1992).

base case. Spent fuel discharges are about 3 percent higher than in the base case. Although not shown in Table 9, the 30-percent life extension case projects substantially more spent fuel beyond the year 2030, with more nuclear capacity still in operation.

Table 9. Sensitivity of Nuclear Capacity, Cumulative Uranium Requirements and Spent Fuel Discharges to Changes in Reactor Operating Life Assumptions in the No New Orders Cases

Year	Base Case ^a			40 Year Life ^b			30 Percent Extended Life ^c		
	Capacity (GWe) ^d	U ₃ O ₈ (million lbs)	Spent Fuel (thousand MTIHM) ^d	Capacity (GWe)	U ₃ O ₈ (million lbs)	Spent Fuel (thousand MTIHM)	Capacity (GWe)	U ₃ O ₈ (million lbs)	Spent Fuel (thousand MTIHM)
1995	100.2	133.7	32.3	100.2	133.7	32.3	100.2	133.7	32.3
2000	101.4	359.1	42.3	101.4	359.1	42.3	101.4	359.1	42.3
2005	101.9	577.6	51.9	102.5	578.1	51.9	102.5	578.1	51.9
2010	88.5	762.2	61.9	89.9	766.6	62.0	91.4	768.4	61.9
2015	63.7	903.2	71.0	63.7	908.4	71.3	70.9	921.4	71.0
2020	49.0	1,005.7	76.7	49.0	1,010.9	76.9	60.6	1,049.5	77.1
2025	24.4	1,067.9	82.1	25.5	1,075.0	82.4	45.2	1,155.3	83.2
2030	4.7	1,083.6	84.5	4.7	1,090.7	84.9	31.5	1,228.1	87.4

^aThe base case assumes that the reactor will operate to its current license expiration date as specified by the NRC.

^bReactors will operate 40 years from when the full power license was issued.

^c30 percent of the reactors will obtain an extension of their operating license for 20 additional years (i.e., 60 years total).

^dGWe = Gigawatts - electric, one billion watts of electric capacity. MTIHM = Metric Tons of Initial Heavy Metal.

Note: U₃O₈ requirements are cumulative from 1993. Spent fuel discharges are cumulative from 1957.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

3. International Nuclear Capacity and Fuel Cycle Requirements

Introduction

In 1992 the future of nuclear power continued to hinge on economics as well as public perception. Although nuclear power reactors worldwide produced over 2,000 net terawatt-hours (TWh) of electricity in 1992, the industry will face stiff challenges. As a result, nuclear power throughout the world is expected to grow at an annual rate of less than one percent through 2010.²² This chapter presents an overview of the status (as of December 31, 1992) of foreign nuclear capacity followed by a broad discussion of the outlook for nuclear power. This includes projections of nuclear capacity, uranium and enrichment service requirements, and spent fuel discharges. A more detailed presentation of nuclear power programs in individual countries is presented in the following chapter.²³

Current Status

At the end of 1992 there were 424 commercial nuclear reactors operating in 28 countries throughout the world, with a capacity of 329.2 net gigawatts electricity (GWe).²⁴ This was a net increase of three units and 3.1 GWe from 1991 (Table 10). Six nuclear units were connected to the electric grid of their countries in 1992. Two units were connected to the grid in India, Narora 2 and Kakrapar 1, each 220 MWe pressurized heavy-water reactors (PHWR), located in Narora, Uttar Pradesh and Kakrapar, Gujarat, respectively. The addition of these two units increases India's total nuclear capacity to 1.8 GWe. Japan also connected two units to the grid, Ohi-4, a 1,127-MWe PWR and Kashiwazaki Kariha-3, a 1,067-MWe BWR. France connected one unit, Penly 2, a 1,330-MWe pressurized water reactor (PWR) to the grid. Canada connected Darlington 3, an 881-MWe PHWR plant.

Three nuclear units were shutdown in 1992. As noted previously, in the United States San Onofre 1 and Yankee Rowe were closed due to economic factors; France's Saint Laurent A2, a 450-MWe gas-cooled reactor (GCR) located in Loir-et-Cher was retired. The retirement of Saint Laurent leaves only Bugey 1, a 540-MWe GCR, still operating out of the eight original GCR's in France.

The Nations with the most nuclear capacity as of 1992 were the United States (99.0 GWe), France (57.7 GWe), and Japan (34.2 GWe), followed by the Commonwealth of Independent States (30.9 GWe), Germany (22.5 GWe), Canada (14.6 GWe), and the United Kingdom (11.9 GWe). Combined, these countries account for 82 percent of worldwide capacity used for generating electricity (Figure 9 and Table 10).

Ninety-seven units totalling 83.8 GWe of capacity are in the construction pipeline in foreign countries (Table 11). Of these, 55 were less than 26 percent complete. Construction has been postponed on 13 units in the Commonwealth of Independent States (C.I.S.) and 3 units in Spain with no definite schedule for completion. Japan has 23 units under construction with a total capacity of 23.9 GWe, including six units over 75 percent complete. The size of Japan's nuclear construction program far surpasses any other country. By comparison, France, India, and South Korea which also have aggressive nuclear construction programs have a combined total of 24 units under construction with a total capacity of 20.8 GWe.

In 1992, nuclear-generated electricity equaled 2,023.1 net terawatt-hours (TWh), a modest 1.2 percent increase over the 1,998.7 net terawatt-hours (TWh) in 1991. Part of the reason for this increase was the fact that average capacity factors for commercial nuclear power plants

²²Based on the Lower Reference case.

²³Information on the current status of nuclear power in foreign countries contained in this chapter was obtained from various issues of *Nuclear Engineering International* (Surrey, United Kingdom: Business Press, Ltd), *Nuclear News World List of Nuclear Power Plants* (March 1993) *Nuclear Fuel and Nuclonics Week* (New York: McGraw-Hill), and *NUKEM Market Report* (March 1993).

²⁴Four of these units are Bilibino 1-4 located in Russia, with a total capacity of 44 MWe. They are used primarily for district heating rather than electricity generation. Therefore, they are not included in the electricity generating statistics and projections contained in this report.

Table 10. Operable Nuclear Power Plant Statistics, 1991 and 1992

Country	Number of Operable Units ^a		Net Capacity (MWe)		Amount of Electricity from Nuclear Units			1992
	1991	1992	1991	1992	Net TWh		Percent Change	Share ^b (percent)
					1991	1992		
United States	111	109	R99,589	98,985	R613.0	618.8	0.9	19.8 ^c
Canada	20	21	13,680	14,561	80.1	75.5	-5.7	14.3
Western Europe								
Belgium	7	7	5,484	5,484	40.5	40.4	-0.2	59.3
Finland	4	4	2,310	2,310	18.1	18.2	0.6	33.3
France	56	56	56,773	57,688	315.0	321.7	2.1	72.9
Germany	21	21	22,408	22,460	139.4	150.0	7.6	30.1
Netherlands	2	2	507	507	3.5	3.5	0.0	5.0
Slovenia	1	1	620	620	4.7	3.8	-19.1	34.6
Spain	9	9	7,071	7,097	53.0	53.0	0.0	34.6
Sweden	12	12	9,937	10,002	73.5	60.8	-17.3	43.1
Switzerland	5	5	2,936	2,936	22.3	22.1	-0.9	39.5
United Kingdom	37	37	11,780	11,934	59.3	66.3	11.8	22.0
Subtotal	154	154	119,826	121,038	729.3	739.8	1.4	41.2
Eastern Europe								
Bulgaria	6	6	3,538	3,526	13.2	11.6	-12.1	32.5
C.I.S.	40	40	32,004	30,906	212.1	191.1	-9.9	NA
Kazakhstan	1	1	135	135	NA	0.5	NA	0.5
Russia ^d	24	24	18,849	17,751	NA	119.6	NA	11.8
Ukraine	R15	15	13,020	13,020	NA	71.0	NA	25.0
Czech Republic	4	4	1,632	1,632	22.2	12.3	NA	20.7
Hungary	4	4	1,695	1,729	12.9	13.1	1.6	46.4
Lithuania	2	2	2,500	2,500	NA	15.6	NA	60.0
Slovak Republic	4	4	1,632	1,632	NA	11.1	NA	49.5
Subtotal	60	60	43,001	41,925	260.4	254.8	-2.2	16.3
Far East								
China	1	1	288	300	NA	0.5	NA	0.1
Japan	42	44	31,994	34,238	201.7	217.0	7.6	27.7
Korea, South	9	9	7,220	7,220	53.5	56.5	5.6	43.2
Taiwan ^e	6	6	4,884	4,884	33.9	32.5	-4.1	25.7
Subtotal	58	60	44,386	46,642	289.1	306.5	6.0	19.9
Other								
Argentina	2	2	935	935	7.2	6.6	-8.3	14.4
Brazil	1	1	626	626	1.3	1.8	38.5	0.7
India	7	9	1,374	1,834	4.7	5.6	19.1	3.3
Mexico	1	1	654	654	4.1	3.9	-4.9	3.2
Pakistan	1	1	125	125	0.4	0.5	25.0	1.2
South Africa	2	2	1,840	1,840	9.1	9.3	2.2	6.0
Subtotal	14	16	5,554	6,014	26.8	27.7	3.4	3.5

See footnotes at end of table.

Table 10. Operable Nuclear Power Plant Statistics, 1991 and 1992 (Continued)

Country	Number of Operable Units ^a		Net Capacity (MWe)		Amount of Electricity from Nuclear Units			1992
					Net TWh		Percent Change	Shared ^b (percent)
	1991	1992	1991	1992	1991	1992		
Total World . . .	417	420	326,036	329,165	1,998.7	2,023.1	1.2	22.4

^aFor all non-U.S. units, operable units are those that have generated electricity to the grid. An operable unit in the United States is one that has been issued a full-power license from the U.S. Nuclear Regulatory Commission. For all non-U.S. units, capacity is the net design electrical rating. For U.S. units, capacity is net summer capability. Capacities of individual units are subject to reratings from year to year. See definitions of capacities in glossary.

^bEach country's net electricity generated from nuclear power generating units as a percentage of net electricity generated from all sources. The sources for nuclear generation data are the Organization for Economic Cooperation and Development (OECD) for OECD countries and the International Atomic Energy Agency (IAEA) for non-OECD countries. The nuclear share of utility-generated electricity for the United States was 22.1 percent.

^cUtility generation was obtained from the Energy Information Administration, *Annual Energy Review, 1991*, DOE/EIA-0384(91) (Washington, DC, July 1992). Preliminary nonutility generation data was obtained from the Energy Information Administration, Form EIA-867, "Annual Nonutility Power Producer Report" (1992).

^dThe four Bilibino units incorporated into Appendix F do not appear in this table since they are primarily used for district water heating.

^eThe source for nuclear share is gross nuclear generation, *Nuclear Engineering International, April 1993* (Surrey, United Kingdom: Business Press, Ltd.).

NA = Not available; MWe = Megawatt-electric; TWh = Terawatt-hours.

R = Revised from previous publication.

Sources: **1991**—Energy Information Administration, *World Nuclear Capacity and Fuel Cycle Requirements 1992*, DOE/EIA-0436(92) (Washington, DC, December 1992). **1992 Nuclear Capacity**—United States, Nuclear Regulatory Commission, "Information Digest, 1992 Edition" (NUREG-0380) (May 1980); Foreign, Nuclear News, "Worldlist of Nuclear Power Plants" (March 1993), pp. 41-60; *Nucleonics Week* (Various issues); Nuclear Engineering International, "World Nuclear Industry Handbook, 1993," Country-by-Country Programme Summary, pp. 26-54. **1992 Generation**—The source of nuclear generation is the OECD, Nuclear Energy Agency, *Draft Summary of Nuclear Power and Fuel Cycle Data in OECD Member Countries, Provisional*, (Paris, France, June 1993). The source of nuclear generation for non-OECD countries is the International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1993). **1992 Nuclear Share**—The source of nuclear share is the OECD, NEA, *Draft Summary of Nuclear Power and Fuel Cycle Data in OECD Member Countries, Provisional* (Paris, France, April 1993). The source of nuclear share of non-OECD countries is the IAEA, *Draft Nuclear Power Reactors in the World* (Vienna, Austria, June 1993).

worldwide increased slightly to 70.8 percent in 1992 from 70.2 percent in 1991 (see Chapter 5 for a discussion of capacity factors worldwide).

France produced 72.9 percent of its electricity with nuclear power, more than the nuclear share of electricity generation in any other country with at least 5 GWe of nuclear capacity.²⁵ Six countries produced 30 percent or more of their electricity from nuclear power—France (72.9 percent), Belgium (59.3 percent), South Korea (43.2 percent), Sweden (43.1 percent), Spain (34.6 percent), and Germany (30.1 percent). With the aggressive nuclear power programs in Japan, it is expected that the percentage of electricity generated by Japanese nuclear plants will increase to 30 percent or more. This will probably be true of Taiwan's program as well (Figure 10).

Nuclear Power Outlook

EIA's projections of operable nuclear capacity for countries with nuclear power programs are based on two different methods. Projections of nuclear capacity are based on an analysis of each country's current nuclear construction program. From this analysis, estimates of construction start dates for planned reactors and construction completion dates for reactors under construction are developed. Long-term capacity projections were derived using the World Integrated Nuclear Evaluation System (WINES) model except for those countries in Eastern Europe (including the C.I.S.), People's Republic of China, and Cuba. The WINES model uses economic growth and energy consumption assumptions which are developed from a statistical analysis of historical data for each country with a

²⁵The ranking of countries according to the percent of electricity generated by nuclear includes only countries that have at least 5 GWe of nuclear capacity at the end of 1992. This was done in an attempt to exclude small countries so that the comparison is based on countries with relatively large nuclear electricity generation programs.

Figure 9. Nations With the Largest Nuclear Generating Capacity, 1992

Source: Table 12.

nuclear power program. Two sets of projections are provided for each country—the Upper Reference and the Lower Reference cases (Table 12 and Figure 11).²⁶ Appendix B contains a discussion of the economic and energy input assumptions used in the WINES model.

For countries in Eastern Europe, the People's Republic of China, and Cuba, nuclear capacity projections were developed with supporting information obtained from the International Atomic Energy Agency's (IAEA) March 1993 Consultancy on Nuclear Capacity Forecasting.

The future of the nuclear power industry remains uncertain except for France, Japan, South Korea and Taiwan. Much of the uncertainty is based on public skepticism about the safety of reactors and on the lower capital costs of other alternative energy sources, such as combined-cycle gas plants. Sweden—where 12 nuclear power plants accounted for 43 percent of the country's electricity needs in 1992—is planning to phase out all

its nuclear plants when a safe and economically viable alternative is found. However, for countries like France and Japan, nuclear power production is projected to increase significantly in order to meet increasing electricity demands. Their total combined capacity of 91.9 GWe represents 28 percent of the world's total net capacity. Most of the capacity increases projected in 2010 in the Lower and Upper Reference cases come from these two countries. The following discussion covering the capacity projections is organized into five categories: (1) Canada, (2) Western Europe, (3) Eastern Europe, (4) Far East, and (5) Other countries.

Canada

Reflecting existing conditions, the Lower Reference case represents limited or no growth of nuclear power in many countries. For Canada, no growth is expected after the completion of Darlington 4. In 1991, the Ontario government instructed the provincial utility, Ontario Hydro, to revise its energy supply and demand plan. The plan, known as the 1992 update, calls for doubling the budget on demand-side management and doubling purchases from nonutilities. Currently, the government will not decide on any new nuclear construction projects until after 2000. The Upper Reference case assumes 7.5 GWe of additional capacity from 2001 through 2010.

Western Europe

For the immediate future, the nuclear industry in Europe is primarily concerned with maintaining the safety and reliable operation of existing nuclear plants and extending their operating lives. A nuclear moratorium or some form of nuclear freeze is in effect in Belgium, Finland, Germany, Italy, Netherlands, Spain, Sweden, Switzerland, and the United Kingdom. The political moratorium in Belgium precludes further investment in nuclear generating capacity. Italy's five-year moratorium, which ended on December 18, 1992, is expected to be extended. Utilities such as Bernische Kraftwerke in Switzerland, however, added additional safety systems to its Muehleberg unit to extend its operating life in response to a freeze on additional nuclear capacity.

Of the 11 countries projected to have nuclear capacity by 2010, only France, Spain, and the United Kingdom have units in their construction pipelines, however, the units in Spain are not expected to be completed. In the Lower Reference Case growth is only expected in

²⁶The WINES model was not used in every case for all countries. For countries in which the model was not used, the increased capacity was obtained from that country's construction pipeline. Appendix B contains a list of the countries whose capacity was projected using the WINES model.

Table 11. Status of Foreign Commercial Nuclear Generating Units in the Construction Pipeline as of December 31, 1992

Country	Percentage of Construction Completed									
	0 to 25		26 to 50		51 to 75		76 to 100		Total	
	No. of Units	Net MWe	No. of Units	Net MWe	No. of Units	Net MWe	No. of Units	Net MWe	No. of Units	Net MWe
Canada	0	0	0	0	0	0	1	881	1	881
Western Europe										
France	6	8,600	0	0	1	1,455	2	2,765	9	12,820
Spain	3	3,027	0	0	2	1,950	0	0	5	4,977
United Kingdom	0	0	0	0			1	1,188	1	1,188
Subtotal	9	11,627	0	0	3	3,405	3	3,953	15	18,985
Eastern Europe										
C.I.S. ^a	13	10,337	1	950	2	1,900	1	950	17	14,137
Armenia	2	752	0	0	0	0	0	0	2	752
Russia	5	3,885	1	950	2	1,900	1	950	9	7,685
Ukraine	6	5,700	0	0	0	0	0	0	6	5,700
Czech Republic	0	0	1	890	1	890	0	0	2	1,780
Lithuania ^a	1	1,000	0	0	0	0	0	0	1	1,000
Romania	3	1,860	1	620	1	620	0	0	5	3,100
Slovak Republic	1	390	1	390	1	390	1	390	4	1,560
Subtotal	18	13,587	4	2,850	5	3,800	2	1,340	29	21,577
Far East										
China	2	1,200	0	0	1	900	1	900	4	3,000
Japan	14	15,775	2	2,442	1	796	6	4,925	23	23,938
Korea, South	5	3,821	0	0	2	1,900	0	0	7	5,721
Philippines	0	0	0	0	0	0	1	620	1	620
Taiwan	2	1,900	0	0	0	0	0	0	2	1,900
Subtotal	23	22,696	2	2,442	4	3,596	8	6,445	37	35,179
Other										
Argentina	0	0	0	0	0	0	1	692	1	692
Brazil	0	0	1	1,229	1	1,229	0	0	2	2,458
Cuba	1	417	0	0	0	0	1	417	2	834
India	3	1,160	4	880	0	0	1	220	8	2,260
Mexico	0	0	0	0	0	0	1	654	1	654
Pakistan	1	300	0	0	0	0	0	0	1	300
Subtotal	5	1,877	5	2,109	1	1,229	4	1,983	15	7,198
Total World	55	49,787	11	7,401	13	12,030	18	14,602	97	83,820

^aInformation on percent complete for units in the construction pipeline of these countries is not available; therefore, we included them in the 0-25 category of percentage complete.

Source: Nuclear News, "World List of Nuclear Power Plants" (March 1993), pp. 41-60. Nucleonics Week (various issues). Information for Japan was derived from consultation with the DOE Office of Uranium Enrichment.

Note: MWe = Megawatts-electric.

France through 2010. France, has a robust nuclear program due primarily to its lack of indigenous energy resources. A modest 4.4 GWe of additional capacity is projected from the current level of 57.7 GWe by 2010 in the Lower Reference case, but 12.1 GWe of additional nuclear capacity is projected by 2010 in the Upper Reference case.

The country's national utility, Electricite de France, exports about 10 percent of its electricity. Its export contract will expire by the end of this decade, however, and it is not seeking any new export contracts. Hence, much of the additional capacity projected is based on domestic demand.

Figure 10. Percentage of Electricity Generated by Nuclear Power Plants, by Country, 1992

Notes: Figure includes only countries that had at least 5 Gigawatts-electric nuclear generating capacity at the end of 1992. Excludes the Commonwealth of Independent States because share of electricity generation from nuclear power was not available.

Source: *Organization of Economic Cooperation and Development, Nuclear Energy Agency Draft Summary of Nuclear Power and Fuel Cycle Data*. OECD Member Countries, provisional (Paris, France, April 1993). Non-OECD Member countries—*International Atomic Energy Agency, Draft Nuclear Power Reactors in the World* (Vienna, Austria, June 1993). Nuclear Share is based on gross generation, *Nuclear Engineering International* (Surrey, United Kingdom: Business Press, Ltd., April 1993).

The United Kingdom's nuclear plants operated extremely well in 1992, obtaining a 22.0 percent share of total electricity generation. The Lower and Upper Reference cases, however, project a drop in nuclear capacity by the year 2010 of 5.8 GWe and 3.9 GWe, respectively, from its current 11.9 GWe of operating capacity. Any new nuclear plants will face very strong price competition with the combined cycle gas turbine (CCGT).

Eastern Europe

The situation in Eastern Europe looks similar to that of Western Europe. Since nuclear power is expensive, the recession that Eastern European countries are experiencing (as they shift to market economies), reinforces the low growth depicted in the Lower Reference case projections.

For much of 1992, the attention of Bulgarian officials was focused on the safety of its Kozloduy station. With the help of the IAEA and the World Association of Nuclear Operators, this station was labeled safe enough to continue operation. The Lower Reference case projects a 1.6 GWe decline by the year 2010 from the country's current 3.5 GWe of operable capacity.

On January 1, 1993, the Czech and Slovakia Federal Republic was replaced by two independent republics, the Czech Republic and the Slovak Republic. Under the new political regime, utility representatives of the countries decided to continue their close cooperation with reference to nuclear energy. Of the two, only the Czech Republic has projected any significant capacity addition. Both the Lower and Upper Reference cases project capacity to more than double by the year 2005 from its current 1.6 GWe of capacity. The Slovak Republic has four 390-MWe units (Mochovce station)

Table 12. 1992 Operable Nuclear Capacities and Projected Capacities for 1995, 2000, 2005, and 2010
(Net Gigawatts-Electric)

Country	1992 ^a	1995		2000		2005		2010	
		Lower Reference Case	Upper Reference Case	Lower Reference Case	Upper Reference Case	Lower Reference Case	Upper Reference Case	Lower Reference Case	Upper Reference Case
United States	99.0	100.2	100.2	101.4	102.6	104.4	105.6	102.4	104.8
Canada	14.6	15.4	15.4	15.4	15.4	15.4	19.1	15.4	22.9
Western Europe									
Belgium	5.5	5.5	5.5	5.5	5.5	3.8	5.5	3.8	5.5
Finland	2.3	2.3	2.3	2.3	2.3	2.3	2.8	2.3	3.3
France	57.7	58.5	58.5	61.4	61.4	61.4	62.8	62.1	69.8
Germany	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	24.7
Italy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Netherlands	0.5	0.5	0.5	0.5	0.5	0.0	0.6	0.0	1.2
Slovenia	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Spain	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	9.1
Sweden	10.0	10.0	10.0	10.0	10.0	6.7	6.7	0.0	6.7
Switzerland	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	3.6
United Kingdom	11.9	11.7	11.7	10.4	11.6	9.9	9.9	6.1	8.0
Subtotal	121.0	121.6	121.6	123.2	124.4	117.3	121.4	107.5	133.7
Eastern Europe									
Bulgaria	3.5	3.5	3.5	2.7	3.5	2.3	3.5	1.9	3.7
C.I.S.	30.9	28.5	28.5	30.9	33.6	31.1	39.3	32.4	43.6
Armenia	0.0	0.4	0.4	0.8	0.8	0.8	1.4	0.6	1.2
Kazakhstan	0.1	0.1	0.1	0.1	0.1	0.1	1.1	0.1	2.1
Russia	17.8	17.8	17.8	17.9	20.6	17.1	22.8	18.9	25.3
Ukraine	13.0 ^b	10.2	10.2	12.1	12.1	13.1	14.0	12.7	15.0
Czech Republic	1.6	1.6	2.5	2.5	3.4	3.4	3.4	3.4	3.4
Hungary	1.7	1.7	1.7	1.7	1.7	1.7	2.9	1.7	2.9
Lithuania	2.5	2.5	2.5	2.5	2.5	2.5	3.5	2.5	3.5
Romania	0.0	0.0	0.6	1.2	1.2	1.2	1.9	1.2	2.5
Slovak Republic	1.6	1.2	1.2	1.2	1.2	1.2	1.6	1.6	2.4
Subtotal	41.9	39.1	40.6	42.9	47.2	43.5	56.1	44.8	62.0
Far East									
China	0.3	1.2	1.2	2.1	2.1	2.7	2.7	2.7	4.2
Japan	34.2	35.1	41.1	41.1	43.7	43.7	47.6	45.7	56.7
Korea, South	7.2	7.2	7.2	7.2	9.8	11.7	12.9	12.9	16.4
Korea, North	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.1	0.9
Philippines	0.0	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Taiwan	4.9	4.9	4.9	4.9	5.8	5.8	6.8	6.8	7.8
Subtotal	46.6	48.4	55.0	56.0	62.1	64.6	70.9	68.8	86.5
Other									
Argentina	0.9	0.9	1.6	1.6	1.6	1.3	1.9	1.3	2.1
Brazil	0.6	0.6	0.6	1.9	1.9	1.9	3.1	3.1	3.9
Cuba	0.0	0.0	0.0	0.0	0.4	0.4	0.8	0.4	0.8
India	1.8	2.1	2.3	2.9	2.9	2.6	4.1	3.8	4.6
Mexico	0.7	0.7	1.3	1.3	1.3	1.3	1.3	1.3	1.9
Pakistan	0.1	0.1	0.1	0.1	0.1	0.0	0.4	0.3	0.7
South Africa	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.8
Subtotal	6.0	6.2	7.8	9.7	10.1	9.3	13.5	12.0	16.8
Total World	329.2	331.0	340.7	348.5	361.8	354.5	386.6	350.9	426.8

^aStatus as of December 31, 1992.

^bThe Chernobyl 2 reactor is assumed to be permanently shutdown and is therefore not considered in the Ukraine's capacity projection from 1995 through 2010.

Note: Totals may not equal sum of components due to independent rounding.

Sources: 1992—United States, Nuclear Regulatory Commission, "Information Digest, 1992 Edition" (NUREG-0380) (May 1980); Foreign, Nuclear News, "Worldlist of Nuclear Power Plants" (March 1993), pp. 41-60; Nucleonics Week (Various issues); Nuclear Engineering International, "World Nuclear Industry Handbook, 1993," Country-by-Country Programme Summary, pp. 26-54. Projections—Energy Information Administration, World Integrated Nuclear Evaluation System file WINES.OUT, April 1993. The remaining projections are based on a critical assessment of detailed country-specific nuclear power plans. Information used in developing the projections for the countries of Eastern Europe, the People's Republic of China, Cuba and North Korea was obtained from the International Atomic Energy Agency's 1993 Consultant's Meeting on International Nuclear Capacity Forecasting.

**Figure 11. Operable Nuclear Capacity at the End of 1992 and Projections Through 2010
(Net Gigawatts Electric)**

Sources: Energy Information Administration, Form EIA-860, "Annual Electric Generator Report." Nuclear Regulatory Commission, "Information Digest, 1992 Edition" (NUREG-0380) (May 1980); Program Summary Report (NUREG-1350, Vol. 4) (March 1992). Nuclear News, "World List of Nuclear Power Plants" (March 1993); Nucleonics Week, (Various Issues) Nuclear Engineering International, "Nuclear Handbook" (June 1993); "Nuclear Power Reactors in the World" (April 1992).

in advanced stages of construction. These reactors are expected to replace the country's older Bohunice station which does not meet Western safety standards. The Lower and Upper Reference cases project capacity at 1.6 GWe and 2.4 GWe, respectively, by 2010.

For the C.I.S., little new capacity is projected in the Lower Reference case in the four republics—Armenia, Kazakhstan, Russia and Ukraine. Currently, the C.I.S. has a combined capacity of 30.9 GWe and is projected to have 32.4 GWe in the Lower Reference case and 43.6 GWe in the Upper Reference case by 2010. Over half of the additional 13.6 GWe projected in the Upper Reference case would be built in Russia. Although Russia has an aggressive nuclear power expansion plan, it may be too poor to fund the plan. The Lower Reference case projects the completion of only a few of the nine units in Russia's pipeline resulting in a projection of 18.9 GWe by 2010. EIA's Upper Reference case, based on Russia's national nuclear plan, provides a more optimistic future for nuclear power.

Far East

Much of the increase for the world in 2010 for the Lower and Upper Reference cases come from the Far East. Of the five countries listed in the Far East region, Japan, South Korea and Taiwan account for over 94 percent of the 86.5 GWe projected by 2010 in the Upper Reference case. These countries all lack any indigenous energy source and are rapidly industrializing, resulting in a growing demand for energy.

Although nuclear plant siting in Japan has become increasingly difficult, the government still has a strong commitment to its nuclear power program. In 1990, Japan released its Atomic White Paper, which stated the country's plan for additional capacity through 2010 would result in 72.5 GWe. The Upper Reference case, however, has a capacity projection of 56.7 GWe. Japanese industry and government officials have admitted that the pace of construction necessary to reach the 72.5 GWe goal will be difficult to achieve.

Like Japan, South Korea is facing a shortage of electricity supply capacity due to explosive energy demand growth. To meet this rapidly growing electricity demand the government has revised its long-term power development program. The plan includes 9 nuclear plants by 2000, totaling 8.1 GWe; however, only 7 have been sited. The Lower and Upper Reference case projections have South Korea's nuclear capacity as 12.9 GWe and 16.4 GWe, respectively, by 2010.

The projections reflect a 3 to 5 percent annual increase from the country's current 7.2 GWe. The lower projections are primarily based on expected citizen opposition that usually comes with a nuclear plant expansion. In addition, the Three Mile Island and Chernobyl accidents were heavily reported by the South Korean press, which created public uncertainty.

Other

Developing and semi-industrialized countries including Argentina, Brazil, India, Mexico, Pakistan, and South Africa have shown slow progress, taking 20 years to complete plants already under construction. However, by 2010 these countries are projected to increase their share of world total capacity, currently at 1.8 percent. By 2010, that share will increase to 3.4 and 3.9 percent in the Lower and Upper Reference cases, respectively.

Of the six countries listed in the Other category, India's nuclear program is considered the most dynamic. Currently, the country has nine nuclear units in operation, totaling 1.8 GWe of capacity. Most of the country's nuclear program is not covered by IAEA safeguards, which has hindered its development.

Projections of Uranium Concentrate Requirements

Worldwide average annual uranium requirements are projected to range between 139.8 and 146.6 million pounds uranium oxide (U_3O_8) per year in 1993 through 1995 (Table 13 and Figure 12). By the years 2006 through 2010, average annual uranium requirements will grow to between 148.8 and 180.3 million pounds per year. The Lower Reference case projects a relatively stable growth rate of only 0.4 percent through 2010. The Upper Reference case projects a worldwide growth rate in uranium requirements of about 1.2 percent. The overall increase in annual uranium requirements reflects the projected worldwide increase in nuclear capacity through 2010 discussed earlier. It is also expected that capacity factors will increase from an average of 71 percent to about 75 percent by 2010, and higher capacity factors require more uranium to fuel the reactors. Since U_3O_8 requirements (as well as Separate Work Units (SWU) requirements presented in the next section) do not account for the use of recycled uranium, the projections show uranium requirements without differentiating as to the source of uranium. The United Kingdom has been reprocessing spent fuel and approximately 75 percent of the initial cores for advanced gas-cooled reactors (AGR) were produced from reprocessed material.

Table 13. Projected Average Annual Uranium Requirements for World Nuclear Power Plants, 1993-2010
(Million Pounds U₃O₈ Equivalent)

Year	United States	Canada	Eastern Europe	China	C.I.S.	Western Europe	Far East	Other	Total
1993-1995									
Lower Reference Case	44.1	4.2	6.1	0.8	11.9	49.5	21.7	1.3	139.8
Upper Reference Case	44.1	4.4	7.0	0.8	12.0	49.5	26.8	2.1	146.6
1996-2000									
Lower Reference Case	45.2	4.9	6.6	1.0	12.8	48.2	25.1	2.5	146.3
Upper Reference Case	46.0	4.9	7.4	1.0	13.3	48.6	28.1	2.7	152.0
2001-2005									
Lower Reference Case	44.4	5.3	7.1	1.4	13.8	47.9	26.2	2.8	148.9
Upper Reference Case	44.9	6.4	9.1	1.4	15.9	49.5	28.9	3.9	159.9
2006-2010									
Lower Reference Case	43.5	5.2	7.5	1.5	13.6	43.4	30.4	3.5	148.8
Upper Reference Case	45.9	7.4	11.2	2.2	17.9	52.2	38.3	5.2	180.3

Note: Totals may not equal sum of components due to independent rounding. C.I.S. = Commonwealth of Independent States.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933 PRJ.INM93 OUTPUT, June, 1993.

For the Lower Reference case, cumulative uranium requirements through 2010 are projected to be 2.6 billion pounds while for the Upper reference case cumulative requirements are projected to be 2.9 billion pounds (Table 14 and Figure 13). In the Lower Reference case, Western Europe accounts for 32 percent of cumulative requirements through 2010, the United States accounts for 30 percent, and the Far East accounts for 18 percent. The projected uranium requirements for both the Upper and Lower reference cases are more than the Western World's (excluding the Commonwealth of Independent States, the PRC and Eastern European countries) Reasonably Assured Resources recoverable at a forward cost of approximately \$20 per pound U₃O₈. These resources are estimated at 2.3 billion pounds U₃O₈.²⁷

Uranium Enrichment Service Requirements

For the near-term years 1993 through 1995, average annual enrichment service requirements worldwide are projected to be in the range of 28.0 to 28.7 million SWU per year (Table 15 and Figure 14). They are projected to grow to an annual average of approximately 30 to 31 million SWU by 1996 in both scenarios. For the period 2006 through 2010, annual SWU requirements are projected to range between 32.7 and 39.0 million SWU. For 1993 through 1995 in the Lower Reference case, West-

ern Europe accounts for 35 percent of annual enrichment requirements, the United States for 31 percent, and the Far East for 17 percent.

Enrichment capacity at the end of 1992 is estimated at 46.1 million SWU (Table 16). About 44 million SWU capacity is available for the commercial market since about 10 out of 12 million SWU capacity in the C.I.S. is available for export. The United States accounts for 42 percent of the world enrichment capacity—this is not to be interpreted as a percent of world enrichment sales—and Eurodif in France accounts for 23 percent of world capacity. The enrichment services market is highly competitive with capacity far in excess of annual requirements. Enrichment capacity is expected to increase to 47.1 million SWU by 1995.

Spent Fuel Discharges

Average annual spent fuel discharges worldwide are 10.1 thousand metric tons of initial heavy metal (MTIHM) for 1993 through 1995, and this level remains about the same through 2010 (Table 17 and Figure 15). The Upper reference case projects an increase in annual spent fuel discharges to 11.6 thousand MTIHM in 2006 through 2010. Cumulative spent fuel discharges from 1993 through 2010 are projected to be between 177.7 and 190.1 thousand MTIHM (Table 18). For the Lower Reference case, Western Europe accounts for 30 percent

²⁷The Uranium Institute, "Uranium in the New World Market Supply and Demand 1990-2010," London, England, December 1991.

Figure 12. Projected Average Annual World Uranium Requirements, 1993-2010
(Million Pounds U_3O_8 Equivalent)

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Table 14. Projected Cumulative Uranium Requirements for World Nuclear Power Plants, from 1993
(Million Pounds U₃O₈ Equivalent)

Year	United States	Canada	Eastern Europe	China	C.I.S.	Western Europe	Far East	Other	Total
1995									
Lower Reference Case	132.4	12.7	18.4	2.5	35.7	148.5	65.2	4.0	419.4
Upper Reference Case	132.4	13.1	20.9	2.5	35.9	148.5	80.3	6.2	439.7
2000									
Lower Reference Case	358.4	37.2	51.4	7.4	99.7	389.7	190.7	16.4	1,151.0
Upper Reference Case	362.2	37.6	57.8	7.4	102.6	391.5	221.0	19.5	1,199.6
2005									
Lower Reference Case	580.4	63.5	86.7	14.5	168.9	629.2	321.9	30.4	1,895.4
Upper Reference Case	586.6	69.5	103.1	14.5	182.3	638.8	365.5	38.9	1,999.0
2010									
Lower Reference Case	798.1	89.6	124.2	22.2	236.7	846.2	474.1	48.1	2,637.2
Upper Reference Case	816.0	106.7	159.1	25.4	271.5	899.8	556.9	64.9	2,900.3

Note: Totals may not equal sum of components due to independent rounding. C.I.S. = Commonwealth of Independent States.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Figure 13. Projected Cumulative World Uranium Requirements, 1993-2010

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

of the total spent fuel discharges, while the United States accounts for 20 percent, Canada 19 percent and the Far East 13 percent.

Reprocessing and the Use of MOX Fuels

Mixed oxide fuel (MOX) can be used as a substitute for uranium oxide fuel in commercial nuclear reactors. MOX is a mixture of reactor-grade plutonium and either natural or depleted uranium (i.e., enrichment plant tailings depleted in U-235). Plutonium is available by reprocessing the fuel discharged from nuclear reactors. A few European countries and Japan are using or plan to use MOX fuel in some of their reactors. Reprocessing and the management of spent fuel are issues associated with the back end of the nuclear fuel cycle (see Appendix A and Figure A1 for a description of the complete nuclear fuel cycle.)²⁸

The Back End of the Nuclear Fuel Cycle

Two strategies are used for managing the back end of the fuel cycle: (1) the once-through option in which spent fuel is placed in interim storage pending final disposal, and (2) the closed fuel cycle in which spent fuel is reprocessed and the recovered plutonium and uranium are available for re-use. A number of factors enter into the choice of strategies, and the choice varies

²⁸Primary sources of information on reprocessing and MOX fuel include "Nuclear Engineering International," June 1992 through May 1993 (Surrey, United Kingdom: Business Press, Ltd); Nuclear Fuel, July 1992 through March 1993, (New York: McGraw-Hill); NUEXCO Review, June 1992 (Denver, Colorado).

Table 15. Projected Average Annual Uranium Enrichment Service Requirements for World Nuclear Power Plants, 1993-2010
(Million Separative Work Units)

Year	United States	Canada	Eastern Europe	China	C.I.S.	Western Europe	Far East	Other	Total
1993-1995									
Lower Reference Case	8.8	0.0	1.2	0.2	2.9	9.9	4.8	0.2	28.0
Upper Reference Case	8.8	0.0	1.4	0.2	2.9	9.9	5.3	0.2	28.7
1996-2000									
Lower Reference Case	9.7	0.0	1.4	0.2	3.3	10.0	5.0	0.3	29.9
Upper Reference Case	9.9	0.0	1.4	0.2	3.4	10.2	5.9	0.3	31.3
2001-2005									
Lower Reference Case	10.1	0.0	1.4	0.3	3.4	11.2	6.1	0.4	32.9
Upper Reference Case	10.2	0.0	1.9	0.3	4.0	11.5	6.4	0.5	34.7
2006-2010									
Lower Reference Case	10.2	0.0	1.6	0.3	3.3	10.3	6.6	0.5	32.7
Upper Reference Case	10.7	0.0	2.3	0.5	4.4	12.0	8.4	0.8	39.0

Note: Totals may not equal sum of components due to independent rounding. C.I.S. = Commonwealth of Independent States.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

from country-to-country (Table 19). However, the structure of the nuclear industry is still evolving, and several countries have opted to keep their spent fuel in interim surface storage, in effect postponing their waste management policy decisions.

In the 1960s and 1970s, as commercial nuclear power first started to develop, a number of factors favored the development of a closed fuel cycle:

- Natural uranium was viewed as a scarce and expensive resource. This assumption encouraged a policy of conservation of uranium and tipped the long-term economic calculations in favor of recycling.
- Some countries did not have indigenous uranium or other energy reserves, and reprocessing offered a means to achieve energy security and independence.
- Reprocessing was perceived as a desirable method of managing spent fuel waste.
- There was a general belief that light water reactors would be a stepping stone towards a breeder economy, and that the plutonium recovered from light water reactor fuels would be used as starter material for emerging breeder reactors.

A small amount of commercial spent fuel was reprocessed at West Valley, New York in the late 1960s and early 1970s. Plans were drawn up for a large-scale reprocessing plant at Barnswell, South Carolina, but because of financial constraints the plant was never completed. Under President Carter, the United States adopted a policy against commercial reprocessing out of concerns about nuclear proliferation.

About the same time, fundamental changes in the nuclear fuel market began to emerge. The price of uranium dropped precipitously as demand was reduced by the cancellation of many nuclear projects and new low-cost ore reserves were discovered. The enrichment industry over-built, leading to substantial uncommitted enrichment capacity worldwide. The recent developments in the former Soviet Bloc countries introduced yet another low-cost source of nuclear fuel. In addition, there is a significant amount of defense grade nuclear fuel that is working its way into the commercial arena through the process of blending. While prices have dropped for the front end of the nuclear fuel cycle, the price of reprocessing has steadily climbed. The upshot of these developments is that the economics of the back end of the fuel cycle have shifted away from reprocessing and towards the once-through option, at least for the near- to mid-term future.

Nonetheless, there are still a number of countries committed to reprocessing, although some are rethinking

Figure 14. Projected Average Annual World Enrichment Service Requirements, 1993-2010
(Million Separative Work Units)

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Table 16. Projected Nominal Capacity of World Uranium Enrichment Facilities at Year End, 1992 and 1995
(Million Separative Work Units)

Facility	Country	1992	1995
U.S. Enrichment Corporation	United States	^a 19.3	19.3
Eurodif S.A.	France	10.8	10.8
Techsnabexport	C.I.S.	^b 12.0	12.0
Urenco	Netherlands	1.4	1.6
	United Kingdom	0.8	0.8
	West Germany	0.5	0.7
The China Nuclear Energy Industry Corporation	People's Republic of China	0.5	0.5
Power Reactor and Nuclear Fuel Development Corporation	Japan	0.3	0.3
Japan Nuclear Fuel Industries Company Inc.	Japan	0.2	0.8
Atomic Energy Commission	South Africa	0.3	0.3
Total		46.1	47.1

^aIncludes plants at Paducah, Kentucky, and Portsmouth, Ohio. The Oak Ridge plant is shut down.

^bIt was reported in a paper presented by E. Mikerin, Head of Technology Development, Ministry of Atomic Energy of the Russian Federation at the USCEA enrichment seminar, June 13-15, 1993, Washington, D.C., that Russia has a capacity to export at least 10 million SWU annually.

Source: Nuclear Assurance Corporation, *Fuel Trac Interim Enrichment Report* (Atlanta, GA, November 1992).

Table 17. Projected Average Annual Discharges of Spent Fuel from World Nuclear Power Plants, 1993-2010
(Thousand Metric Tons of Initial Heavy Metal)

Year	United States	Canada	Eastern Europe	China	C.I.S.	Western Europe	Far East	Other	Total
1993-1995									
Lower Reference Case	2.1	1.4	0.4	0.0	0.9	3.8	1.2	0.3	10.1
Upper Reference Case	2.1	1.4	0.4	0.0	0.9	3.8	1.2	0.3	10.1
1996-2000									
Lower Reference Case	2.0	1.8	0.4	0.0	0.8	3.3	1.2	0.3	9.8
Upper Reference Case	2.0	1.8	0.5	0.0	0.8	3.3	1.4	0.4	10.2
2001-2005									
Lower Reference Case	1.9	1.9	0.5	0.1	0.9	2.7	1.3	0.5	9.8
Upper Reference Case	2.0	2.0	0.5	0.1	0.9	2.7	1.4	0.5	10.2
2006-2010									
Lower Reference Case	1.9	2.0	0.5	0.1	0.9	2.5	1.5	0.5	9.9
Upper Reference Case	1.9	2.7	0.8	0.1	1.1	2.4	1.8	0.8	11.6

^cLess than 0.05 thousand metric tons.

Note: Totals may not equal sum of components due to independent rounding. C.I.S. = Commonwealth of Independent States.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Figure 15. Projected Average Annual World Nuclear Spent Fuel Discharges, 1993-2010
(Thousand Metric Tons of Initial Heavy Metal)

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Table 18. Projected Cumulative Discharges of Spent Fuel for World Nuclear Power Plants, from 1993
(Thousand Metric Tons of Initial Heavy Metal)

Year	United States	Canada	Eastern Europe	China	C.I.S.	Western Europe	Far East	Other	Total
1995									
Lower Reference Case	6.4	4.3	1.1	0.0	2.7	11.4	3.7	0.8	30.4
Upper Reference Case	6.4	4.3	1.1	0.0	2.7	11.4	3.7	0.8	30.4
2000									
Lower Reference Case	16.4	13.3	3.0	0.2	6.6	27.8	9.8	2.3	79.4
Upper Reference Case	16.4	13.4	3.3	0.2	6.5	27.7	10.7	2.9	81.2
2005									
Lower Reference Case	26.0	23.0	5.4	0.5	11.2	41.1	16.1	5.0	128.4
Upper Reference Case	26.2	23.7	6.0	0.5	11.2	41.1	18.0	5.5	132.1
2010									
Lower Reference Case	35.6	33.2	8.1	0.9	15.5	53.4	23.5	7.5	177.7
Upper Reference Case	35.8	37.2	9.9	0.9	16.7	52.9	27.2	9.4	190.1

Notes: Discharges of spent fuel are cumulative from 1993. Totals may not equal sum of components due to independent rounding.

C.I.S. = Commonwealth of Independent States.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Table 19. Spent Fuel Management Strategies by Country

Country	Interim Storage	Reprocessing	Permanent Disposal
Argentina	x	x	
Belgium		x	
Brazil	x		
Bulgaria		x	
Canada			x
China		x	
CIS		x	
Czech and Slovak Federal Republic		x	
Finland	x	x	
France		x	
Germany	x	x	
Hungary		x	
India		x	
Italy		x	
Japan		x	
Mexico	x		
Netherlands		x	
Pakistan	x		
Slovenia	x		
South Africa	x		
South Korea	x		
Spain	x		
Sweden			x
Switzerland		x	
Great Britain		x	
United States			x

Source: International Atomic Energy Agency as reported in NUEXCO's Monthly Report, June 1992.

their commitments. The main reasons cited for a continued commitment to reprocessing are energy security and waste management, although the military aspect of having a reprocessing capability cannot be totally discounted for some countries. In addition, France, Great Britain, and the C.I.S. already have substantial investments in reprocessing facilities (Table 20) and must operate these plants to recoup their sunk costs.

Use of Reprocessed Fuels

Both plutonium and uranium are recovered from the reprocessing of spent fuel. The plutonium is mixed with uranium, generally natural or depleted (i.e., enrichment plant tails) to form a MOX fuel, which is used to replace a fraction of the enriched uranium in a reactor's core. MOX fuel has been successfully used in several LWRs, primarily in Germany and France. Plutonium has also been used in breeder reactors in France, Russia, and a small demonstration plant in Japan, although breeder reactors are not now a mainstream technology.

The economic justification for the use of MOX fuels in LWRs relies upon treating reprocessing as a sunk back-end cost and assigning a zero cost to the recovered plutonium. Consequently, proponents of MOX fuels compare MOX fuel fabrication costs against the cost of uranium oxide fuels, i.e., natural uranium and conversion, enrichment and fabrication services. Even with assigning a zero cost to the recovered plutonium, there is still significant disagreement on the economics of MOX fuel. Moreover, if the cost of reprocessing is included, the closed fuel cycle is currently not economically competitive with the once-through fuel cycle.

Another property of plutonium when used in MOX fuels in LWRs is its short shelf life which is due to the rapid buildup of Americium-241, a neutron poison. As a rule of thumb, plutonium should be recycled in LWRs

within two to three years of reprocessing and this presents a potential problem for several reasons:

- It appears that the MOX fabrication capacity in Europe may not keep pace with the amount of fuel scheduled to be reprocessed. There is considerable political opposition to some of the proposed MOX facilities, especially in Germany.
- If all proposed European MOX facilities (Table 21) were brought on-line, there would be sufficient MOX fabrication to process all the plutonium recovered from European reprocessing. However, the equivalent of an additional 20 large reactors would have to be licensed to burn the MOX fuel.
- Some utilities may not be able to utilize the plutonium recovered from their reprocessed spent fuel because of emerging restrictions on the use MOX fuel. With the exception of a few small utility consortiums, primarily in Germany, there are no mechanisms in place for exchanging plutonium among utilities.

Outside of small demonstration projects, there has been essentially no use of uranium recovered from reprocessing LWR spent fuel. The reason for this is that the recovered uranium contains U-236, a nonnaturally occurring neutron poison. The presence of U-236 in fuel being inserted into an LWR presents two problems: (1) the U-235 enrichment must be increased to compensate for its presence; and (2) new reactor core management schemes have to be developed. Moreover, U-236 is close to U-235 in isotopic weight, and consequently its concentration is also increased in the enrichment process.

With the low cost of natural uranium fuel, LWR operators have not opted to use recovered uranium at the present time. The recovered uranium is currently being stockpiled pending potential future use.

Table 20. Commercial Reprocessing Capacities by Country
(Metric Tons Heavy Metal per Year)

Country	Current	Planned	Total
France	1500	700	2200
Great Britain	1500	1200	2700
Commonwealth of Independent States	400+	1500	1900+
Japan	210	800	1010
Total	3610+	4200	7810+

Note: Excludes facility in the Commonwealth of Independent States which was used for reprocessing military production reactor fuel.

Source: NUEXCO Monthly Report, June 1992.

Table 21. Current and Projected Light Water Reactor Mixed Oxide Fuel Fabrication Capacities

Country	Plant	Capacity MTIHM/year	Status
Belgium	Belgonucleaire Dessel	35	In operation
Belgium	Belgonucleaire Dessel	35	Planned
Germany ^a	Siemens/Hanau	30	In operation
Germany	Siemens/Hanau	120	Construction
France	Cogema/CEA Cadarache	15	In operation
France	Melox/Marcoule	120	Construction
France	Cogema/CEA Cadarache	15	Planned
Great Britain	BNFL MDF	8	Construction
Great Britain	BNFL SMP	120	Planned
Japan	Rokkasho	100	Planned

^aThis plant will be replaced by the plant under construction.

Source: David Wolf, British Nuclear Fuels, "Mixed Oxide Fuel, Past, Present, Future" Paper presented at the United States Council of Energy Awareness seminar, Dallas, Texas, March 23, 1993.

Note: MTIHM = Metric Ton of Initial Heavy Metal.

In addition, enrichment gaseous-diffusion-plant operators do not want to inject recovered uranium in the enrichment cascade since the U-236 would likely contaminate all the uranium in the cascade. This is not a problem in the centrifuge enrichment plants, since they can process small batches. Both URENCO and the Russians are actively soliciting recovered uranium for re-enrichment.

The only large-scale use of recovered uranium has been in Great Britain where uranium recovered from reprocessing MAGNOX²⁹ spent fuel has been used in advanced gas-cooled reactors (AGR) for a number of years.

Germany

Germany made an early commitment to reprocessing and has the most experience with the use of MOX fuel. German law had required all spent fuel to be reprocessed as a form of waste management. However, there is growing public opposition to reprocessing, and the law was recently amended to allow utilities to choose the once-through option. At the present time, 10 German reactors are licensed for MOX fuel, of which 7 have actually loaded MOX fuel. Another eight German reactors have license applications pending.

Currently, German MOX fabrication capability is 35 metric tons per year. Siemens has plans to construct a MOX fabrication facility at Hanau, peaking at 100 to

120 metric tons per year. While Siemens was awarded a definitive operating license on March 12, 1991, there is considerable public opposition against this plant and the ultimate outcome is uncertain.

Germany has abandoned efforts for constructing large-scale reprocessing facilities and is relying on foreign capacity primarily in Britain and France. Because of political uncertainty in Germany, it is now common for German utilities to insist on escape clauses in their reprocessing contracts that would be activated if the German government enacts regulations limiting the use of recycled fuels.

France

France is firmly committed to reprocessing and the use of MOX fuels. There has been little public opposition to nuclear power in France, and EDF has clearly defined goals. However, a technological risk report issued in 1991 called for a review of French nuclear goals and recommended the formulation of a plan for the final disposal of nuclear waste. Specific questions were raised concerning the availability of MOX fabrication and problems with the French breeder reactor program.

There are currently 5 PWRs using MOX fuel for 30 percent of their core. The number of reactors using MOX fuel is scheduled to increase to 16 by the turn of the century. From a technical point of view, the use of MOX fuels in French reactors has been very successful,

²⁹MAGNOX is a gas-cooled power reactor.

and the French are pursuing demonstration programs to increase MOX fuel burnup. France has a considerable investment in reprocessing with three plants. The UP1 plant has a capacity of 600 metric tons heavy metal (MTHM). The UP2 plant is slated to increase its capacity from 400 to 800 MTHM per year and will be dedicated to French reactors. The UP3 plant is also slated increase its capacity from 500 to 800 MTHM per year and has contracts to service foreign reactors through the end of the decade.

Great Britain

Since MAGNOX fuel assemblies are highly corrosive when stored under water in a spent fuel pool, they must be reprocessed within a year or two after discharge. Britain has reprocessed about 30,000 metric tons of MAGNOX fuel over the past 30 years. The recovered uranium is recycled into AGRs, and has supplied about 70 percent of the AGR uranium requirements. To date, Britain has not recycled the recovered plutonium.

The country currently has 1,500 MTHM reprocessing capacity with plans to increase its capacity to 2,200 MTHM per year. Both plants are located at Sellafield. The MAGNOX plants have been operating since 1952. The British Thermal Oxide Reprocessing Plant (THORP) is currently going through a two-year commissioning. It will operate at 700 MTHM capacity for its first 10 years of operation and has target annual capacity of 1,200 MTHM.

Other European Countries

Switzerland is the only other European country currently using MOX fuel. At the present time, MOX fuel used only in the Benzau units, but there are plans to use MOX fuel in several other Swiss reactors in the latter part of the decade.

Operators of the Belgian Doel and Tihange units announced plans for MOX reloads into these units, but the political climate concerning plutonium recycle in Belgium is uncertain. Belgium has an interest in French and British reprocessing facilities and has a MOX fabrication facility with a capacity of about 35 metric tons per year. There are plans to double this capacity if the political climate is favorable.

Japan

The Japanese have traditionally viewed closing the fuel cycle as a means of energy security. However, recently

there has been some rethinking of how quickly to pursue that goal. Japanese utilities are reevaluating both the economics of MOX fuel in thermal reactors and their commitment to advanced breeders and Advanced Thermal Reactors (ATR's). Japan is currently fabricating fuel for its Monju breeder reactor demonstration program, but has experienced fabrication problems that have delayed Monju's start. Japan is also experiencing international pressure with regard to sea transport of recovered plutonium from Europe, and Eastern rim countries have raised concerns about the possible stockpiling of plutonium. Officials of Japanese utilities recently announced they may ask Cogema and British Nuclear Fuel to slow the pace of reprocessing to match any scaling back of Japanese plutonium recycle plans.

The Japanese plan to use the recovered plutonium in their nascent breeder (Joyo and Monju) and Advanced Thermal Reactor (Fugen) programs and in a number of light water reactors. By 2010, plutonium usage in breeder reactors is expected to account for about one-third of the recovered plutonium. Present plans call for the use of MOX fuel in two 800-MWe light water reactors (LWRs) by 1995, with an additional two 1,000-MWe LWRs using MOX fuel by 2000. By 2010, an equivalent of one-third MOX fuel loads is expected to be used in about 12,000 MWe of LWR capacity, accounting for about half of the plutonium recycle.

Japan is currently operating a small reprocessing plant at Tokai with a capacity of 210 metric tons per year and is about to begin construction of a large-scale reprocessing facility at Rokkasho with a capacity of 800 metric tons per year and a projected start date just after the turn of the century. There are also plans to collocate a MOX fabrication facility at Rokkasho. In the meantime, Japan has entered into agreements with France and Britain to supply reprocessing services for the remainder of the decade.

Commonwealth of Independent States

The Commonwealth of Independent States (C.I.S.) is committed to reprocessing and operates two known reprocessing facilities. Russia recently announced plans to restart construction on a third site at Krasnoyarsk, with a capacity of 1,500 metric tons per year.

Estimates of Uranium Saving by Using MOX Fuel

Under the most optimistic scenario concerning the use of MOX fuel, it is estimated that total uranium requirements can be reduced 9 percent through 2010 in

Table 22. Sensitivity of Lower-Reference-Case Projections for Western European Nuclear Fuel Cycle Requirements to Mixed-Oxide Fuel (MOX) Use Assumptions, 1993-2010

Projection	Without MOX Fuel	With MOX Fuel	Percent Difference
<i>Average Annual Natural Uranium Requirements (million pounds U₃O₈ equivalent)</i>			
1993-1995	49.5	47.1	-4.8
1996-2000	48.2	44.9	-6.8
2001-2005	47.9	43.0	-10.2
2006-2010	43.4	37.1	-14.5
<i>Total Natural Uranium Requirements (million pounds U₃O₈ equivalent)</i>			
1995	148.5	141.3	-4.8
2000	389.7	365.8	-6.1
2005	629.2	580.8	-7.7
2010	846.2	766.3	-9.4
<i>Average Annual Uranium Enrichment Service Requirements (million separative work units)</i>			
1993-1995	9.9	9.2	-7.1
1996-2000	10.0	9.6	-4.0
2001-2005	11.2	10.2	-8.9
2006-2010	10.3	9.0	-12.6

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933 PRJ INM93 OUTPUT, June 1993.

European reactors, notably French, German, and Swiss reactors (Table 22). This projection assumes that all reactors applying for a MOX license will receive the license, that all reactors with a MOX license will choose to use MOX fuel in about 30 percent of the reactor core, and that if a reactor using MOX fuel retires, it will be replaced with another reactor using MOX fuel. Estimates are that by 2010, approximately 37 reactors may be using MOX fuel in Europe. The use of MOX fuel in Europe can also result in a 7 percent saving in SWU's in 1993 through 1995, reaching 13 percent in the years 2006 through 2010. These estimated savings are to be considered an upper limit. It is certainly possible that

some of the reactors will not always use MOX fuel even though they have a license to do so, and that the percentage of MOX fuel will not always be 30 percent of the reactor's core.

MOX fuel use in Japan can reduce total uranium requirements in the Far East by 4 percent through 2010 (Table 23). This projection assumes that by 2010, twelve reactors in Japan will be using MOX fuel. Enrichment requirements will be reduced by 2 percent in 1996 through 2000 and by almost 8 percent per year in 2006 through 2010.

Table 23. Sensitivity of Lower-Reference-Case Projections for the Far East to Mixed-Oxide Fuel (MOX) Use Assumptions, 1993-2010

Projection	Without MOX Fuel	With MOX Fuel	Percent Difference
<i>Average Annual Natural Uranium Requirements (million pounds U₃O₈ equivalent)</i>			
1993-1995	21.7	21.6	-0.5
1996-2000	25.1	24.6	-2.0
2001-2005	26.2	24.9	-5.0
2006-2010	30.4	28.3	-6.9
<i>Total Natural Uranium Requirements (million pounds U₃O₈ equivalent)</i>			
1995	65.2	64.8	-0.6
2000	190.7	187.8	-1.5
2005	321.9	312.3	-3.0
2010	474.1	453.8	-4.3
<i>Average Annual Uranium Enrichment Service Requirements (million separative work units)</i>			
1993-1995	4.8	4.8	0.0
1996-2000	5.0	4.9	-2.0
2001-2005	6.1	5.8	-4.9
2006-2010	6.6	6.1	-7.6

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

4. Summary of Foreign Nuclear Power Programs

Introduction

Thirty-six years after the first commercial nuclear plant, Shippingport, went critical in Shippingport, Pennsylvania, nuclear power now accounts for over one fifth of the electricity produced in the world. However, mixed views exist on the future of nuclear power, ranging from France, with a total commitment to nuclear as its primary energy source, to Italy, where nuclear units have shut down presumably never to operate again. The purpose of this chapter is to review the nuclear programs in foreign countries with commercial nuclear power plants in operation, under construction, or planned. The discussion is organized by regional categories (see Table 3-3 in Chapter 3): (1) Canada, (2) Western Europe, (3) Eastern Europe, (4) Far East, and (5) Other.²⁸ In some cases, the country discussions may not be completely consistent with the accompanying Appendix G, "Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, in Foreign Countries." Units that are included in the country-specific discussion but not included in the roster are those which were judged to have little chance of becoming operable based on the forecast to 2010.

Canada

Number of Operable Reactors:	21
Total Operable Capacity:	14,561 (net) MWe
Number of Reactors in Construction: . .	1
Total Construction Capacity:	881 (net) MWe
1992 Capacity Factor:	68%
1992 Nuclear TWh:	75.5 TWh
1992 Nuclear Share:	14.3%

Ontario Hydro, Canada's largest utility, manages 18 of the country's 21 operable reactors. The only exceptions to Ontario Hydro's management are the 638-megawatts-electric (MWe) Gentilly 2 reactor operated by Hydro Quebec and the 640-MWe Point Lepreau 1 operated by

the New Brunswick Electric Power Company. All of the country's units are Candu reactors, pressurized heavy-water reactors (PHWR) supplied by Atomic Energy of Canada, Ltd. Total nuclear generation for Canada's operable nuclear units fell from 80.1 terawatthours (TWh) in 1991 to 75.5 TWh in 1992. The lower 1992 level is largely the result of extended maintenance outages at the country's Darlington, Bruce, and Pickering nuclear stations.

One of Ontario Hydro's biggest problems in 1992 was the restart of two of the Darlington units. After receiving approval from the country's nuclear regulatory agency, the Canadian Atomic Energy Control Board, Ontario Hydro restarted Darlington 1 on July 13 and Darlington 2 on September 8. Darlington 1 and 2 were first connected to the grid in 1991 and 1990, respectively, and have experienced problems since. Darlington 3 was connected to the grid in 1992. In mid-1992, Ontario Hydro's nuclear engineers replaced the five-vane impeller pumps in the heat transport system of both units with seven-vane impellers. While replacing the impeller pumps, Ontario Hydro's engineers found a second and previously undetected problem—small cracks in the journal bearings of the primary heat transport pump, which have also been replaced in both units. Five years behind schedule, Darlington is Ontario Hydro's last nuclear station. The delay was due to provincial government spending restraints and the testing of sophisticated new computerized shutdown controls. The cost of the station has escalated because of the construction delay from an estimated \$10 billion to \$13.8 billion in Canadian dollars. At the end of 1992, only one unit remains in the construction pipeline, Darlington 4, which is 99 percent complete and has a capacity of 881 MWe.

In 1989 Ontario Hydro had incorporated 10 new Candu reactors at 880 MWe each into a plan to meet its long-term electricity supply and demand by 2014. The original plan also called for conservation and efficiency improvements, new hydroelectric facilities, natural

²⁸Primary sources of information in this chapter include *Nuclear Engineering International*, June 1992 through March 1993 (Surrey, United Kingdom: Business Press, Ltd.); *1992 Nuexco Review* (Denver, Colorado, Nuexco); *Nuclear News*, June 1992 through March 1993 (LaGrange, Illinois: American Nuclear Society); *Nuclear Fuel*, July 1992 through March 1993 (New York: McGraw-Hill); *Nucleonics Week*, July 1992 through March 1993 (New York: McGraw-Hill); *The Washington Post* (Washington DC); and various papers presented at seminars sponsored by the Uranium Institute and the U.S. Council for Energy Awareness (1991 through 1992).

gas-fired plants, and increasing purchases from non-utility generators (independent power producers) and from neighboring Canadian and U.S. utilities. In 1991, the Ontario government instructed the utility to revise its plan. The revised plan, now labeled the "1992 Update," calls for doubling the budget on demand-side management and doubling purchases from nonutilities. The utility, however, canceled its plan to bring in 1,000 MWe of hydro power from Manitoba Hydro, citing a reduction in industry demand.

After a 30-year relationship with the Canadian Nuclear Association, Ontario Hydro has decided to terminate its membership. Ontario Hydro's Chairman Marc Eliesen stated that it was no longer appropriate to be a member of the Canadian Nuclear Association, which advocates nuclear energy.

Western Europe

Belgium

Number of Operable Reactors:	7
Total Operable Capacity:	5,484 (net) MWe
Number of Reactors in Construction: . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	86%
1992 Nuclear TWh:	40.4 TWh
1992 Nuclear Share:	59.3%

Nuclear energy's contribution to total electricity generated in Belgium changed slightly in 1992 from its 1991 level. A political moratorium precludes further investment in nuclear generating capacity in Belgium. Belgian priorities have been switched to use natural gas in an effort to combat the greenhouse effect. In 1992, gas contributed 12.9 percent of total electricity generation, compared with 10.6 percent in 1991. Gas-fired generation is projected to be 16.4 percent of the total in 1993.

Belgium has a total of seven operable nuclear units at its Doel and Tihange sites. The reactors are based on a standardized design, but (unlike in France) some equipment and components are not standardized. Because of the industry's close relationship with both Framatome and Westinghouse, three different designs have evolved at the sites. The differences, however, have not prevented Belgian operators from obtaining high capacity factors. In 1992 the average capacity factor was 86 percent.

In 1990, Belgium's three largest utilities merged to form a privately owned utility, Electrabel, which is respon-

sible for operating the Nation's nuclear reactors. Currently, about 3,000-MWe of conventional capacity is scheduled to come on-line by 1998. In addition to Electrabel's available capacity, the country has a 25 percent share in France's Chooz nuclear power station, with a capacity of 2,910-MWe.

If annual power consumption continues to increase by more than 2.5 percent, as forecast in the country's 1988 through 1998 capital investment plan, additional capacity may be needed. At present, electricity demand growth will have to be supplied by combined-cycle gas turbines. Electrabel, however, is suggesting that additional nuclear capacity might be needed if electricity demand continues to rise more steeply than the official forecast.

Finland

Number of Operable Reactors:	4
Total Operable Capacity:	2,310 (net) MWe
Number of Reactors in Construction: . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	89%
1992 Nuclear TWh:	18.2 TWh
1992 Nuclear Share:	33.3%

On November 23, 1992, Finnish legislators approved a resolution that eliminates any new nuclear reactors in the country's National Energy Strategy (NES) through 1995. The legislature's 96 to 78 vote leaves the government and its electrical utilities scrambling for solutions to Finland's growing energy demand. Government forecasts estimate that electricity demand in Finland will increase from 54.7 TWh in 1992 to 80.0 TWh by 2000, despite energy saving programs. In the original NES, nuclear power is considered to be a possible source for new baseload power; however, the recent parliamentary vote added the nonnuclear statement. In addition to the nonnuclear initiative, the legislature also rejected the idea of a natural gas pipeline from Norway to Finland, citing the project's high cost and insufficient demand for gas since Sweden has declined to participate.

In 1990, the two Finnish power companies—Imatran Voima Oy (IVO), a state-owned utility, and Teollisuuden Voima Oy (TVO), a privately owned utility—requested that the government make a decision in principle that a new nuclear unit would fulfill the Finnish Nuclear Energy Act, in that the construction of a new nuclear power plant is in line with the overall good of society. Finnish power utilities and industries

still regard coal and nuclear power as the two realistic energy sources for new baseload power.

Currently, Finland has four operable commercial nuclear power units. Loviisa units 1 and 2, each 445-MWe pressurized-water reactors (PWRs), and TVO 1 and 2. Loviisa 1 and 2, located in Loviisa, Uusimaa, were built by the former Soviet Union's Atomenergosexport and put into service in 1977 and 1980. The units were scheduled to operate for 30 to 40 years, but with no new capacity being added in the near future, they are now expected to operate for 45 years. To achieve that goal, IVO has invested about \$20 million annually over the past several years on upgrades and new safety components. Replacement part purchases were mostly from the west, and as a result the Loviisa reactor bears little resemblance to its original VVER-440 design.

France

Number of Operable Reactors:	56
Total Operable Capacity:	57,688 (net) MWe
Number of Reactors in Construction: . .	9
Total Construction Capacity:	12,820 (net) MWe
1992 Capacity Factor:	63%
1992 Nuclear TWh:	321.7 TWh
1992 Nuclear Share:	72.9%

The oil shocks of 1974 and 1978 forced France to confront its lack of indigenous energy resources. As a result, the country began an aggressive program of constructing nuclear power plants. Since then, France has demonstrated that nuclear reactors can be built in fewer than 6 years, commissioned at a rate as high as one unit every 2 months, and operated economically.

In 1992, nuclear generation in France increased to 321.7 TWh. The country's 56 operating nuclear units contributed 72.9 percent of its electricity requirements.

On January 1, Electricite de France (EDF), the country's national utility, instructed Framatome to begin building Civaux 2, a 1,455-MWe PWR, which is needed to meet projected growth in electricity demand. Civaux 2, located on the upper Vienne River near Poitiers in west central France, will be EDF's fourth unit in Framatome's N4 series. Civaux 1, which was ordered on June 1, 1991, is now 15 percent complete. Civaux 1 is scheduled to enter into service in April 1997, Civaux 2 in 1999. After Civaux 1 and 2, EDF plans to build two more N4's at an existing two-unit PWR site (Penly, Flamanville, or Saint Alban). Other N4 units, Chooz B1 and B2 are currently being built near the French and

Belgian borders. Chooz B1 and B2 will be the first totally computerized nuclear stations. Chooz B1 is expected to become operable in early 1996, while Chooz B2 is scheduled to come on-line in mid-1996.

Golfech 2, a 1,310-MWe PWR, achieved initial criticality in December 1992 and is expected to become operable in 1993. Currently, France has nine reactors in its construction pipeline with a total capacity of 12,820 MWe.

If demand continues to grow at a steady pace, the next nuclear plant order could be placed as early as 1994 followed by one each year throughout the decade. Capacity additions are based on a plausible projected average annual electricity demand growth of 2.1 percent through 2000, which corresponds to GNP growth averaging 2.4 percent over the same period.

One unit, Penly 2, a 1,330-MWe PWR, was connected to the Nation's electric grid in 1992, while one unit of the same size was shut down. The retirement in May of Saint Laurent A2 after 21 years of operation leaves only Bugey 1, a 540-MWe gas-cooled reactor (GCR), still operating out of France's original eight GCR's. Bugey 1 will be shut down in 1994.

Given that the utility is not seeking any new export contracts, EDF's electricity exports will level out beginning in 1997. Currently, EDF's export contracts total 70 billion kilowatthours per year through 2000.

Despite France's unparalleled success with nuclear power, problems do exist. One troubling event for EDF has been the cracked reactor vessel heads at several reactors. EDF has elected to replace these heads at some of the units. The utility, however, is still awaiting judgement from regulatory authorities on cracking allowance guidelines for its reactors.

Despite EDF's commitment to nuclear power, management has begun to diversify to gas turbines, primarily to provide generating capacity to meet France's high winter peak demand. Recently, the French utility ordered 2,000 MWe of gas turbine equipment from European Gas Turbines. The 16 combustion turbines, grouped in eight pairs of 246 MWe each, will be run on oil, although they also will be able to burn natural gas.

Germany

Germany continues to operate some of the most productive nuclear reactors in the world despite the Social Democratic Party's opposition to them and the seemingly endless court cases to close them down.

In 1992, the top three reactors in the world in terms of total electricity generation were located in Germany. Preussener Elektra's Brokdorf unit, a 1,307-MWe PWR, generated the most electricity of any unit (10.7 TWh). Grohnde unit, a 1,325-MWe PWR, and Gemeinschaftskernkraftwerk Neckar's Neckarwestheim 2, a 1,269-MWe PWR, generated 10.5 TWh and 10.1 TWh, respectively, placing second and third in terms of total generation for the year.

Number of Operable Reactors:	21
Total Operable Capacity:	22,460 (net) MWe
Number of Reactors in Construction: . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	72%
1992 Nuclear TWh:	150.0 TWh
1992 Nuclear Share:	30.1%

Despite Germany's success with its nuclear plants, the country's perception of nuclear power is negative. After the Chernobyl accident in 1986, the Social Democratic Party focused its efforts on phasing out nuclear plants in Germany. Despite defeats in national elections, the Social Democratic Party remains committed to ending nuclear power. However, its members are more divided than before. Despite the Chernobyl accident, some members recognize that German plants are safe and believe that the first priority of the party should be to restore economic growth in eastern Germany. In addition, seven of the eight German federal states generate nuclear power under the responsibility of Social Democratic Party cabinet ministers and have no interest in shutting down their reactors. The future of nuclear power may rest on the country's upcoming elections. The next federal election will be held in late 1994.

The other major concern regarding nuclear power's future is the revision of Germany's Nuclear Energy Act (NEA). The NEA, which first came into force in 1960 and was significantly revised in 1976, is being overhauled in several key areas to reflect current realities in the political climate. A draft of the revised Act was completed in mid-1992 by the Federal Ministry of Environment and is now being reviewed by other federal ministries and the state government. The most significant changes make German utilities responsible for disposal of their own wastes; the responsibility for construction and operation of waste repositories will fall to the utilities as well. The German government began developing high-level waste facilities at Gorleben and Konrad in 1976, but neither one has opened. The most important implication of these changes is that the

government, in a sense, no longer requires reprocessing and recycling of spent fuel from German reactors. The NEA currently requires spent fuel to be reprocessed unless it is economically infeasible. The important potential drawback of this change in spent fuel disposition is that utilities could now find their existing operating licenses in jeopardy unless specific, long-term spent fuel repository plans and facilities are in place.

Since no new nuclear business is available domestically, Siemens AG and Bayernwerk AG announced plans designed to win energy-related business in the Commonwealth of Independent States (C.I.S.) and elsewhere in eastern Europe. Siemens and Bayernwerk AG are proceeding to fund nuclear-safety improvements in Eastern Europe. However, these firms are counting on government bilateral and multilateral assistance to fund at least some of the work. In addition to numerous short-range safety improvement projects, Siemens is aiming to win contracts to complete more than a dozen VVER-1000 PWR's in the C.I.S. and Eastern Europe.

Italy

Italy's 5-year moratorium on nuclear plant operation ended on December 18, 1992. Both Caorso, a 862-MWe General Electric BWR, and Tino Vercellese, a 270-MWe Westinghouse PWR, have been in a decommission status since they were shut down in 1987. Italy's national utility Ente Nazionale per l'Energia Elettrica (ENEL) is responsible for decommissioning both units.

In 1992, Italian scientists called for the reopening of the two plants, arguing that the units offer safety guarantees comparable to those of other plants currently operating in Europe. The reopening of one of the plants is plausible, but would require a number of modifications that could take a few years to complete. However, antinuclear legislators have already submitted a motion in Parliament aimed at extending the moratorium. Despite the moratorium, the Italian government has continued to concentrate on research and development (R&D) of the next generation of reactors. The country will spend roughly \$55 million on R&D over the 1991 through 1993 period.

Netherlands

Most of Netherlands's 15 GWe of electrical generating capacity is now gas- or coal-fired plants. The two nuclear units, the 452-MWe Borssele PWR and the 55-MWe Dodewaard BWR, produced 5 percent of the electricity generated. The Dodewaard nuclear unit, which

was connected to the grid in 1968, was originally scheduled to be shut down in 1995 but will keep operating through 2004. About 7 percent of total electricity consumption comes from net imports of electricity—mainly from nuclear reactors in Belgium, France, and Germany.

Number of Operable Reactors:	2
Total Operable Capacity:	507 (net) MWe
Number of Reactors in Construction: . . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	82%
1992 Nuclear Twh:	3.5 TWh
1992 Nuclear Share:	5.0%

Before the Chernobyl accident in 1986, the Dutch government was proceeding with the planned construction of four 1,000-MWe nuclear reactors. The government's commitment to a nonnuclear energy policy has failed to halt the operation of existing reactors. However, it has prevented Dutch utilities from building any new ones. Recently, new attempts have been made to open the political debate on the possible building of more nuclear capacity around the turn of the century.

Dutch Economy Minister Koos Andriessen has stated his intentions to reopen the debate on nuclear power for the Netherlands. The Minister believes that the long-term energy problems of the country cannot be solved without more nuclear power plants and that alternative policies, such as energy saving and renewable energy sources, cannot deliver the cuts in carbon dioxide emissions that the country should be making.

No substantial movement in Netherlands' nuclear program will be made in the near future since public opposition is still a major challenge, and the ruling coalition government, dominated by Christian Democrats, firmly supports a nonnuclear policy.

Slovenia

Number of Operable Reactors:	1
Total Operable Capacity:	620 (net) MWe
Number of Reactors in Construction: . . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	68%
1992 Nuclear Twh:	3.8 TWh
1992 Nuclear Share:	34.6%

In January 1992, Slovenia was recognized as an independent country. It operates one nuclear power plant,

Krsko, a 620-MWe PWR which provides electricity for both countries and is located on the border of Croatia and Serbia. The unit was connected to the grid in September 1981, and began commercial operation in January 1983. In September 1992, Slovenia gained membership in the International Atomic Energy Agency (IAEA), as did Croatia. Slovenia was the only republic in the former Yugoslavia that had a production center for uranium. Zirovski Vrh, the country's sole uranium mine, was shut down in 1990 due to high costs and environmental concerns. Slovenia and Croatia are working to develop a permanent waste storage facility by the turn of the century. Currently all waste is stored on site.

Traditionally, the republic of Slovenia has had a strong antinuclear movement. However, the Croatian government has been consistently pronuclear and Croatia has considered nuclear power as an option for the future supply of electricity requirements.

Prior to the Chernobyl accident in 1986, the former Yugoslavia had planned construction of four additional units, each 1,000 MWe. Following the accident, the government abolished its nuclear construction plans.

Croatia's need for Krsko became more critical after the 1989 through 1990 Yugoslavian civil war. The war destroyed most of Croatia's industrial production capability and caused extensive damage to conventional power plants. The Krsko unit has been plagued with a number of forced outages, and in May 1990 officials announced a decision to close the plant by 1995.

Spain

Number of Operable Reactors:	9
Total Operable Capacity:	7,097 (net) MWe
Number of Reactors in Construction: . . .	5
Total Construction Capacity:	4,977 (net) MWe
1992 Capacity Factor:	85%
1992 Nuclear TWh:	53.0 TWh
1992 Nuclear Share:	34.6%

Spain currently operates nine nuclear reactors totaling 7,097 MWe of capacity and contributing 34.6 percent of the electricity generated within the country. In 1992, the nine reactors had an average capacity factor of 85 percent, slightly lower than in 1991.

In 1991, Spain's National Energy Plan (PEN) imposed a moratorium on nuclear plant construction prohibiting the operation of any new nuclear plants before 2000. As a result, two reactors at advanced stages of construction

remain uncompleted. Under the current moratorium, nuclear power's electrical share of total installed electrical generating capacity will fall from 35 percent in 1992 to approximately 14 percent by 2000.

In the PEN, the government has opted to rely upon additional imports of natural gas and electricity to meet expected demand. Currently, Spain imports about two-thirds of its total energy requirements. With Spain's large dependency on imported electricity, the country's nuclear share is about 20 percent when compared to the amount of electricity consumed from both domestic and imported sources. Over the previous decade electricity demand grew between 4 and 5 percent per year. The most recent government forecast projected demand to increase 3.5 percent annually through 2000.

During 1992, Spain's Trillo 1, a 1,000-MWe PWR, and Vandellos 2, a 950-MWe PWR, were upgraded by 26 MWe and 8 MWe respectively, as a result of improvement of the plant's turbines.

Spain's integration into the European community has forced the electricity sector to consolidate in order to be more competitive. In November 1992, Iberduero S.A. and Hidrelectrica Espanola S.A. merged to form HI Holding, now Spain's largest private utility. The rationale behind consolidation is that once larger utilities are created from numerous smaller ones, separating electricity generating facilities from electricity distribution systems will be easier.

One of the biggest challenges facing Spanish utility managers has been steam generator degradation. The country's first PWR, Jose Cabrera (Zorita), a 153-MWe Westinghouse reactor located in Zorita, Guadalajara, suffers from tube thinning. Previously, the reactor had only 5 percent of the tubes plugged after 23 years of operation. To deal with this problem, plant owners formed the Steam Generators Committee to coordinate a national response. The licensing authority, Le Consejo de Seguridad Nuclear, has also been active in assessing the application for continued operation of the steam generators from the licensees.

Sweden

In the early 1980's, Sweden made international headlines when it voted in a referendum to phase out nuclear power. The Parliament translated the voters choice into law by setting a 2010 date for the phaseout to be completed. Earlier plans by then Energy and Environmental Minister Birgitta Dahl called for the shutdown to begin around 1995, a decision confirmed

in 1988 by the Swedish Legislature. Shortly before the 1991 election, three of Sweden's four largest parties agreed that nuclear power should be phased out only when a safe, economically viable alternative is found. In effect, the compromise put the phaseout in limbo, angering many in the pro-phaseout movement. In response, the Swedish government voted in 1992 to adopt a \$750 million development program for renewable energy in an effort to find an acceptable alternative to nuclear power.

Number of Operable Reactors:	12
Total Operable Capacity:	10,002 (net) MWe
Number of Reactors in Construction: . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	66%
1992 Nuclear TWh:	60.8 TWh
1992 Nuclear Share:	43.1%

In 1992, Sweden's 12 nuclear units provided the country with 43.1 percent of its electricity. The Barsebaeck station, a two-unit plant, is just 23 kilometers from Copenhagen. The Ringhals station is located on Sweden's west coast some 70 kilometers from Gothenburg, the country's second largest city. It consists of four units with a total capacity of 3.5 GWe and generates about 17 percent of Sweden's electricity.

Danish antinuclear groups and politicians have repeated demands that the Barsebaeck plant be shut down. The recent debate was initiated when the Swedish Nuclear Power Inspectorate (SKI) ordered five first-generation BWRs shut down (Swedish State Power Board's Ringhals 1, Barsebaeck 1 and 2, and Oskarshamn 1 and 2) after problems were found in their emergency core cooling systems. SKI was criticized for not ordering the reactors shut down sooner for economic reasons. Of the five units, all but one was already down for maintenance when the order was issued. The units produce about 20 percent of the country's electricity.

After careful examination of the steam generators in Ringhals 3 and 4, the Swedish utility Vattenfall has decided to replace the generators in unit 3 rather than operate with the existing ones and to reduce the rate of degradation by lowering the primary water temperature. The initial economic evaluation for Ringhals 4 also indicates that replacement of the steam generators would be cost effective; however, a later evaluation was inconclusive. The replacement would create a potential increase in the unit's capacity of about 12 percent.

The replacement outage for Ringhals 3 will start in June 1995 and will take approximately 3 months. The new steam generator is a Siemens design and will be manufactured at Framatome's workshop in Chalon, France. It will cost approximately \$235 million.

Switzerland

Number of Operable Reactors:	5
Total Operable Capacity:	2,936 (net) MWe
Number of Reactors in Construction: . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	84%
1992 Nuclear TWh:	22.1 TWh
1992 Nuclear Share:	39.5%

Switzerland's five installed nuclear power reactors all operated successfully during the year. The plants generated 22.1 TWh of electricity in 1992, compared with 22.3 TWh in 1991. Overall, the five reactors averaged an 84 percent capacity factor and supplied 39.5 percent of the country's total electricity generation. Currently, Switzerland's national referendum bars any new nuclear construction before 2000.

In 1992, Switzerland's Federal Executive Council approved the renewal of an operating license for the Muehleberg unit, a 326-MWe BWR, located in Muehleberg, Bern. The renewal was for 10 years, rather than the unlimited renewal Bernische Kraftwerk, its owner, sought. Depending on the national energy and economic situation at the end of 2002, when the newly granted license expires, it is possible that Bernische Kraftwerke could receive a further extension—possibly an additional 20 years. The utility has invested some 150 million Swiss francs in additional safety systems and modifications, along with 10 million Swiss francs for special studies required by federal authorities.

Gosgen, a 920-MWe PWR operated by Kernkraftwerk Gosgen-Daeniken AG (KKG), and Leibstadt, a 990-MWe BWR operated by Kernkraftwerk Leibstadt AG (KKL), performed well in 1992. Gosgen generated 7.8 TWh and Leibstadt 7.9 TWh.²⁹ As part of the Swiss Energy 2000 program, KKL ordered three low-pressure turbines in July 1992 to upgrade the Leibstadt unit to 1,013 MWe. The new turbine will be installed in August 1994.

United Kingdom (U.K.)

Number of Operable Reactors:	37
Total Operable Capacity:	11,934 (net) MWe
Number of Reactors in Construction: . .	1
Total Construction Capacity:	1,188 (net) MWe
1992 Capacity Factor:	57%
1992 Nuclear TWh:	66.3 TWh
1992 Nuclear Share:	22.0%

In 1992, the British nuclear industry performed well, accounting for 22.0 percent of the country's electricity generation. The 37 nuclear reactors had an average capacity factor of 57 percent and generated a total of 66.3 TWh, an increase of 11.8 percent over 1991. Based on combined cycle gas turbine (CCGT) technology and the progressive retirement of the less efficient coal-fired stations, the fossil fuel mix will be dramatically changed in the following years. The introduction of the CCGT plant is projected to present strong price competition in the United Kingdom market and pose a challenge to future investments in nuclear plants.

The government's review of nuclear power in 1994 will take account of the performance of nuclear utilities in addition to the construction of Britain's Sizewell B nuclear unit. The purpose of the review is to take a complete look at the total energy situation in the United Kingdom. The review was pushed to the front of the United Kingdom's political agenda by last year's government proposal to close 31 unprofitable coal mining operations. The proposal, which would have left 30,000 miners unemployed, was tabled until the review could be conducted.

The U.K.'s Nuclear Installation Inspectorate approved the continued operation of the 30-year-old Bradwell 1 reactor in October 1992, and the Bradwell 2 reactor in August 1992. The Bradwell station, located in Essex, is the first of Nuclear Electric's five operating Magnox stations to obtain approval to operate for more than 30 years. This approval allows the station to operate for another 10 years, although Nuclear Electric expects to close both units around 1996. Bradwell passed most of the safety issues, but possible embrittlement of the welding of the fueling penetration in the top dome of the steel reactor pressure vessel is being investigated further. The other area of reservation is the long-term

²⁹Gross generation.

stability of the graphite moderator. The Nuclear Installation Inspectorate has asked for a more rigorous site specific analysis of the case structures in the Bradwell reactors.

Nuclear Electric is currently awaiting similar approval for continued operation of the Trawsfynydd plant in central Wales. The two-unit plant has not operated since February 1991 due to the discovery of embrittlement in the reactor's pressure vessels. However, the station is likely to be phased out around 1994 or 1995.

The United Kingdom's oldest Magnox stations still operating are British Nuclear Fuel's Calder Hall and Chapelcross, which were originally built for military applications. Both are four-reactor MAGNOX stations commissioned in 1959, and authorized by the Nuclear Installation Inspectorate to operate until each of the reactors is at least 40 years old.

On August 5, 1992, the Department of Trade and Industry announced that the Dounreay Prototype Fast Reactor (PFR) will be closing in March 1994. The government, which has spent more than \$77 billion on fast reactor research and development since 1955, justified its 1988 decision for a 1994 closure date for the PFR on the grounds that commercial deployment of fast reactors in the U.K. will not be required for 30 to 40 years. Government support for Atomic Energy Authority Technology's base program of fast breeder reactor research and development will end in March 1993. The utility wanted to operate the unit until 1997 in order to promote research and development work being done to benefit the planned European Fast Reactor operators. Currently, France's Phoenix reactor is the only remaining operable European breeder. Japan and the C.I.S are the other two countries with strong breeder programs.

Eastern Europe

Bulgaria

Number of Operable Reactors:	6
Total Operable Capacity:	3,526 (net) MWe
Number of Reactors in Construction: . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	37.6%
1992 Nuclear TWh:	11.6 TWh
1992 Nuclear Share:	32.5%

The Bulgarian government has focused much attention on the country's Kozloduy nuclear power station. The

six-unit station was the target of a concerted effort by numerous organizations to improve the safety and operation of the reactors. In 1991, a team of experts from the International Atomic Energy Agency (IAEA) found the Kozloduy nuclear power station to be in unsatisfactory condition. The team discovered major problems, including reactor design flaws, as well as poor record keeping and lack of proper maintenance.

A complete shutdown of the station for upgrades was not feasible since the country needs the power produced by these units. Any interruption of reactor operation results in immediate power cuts throughout the country. In 1992, Kozloduy generated more than 11 thousand GWh, accounting for 32.5 percent of the country's total generation.

Bulgaria's two oldest reactors, Kozloduy 1 and 2, are completing year-long outages for essential maintenance and backfitting. When these two units return to service, the next two units, Kozloduy 3 and 4, will be taken off-line for similar work. Kozloduy 2 was reconnected to the grid in January 9, 1993, while unit 1 will remain shut down through the first half of 1993.

Spare parts for the units were donated by Germany from its retired Greifswald unit. Officials of the World Association of Nuclear Operators (WANO) have determined that Kozloduy 1 and 2 are safe enough to continue operation through 1995. The decision on whether to undertake more extensive programs for safety-related backfitting has not yet been made.

More important than the backfitting and operation of the units is the introduction of new management. In addition, salaries were increased three- to five-fold to increase the morale of the staff. With direct advice and assistance from WANO's international team of 20 specialists, Kozloduy's new managers now have clearly defined responsibilities. In parallel, the Bulgarian nuclear regulatory body is being reorganized with technical assistance from the IAEA.

Unplanned outages at Bulgaria's nuclear units happen almost monthly. In previous years, the grid supplied 8,000 MWe of capacity with high reliability. Since Kozloduy 1 and 2 were shut down for upgrading, the country must rely on units 5 and 6, which have not proven to be as reliable. Kozloduy 5 and 6, each 953-MWe VVER's, are also Soviet-designed reactors, but incorporate modern safety features common in the West.

The Commission of the European Communities (CEC) is considering funding an emergency program to

improve the reliability of Kozloduy 5 and 6. The fund was proposed in response to a series of equipment defects and human errors at the units, in which a main electrical switch and electrical panel were destroyed. If the CEC funds the program, it would be the first time that CEC money would flow directly to the larger, more modern VVER-1,000 reactors. The CEC awarded a \$13 million program for an older VVER 230 reactor in 1991.

Commonwealth of Independent States

Number of Operable Reactors:	40
Total Operable Capacity:	30,906 (net) MWe
Number of Reactors in Construction: . .	17
Total Construction Capacity:	14,137 (net) MWe
1992 Capacity Factor:	N/A
Kazakhstan	42.3%
Russia	76.9%
Ukraine	67.0%
1992 Nuclear TWh:	191.1 TWh
1992 Nuclear Share:	N/A
Kazakhstan	0.5%
Russia	11.8%
Ukraine	25.0%

The republics in the Commonwealth of Independent States (C.I.S.) with nuclear power programs are Armenia, Kazakhstan, Russia, and the Ukraine.

Armenia—Armenia has two units which have been shut down since late 1988 or early 1989 as a result of an earthquake that devastated parts of that republic. The Armenian government is interested in restarting at least one of the two VVER-440 reactors, because Armenia's energy supply is degenerating rapidly due to a blockade of fossil fuel supplies by neighboring, hostile Azerbaijan. Both units are of the Model 230, first generation VVER-440 design, that is under heavy criticism concerning its safety. Armenskaya 2, which went on-line in 1980, has more safeguards than unit 1 which went on-line in 1977 and therefore is the better candidate for returning to an operating status. However, work still needs to be done.

Kazakhstan—Kazakhstan, a republic located in Central Asia, has one nuclear power plant, a 135-MWe fast breeder reactor. The reactor, known as BN-350, was started in 1973 and has performed well over the past years. In 1992, the unit was granted a license to operate through 2003 by the Kazakh Atomic Energy Agency. Kazakhstan has announced plans to build at least 8 GWe of nuclear capacity and last year announced that a second 350-MWe fast breeder reactor will be built to

replace the existing unit. Kazakhstan has a major fuel cycle facility, which, among other things, converts U_3O_8 to UO_2 and UF_6 to UO_2 , and pelletizes the fuel. The facility pelletizes all of the fuel used by RBMK reactors and 80 percent of the VVER's of the former Soviet Union and former Eastern bloc countries.

Russia—Russia has 24 operating reactors, 11 of which are of the RBMK type, 13 are VVER's and 1 a LMFBR. Nuclear power accounted for about 12 percent of Russia's total electricity generation in 1992. No new nuclear reactors entered commercial operation in 1992, nor were any retired.

Construction of new reactors in Russia was suspended or slowed down after the Chernobyl accident. In 1992, the Russian government approved a plan to build at least 30 new nuclear power stations by 2010. If implemented, this plan would double that Nation's nuclear capacity. This building of new reactors is unlikely to happen, however, because Russia does not have the money. There is also strong internal and worldwide opposition to this plan. The most likely additions for operating reactors to the year 2000 will come from the completion of units on which construction was halted or slowed down after the Chernobyl accident. These include four VVER-1000 units and one RBMK-1000. There are also two 800-MWe fast breeder reactor projects, South Urals 1 and 2, on which a small amount of construction work has been undertaken. Capacity based on designs meeting Western safety standards should be ready for the start on construction by the late 1990s, and could contribute to an increase in nuclear capacity in the first decade of the next century.

Russia has a complete line of nuclear fuel cycle facilities, including four uranium enrichment plants with a total capacity of 12 million SWU; a uranium hexafluoride conversion facility, located at the Angarsk enrichment complex, which supplies conversion services for all Russian reactors; and two fuel fabrication facilities, one for the VVER reactors and the other for the RBMK reactors.

Ukraine—Ukraine has 15 operable reactors with a capacity of 13.0 GWe which accounts for 25 percent of annual electric power production. Ukraine still has three operable RBMK reactors at the Chernobyl plant although Unit 2 was damaged in a fire in October 1991. Unit 4 was destroyed in the nuclear accident in April 1986. Units 1 and 3 are scheduled to be shut down by the end of 1993. However, because of conflicts between the goals of halting nuclear plant construction and meeting the country's energy requirements, the two units may not be closed at the end of 1993, as planned.

The Ukrainian Parliament declared a moratorium on all new nuclear plants until 1995. However, as the need for energy grows, pressure to lift the moratorium is increasing. If the moratorium is lifted, it is likely that Zaparozhe 6, a 950-MWe VVER reactor, will be started up, and a fourth unit at South Ukraine, Khmelnytski 2 or Rovno 4, will be started later. All three reactors are advanced designs of the VVER that incorporate many Western safety features and conform to IAEA standards.

Ukraine has no domestic fuel cycle facilities and has relied upon Russia for its conversion, enrichment, and fuel fabrication needs.

Decommissioning of old plants is fast becoming an issue in many countries with nuclear power programs. The Russian government has no clear decommissioning or dismantling plan for its reactors. Because of safety issues and the growth of a public opposition toward nuclear plants, especially RBMK reactors, shutdown of 13 RBMK units is possible within 5 to 10 years. There are also several first-generation VVER units technically approaching retirement age, as well as two older sodium-cooled breeder reactors. Strategies for decommissioning can vary depending on the condition of the reactor, the level of radioactive contamination throughout the unit, and the estimate of the long-term integrity of the reactor's structure if left in place.

Czech & Slovak Republics

Czech Republic

Number of Operable Reactors:	4
Total Operable Capacity:	1,632 (net) MWe
Number of Reactors in Construction: . .	2
Total Construction Capacity:	1,780 (net) MWe
1992 Capacity Factor:	86.0%
1992 Nuclear TWh:	12.3 TWh
1992 Nuclear Share:	20.7%

Slovak Republic

Number of Operable Reactors:	4
Total Operable Capacity:	1,632 (net) MWe
Number of Reactors in Construction: . .	4
Total Construction Capacity:	1,560 (net) MWe
1992 Capacity Factor:	77.6%
1992 Nuclear TWh:	11.1 TWh
1992 Nuclear Share:	49.5%

The reactors in the former Czechoslovakia have been well maintained, and have undergone many safety backfits and improvements even before the Western

nuclear community turned its critical eye upon the safety of the Soviet-designed reactors. Currently, the eight operable commercial nuclear reactors provide roughly 30 percent of the region's electrical output. On January 1, 1993, the Czech and Slovakia Federal Republic (CFSR) was replaced by two independent republics, the Czech Republic and the Slovak Republic. The utility representatives, however, have continued to cooperate closely on matters of nuclear energy.

In the Slovak Republic, Slovensky Energeticky Podnik remains responsible for operating the four 408-MWe VVERs at Bohunice station, and for constructing the four 390-MWe VVERs at Mochovce. The four Mochovce units are due to start up between 1994 and 1997. Bohunice 1 and 2, the two oldest reactors, are expected to be retired between 1994 and 1995 because they do not meet Western safety standards. The power will be replaced by the four Mochovce units.

Ceske Energeticke Zavody operates the four 408-MWe VVER's which have a combined capacity of 1.6 GWe, at the Dukovany station, located in the Czech Republic. In addition, Ceske Energeticke Zavody is the overseer of Temelin 1 and 2, which are currently under construction. According to official plans, Temelin 1 is expected to be completed in 1995 and Temelin 2 about 18 months later; the two 890-MWe units are around 65 and 45 percent complete, respectively.

The financial, organizational, and technical problems of Ceske Energeticke Zavody could make the 1995 completion date difficult to achieve in an economy that is being restructured. About half of Temelin's capital budget has been spent. Originally, construction management was split between Russia's Atomenergoexport, which dealt with the nuclear island, and Energoprojekt of the former CSFR, which handled the conventional side. Engineering from the plant was carried out by Skoda Praha, with Skoda Plzen as the supplier of components such as the turbine generator. With the Russian company withdrawing from the project, Energoprojekt has been forced to handle the entire project on its own. This has been difficult because many staff members have left the company.

Some political doubts linger about the need to complete the Temelin station, because electricity consumption has dropped sharply in the past year. Only recently did the Czech cabinet of ministers vote to approve the completion of the station.

In a deal worth about \$345 million, Westinghouse was selected to supply the instrumentation and control, and fuel for the Temelin station. The instrumentation and

control contract is part of an upgrade of the Temelin plant recommended by the U.S. firm NUS Halliburton, which conducted a study of the plant following the breakup of COMECON. Under the contract, financing is to be provided by the U.S. Import/Export Bank and credit insurance provided by Dugroice of Belgium. The contract covers the first fuel load and four reloads for each of the two units, as well as control rods and engineering services. In the past, the former U.S.S.R. supplied all VVER fuel; Westinghouse will be the first Western company to do so.

Hungary

Number of Operable Reactors:	4
Total Operable Capacity:	1,729 (net) MWe
Number of Reactors in Construction: . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	86%
1992 Nuclear TWh:	13.1 TWh
1992 Nuclear Share:	46.4%

Hungary's Paks nuclear station consists of four Soviet VVER-440 designed reactors, and is located on the Danube river, 114 kilometers south of Budapest. The station is operated by the state-owned utility, Paks Atomeromu Vallat (PAV). The Hungarian Electricity Board (Magyar Villamos Muvek Troszt-MVMT) oversees all the country's power plants, including Paks and became a public limited company on January 1, 1992.

The original contract relating to the Paks site, for the supply of two first-generation VVER-440 units (model 230), was signed in 1966. Construction started in 1968, but was stopped in 1970 because at that time oil-fired stations were considered more economical. After the oil crisis in 1975, the contract was modified to include four units of the same size. In the meantime, the former U.S.S.R. had introduced new safety requirements for its nuclear plants and the second generation VVER-440 (model 213) had been developed. The fortunate part of this delay was that it resulted in the installation of the second generation units, with up-to-date safety features.

Commercial operation of the four Paks units started in 1982, 1984, 1986, and 1987, respectively. These units have been highly reliable, and have operated with few outages. In 1992, the station generated 13.1 TWh with an average capacity factor of 86 percent. Even with the high performance record, Hungarian authorities embarked on a comprehensive safety assessment of the reactors at the end of 1991; the goal is to meet

international safety standards. The assessment is due to be completed in 1993 and could lead to improvement work.

With a 46.4-percent share of the total electricity produced in the country, nuclear power is the most important source of domestic electricity generation. Coal is the next most important source, fueling about one-third of the country's domestic electricity generation. However, much of the coal must be imported due to the country's low-grade domestic reserves.

Hungary has experimented with free market concepts for a number of years, and its new government favors rapid economic integration with western Europe. Hungary has one of the strongest industrial bases in all of Eastern Europe, and the industrial output accounts for more than 50 percent of the country's gross domestic product.

Currently, Hungary plans to be connected to Western Europe's electricity grid by 1993 or 1994, both to provide near-term access to a diversity of electricity supplies for import, and, for the long term, to provide a means of exporting electricity for revenue.

Total net energy growth is expected to remain at modest levels, but demand for electricity is expected to grow much more rapidly, as Hungary's market reforms improve the economy. Forecasts indicate that electrical demand will increase to 48 thousand GWh by 2005, a 33 percent jump from 1988 levels.

With the country's projected demand growth, two more reactors were planned for the Paks station, each a 1,000-MWe VVER from the former Soviet Union; however, those plans were canceled in late 1990 because the government wished to examine other alternatives. Although the government again in 1991 showed interest in additional nuclear power plants, the country's major economic and financial problems have delayed any significant progress on such reactors. Regardless of the reactor type and projected completion schedule, Hungary's limited resources compel the reactors' construction to be financed by loans from the reactor supplier, with repayment possibly in the form of electricity exports.

Like many of the former Soviet satellite countries in Eastern Europe, Hungary's initial entry into a market economy has been accompanied by an industrial recession with a sharp drop in electricity consumption, and this has taken some of the pressure off the need to reach decisions on new nuclear power stations.

Lithuania

Number of Operable Reactors:	2
Total Operable Capacity:	2,500 (net) MWe
Number of Reactors in Construction: . .	1
Total Construction Capacity:	1,000 (net) MWe
1992 Capacity Factor:	71.2%
1992 Nuclear TWh:	15.6 TWh
1992 Nuclear Share:	60.0%

Lithuania, which declared its independence in mid-1991, has two of the largest nuclear units in Eastern Europe. Ignalina 1 and Ignalina 2, located in Sniekus, are Soviet-designed, boiling pressure tube graphite-moderated reactors. The units began operation in 1983 and 1987, respectively, and have capacities of 1,250 MWe each. Originally designed at 1,500 MWe (gross) capacity, the units were later downrated due to safety concerns. More than half of the country's electricity demand is met through nuclear power, which makes this country's dependence on nuclear power strong.

The two-unit Ignalina station has experienced numerous problems including steam generator leakage and welding defects. However, the Lithuanian government is concentrating on improving plant operations and safety conditions, with aid from the Swedish Nuclear Power Board. In addition to coping with technological problems, the Ignalina station has had to deal with political disturbances since the breakaway of the Baltic States from the Soviet Union.

In 1991, the Lithuanian government signed an agreement with the Swedish Nuclear Power Inspectorate (SKI) to assist the country in establishing its own nuclear regulatory agency. This agreement led to the creation of the Lithuanian Nuclear Power Safety Inspectorate (VATESI), which is responsible for the safety of the units and has already identified actions to come.

Currently, the country has one unit in its construction pipeline, Ignalina 3, a 1,000-MWe light-water-cooled, graphite-moderated reactor located on the same site as Ignalina 1 and Ignalina 2. Due to safety and financial constraints, the construction was halted in 1989 after about \$300 million had been invested.

Far East

China

China has only one indigenous power plant, Qinshin 1, a 300-MWe PWR. This unit is located about 126 kilo-

meters from Shanghai, in Haiyan Zhejiang. Qinshin 1 was connected to the east China grid in December 1991 and reached full power in August 1992. Commercial operation is expected to begin in August 1993. Qinshin 1 was designed by the Shanghai Nuclear Engineering Research and Design Institute.

Number of Operable Reactors:	1
Total Operable Capacity:	300 (net) MWe
Number of Reactors in Construction: . .	4
Total Construction Capacity:	3,000 (net) MWe
1992 Capacity Factor:	19.0%
1992 Nuclear TWh:	0.5 TWh
1992 Nuclear Share:	0.1%

China has four units in the construction pipeline. Guangdong 1 and 2 and Qinshan 2 and 3. The Guangdong units, each rated at 900 MWe, are expected to be in operation in 1993 and 1994, respectively. Qinshin 2 and Qinshin 3 are expected to be on-line in 2005 and 2010, respectively. Both are 600-MWe PWR units. The two-unit Guangdong plant is owned by Guangdong Nuclear Power Joint Venture Company, Ltd., which is a combined Chinese and Hong Kong utility. Guangdong 1 and 2 are 80 and 70 percent complete, respectively. The additional units will relieve some of China's reliance on coal-fired generation. Over half of China's generating capacity is coal-fired.

In December 1992, China announced that it had signed a memorandum of understanding with Russia to buy two VVER-1000 reactors. Final stages of the negotiations are still underway.

China is also building a 600-MWe PWR reactor to sell to Third World countries, which is supposedly cost effective, easy to operate, and contains greater safety provisions than its own reactors. It is being developed in collaboration with Westinghouse.

Japan

Number of Operable Reactors:	44
Total Operable Capacity:	34,238 (net) MWe
Number of Reactors in Construction: . .	23
Total Construction Capacity:	23,938 (net) MWe
1992 Capacity Factor:	72%
1992 Nuclear TWh:	217.0 TWh
1992 Nuclear Share:	27.7%

Nuclear plant siting has become increasingly difficult in Japan; however, in August 1992, a new plant site was

approved, thanks to local fisheries agreeing to a compensation deal for the use of the coastline. Tokyo Electric Power Company and Tohoku Electric Power Company will each build two 1,067-MWe BWR's along the Pacific shoreline just north of Rokkasho, with the first unit to be in service around 2004.

The site, known as Higashidori, can accommodate up to 16 nuclear plants and it is located in Aomori Prefecture at the northern end of Japan's main island, Honshu. The Higashidori-mura local assembly first invited utilities to consider the area for nuclear power in 1965, but the issue of compensation for the local fisheries has always been a major obstacle. On June 1, 1992, Aomori Governor Masya Kitamura proposed a compensation package worth \$145 million to which the Shinakura Fisheries Cooperative Association and the Odanozawa Fisheries Cooperative Association agreed. Because local residents are demanding that an environmental impact assessment be conducted, the start of construction of the Higashidori Complex has been delayed 1 year.

The Electric Power Development Corporation has offered a similar deal to the fisheries near the Ohma site, which is earmarked for a 606-MWe reactor. The planned reactor is a heavy-water moderated BWR, i.e., basically a scaled up version of the 148-MWe Fugen unit located in Tsuruga. The Ohma offer is another example of the serious siting problem facing Japanese utilities that want to build new nuclear plants. Although there are various areas of the country where siting is being evaluated, there is no urgent need for such facilities in those areas.

Currently, Japan has 44 operable nuclear units with a capacity of 34,238 MWe. In addition, the country has 23 units remaining in the construction pipeline. The average capacity factor for 1992 was 72 percent. With the third largest nuclear power program in the world, Japan is looking ahead to doubling the number of its nuclear power reactors by 2010. Japan's primary goal in its overall energy strategy is to reduce the country's dependence on imported energy supplies. To accomplish this goal, the Ministry of International Trade and Industry has emphasized nuclear power. Although many Japanese citizens consider nuclear power a necessity, recent polls have shown that only half consider it to be safe. The Atomic White Paper released by the Atomic Energy Commission of Japan, and then approved by the cabinet in October 1990, set targets for the country's nuclear capacity of 50.5 GWe by 2000 and 72.5 GWe by 2010. Industry and government officials, however, admit that the pace of construction necessary to reach this goal may be difficult to achieve.

In 1992, the Kansai Electric Power Company's Ohi 4 unit, a 1,127-MWe PWR was connected to the grid. Kansai Electric Power Company generates the largest share of nuclear power at 28 percent, outpacing the Tohoku Electric Power Company units at 26 percent. Two units, Chubu Electric's Hamaoka 4, a 1,092-MWe BWR built by Toshiba, and Hokuriku Electric's Shika 1, a 513-MWe BWR built by Hitachi, will likely begin commercial operation in September and July 1993, respectively.

Tokyo Electric Power Company's Kashiwazaki Kariwa 3 and 4 units will start commercial operation in July 1993 and July 1994, respectively. Units 6 and 7, rated at 1,315 MWe each, are the first advanced BWRs; they are expected to begin commercial operation in 1996 and 1997, respectively.

Japan's Atomic Power Company asked Tsuruga City for permission to build two more nuclear power plants in the north central area of the city. Currently, JAPCO operates two units located in Tsuruga City—Tsuruga 1, a 341-MWe BWR, and Tsuruga 2, a 1,115-MWe PWR.

South Korea

Number of Operable Reactors:	9
Total Operable Capacity:	7,220 (net) MWe
Number of Reactors in Construction: . .	7
Total Construction Capacity:	5,721 (net) MWe
1992 Capacity Factor:	84%
1992 Nuclear TWh:	56.5 TWh
1992 Nuclear Share:	43.2%

Despite its relatively small size, South Korea's nuclear program has become one of the fastest growing in the world. Through a series of 5-year economic plans, the country has worked to constantly upgrade its power generation structure in order to sustain the explosive growth it has experienced. As a result, peak electricity demand has grown at an average annual rate of 15 percent during the past 30 years. Because actual growth surpassed projected growth, South Korea is now faced with a shortage of capacity. To meet the rapidly growing demand, the government has once again revised its long-term power development program.

The country's nine operating nuclear reactors, located at four sites, have a total net generating capacity of 7,220 MWe. In 1992, Korea Electric Power Corporation's nine existing reactors provided 43 percent of the nation's electricity.

Korea Electric Power Corporation has seven nuclear units with a total capacity of 5,721 MWe under construction. Yonggwang 3 and 4, each with a capacity of 950 MWe, are expected to begin operation in March 1995 and 1996, respectively. Ulchin 3 and 4 were 18 percent complete at the end of 1992, and are scheduled for operation in 1998 and 1999. Wolsong 2 and 3, with capacities of 663 and 629 MWe, respectively, are expected to begin operation in 1997 and 1998. Korean participation in the construction of these stations is particularly important since South Korea is trying to develop its own in-country nuclear power expertise and manufacturing infrastructure. Technical knowledge from Asea Brown Boveri Combustion Engineering Nuclear Power, a U.S.-based subsidiary of Asea Brown Boveri, Ltd, will thereby be transferred to South Korea's domestic nuclear industry. Although South Korea has committed itself to nuclear power, there is no sign that the country wishes to become an exporter of nuclear plants.

The government's development plans through 2001 include bringing on new generating facilities of all types, with additional capacity totalling 27,520 MWe. The additions will include 25 coal-fired plants (12,440 MWe), 9 nuclear plants (8,100 MWe), 8 liquid natural gas combined-cycle plants (1,960 MWe), and 2 internal combustion facilities (20 MWe).

The nine nuclear units include six 1,000-MWe PWRs, and three 700-MWe PHWRs, planned for construction by 2006. Nine localities have been identified as possible future nuclear power plant sites—most of them near the southern and western coasts.

Some local citizens oppose the government's selection of possible sites. The Three Mile Island and the Chernobyl accidents were heavily reported by the press, creating public uncertainty, especially for citizens in the vicinity of nuclear power plants. To address opposition to nuclear power, Korea Electric Power Corporation is actively engaged in a multifaceted nuclear public awareness program. Korean law mandates that the utility spend an amount equal to 0.3 percent of electricity sales on community programs for areas near its power plants, nuclear and nonnuclear. Under this program, \$4.8 million was distributed among the four nuclear sites in 1991.

Although Korea Electric Power Corporation's construction schedule includes a mix of PWRs and PHWRs, the majority of new reactors will be the new Korean Standard Nuclear series of 1,000-MWe class PWRs. The Korean Standard Nuclear series, the culmination of South Korea's effort to develop its own nuclear power

expertise and manufacturing infrastructure, is based on a modified Asea Brown Boveri Combustion Engineering Nuclear Power System 80 design, and encompasses some aspects of the System 80 plus, as well as other characteristics of advanced light water reactor technology.

Philippines

Number of Operable Reactors:	0
Total Operable Capacity:	0 (net) MWe
Number of Reactors in Construction: . . .	1
Total Construction Capacity:	620 (net) MWe
1992 Capacity Factor:	0%
1992 Nuclear TWh:	0 TWh
1992 Nuclear Share:	0%

The Philippine government is planning to restart the mothballed Philippine Nuclear Power Plant (PNPP-1), a 620-MWe PWR. Located in Morong, Luzon near Manila, PNPP-1 is 98 percent complete and the sole nuclear power plant in the Philippines. The operation of PNPP-1 could help solve the Nation's severe power shortages, brownouts, and shortened workweeks.

Westinghouse was awarded the contract to build the reactor. The contract calls for the U.S. vendor to provide training for the Nuclear Power Corporation, a Philippine government-owned electric utility. The Nuclear Power Corporation requires its operators to have engineering degrees and licenses. To fulfill this requirement the operators spent more than 160 weeks at the Westinghouse training facility.

For years, litigation and other legal challenges prevented the operation of this plant. In 1979, following the Three Mile Island accident, President Ferdinand Marcos halted construction of the unit. Subsequently, an investigation by the government concluded that the plant design was unsafe. In December 1988, the Philippine government filed suit against Westinghouse alleging that the United States bribed Ferdinand Marcos in order to win the contract to build the plant. In March 1992, it appeared that the Philippine government had settled its long-standing lawsuit. Westinghouse agreed to complete the construction of PNPP-1, bringing the unit up to NRC's regulations, and to bring the unit into commercial operation within 3 to 4 years. It has been estimated that it would cost about \$400 million to complete the project, of which Westinghouse would provide up to \$100 million in cash and services over a period of 3 years. The balance would be paid by the Philippines, financed by the Export/Import Bank. However, President Ramos was not satisfied with the

settlement and has reopened negotiations. Therefore, the whole case has gone back to court.

Taiwan

Number of Operable Reactors:	6
Total Operable Capacity:	4,884 (net) MWe
Number of Reactors in Construction: . .	2
Total Construction Capacity:	1,900 (net) MWe
1992 Capacity Factor:	75%
1992 Nuclear TWh:	32.5 TWh
1992 Nuclear Share:	25.7%

With Taiwan's rapid industrialization comes a growing demand for energy. Taiwan's state-owned utility, Taiwan Power Company, plans to add 19,000 MWe of capacity in the coming decade to meet the growing power demand. Taiwan Power estimates that the average increase in electrical load demand in the country will be about 6 percent annually from 1991 through 2001. From 1985 through 1990, peak load increased at an average annual rate of 9 percent; the reserve margin dropped from 55 percent in 1985 to 5 percent in 1991. Power shortages in 1991 caused power curtailments. In 1992 peak load reserve margin dropped to 0.95 percent.

To meet immediate demand, Taiwan Power has moved up the scheduled completion dates of oil, natural gas, and coal-fired plants under construction and in the planning stages. In August 1992, Taiwan's first cogeneration company was established to help relieve some of the electricity shortages on the island. With the addition of combined-cycle, thermal pumped-storage, gas-turbine, and cogeneration units, Taiwan Power plans to lift its reserve margin to 14 percent by 1996.

With limited natural resources, Taiwan must import most of its energy supplies. Imported oil and natural gas account for more than half the country's total energy supply. Taiwan Power plans to rely on fossil-fuels, particularly coal and liquid natural gas, for 15,000 MWe of new generating capacity. The remaining 4,000 MWe will be split between hydroelectric and nuclear power. Due to the increased power demand, the importance of nuclear energy has become more evident than ever, and the need for the country's seventh and eighth units has been great enough to overcome political opposition.

In 1982, after Taiwan Power had designated Combustion Engineering as the preferred supplier for its seventh and eighth reactors at the fourth nuclear site, Yenliao, but the project was suspended in May 1986, as

directed by the government's Executive Yuan. Reasons for the suspension included public concern over waste disposal and safety of nuclear power, government concern about the need for the plant given the current electricity demand level, the high reserve margin, and a slowdown in load demand growth.

Public fears about nuclear safety were largely in response to the Three Mile Island and the Chernobyl accidents, and the fire at Taiwan's own Maanshan 1 in July 1985. Taiwan Power, however, has been increasing its public awareness programs by using two approaches. The first approach is its "sunshine law," where plant information is released to the public. The second approach is a statutory program which, for every kilowatt-hour generated from nuclear units, Taiwan Power donates a percentage of its profits to the local government.

Currently Taiwan Power operates six nuclear units at three stations with a total net capacity of 4,884 MWe. Kuosheng and Chinshan stations in northern Taiwan each contain two BWR units, and the Maanshan station on the southern tip of the country contains two PWRs. The country's nuclear plants generated 32.5 TWh in 1992 with an average capacity factor of 75 percent. The power generated by the six reactors contributed 25.7 percent of Taiwan's total electricity in 1992.

On June 3, 1992, the Taiwan legislature's budget committee approved the construction of Taiwan's fourth nuclear power plant. Taiwan Power officials hope to have unit 7 in operation by 2000 and unit 8 the following year, at an estimated total cost of about \$7 billion.

Other

Argentina

Number of Operable Reactors:	2
Total Operable Capacity:	935 (net) MWe
Number of Reactors in Construction: . .	1
Total Construction Capacity:	692 (net) MWe
1992 Capacity Factor:	78%
1992 Nuclear TWh:	6.6 TWh
1992 Nuclear Share:	14.4%

Argentina's two commercial operating reactors, Embalse, a 600-MWe PHWR, and Atucha 1, a 335-MWe PHWR, generated a combined 6.6 TWh of electricity in 1992, with an average capacity factor of 78 percent. Comision Nacional de Energia Atomica, the country's national utility, owns and operates the two reactors.

The utility also heads the construction of Atucha 2, currently 80 percent complete and projected to go on-line in 1996. Initially, the unit was scheduled for completion in 1987, but was delayed due to the country's large foreign debt and hyperinflation. In 1992, the Argentine government granted an estimated \$19 million for work on the unit.

The government's commitment was reinforced last May when Argentine Economy Minister announced that it would even consider selling Atucha 1 and Embalse to private investors to raise the estimated \$1 billion needed to complete Atucha 2. State-owned industries in Argentina are currently being privatized, and a government decree allowing parts of the Comision to be transformed into a private company is expected in 1993. Acting under the assumption that its privatization is inevitable, Comision Nacional de Energia Atomica is concentrating on restructuring its activities to form the most appropriate successor companies.

Current plans are to split the utility's activities five ways. Three sectors—technological services, radio-isotopes, and fuel cycle activities—will form private companies. The fourth sector—operation of the power plants—will be opened for international bids. The winning company will operate the Embalse and Atucha 1 plants during their lifetimes, and will be responsible for the completion and operation of Atucha 2. The plant will remain the property of the Comision Nacional de Energia Atomica, which is expected to be responsible for its decommissioning. The fifth sector includes promotion and regulation of the nuclear industry and will remain in the public sector.

Brazil

Number of Operable Reactors:	1
Total Operable Capacity:	626 (net) MWe
Number of Reactors in Construction: . .	2
Total Construction Capacity:	2,458 (net) MWe
1992 Capacity Factor:	28%
1992 Nuclear TWh:	1.8 TWh
1992 Nuclear Share:	0.7%

In 1975 the Brazilian government signed an agreement with Germany for construction of 8 Siemens units by 1990. Angra 2 and 3 are the first two of four 1,229-MWe class PWR's which Brazil agreed to build using Siemens equipment and technology, with an option for four more units. Angra 1, a turnkey 626-MWe unit by Westinghouse, and Brazil's only operable nuclear unit, was connected to the Brazilian grid in 1982. The unit

provides the metropolitan area of Rio de Janeiro with about 20 percent of its electrical energy.

Brazilian utility Furnas Centrais Electricas SA, which operates Angra 1, projects that Angra 2 will have an annual output of 8.5 million megawatt-hours and will account for approximately 40 percent of all the electricity consumed by Rio de Janeiro. The output has been earmarked for Brazil's industrialized southeast where sites for hydroelectric plants are all but exhausted.

Although work began on Angra 2 and 3 in 1977, construction has been sporadic. Due primarily to financial difficulties, the government decided to concentrate its efforts on completing Angra 2, but work on that unit virtually stopped after 1988 when ownership of the plant transferred from Nuclebras to the utility Furnas. Currently, the Angra 2 unit is 65 percent complete whereas construction on Angra 3 has been deferred indefinitely.

In July 1992, Brazilian Minister of Mines and Energy Marcus Vinicius Pratini de Moraes, Germany's economic minister for development projects, and the Dresdener Bank negotiated a new finance package, making it possible to complete Angra 2 by 1997. Approximately \$1.5 billion will be needed to finish the plant. Germany will provide a total of \$860 million, and Brazil \$640 million over the next 5 years. Originally, \$580 million was allocated for both Angra 2 and 3. The timing of the agreement coincides with the Brazilian government's reaching a long-term solution to its massive debt with private foreign banks. The Brazilian government is spending \$100 million a year just to maintain equipment for the plant.

The restart of work on Angra 2, however, does not signal that Brazil is opting for nuclear energy. When Angra 2 is completed, nuclear power will only account for 1 percent of Brazil's energy needs. Currently, Brazil's policy objective calls for using natural gas to meet the country's electricity demand.

The impeachment of Brazil's president Fernando Collor de Melo in November 1992 could further delay the completion of the Angra 2 unit. Acting President Itamar Franco's first move was to appoint Eliseu Resende head of the state electricity company, Eletronbras. Resende was previously head of Furnas, the subsidiary that operates Angra 1. Franco has also changed the responsibilities of the Comision Nacional de Energia Atomica. The Comision will continue to have responsibility to draw up nuclear policies but will lose control of the organizations carrying out those policies.

Cuba

Number of Operable Reactors:	0
Total Operable Capacity:	0 (net) MWe
Number of Reactors in Construction: . . .	2
Total Construction Capacity:	834 (net) MWe
1992 Capacity Factor:	0%
1992 Nuclear TWh:	0 TWh
1992 Nuclear Share:	0%

While COMECON was still in operation, Cuba planned to build four commercial nuclear reactors at the Juragua site. There are two Russian designed VVER-440 units under construction at this site, Juragua 1 and 2, each 417 (net) MWe. They are late design reactors based on the VVER-213, but with extra safety systems including a containment vessel, additional emergency core cooling systems, and other Western-style features.

Cuban President Fidel Castro announced in September 1992 that the country would suspend construction on the Juragua nuclear power station. The terms and conditions that the Russian authorities had proposed—payment in hard currency rather than the original bartering system—were no longer possible.

As late as October 1991, Cuban officials had hoped to startup Juragua 1 by the end of 1993. At that time, Castro's son headed the project, but was fired by the elder Castro in June 1992 for inefficient management. The plant was set to replace 20 percent of Cuba's 1987 oil consumption, which has since fallen by at least half. Currently, the island suffers frequent and widespread power blackouts.

Although civil engineering construction work on the Juragua 1 is reportedly between 80 and 90 percent complete, installation of expensive technical parts and equipment is less than 50 percent complete. The country has spent more than \$1 billion on the project over the past 10 years, and the Russians are seeking another \$200 million.

Even though the project has come to a halt, the two countries are seeking help from a third country—most likely France—in an effort to complete the station. Without additional electrical capacity, the prospect of economic growth remains dim. The country possesses no oil, gas, coal or hydroelectric resources.

India

Number of Operable Reactors:	9
Total Operable Capacity:	1,834 (net) MWe
Number of Reactors in Construction: . .	8
Total Construction Capacity:	2,260 (net) MWe
1992 Capacity Factor:	40%
1992 Nuclear TWh:	5.6 TWh
1992 Nuclear Share:	3.3%

Prior to the 1974 explosion of what India termed a "peaceful" nuclear device, the Atomic Energy of Canada Ltd. (AECL) had been assisting the Indian government in building the Rajasthan nuclear station. However, after the nuclear explosion, Canada stopped all assistance to India, canceling the supply of equipment for the nuclear units. Eventually, India either procured most of the fuel and equipment from European suppliers or fabricated parts domestically. Today, most of the country's nuclear program is not covered by any international safeguard agreement, which in turn has hindered the country's nuclear program development.

Two nuclear units were connected to the grid in 1992, Narora 2 and Kakrapar 1, giving India a total of nine operable nuclear units. The nuclear plants in the country's current 5-year plan (1992 through 1997) are Tarapur 3 and 4 in western Maharashtra State, each 470 MWe; Kaiga 3, 4, 5, and 6 in Southern Karnataka State, each 220 MWe; Rajasthan 5 and 6 at Rawatbhata in western Rajasthan State, each 500 MWe, and Kudankulam 1 and 2 in Tamil Nadu State, each 500 MWe. India's initial 5-year plan called for 12 nuclear units. In 1991, the government agreed to finance four units. The projects have been granted the necessary environmental, technological, and safety approvals.

Work on four 220-MWe PHWR units continues. The government would like to see nuclear energy developed faster, but it is unable to provide more funds. International financing institutions like the World Bank do not invest in nuclear energy.

The Kudankulam nuclear power plant, which is to be located in Tamil Nadu on India's southeast coast, was once to be financed by the Soviet Union, but will now be financed by five southern Indian States. The States will fund one-sixth of the cost and get matching contributions from the federal government.

Originally, the Soviet Union was to supply two VVER-1000 units; the replacement units are expected to be 500-MWe Indian-designed PHWRs and to cost about \$1.5 billion. The new type of financing will help the Nuclear Power Corporation (NPC), which has been finding it tough to raise resources to implement its plans in the wake of government funding cutbacks. The Nuclear Power Corporation is suggesting the same kind of funding to the western Indian states of Gujarat and Maharashtra for the 1000-MWe project to be built on the site of the Tarapur nuclear station.

Like other countries, India is considering extending the life of its older plants by 20 years. Preliminary results indicate that the additional 20 years of plant operation are both economically and technically feasible.

Mexico

Number of Operable Reactors:	1
Total Operable Capacity:	654 (net) MWe
Number of Reactors in Construction: . . .	1
Total Construction Capacity:	654 (net) MWe
1992 Capacity Factor:	66%
1992 Nuclear TWh:	3.9 TWh
1992 Nuclear Share:	3.2%

Mexico's expanding population exceeds 80 million, and energy demand is growing rapidly. In the 1980s, electricity demand grew at an average annual rate of 6 percent; it is currently expected to exceed 7 percent per year during the 1990s. In response, the country's national utility, Comision Federal de Electricidad, is pursuing a number of options to meet rising demand. Currently, Mexico relies on oil to meet over 50 percent of its electrical energy needs. Hydroelectricity accounts for over 25 percent of the total electrical share.

Mexico possesses vast natural resources, including large reserves of oil and natural gas. Mexico also has large coal reserves, although most are of low quality. Therefore, the country imports coal for its coal-fired stations, which represent about 4.5 percent of total installed generating capacity.

In 1956, Mexico established its National Comision for Nuclear Energy and in 1972 selected General Electric to supply a 654-MWe BWR at Laguna Verde, approximately 70 kilometers north of the city of Veracruz on the Gulf of Mexico. The Comision, which became the Institute for Nuclear Energy in 1991, handles all nuclear research and development. The National Nuclear Safety and Safeguards Comision oversees nuclear regulatory functions and the country's non-proliferation efforts.

Mexico's national energy plan had once called for installing 20,000 MWe of nuclear capacity by 2000, but low oil prices in the 1980s and the country's resulting economic crisis led to the cancellation of all but one station. In April 1989, Laguna Verde 1 was connected to the Mexican grid and is currently the country's sole operable commercial nuclear unit. Financing for the construction of the unit was provided by international sources, in the form of loans warranted by the Export/Import Bank. Construction was delayed by a combination of political, regulatory, and economic factors. Since going commercial, the unit has performed well, achieving a capacity factor of 66.1 percent in 1992.

Laguna Verde 2, ordered in 1977, faces the same challenges that unit 1 faced. In 1981, budget cuts halted construction, which was resumed in 1984. Several problems occurred in the later stages of construction, including the need to replace obsolete parts for electrical and mechanical equipment, and the lack of money to acquire components. Comision Federal de Electricidad remains committed to completing the units and recently has increased its rate of progress towards the goal. The unit is now 82 percent complete; the present schedule anticipates fuel loading in December 1993 and commercial operation in December 1994.

Currently nuclear power accounts for 3.2 percent of the total electricity produced. This total is expected to reach 5 percent once Laguna Verde 2 becomes operable.

Pakistan

Number of Operable Reactors:	1
Total Operable Capacity:	125 (net) MWe
Number of Reactors in Construction: . . .	1
Total Construction Capacity:	300 (net) MWe
1992 Capacity Factor:	46%
1992 Nuclear TWh:	0.5 TWh
1992 Nuclear Share:	1.2%

In 1974, Canada stopped all nuclear assistance to Pakistan, due to the latter country's nuclear weapons-related work and the Pakistani government's refusal to sign the Non-Proliferation Treaty. Because of the government's refusal, Pakistan was then forced to build its nuclear program without Western assistance. Today the country operates only one commercial reactor, the Kanupp unit, a 125-MWe CANDU PHWR. Kanupp was connected to the grid in 1971 and is the only nuclear plant in the Muslim world that has successfully functioned without outside aid.

Currently, Pakistan is facing chronic power shortages. The country's total generation capacity amounts to about 6.5 GWe; anticipated demand exceeds 8.5 GWe and could reach 12.5 GWe by the end of the decade. The government's aim is to fulfill half of its electricity deficit with nuclear power.

In 1992, the Kanupp unit reached 20 years of commercial use and is scheduled to be retired in 2002. Also in 1992, the Pakistan Atomic Energy Commission, the plant's operator, negotiated a contract with Atomic Energy of Canada Ltd., Ontario Hydro, New Brunswick Power, and Babcock and Wilcox of Canada, for the development of a safety analysis report aimed at an eventual overhaul of the dated reactor. Since Canada had refused to assist in any further construction or maintenance of Kanupp, no upgrade work had been done. The project, named Safe Operation of Kanupp, is an investigation of upgrades intended to ensure safety at the plant and to extend its life by 10 years to 2012. The program is expected to cost around \$25 million over a 6-year period. Some funds will be released by the finance ministry for the 1992-1993 program of work, and followup funding will be supplied each year from the Annual Development Program. The first stages of the program covered analysis and planning in three main areas of work: obsolescence, aging, and safety.

A team of Pakistan and Chinese engineers have nearly completed the basic design of Pakistan's Chasnupp nuclear plant. The 30-member team of experts from the Pakistan Atomic Energy Commission is in China working with the Shanghai Nuclear Research and Development Institute. Although modeled after China's only nuclear unit Qinshan 1, the Chasnupp plant will have many improvements over the original design. In June 1992, Pakistan's national assembly approved a downpayment to China National Nuclear Corp, the

builder of the plant. Some doubt has been cast on the Pakistan-Chinese deal, since the suppliers of the Qinshan 1 key components will not sell the same components for use in Pakistan. China, however, believes that it will be able to supply the plant with components from other sources.

South Africa

Number of Operable Reactors:	2
Total Operable Capacity:	1,840 (net) MWe
Number of Reactors in Construction: . .	0
Total Construction Capacity:	0 (net) MWe
1992 Capacity Factor:	58%
1992 Nuclear TWh:	9.3 TWh
1992 Nuclear Share:	6.0%

In 1976, South Africa ordered its first commercial nuclear power plant near Capetown. The Koeberg 1 and 2 units, provided by the French vendor Framatome, went into operation in 1983 and 1985, respectively, giving South Africa 1.8 GWe of nuclear capacity. In 1992, the Koeberg station produced 9.3 TWh of electricity and had an average capacity factor of 58 percent. The units accounted for approximately 6 percent of South Africa's total electricity generation.

The station, owned and operated by the national utility, Electricity Supply Commission of South Africa, accounts for about 5 percent of the country's installed generating capacity and about 10 percent of the electricity generated in Capetown. It is not likely that any new nuclear units will be built in the near future since coal-fired stations burning low-grade coal have lower generation costs than the Koeberg 1 and 2 nuclear units.

5. Nuclear Power Capacity Factors

The system-wide average capacity factor achieved by U.S. domestic nuclear power plants reached an all-time high of 70.9 percent in 1992 (Figure 16), an increase of 0.7 percentage points over the previous record of 70.2 percent set in 1991. Current capacity factor levels are in sharp contrast to those in the 8 years following the 1979 accident at Three Mile Island unit 2 reactor, when the average annual capacity factor stayed in the mid-to upper 50 percent range. In 1988, the average annual capacity factor rose to 63.5 percent, followed by the further increase to the current level.

Figure 16. U.S. Nuclear Power Plant Average Capacity Factor, 1975-1992

Source: Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035 (93/106).

Some interesting trends are revealed by examining the 18-month moving average³⁰ for the overall capacity factor, the duty-cycle capacity factor, and the percent of capacity on line (Figure 17). After the Three Mile Island accident, an upward turn in capacity factors is first observable in 1987. The percent of capacity on-line was very high before the accident (92.8 percent in 1975), dropped immediately afterwards, stayed fairly constant throughout the 1980's, and started rising around 1990. The duty-cycle capacity factor, on the other hand, shows a slow but steady increase over most of the period.

The general improvement in capacity factors is attributable to a number of causes:

- Utilities have adapted to the increased safety and regulatory requirements imposed by the NRC after the Three Mile Island accident.
- Utilities and vendors have remedied a number of equipment and component failure problems that plagued reactor operations.
- Utilities have made substantial progress in outage management and quality control.
- There have been significant improvements in the approaches adopted by utility management with regard to nuclear power plant operations.

For further discussion of the items listed above, the reader is referred to a recent EIA analysis, *Improvements in Nuclear Power Plant Capacity Factors*, which appeared in the February 1993 edition of EIA's *Electric Power Monthly* (DOE/EIA-0226(93/02) (February 1993). That article takes an in-depth look at the factors that caused the poor performance of nuclear power plants in the 1980's and reviews industry programs that contributed to the recent performance improvements. The article also presents a statistical analysis of domestic capacity factors through 1991, which this chapter updates with data through 1992.

³⁰An 18-month moving average was chosen to smooth the influence of refueling outages on monthly capacity factors. The majority of U.S. reactors moved to 18-month cycles in the early to mid-1980's.

Figure 17. 18-Month Moving Average Data for Overall Capacity Factor, Duty Cycle Factor and Percent of On-Line Capacity, 1976-1992

Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (Nureg-0020).

Annual capacity factors and monthly updates are based on data reported in Energy Information Administration's *Monthly Energy Review*, DOE/EIA-0035. Additional historical data were obtained from the U.S. Nuclear Regulatory Commission (NRC), *Licensed Operating Reactors Status Summary Report* (NUREG-0020), which contains historical data on outage times, electricity generation, and other detailed information for individual reactors.

Outage Rates

The outage rate of a nuclear plant is the percent of time the unit is not generating electricity. From 1980 through 1987, nuclear units had an average outage rate of about 35 percent, with a high of 37 percent in 1984 (Figure 18). During these years, nuclear units had an average

refueling outage rate of 24 percent and an average duty-cycle outage rate of 11 percent. Overall outage rates began to decline in 1988 and continued down to about 25 percent in 1992, with a refueling outage rate of 18 percent and a duty-cycle outage rate of 7 percent. Average outage rates reached a high of 46 percent in 1984 for BWRs and 37 percent in 1982 for PWRs. In 1992, average outage rates for BWRs and PWRs were 34 and 22 percent, respectively. Since 1980, the BWR outage rate has exceeded the PWR outage rate, with the largest difference attributable to the refueling outage rate.

From 1980 through 1987, on average about 11 percent of the installed U.S. nuclear capacity was out of service for extended periods of more than 6 months (Figure 19). Extended outages were caused by: administrative decisions, such as those made by Tennessee Valley

Figure 18. Annual Outage Rates, 1975-1992

Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (Nureg-0020).

Authority's Browns Ferry units; regulatory actions imposed by the NRC (as was the case with Philadelphia Electric's Peach Bottom units); and equipment problems and failures like those caused by PWR steam generator replacements and BWR torus modifications. The percent of capacity out of service because of extended outages has declined steadily since 1988, dropping to about 4 percent in 1992.³¹ This large reduction in extended outages has had a positive impact on capacity factors.

Utilities have made considerable progress in both overall outage management and the reduction of extended outage periods. Reasons for these improvements include better planning and scheduling of refueling and maintenance activities through procedures such as critical path scheduling; more reliable equipment; improvements in diagnostic procedures and problem identification; and the transition to longer fuel cycles.

³¹The Browns Ferry 1 and 3 units, which have been out of service since 1985, were responsible for half of these extended outages in 1992.

Figure 19. Percent of Capacity with Outages Greater than Six Months, 1975-1992

Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (Nureg-0020).

The spate of major component problems that troubled reactors in the early 1980's has diminished considerably, with the exception of the PWR steam generator problem. This is a major concern, however, and it is expected that all PWRs will require steam generator replacements if they are to operate for their planned lifetimes. Steam generator replacements are costly and time-consuming propositions, and each utility will have to assess the economics of steam generator replacement case by case. As noted previously, the need for a steam generator replacement was one of the factors contributing to the early retirement of Portland General's Trojan unit.

Reactors were off-line for an average of 336 days for the first seven PWR steam generator replacements (Table 24). However, with the application of lessons learned from past experience and improved project planning, the trend in steam generator replacement time appears

Table 24. U.S. Reactors That Had Steam Generator Replacement

Unit	Length of Refueling Outage	Utility	No. of Steam Generators	Month Operable	Size	Replacement Date	Total Cost (Million Dollars)
Surry 2	562	Virginia Electric & Power Co.	3	5/72	781	1979	94
Surry 1	298	Virginia Electric & Power Co.	3	1/73	781	1981	94
Turkey Point 3	406	Florida Power & Light	3	7/72	666	1982	90
Turkey Point 4	219	Florida Power & Light	3	4/73	666	1982	90
Point Beach 1	191	Wisconsin Electric Power Co.	2	10/70	495	1984	77
H.B. Robinson 2	350	Carolina Power & Light Co.	3	9/70	683	1984	85
D.C. Cook 2	328	Indiana & Michigan Power Co.	4	12/77	1060	1988	112
Indian Point 3	140	Power Authority of the State of New York	4	4/76	980	1989	120
Palisades	181	Consumers Power	3	10/72	755	1990	100
Millstone 2 ^a	298	Northeast Nuclear Energy Co.	3	9/75	863	1992	200
North Anna 1	96	Virginia Electric & Power Co.	3	4/78	911	1993	130

^aTotal cost and length of refueling outage was obtained from the utility.

Source: Electric Power Research Institute "Steam Generator Progress Report," September 1991, and Nucleonics Week (various issues).

to be headed downward. The Indian Point 3 steam generator replacement in 1989 set a U.S. record at that time of 140 days, and the recently completed North Anna 1 steam generator replacement set both a U.S. and world record of 96 days. If the lessons learned from the North Anna steam generator replacement can be transferred to other plants, it would be of major significance to the nuclear industry, as about two-thirds of the operating U.S. reactors are PWRs. The 96-day replacement time was only about a month longer than a normally scheduled refueling outage.

Ironically, there is a positive side to steam generator replacement. As a reactor's steam generator deteriorates, the utility is forced to plug a number of the steam generator tubes, and eventually must operate at reduced levels to comply with safety regulations. Estimates of power derating for plants with ailing steam generators are between 5 and 10 percent. When its steam generator has been replaced, a plant can be operated at its full rated capacity, absent other problems.

Individual Reactor Performance

The best performing unit in 1992 was Three Mile Island 1, with a capacity factor of 100.5³² percent (Table 25), representing a significant turnaround for a plant whose sister unit experienced the worst nuclear accident in

U.S. history. Three Mile Island 1 was shut down for an extended period (approximately 6 years) after the Three Mile Island 2 accident and operated poorly on its first cycle after it reentered service. The second best performer in 1992 was Davis-Besse 1, with a capacity factor of 99.3 percent. The Three Mile Island 1 and Davis-Besse units are similar in that both are Babcock & Wilcox reactors, which were shutdown by the NRC for safety improvements resulting from the Three Mile Island 2 accident, or had operated poorly for a number of years after the accident. In general, all seven of the currently operating Babcock & Wilcox reactors seem to have recovered from their problems and are operating at relatively high levels.

Rounding out the top five best performers for 1992 are St. Lucie 1, Diablo Canyon 2, and Vogtle 1, with capacity factors for the year of just under 97 percent. These three units have all operated well over their lifetimes.

Of the reactors that have completed at least three cycles by the end of 1992, those with the best lifetime capacity factors are Point Beach 2, Prairie Island 1 and 2, Kewaunee, and St. Lucie 2, with capacity factors between 83 and 85 percent (Table 25). The first four of these are all Westinghouse two-loop reactors. The two remaining Westinghouse two-loop reactors, Point Beach 1 and Ginna have lifetime capacity factors of around 77

³²The capacity factor is computed using an estimated reactor capacity. Occasionally reactors operate beyond their estimated capacity.

Table 25. Nuclear-Generating Units Achieving the Best Performance Records as of 1992

Ranking Unit	Operating Utility	Reactor Type	Year of Initial Operation ^a	Average Capacity Factor (percent)
Highest Lifetime Capacity Factors				
1 Point Beach 2	Wisconsin Electric Power Co.	PWR	1973	85.1
2. Prairie Island 2	Northern States Power Co.	PWR	1974	85.0
3. Prairie Island 1	Northern States Power Co.	PWR	1974	84.3
4. Kewaunee	Wisconsin Public Service Corp.	PWR	1973	83.2
5. St. Lucie 2	Florida Power & Light Co.	PWR	1983	82.7
6. Callaway 1	Union Electric Co.	PWR	1984	82.4
7. Farley 2	Alabama Power Co.	PWR	1981	81.6
8. Vogtle 1	Georgia Power Co.	PWR	1987	80.6
9. Hope Creek	Public Service Electric & Gas Co.	BWR	1986	80.2
10. Diablo Canyon 2	Pacific Gas & Electric Co.	PWR	1985	79.6
Lowest Lifetime Forced Outage Rates^b				
1. Point Beach 2	Wisconsin Electric Power Co.	PWR	1973	0.7
2. Monticello	Northern States Power Co.	BWR	1971	1.4
3. Point Beach 1	Wisconsin Electric Power Co.	PWR	1970	1.6
4. Kewaunee	Wisconsin Public Service Corp.	PWR	1973	1.9
5. Byron 1	Commonwealth Edison Co.	PWR	1985	2.1
6. Haddam Neck	Connecticut Yankee Atomic Power Co.	PWR	1967	2.2
7. Diablo Canyon 1	Pacific Gas & Electric Co.	PWR	1984	2.3
8. Callaway 1	Union Electric Co.	PWR	1984	2.4
9. Byron 2	Commonwealth Edison Co.	PWR	1987	2.4
10. Prairie Island 2	Northern States Power	PWR	1974	2.6
Highest Capacity Factors for 1992				
1 3 Mile Island 1	GPU Nuclear Corp.	PWR	1974	100.5
2. Davis-Besse 1	Toledo Edison Co.	PWR	1977	99.3
3. St. Lucie 1	Florida Power & Light Co.	PWR	1976	96.9
4. Diablo Canyon 2	Pacific Gas & Electric Co.	PWR	1985	96.9
5. Vogtle 1	Georgia Power Co.	PWR	1987	96.7
6. Summer 1	South Carolina Electric & Gas Co.	PWR	1982	96.7
7. Hatch 1	Georgia Power Co.	BWR	1974	94.6
8. Monticello	Northern States Power Co.	BWR	1971	94.6
9. Indian Point 2	Consolidated Edison Co.	PWR	1973	94.3
10. Palo Verde 2	Arizona Public Service Co.	PWR	1986	94.2

^aYear of Initial Operation is the date the unit received its full-power license

^bRepresents only unscheduled downtime (excludes refueling and scheduled maintenance)

BWR = boiling-water reactor.

PWR = pressurized-water reactor.

Note: Only reactors that had operated for at least three complete fuel cycles by December 31, 1992, are listed.

Source: Nuclear Regulatory Commission, Licensed Operating Reactors: Status Summary Report NUREG-0020 (Washington, DC).

percent. The units with the lowest lifetime forced outage rate (Table 25) are Point Beach 2, Monticello, Point Beach 1, Kewaunee, and Byron 1. There is, of course, a strong relationship between low forced outage rates and good performance.

Trends in Reactor Performance

This section looks at trends in reactor performance by analyzing changes in capacity factors for 3-year intervals from 1981 through 1992. Three-year intervals are used to reduce yearly variations in capacity factors resulting from cycles greater than 12 months. The analysis is based on individual plant capacity factors.

To be included in the statistics for a 3-year period, the plant must have been in operation past the first cycle for the entire period. Data for the first cycle were not included, since those capacity factors are typically lower than subsequent cycles.

A cumulative distribution plot of capacity factors over the four intervals (1981 through 1983, 1984 through 1986, 1987 through 1989, 1990 through 1992) shows a clear and consistent trend in nuclear power plant performance (Figure 20). Fewer reactors have capacity factors of less than 60 percent. The median capacity factor from 1981 through 1983 was about 60 percent, while the median capacity factor from 1990 through 1992 was about 75 percent, a significant increase. About one-half of the reactors operated below 60 percent from 1981 through 1983, while only about 20 percent of the reactors did so from 1990 through 1992. Of particular interest is the number of reactors operating above the

80 percent level. From 1981 through 1983, only about 10 percent of the reactors operated above the 80 percent level, while from 1990 through 1992 almost one-third of them did (Figure 21).

Comparison of Newer and Older Units in 1990 through 1992

Newer units are defined as those that were less than 12 years old as of December 31, 1992, and older units are defined as those that were more than 12 years old. Thirty-nine of the 47 newer U.S. units were used in this analysis; the other 8 had not completed a full 3 years of operation past their first cycle by the end of 1992.

From 1990 through 1992, the 39 newer reactors performed better as a group than the 61 older reactors,

Figure 20. Cumulative Percent of Nuclear Units at Different Capacity Factor Levels by 3-Year Intervals, 1981-1992

Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (Nureg-0020).

Figure 21. Percent of Nuclear Units at Different Capacity Factor Levels, by 3-Year Intervals, 1981-1992

Note: Number in parentheses indicates the number of reactors.

Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (Nureg-0020).

with an average capacity factor of 74.8 percent versus 65.0 percent for the older reactors (Table 26) and a median capacity factor of 76.6 percent versus 69.4 percent. It appears that plants entering service after 1981 benefit from the experience of older units. In addition, many newer plants completed the regulatory-mandated safety requirements and incorporated the latest equipment upgrades prior to their start of operation, hence avoiding lengthy outages for plant and component modifications.

Performance by Age, Size, and Reactor Type

For this analysis, large units are defined as those with capacities greater than 1,000 megawatts electric (MWe);

mid-sized units are greater than 700 MWe and not more than 1,000 MWe; and small units are 700 MWe or less. When the nuclear units used in this analysis are further grouped by age, size, and type (BWR and PWR), some interesting observations can be made.

The performance of the new reactors was uniformly high with respect to certain age groups and size. Average capacity factors ranged from 72.3 to 75.7 percent for different age groupings (Table 26) and from 73.9 to 75.0 for different size groupings (Figure 22). However, there was significant variation in the performance of individual new reactors, with capacity factors ranging from 50 to 90 percent. Seven of the 39 newer units had capacity factors under 65 percent, while 14 of the 39 newer units had capacity factors exceeding 80 percent (Table 26).

Table 26. Number and Percent of Nuclear Units at Different Capacity Factor Levels by Age Group, 1990 to 1992

Age Group (Years)	Capacity Factor Levels				Total	Average Capacity Factor
	≤ 50	> 50 and ≤ 65	> 65 and ≤ 80	> 80		
> 3 and ≤ 6	0 (0)	2 (22)	6 (67)	1 (11)	9 (100)	72.3
> 6 and ≤ 9	0 (0)	3 (14)	10 (45)	9 (41)	22 (100)	75.7
> 9 and ≤ 12	0 (0)	2 (25)	2 (25)	4 (50)	8 (100)	75.2
Total New Units	0 (0)	7 (18)	18 (46)	14 (36)	39 (100)	74.8
> 12 and ≤ 15	0 (0)	1 (17)	1 (17)	4 (67)	6 (100)	74.8
> 15 and ≤ 18	5 (29)	4 (24)	7 (41)	1 (6)	17 (100)	56.9
> 18 and ≤ 21	4 (15)	4 (15)	7 (27)	11 (38)	26 (100)	68.0
> 21	1 (8)	4 (33)	4 (33)	3 (25)	12 (100)	66.1
Total Old Units	10 (16)	13 (21)	19 (31)	19 (31)	61 (100)	65.0

Note: Number in parentheses indicates the percent of reactors for the age group.

Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (NUREG-0020).

Older units had much greater diversity in individual performance than the newer units, with some of the best and worst performing reactors in this group. As noted above, the best performing reactors overall were the old Westinghouse two-loop reactors, with an average capacity factor of approximately 86 percent from 1990 through 1992. These units, all of which have a net capacity rating of about 500 MWe and are between 18 and 22 years old, have consistently been the top performers throughout their operating lives. The six units in the 12 to 15 year age group achieved an average capacity factor of 74.8 percent, while the 17 units in the 15 to 18 year age group had an average capacity factor of only 56.9 percent. The 38 units older than 18 years had an average capacity factor of about 67 percent (Table 26).

The 21 small and 32 mid-sized older units had an average capacity factor of about 69.4 percent, while the 10 large older reactors achieved a capacity factor of only 45.4 percent (Figure 23). The poor performance of the large old units, especially compared to the good performance of the large new units, attests to the technical and engineering difficulties that were encountered when reactor capacities were first increased to take advantage of economies of scale.

There was also a significant difference between BWR and PWR capacity factors (55.7 and 70.4 percent, respectively.) The three large Browns Ferry BWR units were a major, though not the only, factor in the low capacity factors of both the large and BWR groups. Two of these units have been out of service since 1985. The second unit was recently returned to service but had a capacity factor of only 43 percent from 1990 through 1992.

Changes in Performance of Older Units

When looking at capacity factors over three-year intervals from 1981 through 1992 for older units, both small and mid-sized units show improvements (Figure 24). Small units had an average capacity factor of 63.1 percent from 1981 through 1983, compared with 71.8 percent for 1990 through 1992. Mid-sized units showed a significant improvement in performance, with average capacity factors of 55.9 percent for 1981 through 1983 increasing to 70.3 percent for 1990 through 1992. From 1981 through 1983, only 27 percent of the mid-sized reactors achieved capacity factors above 65 percent, while from 1990 through 1992, 69 percent did. Large units performed relatively poorly over the entire period, with an average capacity factor of 58.5 percent

Figure 22. Percent of Nuclear Units, 12 Years Old or Less, at Different Capacity Factor Levels in 1990-1992, by Size

Note: Number in parentheses indicates the number of reactors. MWe, Megawatts-electric.

Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (Nureg-0020).

from 1981 through 1983 compared to an average capacity factor of 45.4 for 1990 through 1992. Some improvement in this group can be expected in the future, with the return of Browns Ferry 2 to service.

Reactors Not Included in the Above Statistics

There were eight nuclear units not included in this analysis because they had not completed their first cycle prior to 1990. These units, as a whole, had an average capacity factor of 68.7 percent over their cumulative lives—including the first cycle, which is generally lower than subsequent cycles. All these units are large reactors (greater than 1,000 MWe) and

consequently will have a significant influence on future capacity factors.

Comparison with Foreign Reactors

From 1988 through 1992 average U.S. annual capacity factors were approximately equal to the worldwide average annual capacity factors (Table 27). However, U.S. capacity factors trailed the average capacity factors from 1980 through 1987. During this period, U.S. capacity factors averaged about 55 percent versus about 63 percent for all countries (including the United States).

A number of reasons and speculations have been proposed as to why U.S. capacity factors lagged behind

Figure 23. Percent of Nuclear Units Over 12 Years Old at Different Capacity Factors Levels in 1990-1992, by Size

Note: Number in parentheses indicates the number of reactors. MWe, Megawatts-electric.

Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (Nureg-0020).

those of most major free-market countries in the early to mid-1980's. The main factors that have been identified are a lack of standardization in U.S. plant design; poor management of some domestic utilities; a stricter domestic regulatory program; and an excess of domestic electricity generating capacity.

Since 1984, Finnish reactors have turned in the best per-country performance, with capacity factors averaging about 90 percent. Swiss reactors have historically been consistently good performers with capacity factors at the middle 80 percent level, and the recent performance of Belgium's reactors has been at the same level. Swedish and German reactors have capacity factors in the middle 70 percent range. Spanish reactors had poor performance records in the early 1980's, but have

operated at about 80 percent since 1987. British reactors have operated with capacity factors lower than 60 percent.

Average annual capacity factors for French reactors are in the lower 60 percent range for 1980 through 1992. France, which has the largest nuclear program of any country outside the United States, has a surplus of nuclear capacity at present, and some of its reactors are not being fully utilized. Many of the reactors were operated in a load following mode. France is currently embarking on a program to export electricity to other European countries, and this should have a positive impact on capacity factors as idle capacity is returned to service.

Figure 24. Percent of Reactors Over 12 Years Old With Capacity Factors Greater than 65 Percent, by Size, 1981-1992

Note: Number in parentheses is the average capacity factor for all reactors in the group. MWe, Megawatts-electric.
 Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (Nureg-0020).

Canadian CANDU reactors operated very well in the early 1980's, at about 80 percent average capacity factor, but their average has dropped to about 70 percent in recent years.

down for a minimum of 3 months after every 12 months of operation, for safety inspections. This limits the maximum achievable capacity factor of any Japanese reactor to 80 percent.

Capacity factors for Japanese reactors are in the low 70 percent range. By law, Japanese reactors must be shut

Table 27. Historical Capacity Factors for Commercial Nuclear Power Plants, 1980 to 1992
(Percent)

Country	Annual Capacity Factor ^a												
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Argentina	75	90	60	51	20	66	65	68	57	44	72	89	78
Belgium	81	84	72	76	87	68	77	83	85	81	83	85	86
Brazil	b	b	b	b	36	65	2	17	6	28	35	25	28
Canada	82	88	82	79	72	64	73	72	77	74	61	71	68
Finland	57	72	82	87	92	89	89	92	91	90	89	91	89
France	60	58	53	62	70	65	67	60	58	62	63	63	63
Germany	55	67	70	70	76	83	78	75	74	69	66	66	72
Hungary	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	86	86
India	49	41	29	33	43	65	44	47	52	34	51	40	40
Italy	17	21	58	62	63	59	74	2	b	b	b	b	b
Japan	61	60	69	68	70	74	76	77	71	71	72	72	72
Korea, South	67	56	73	60	70	65	77	82	67	74	79	85	84
Mexico	b	b	b	b	b	b	b	b	b	b	36	72	66
Netherlands	90	78	84	76	81	84	88	75	82	80	74	76	82
Pakistan	7	19	7	19	24	67	44	26	16	6	32	35	46
Slovenia	NA	NA	NA	NA	55	65	69	77	71	71	79	85	68
South Africa	b	b	b	b	69	65	55	39	67	69	53	57	58
Spain	53	65	49	47	64	64	74	80	78	81	73	86	85
Sweden	65	64	61	60	76	66	81	77	77	74	75	85	66
Switzerland	80	85	84	87	88	84	83	85	83	84	87	85	84
Taiwan	73	66	53	66	72	65	60	73	68	62	71	78	75
United Kingdom	47	49	56	57	56	52	51	54	56	55	52	54	57
United States	56	58	57	54	56	58	57	57	64	62	66	70	71
Average	60	62	61	62	64	65	66	63	62	61	65	70	71

^aAnnual capacity factors of individual countries are based on gross generation. Historical capacity factors for Eastern Europe, China, Commonwealth of Independent States, Cuba, and the Philippines are not available.

^bNo operable commercial nuclear capacity.

NA = not available.

Note: The capacity factors do not include electricity generated during precommercial operation.

Sources: 1980-1992: United States: Energy Information Administration, *Monthly Energy Review* DOE/EIA-0036 (92/101). Foreign: *Nucleonics Week* (New York: McGraw-Hill) (February 11, 1993).

6. Comparison With Other Projections

In this chapter, EIA's projections of nuclear capacity and nuclear fuel cycle requirements are compared with other projections, namely:

1. Projections made by EIA in 1992
2. Market analysis by Energy Resources International (ERI)
3. NUEXCO's market analysis report
4. The Uranium Institute's statistical update.

Projections of nuclear capacity are presented for the years 1995, 2000, and 2005. The fuel cycle requirements and spent fuel discharges are given for 1993 through 1995 and 1996 through 2000. EIA's Upper Reference case is compared to the mid-range of the other forecasts because they are the most comparable cases.

Comparison with Last Year's EIA Report

The No New Orders case is defined as a case where capacity projections depend solely on the assumption of no new orders for nuclear reactors, and the reactor's expiration dates are determined by the Nuclear Regulatory Commission. In most cases, the nuclear units are in operation for 40 years. In last year's No New Orders case, it was assumed that the operating life of 30 percent of the existing units was extended 20 years. This change in definition has very little effect on the projections through 2005. The capacity projection for the United States for the No New Orders case decreased this year by one net gigawatt in 1995 and 2000, and is identical in 2005 to last year's projection (Table 28). This is due to the retirement of the Trojan unit in 1993 instead of 2015 as assumed last year and the startup of Bellefonte 1 in 2001. EIA's current projections of U.S. capacity for the Lower and Upper Reference cases are less than the 1992 projections, due to changes in assumed startup and retirement dates of U.S. reactors in the construction pipeline (Table 29).

EIA's projection of foreign nuclear capacity for 1995 is 240 net GWe, increasing to 281 net GWe by 2005 (Table 30). These projections are about one percent less, for 1995 and 2000, than last year's. The foreign nuclear

capacity projection for 2005 is 6 percent less than projected last year. This difference in 2005 occurs because EIA has a less optimistic outlook for nuclear growth in Western Europe and the Far East than last year.

The cumulative U.S. uranium requirements from 1993 through 2000, 362 million pounds, are 2 percent lower than those projected in last year's report, and the cumulative U.S. enrichment service requirements through 2000, of 75 million separative work units, are 5 percent lower than those projected last year (Table 31). These lower forecasts of uranium and enrichment service requirements are due primarily to lower estimates of nuclear capacity. A capacity factor of 70 percent in 1993 through 2010 was assumed this year and last. The tails assay assumption remained at 0.3 percent, the same as last year. The cumulative projections of U.S. spent fuel discharges (16.4 thousand metric tons of initial heavy metal) are identical to those presented in last year's report.

In last year's report, EIA's projection of uranium requirements for foreign countries, 1993 through 2000, was 9 percent higher than the current projection (Table 32). Similarly, the projections of enrichment service requirements were 7 percent higher. This corresponds to the higher foreign nuclear capacities projected last year.

Comparison With Other Reports

EIA's projections are comparable to projections made by other organizations. Variances can be attributed to differences in assumptions. Nuclear capacity forecasts made by other organizations are primarily based on their judgment concerning the expected completion of nuclear units in the construction pipeline.

Other organization's projections of uranium and enrichment service requirements are made using techniques similar to those used by the EIA. Uranium and enrichment service requirements are a function of five major interrelated variables concerning the fuel management and operating characteristics of the reactor. To compute uranium and enrichment services requirements, a value

Table 28. Comparison of Projections for U.S. Nuclear Capacity at Year End, 1995, 2000, and 2005

Source	Capacity (net GWe) ^a		
	1995	2000	2005
Energy Information Administration			
<i>World Nuclear Capacity and Fuel Cycle Requirements 1993</i>			
No New Order Case	100	101	102
Lower Reference Case	100	101	104
Upper Reference Case	100	103	106
<i>World Nuclear Capacity and Fuel Cycle Requirements 1992</i>			
No New Orders Case	101	102	102
Lower Reference Case	101	104	105
Upper Reference Case	102	105	109
NUEXCO ^b	101	104	109
Energy Resources International ^c	100	100	101
Uranium Institute ^d	101	101	101

^aCapacity values are based on net summer capability ratings. GWe = Gigawatts-electric.

^bNUEXCO = *Nuclear Fuel Market Analysis and Price Trend Projections 1992* (Denver, Colorado), p. 2-11.

^cEnergy Resources International, Inc., *1993 Nuclear Fuel Cycle Supply and Price Report* (midrange) (Washington, DC, April 1993), p. 3-18.

^dUranium Institute, "Uranium in the New World Market: A Statistical Update of Supply and Demand 1991-2010" (London, England, October 1992), p. 38.

Table 29. Assumptions on Start up Dates and Early Retirements for Existing U.S. Reactors in 1992 and 1993

	No New Orders		Lower Reference		Upper Reference	
	1992 Report	1993 Report	1992 Report	1993 Report	1992 Report	1993 Report
Reactor Startups						
Comanche Peak 2	1993	1993	1993	1993	1993	1993
Watts Bar 1	1995	1995	1994	1994	1994	1994
Watts Bar 2	1996	1996	1996	1996	1995	1996
Bellefonte 1	--	2001	1998	2001	1997	2000
Bellefonte 2	--	--	--	--	2003	2002
WNP 1	--	--	2001	2005	2000	2002
WNP 3	--	--	--	--	2005	--
Perry 2	--	--	--	--	--	--
Early Retirements						
Yankee Rowe	1992	1992	1992	1992	1992	1992
San Onofre 1	1992	1992	1992	1992	1992	1992
Trojan	2015	1993	2015	1993	2035	1993

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

(--) = Unknown.

for these variables must be estimated. The variables are capacity factor (a measure of capacity utilization), uranium enrichment product assay and tails assay used while enriching the uranium, the fuel burnup (i.e., the amount of energy generated from the fuel), and the length of the fuel cycle (i.e., the length of time the

reactor operates before refueling). EIA conducts statistical analysis of historical reactor operating data to obtain values for these variables. The assumptions used for the values of these variables will affect the projected uranium and enrichment service requirements, some more than others.

Table 30. Comparison of Projections of Foreign Nuclear Capacity at Year End, 1995, 2000 and 2005

Source	Capacity (net GWe) ^a		
	1995	2000	2005
EIA ^b —1993 Report	240	259	281
EIA ^b —1992 Report	242	261	301
NUEXCO ^c	243	281	344
ERI ^d	243	267	288
Uranium Institute ^e	243	265	283

^aGWe = Gigawatts-electric.

^bEnergy Information Administration projections shown are the Upper Reference case.

^cNUEXCO, *Nuclear Fuel Market Analyses and Price Trend Projections 1992* (Denver, Colorado), p. 2-11.

^dEnergy Resources International, Inc., *1993 Nuclear Fuel Cycle Supply and Price Report* (midrange) (Washington, DC, April 1993), p. 3-18.

^eUranium Institute, "Uranium in the New World Market: A Statistical Update of Supply and Demand 1991-2010" (London, England, October 1992), p. 33.

Table 31. Comparison of Selected Forecasts of United States Fuel Cycle Requirements, 1993 to 2000

Source	Projection Period		Total, 1993-2000
	1993-1995	1996-2000	
Total Uranium Requirements (million pounds U ₃ O ₈)			
Energy Information Administration			
This Report ^a	132.4	229.8	362.2
Last Year's Report ^b	139.9	230.0	369.9
Energy Resources International, Inc. ^c	123.8	200.9	324.7
NUEXCO ^d	131.4	225.8	357.1
Uranium Institute ^e	133.0	224.5	357.6
Total Enrichment Service Requirements (million separative work units)			
Energy Information Administration			
This Report ^a	26.4	49.3	75.7
Last Year's Report ^b	29.5	49.5	79.0
Energy Resources International, Inc. ^c	27.3	45.6	72.9
NUEXCO ^d	29.3	51.0	80.2
Total Spent Fuel Discharges (thousand metric tons of initial heavy metal)			
Energy Information Administration			
This Report ^a	6.4	10.0	16.4
Last Year's Report ^b	6.2	10.2	16.4

^aEnergy Information Administration, 1993 Upper Reference case projections.

^bEnergy Information Administration, *World Nuclear Capacity and Fuel Cycle Requirements 1992*, DOE/EIA-0436(92) (Washington, DC, October 1992). Upper Reference case Projections.

^cEnergy Resources International, Inc., *1993 Nuclear Fuel Cycle Supply and Price Report* (midrange) (Washington, DC, April 1993), p. 4-40.

^dNUEXCO, *Nuclear Fuel Market Analyses and Price Trend Projections 1992* (Denver, Colorado), p. 4-26, p. 6-4.

^eUranium Institute, "Uranium in the New World Market: A Statistical Update of Supply and Demand 1991-2010" (London, England, October 1992), p. 39.

Table 32. Comparison of Selected Forecasts of Fuel Cycle Requirements for Foreign Countries, 1993 to 2000

Source	Projection Period		Total, 1993-2000
	1993-1995	1996-2000	
Total Uranium Requirements (million pounds U ₃ O ₈)			
EIA ^a 1993 Report	307	530	837
EIA ^a 1992 Report	333	587	920
NUEXCO ^b	325	596	921
ERI ^c	309	508	817
Uranium Institute ^d	314	558	872
Total Enrichment Service Requirements (million separative work units)			
EIA ^a 1993 Report	61	106	167
EIA ^a 1992 Report	63	116	179
NUEXCO ^b	60	115	175
ERI ^c	61	104	165
Total Spent Fuel Discharges (thousand metric tons of initial heavy metal)			
EIA ^a 1993 Report	24	41	65
EIA ^a 1992 Report	30	46	76

^a1992 and 1993 Energy Information Administration projections shown are the Upper Reference case.

^bNUEXCO, *Nuclear Fuel Market Analyses and Price Trend Projections 1992* (Denver, Colorado), pp. 4-26, 6-4.

^cEnergy Resources International, Inc., *1993 Nuclear Fuel Cycle Supply and Price Report* (midrange) (Washington, DC, April 1993), p. 4-40.

^dUranium Institute, "Uranium in the New World Market: A Statistical Update of Supply and Demand 1991-2010" (London, England, October 1992), p. 39.

Only limited documentation on the assumptions made in determining these variables is available for other forecasts. In a few instances, some of the assumptions are documented in the reports of other organizations along with the projections. Like the comparison of projected nuclear capacity, a comparison of uranium and enrichment service requirements is made to determine if EIA's projections are reasonable.

In general, EIA's projections of nuclear capacity for both the U.S. and foreign countries through 2005 are very close to those made by other knowledgeable organizations. Minor differences in U.S. capacity projections are attributable to varying estimates of startup and retirement dates of a few reactors (Appendices D and E). For foreign nuclear capacity projections, EIA's projections are within 2 percent of other organizations,

excluding NUEXCO. Unlike the other organizations, NUEXCO's projection for 2005 is greater than their projection last year.

Regarding projections of uranium requirements and enrichment service requirements in the United States through 2000, EIA is within 10 percent of projections made by other organizations (Table 31). For projections of uranium and enrichment service requirements in foreign countries through 2000, EIA's projections are also within 10 percent for uranium requirements and 8 percent for enrichment service requirements (Table 32). Projections from NUEXCO are responsible for the largest differences, while projections of the remaining organizations are smaller. A more detailed discussion of each organization's projections follows.

Comparison to NUEXCO

The differences between EIA's and NUEXCO's projections of U.S. nuclear capacity are slight. NUEXCO is assuming that all five indefinitely deferred units will become operable by 2005.

NUEXCO's projections of nuclear capacity in foreign countries exhibit an average annual compound growth rate of 3.2 percent from 1995 to 2005 whereas EIA's average annual compound growth rate is 1.5 percent. These differences are attributable to higher estimates of nuclear capacity growth in Russia, France and Japan.

NUEXCO's projections of total U.S. uranium requirements are 1 percent lower than EIA's. Their projections of total enrichment service requirements are 6 percent higher than EIA's.

When estimating foreign uranium requirements and enrichment service requirements, NUEXCO's projections are 10 percent and 5 percent higher, respectively. This is due to NUEXCO's higher projections of foreign nuclear capacity.

Comparison to Energy Resources International

Energy Resources International's (ERI) projection of nuclear capacity in the United States is less than 5 percent lower than the Upper Reference case projections made by EIA. ERI is assuming that only the three units actively under construction will become operable by 2005.

For foreign countries, ERI's projected nuclear capacity for the 3 years shown in Table 30 is between 1 and 3 percent higher than EIA's.

ERI's estimate of total uranium requirements for the United States is 10 percent lower than EIA's and their enrichment service requirements are 4 percent lower. This is consistent with their U.S. capacity projections which are slightly lower than EIA's.

ERI's projection of uranium requirements for foreign countries for 1993 through 2000 (817 million pounds) is only 20 million pounds (2 percent) less than EIA's estimate. ERI projects 165 million separative work units for this same period, which differs by less than 1 percent from EIA's projection.

Comparison to Uranium Institute

U.S. capacity projections made by the Uranium Institute (UI) are 101 net GWe for 1995, 2000 and 2005. This is based on the assumption that only the three units actively under construction will be completed by 2005 and they will all become operable by 1995.

For foreign reactors, the UI's projections of nuclear capacity are about 2 percent higher than EIA's in 1995 and 2000 and they are equal to EIA's in 2005. These match EIA's projections more closely than those of the other organizations.

Projections of U.S. total uranium requirements made by the UI are slightly lower than those made by EIA (1 percent). The UI does not project enrichment service requirements or spent fuel discharges.

The UI projects 872 million pounds of uranium requirements for the period 1993 through 2000 for foreign reactors. This is 4 percent higher than EIA's projection, which is expected because UI's nuclear capacity projections are somewhat higher.

Appendix A

**Nuclear Power
Technology and the
Nuclear Fuel Cycle**

A simplified illustration of the nuclear fuel cycle.

Appendix A

Nuclear Power Technology and the Nuclear Fuel Cycle

Nuclear Fission

When the feasibility of the nuclear fission reaction was confirmed in 1939, scientists recognized that tremendous amounts of energy could be released by this process. Although early attempts to harness this energy were directed to military purposes, the harnessing of nuclear fission to produce electricity eventually became a commercial technology.

The nuclear fission process is one in which a heavy atomic nucleus (such as uranium) reacts with a free neutron.³³ Most of the time this "reaction" is one in which the uranium nucleus splits (or "fissions") into two smaller nuclei, concurrently releasing energy and two or three additional free neutrons. Because more neutrons are released from a fission event than are needed to induce the event, a "chain reaction" can be sustained.

Of course, to be useful for commercial purposes, the rate of the chain reaction must be controlled. This is not as difficult as it might seem because nearly every other nucleus besides uranium reacts with free neutrons, usually by absorbing the neutron rather than by fissioning. Thus, a fission chain reaction is controlled by diluting the fissionable uranium atoms with other nonfissionable atoms.

Uranium in nature consists primarily of two "isotopes"—atoms with the same number of protons in the nucleus but different numbers of neutrons. One isotope is designated uranium-235 (or U-235); the other is uranium-238 (U-238). The numbers refer to the atomic mass, which is the sum of the number of protons and neutrons in the nucleus.

U-235 makes up only 0.7 percent of naturally occurring uranium; U-238 makes up almost all of the other 99.3

percent. U-235 nearly always reacts with a free neutron (that is, one outside the nucleus) by fissioning; thus, U-235 is called a "fissile" isotope. On the other hand, U-238 nearly always reacts with a free neutron by absorbing it rather than by fissioning. This absorption forms the isotope U-239, which in turn undergoes radioactive decay and eventually becomes Pu-239, an isotope of the element plutonium. Pu-239, like U-235, is a fissile isotope. U-238 is referred to as a "fertile" isotope, because it eventually produces the fissile Pu-239 isotope.

The vast majority of the world's nuclear power plants operate by passing ordinary (that is, "light") water through a nuclear reactor in which uranium fuel, housed in an array of "fuel assemblies," undergoes a controlled chain reaction. The heat produced by nuclear fission events in the reactor core is carried away by the water, either as steam in a "boiling-water reactor" or as superheated water in a "pressurized-water reactor." In a pressurized-water reactor, a device called a "steam generator" transfers the heat from water in the primary loop (which has passed through the reactor core) to water in a secondary loop, which is turned into steam. Steam produced in either a boiling-water reactor or a pressurized-water reactor then passes to an electrical turbine-generator, which actually produces the electricity. Boiling-water reactors and pressurized-water reactors are collectively called "light-water reactors." Other reactor designs have also been developed, such as the gas-cooled reactor, advanced gas-cooled reactor, and pressurized heavy-water reactor; these are used for commercial power generation in a number of foreign countries.

Because the coolant (water) in light-water reactors absorbs free neutrons, the concentration of fissile U-235 in uranium fuel must be increased over the concentration of 0.7 percent found in natural uranium in order

³³Atomic nuclei consist of combinations of two types of subatomic particles, protons and neutrons, of about equal mass. The number of electrically charged protons in a nucleus determines which element it is—that is, its chemical properties. The number of protons plus the number of electrically neutral neutrons determines the weight or "atomic mass" of the nucleus. A "free neutron" is one that has been released from an atomic nucleus.

for light-water reactors to sustain a nuclear chain reaction. The process of uranium enrichment, as discussed below, is used to increase the concentration of U-235 in the nuclear fuel used in light-water reactors to about 3 percent.

Before the initial startup of a nuclear power reactor, the core is loaded with fresh nuclear fuel. This fuel can be thought of as a reservoir from which energy is extracted as long as a chain reaction can be sustained. During the operation of the reactor, the concentration of U-235 decreases as U-235 nuclei fission to produce energy. In addition, fertile U-238 nuclei are constantly being converted into fissile Pu-239 nuclei, some of which will, in turn, fission and produce energy. While these reactions are taking place, the concentration of neutron-absorbing fission products (also called "poisons") increases within the nuclear fuel assemblies. When the declining concentration of fissile nuclei and the increasing concentration of poisons reach the point at which a chain reaction can no longer be sustained (that is, when free neutrons are absorbed at a rate greater than the rate of fission events), the reactor must be shut down and refueled.

The amount of energy in the "reservoir" of nuclear fuel is frequently expressed in terms of "full-power days," which is the number of days the reactor could operate at full output before a fission chain reaction would cease to be sustained. If a reactor is not operated at full power, or if it is not operated at all times, the chronological operating period is increased correspondingly. The operating period varies inversely with the plant's "capacity factor," which is the ratio of its actual level of operation to the maximum, full-power level of operation for which it is designed.

As might be expected, the number of full-power days in a nuclear reactor's operating cycle (from one refueling to the next) is related to the amount of fissile U-235 contained in the fuel assemblies at the beginning of the cycle. The higher the percentage of U-235 at the initiation of a cycle, the greater the number of full-power days of operation in that cycle.

At the end of an operating cycle (when the chain reaction can no longer be sustained), some of the "spent" nuclear fuel is discharged and replaced with fresh fuel. The fraction of the reactor's fuel replaced at a refueling is called its "batch fraction"—typically, one-fourth for boiling-water reactors and one-third for pressurized-water reactors.

The amount of energy extracted from spent fuel is called its "burnup," expressed in terms of energy (heat)

produced per initial fuel weight—such as, megawatt-days thermal per metric ton of initial heavy metal.

The Nuclear Fuel Cycle

The nuclear fuel cycle for a typical light-water reactor is illustrated in Figure A1. The cycle consists of a "front end" that comprises the steps necessary to prepare nuclear fuel for reactor operation and a "back end" that comprises the steps necessary to manage the spent nuclear fuel, which is highly radioactive. It is technically possible to extract the unused uranium and plutonium from spent nuclear fuel through chemical reprocessing and to recycle the recovered uranium and plutonium as nuclear fuel. The front end of the cycle is divided into the following steps:

- **Exploration.** Ore bodies containing uranium are first located by drilling and other geological techniques. Known deposits of ore for which enough information is available to estimate the quantity and cost of production are called reserves. Ore deposits inferred to exist but as yet undiscovered are called potential resources.
- **Mining.** Uranium-bearing ore is mined by methods similar to those used for other metal ores. The uranium content of ores in the United States typically ranges from 0.05 to 0.3 percent uranium oxide (U_3O_8). In foreign countries the uranium content of ores varies widely, from 0.035 percent in South West Africa to 2.5 percent in northern Saskatchewan, Canada. In general, foreign ores are of a higher grade than those mined in the United States. Commercially significant amounts of uranium are also obtained by methods other than conventional mining, such as solution mining, and as a byproduct of phosphate mining.
- **Milling.** At uranium mills, usually located near the mines, uranium-bearing ore is crushed and ground, and the uranium oxide is chemically extracted. The mill product, called uranium concentrate or "yellowcake," is then marketed and sold as pounds or short tons of U_3O_8 .
- **Conversion to UF_6 .** Next, the U_3O_8 is chemically converted to uranium hexafluoride (UF_6), which is a solid at room temperature but changes to a gas at slightly higher temperatures. This is a necessary feature for the next step, enrichment.

Figure A1. The Nuclear Fuel Cycle

- **Enrichment.** Natural uranium cannot be used as fuel in light-water reactors because its content of fissile U-235 is too low to sustain a nuclear chain reaction. The gaseous diffusion process currently used for uranium enrichment (that is, increasing its U-235 content) consists of passing a "feed stream" of UF_6 gas through a long series of diffusion barriers that pass U-235 at a faster rate than the heavier U-238 atoms. This differential treatment progressively increases the percentage of U-235 in the "product stream." The "waste stream" or "enrichment tails stream" contains the depleted uranium (that is, uranium having a U-235 concentration below the natural concentration of 0.7 percent). The U-235 concentration in the waste stream, called the "enrichment tails assay," is fixed by the operator of the enrichment facility. The gaseous diffusion enrichment process is extremely energy intensive. The work or energy expenditure required for uranium enrichment is measured in terms of separative work units.

A second enrichment technology, gas centrifuge separation, has been used commercially in the Netherlands. A domestic gas centrifuge separation plant was under construction but has now been canceled. A third enrichment technology, laser separation, is currently under development.

- **Fabrication.** The enriched UF_6 is changed to an oxide and then into pellets of ceramic uranium dioxide (UO_2), which are then sealed into corrosion-resistant tubes of zirconium alloy or stainless steel. The loaded tubes, called elements or rods, are mounted into special assemblies for loading into the reactor.

The back end of the cycle is divided into the following steps:

- **Interim Storage.** After its operating cycle, the reactor is shut down for refueling. The fuel discharged at that time (spent fuel) is stored either at the reactor site or, potentially, in a common facility away from reactor sites. If on-site pool storage capacity is exceeded, it may be desirable to store aged fuel in modular dry storage facilities known as Independent Spent Fuel Storage Installations (ISFSI) at the reactor site or at a facility away from the site. The spent fuel rods are usually stored in water, which provides both cooling (the spent fuel continues to generate heat as a result of residual radioactive decay) and shielding (to protect the environment from residual ionizing radiation).
- **Reprocessing.** Spent fuel discharged from light-water reactors contains appreciable quantities of fissile (U-235, Pu-239), fertile (U-238), and other radioactive materials. These fissile and fertile materials can be chemically separated and recovered from the spent fuel. The recovered uranium and plutonium can, if economic and institutional conditions permit, be recycled for use as nuclear fuel.
- **Waste Disposal.** A current concern in the nuclear power field is the safe disposal and isolation of either spent fuel from reactors or, if the reprocessing option is used, wastes from reprocessing plants. These materials must be isolated from the biosphere until the radioactivity contained in them has diminished to a safe level. Under the Nuclear Waste Policy Act of 1982, as amended, the Department of Energy has responsibility for the development of the waste disposal system for spent nuclear fuel and high-level radioactive waste. Current plans call for the ultimate disposal of the wastes in solid form in licensed deep, stable geologic structures.

Appendix B

Economic and Energy Parameter Input Assumptions

The reactor's core is loaded with fuel assemblies which are needed for the fissioning process.

Appendix B

Economic and Energy Parameter Input Assumptions

Commercial nuclear power economic and energy parameter assumptions and forecasts were prepared by the Office of Integrated Analysis and Forecasting, Energy Supply and Conversion Division, using the World Integrated Nuclear Evaluation System (WINES) model.³⁴ The primary objective of the model is to produce projections of long-range world energy, electrical generation, and nuclear capacity.

Tables B1 through B5 present economic and energy parameter inputs to the model for countries that are projected to have nuclear power plants by 2010. Within the model framework, economic (GNP) growth is defined as the sum of growth rates for the labor-age population, the labor force participation fraction, and labor productivity. Foreign assumptions were derived from statistical studies of historical data for each country and (where available) forecasts from the Organization for Economic Cooperation and Development (OECD), International Atomic Energy Agency (IAEA), and analyst judgment. The following chiefly concentrates on the parameter input values in relation to the United States.

The labor-age population growth rate is derived from the U.S. Census Bureau middle series projections. From 1990 through 2009 it is projected to grow at an annual rate of about 0.76 percent, and from 2010 to 2030 it is projected to decline at an annual rate of about 0.2 percent.³⁵ For other countries, labor-age population growth rates are derived from the World Bank population projections.

³⁴The projections for countries listed under the Eastern Europe category, Bulgaria, Czech Republic, Slovak Republic, Hungary, Lithuania, Romania, plus the Commonwealth of Independent States (CIS), the People's Republic of China, and Cuba were not derived from the WINES model because the economic and energy input data needed to run WINES were either unavailable or deemed to be non-credible. Their projections are based on a critical assessment of detailed country-specific nuclear power plants and information obtained from the International Atomic Energy Agency (IAEA) 1993 Consultant's Meeting on International Nuclear Capacity Forecasting.

³⁵However, 5-year growth rates are used as model inputs rather than the 20-year averages since WINES produces outputs at 5-year intervals.

³⁶Bureau of Labor Statistics, U.S. Department of Labor, *Outlook 2000*, Bulletin 2352 (Washington, DC, April 1990).

³⁷Bureau of the Census, U.S. Department of Commerce, *Statistical Abstract of the United States 1990*, 110th ed., Table No. 664, "Indices of Productivity and Related Measures: 1960 to 1988," p. 406 (Washington, DC, January 1990).

³⁸Op. Cit., Bureau of Labor Statistics.

³⁹Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383(93), Tables A2 and B2, "Energy Consumption by End-Use Sector and Source" (Washington, DC, January 1993), pp. 82, 100.

The labor force participation fraction rate is assumed to increase at an annual rate of 0.30 to 0.40 percent (Table B1). These rates bracket an estimate of .40 percent per year by the U.S. Bureau of Labor Statistics (BLS) for the period 1988 through 2000.³⁶ The BLS value is at the lower end of the range of historical rates for this parameter, reflecting the anticipated aging of the population and leveling off of the entry of women into the labor force. The range of values reflects the uncertainty of this parameter in the period beyond the BLS projection.

Labor productivity is assumed to grow at a rate of 1.6 to 1.8 percent per year (Table B1). These values are expected to be higher than the average annual productivity growth rate for the past 25 years of about 1.5 percent, based upon BLS productivity indices.³⁷ Also, the BLS has developed projections of labor productivity growth rates of 1.3 to 1.4 percent per year for the period 1988 through 2000.³⁸

Domestic labor-age population, participation, and productivity growth rates yield average GNP growth rates of 1.7 and 2.1 percent annually between 2010 and 2030 for the Lower and Upper Reference cases, respectively.

The baseline values (for 2010) for the Lower and Upper Reference case for delivered energy are those from the *Annual Energy Outlook 1993 (AEO93)* Reference and High Macroeconomic Growth cases, respectively.³⁹ The function describing growth in demand for delivered

Table B1. Economic Parameter Values Assumptions for OECD and Non-OECD Countries

Country	Labor Force Participation Annual Growth Rate (percent)		Labor Productivity Annual Growth Rate (percent)	
	Lower Reference Case	Upper Reference Case	Lower Reference Case	Upper Reference Case
OECD Countries				
Canada	--	1.0	--	2.0
Belgium	--	--	--	--
Finland	--	0.2	--	3.0
France	-0.1	0.1	2.0	3.0
Germany	--	0.0	--	3.0
Italy	--	0.1	--	3.0
Netherlands	--	--	--	--
Spain	--	0.1	--	3.2
Sweden	--	--	--	--
Switzerland	--	0.1	--	2.0
United Kingdom	--	0.3	--	2.0
United States	0.3	0.4	1.6	1.8
Japan	0.0	0.1	2.5	3.5
Non-OECD Countries				
Argentina	--	0.4	--	1.0
Brazil	--	0.5	--	1.5
India	--	0.3	--	2.0
Korea, South	--	0.6	--	3.0
Mexico	--	0.8	--	2.0
Pakistan	--	0.9	--	2.5
Slovenia	--	--	--	--
South Africa	--	0.6	--	2.0
Taiwan	--	0.6	--	3.0

Note: Values are indicated for those countries where WINES was used to develop the forecasts. In the Lower Reference case, WINES was only used for France and Japan. In the Upper Reference case, WINES was used for all countries except Belgium, the Netherlands, Sweden and Slovenia.

Source: Decision Analysis Corporation of Virginia, *Final Report: WINES Model Analysis (OECD Countries)*, DOE Contract No. DE-AC01-87EI-19801 (Vienna, VA, November 15, 1991), Volumes 1-3; *WINES Model Analysis (Non-OECD Countries)*, DOE Contract No. DE-AC01-92EI-22941 (Vienna, VA, March 27, 1992); Energy Information Administration, Office of Integrated Analysis and Forecasting.

energy uses GNP growth rates plus assumptions regarding growth in the real price of aggregate energy and corresponding price and income elasticities of demand for energy as inputs. The real aggregate energy price is assumed to increase at annual rates of 1.8 and 1.6 percent, for the Lower and Upper Reference cases, respectively (Table B2). The rates approximate the AEO93 aggregate end-use energy price projections for the period 1990-2010.⁴⁰

Price elasticities of aggregate energy demand are assumed to be -0.12 to -0.1 (Table B2). These elasticities are consistent with the aggregate end-use energy price elasticities computed from data for the period 1970 to

1987. Energy price elasticities are generally considered to be greater (in absolute value) for developed countries than for developing countries, reflecting the premise that higher income countries have better opportunities for energy substitution than do countries with relatively lower incomes. Income elasticities of aggregate energy demand are assumed to be 0.63 in the Upper Reference case. These elasticities are consistent with the income elasticity of 0.6 computed with data for the period 1970 to 1987 as well as that of 0.6 in the National Energy Strategy (NES) projections through 2030. For developing countries, the greater values for income elasticities are due to the potential for energy-intensive industrialization as income increases.

⁴⁰Ibid, Tables A3 and B3, "Energy Prices by End-Use Sector," pp. 84, 102.

Table B2. Energy Assumptions for OECD and Non-OECD Countries

Country	Aggregate Delivered Energy Real Annual Price Growth Rate (percent)		Price Elasticity of Aggregate Delivered Energy Demand		Income Elasticity of Aggregate Delivered Energy Demand	
	Lower Reference Case	Upper Reference Case	Lower Reference Case	Upper Reference Case	Lower Reference Case	Upper Reference Case
OECD Countries						
Canada	--	1.0	--	-0.3	--	0.6
Belgium	--	--	--	--	--	--
Finland	--	0.5	--	-0.3	--	0.6
France	1.5	1.0	-0.4	-0.3	0.6	0.6
Germany	--	1.0	--	-0.3	--	0.6
Italy	--	1.5	--	-0.3	--	0.6
Netherlands	--	--	--	--	--	--
Spain	--	0.5	--	-0.3	--	0.6
Sweden	--	--	--	--	--	--
Switzerland	--	0.5	--	-0.3	--	0.6
United Kingdom	--	0.5	--	-0.3	--	0.6
United States	1.8	1.6	-1.2	-0.1	0.6	0.6
Japan	2.0	1.0	-0.4	-0.3	0.6	0.6
Non-OECD Countries						
Argentina	--	1.5	--	-0.3	--	0.6
Brazil	--	1.5	--	-0.3	--	0.8
India	--	1.5	--	-0.3	--	0.9
Korea, South	--	1.5	--	-0.3	--	0.6
Mexico	--	1.5	--	-0.3	--	0.6
Pakistan	--	1.5	--	-0.3	--	0.9
Slovenia	--	--	--	--	--	--
South Africa	--	1.5	--	-0.3	--	0.6
Taiwan	--	1.5	--	-0.3	--	0.6

Note: Values are indicated for those countries where WINES was used to develop the forecasts. In the Lower Reference, case WINES was only used for France and Japan. In the Upper Reference case, WINES was used for all countries except Belgium, the Netherlands, Sweden and Slovenia.

Source: Decision Analysis Corporation of Virginia, *Final Report: WINES Model Analysis (OECD Countries)*, DOE Contract No. DE-AC01-87EI-19801 (Vienna, VA, November 15, 1991), Volumes 1-3; *WINES Model Analysis (Non-OECD Countries)*, DOE Contract No. DE-AC01-92EI-22941 (Vienna, VA, March 27, 1992); Energy Information Administration, Office of Integrated Analysis and Forecasting.

The electrical share of delivered energy and the nuclear share of electricity are derived using market penetration functions. These functions require assumptions regarding the long-run asymptotic shares and halving factors. The halving factor determines how fast the share from the base-year value approaches the asymptotic value. The base year for electrical and nuclear share for the Lower Reference and the Upper Reference cases is 2010.

The asymptotic electrical share of delivered energy is assumed to be 19 and 22 percent in the Lower and Upper Reference cases, respectively (Table B3). These assumptions are based on an analysis of the historical penetration of electricity in the United States and by fitting the best logistic curve to these historical data.

The 1992 electrical share (utility and non-utility) of delivered energy was 19.8 percent. The halving factor in both cases is assumed to be 8 years since there are many new end-use technologies on the horizon and the electric industry is a mature one. It is assumed, therefore, that increases in electricity can be achieved relatively quickly. Electrical generation and delivered energy are forecast using the 2010 values from the AEO93 Reference and High Macroeconomic Growth Cases.

The asymptotic nuclear share of electrical generation, derived in a manner similar to that used for the asymptotic electrical share, is assumed to be 15 to 20 percent for the Lower and Upper Reference cases,

Table B3. Electrical and Nuclear Share Parameter Values Assumed for OECD and Non-OECD Countries

Country	Asymptotic Electrical Share of Total Delivered Energy (percent)		Asymptotic Nuclear Share of Total Electricity (percent)		Halving Factor (years)	
	Lower Reference Case	Upper Reference Case	Lower Reference Case	Upper Reference Case	Electrical	Nuclear
OECD Countries						
Canada	--	35	--	20	--	15
Belgium	--	--	--	--	--	--
Finland	--	27	--	35	--	20
France	28	30	80	85	10	15
Germany	--	20	--	30	--	20
Italy	--	30	--	10	--	20
Netherlands	--	--	--	--	--	--
Spain	--	30	--	33	--	15
Sweden	--	--	--	--	--	--
Switzerland	--	35	--	40	--	15
United Kingdom	--	22	--	20	--	15
United States	19	22	15	20	8	25
Japan	25	30	32	35	10	15
Non-OECD Countries						
Argentina	--	15	--	25	--	25
Brazil	--	25	--	15	--	25
India	--	20	--	12	--	25
Korea, South	--	20	--	60	--	15
Mexico	--	15	--	15	--	25
Pakistan	--	20	--	20	--	25
Slovenia	--	--	--	--	--	--
South Africa	--	35	--	15	--	15
Taiwan	--	25	--	50	--	15

Note: Values are indicated for those countries where WINES was used to develop the forecasts. In the Lower Reference case WINES was only used for France and Japan. In the Upper Reference case, WINES was used for all countries except Belgium, the Netherlands, Sweden and Slovenia.

Source: Decision Analysis Corporation of Virginia, *Final Report: WINES Model Analysis (OECD) Countries*, DOE Contract No. DE-AC01-87EI-19801 (Vienna, VA, November 15, 1991), Volumes 1-3; *WINES Model Analysis (Non-OECD Countries)*, DOE Contract No. DE-AC01-92EI-22941 (Vienna, VA, March 27, 1992); Energy Information Administration, Office of Integrated Analysis and Forecasting.

respectively (Table B3). OECD countries were estimated by analyzing historical shares and fitting logistic market penetration functions to these historical data. The asymptotic electrical shares of delivered energy vary from 19 to 35 percent for the OECD countries, while the asymptotic nuclear shares of electrical generation range from 10 to 85 percent. For non-OECD countries, the asymptotic electrical shares of delivered energy are assumed to fall in a range from 15 to 35 percent, while the asymptotic nuclear share of electrical generation range from 12 to 60 percent. The 1991 domestic nuclear share of total utility-electrical generation was 22.1 percent. The continuing uncertainty regarding waste disposal, licensing, and safety verification procedures makes it likely that more time will be required to

achieve the nuclear asymptotic share. Therefore, the halving factor in both cases is assumed to be 25 years. In 2010, the nuclear share of electrical generation is projected to be about 14.5 percent in both the Lower and Upper Reference cases, based on the AEO92 Reference and High Economic Growth cases.

The projected growth rates of real gross domestic product, electrical generation, nuclear capacity and the ratio of electrical generation to gross domestic product associated with the capacity projections for the actual or planned nuclear power programs in the Lower and Upper Reference cases are listed in Tables B4 and B5, respectively.

Table B4. Economic and Energy Growth Rates for OECD and Non-OECD Countries, Lower Reference Case, 1990-2010

Country	Annual Growth Rates (mean percent)			Ratio of Electrical Generation to GDP Growth Rates For 1990 2010
	Real Gross Domestic Product (GDP)	Electrical Generation	Nuclear Capacity	
OECD Countries				
Canada	1.94	2.83	0.59	1.59
Belgium	1.77	1.62	-1.83	0.90
Finland	2.10	2.90	0.00	1.50
France	2.21	1.41	0.54	0.59
Germany	1.47	0.65	0.00	0.41
Italy	2.18	3.35	0.00	1.73
Netherlands	2.25	1.94	0.00	0.83
Spain	2.57	3.07	0.00	1.30
Sweden	1.49	-0.29	0.00	-0.16
Switzerland	1.23	0.79	0.00	0.61
United Kingdom	1.95	1.67	-3.12	0.83
United States	1.71	1.01	0.76	0.55
Japan	2.36	1.57	1.52	0.61
Non-OECD Countries				
Argentina	1.26	3.29	1.60	3.21
Brazil	2.11	3.28	8.26	1.76
India	3.06	1.98	5.19	0.58
Korea,South	2.09	2.30	2.96	1.12
Mexico	3.57	2.33	3.57	0.57
Pakistan	4.00	2.78	4.27	0.61
Slovenia	0.79	2.13	-0.08	3.09
South Africa	3.46	2.56	0.00	0.68
Taiwan	3.23	2.00	1.66	0.55

Note: In the Lower Reference case WINES was only used for France and Japan. In the Upper Reference case, WINES was used for all countries except Belgium, the Netherlands, Sweden and Slovenia. The WINES model was used to solve the growth rates in all countries shown in this table, including those for which WINES was not used to develop projections of nuclear capacity.

Source: WINES Model, March 1993, Energy Information Administration, Office of Integrated Analysis and Forecasting.

Total operable nuclear capacity for the U.S. is projected in the Lower Reference case to increase from its 99.0 GWe at a compound average annual growth rate of

about 0.8 percent, reaching 119 GWe in 2030. This compares with a growth rate of 2.4 percent in the Upper Reference case, reaching 168 GWe in 2030.

2 of 2

Table B5. Economic and Energy Growth Rates for OECD and Non-OECD Countries, Upper Reference Case, 1990-2010

Country	Annual Growth Rates (mean percent)			Ratio of Electrical Generation to GDP Growth Rates For 1990-2010
	Real Gross Domestic Product (GDP)	Electrical Generation	Nuclear Capacity	
OECD Countries				
Canada	3.51	3.24	2.60	0.90
Belgium	2.88	1.62	0.00	0.50
Finland	3.30	3.08	1.83	0.91
France	3.39	1.84	1.13	0.46
Germany	2.39	0.84	0.47	0.30
Italy	2.89	3.25	a	1.17
Netherlands	3.35	1.94	4.47	0.50
Spain	3.70	3.27	1.26	0.85
Sweden	2.09	-0.29	-1.91	-0.11
Switzerland	1.84	1.52	1.12	0.80
United Kingdom	2.35	1.76	0.12	0.71
United States	2.06	1.99	2.38	0.96
Japan	3.47	2.22	3.20	0.56
Non-OECD Countries				
Argentina	2.77	3.39	4.53	1.30
Brazil	3.95	3.17	9.58	0.74
India	4.22	2.20	6.20	0.42
Korea,South	4.59	2.73	4.19	0.49
Mexico	5.16	2.87	5.38	0.44
Pakistan	6.15	3.59	8.93	0.45
Slovenia	1.38	2.13	0.00	1.66
South Africa	4.91	2.65	1.72	0.43
Taiwan	4.76	2.12	2.36	0.34

^aGrowth rate from zero is not meaningful.

Note: In the Lower Reference case, WINES was only used for France and Japan. In the Upper Reference case, WINES was used for all countries except Belgium, the Netherlands, Sweden and Slovenia. The WINES model was used to solve the growth rates in all countries shown in this table, including those for which WINES was not used to develop projections of nuclear capacity.

Source: WINES Model, March 1993, Energy Information Administration, Office of Integrated Analysis and Forecasting.

**Methodology and
Assumed Fuel Cycle
Plans for Increased
Fuel Burnup**

Diagram of a fission reaction.

Appendix C

Methodology and Assumed Fuel Cycle Plans for Increased Fuel Burnup

The Model

The estimates of the nuclear fuel cycle requirements in this report were produced with the International Nuclear Model (INM). This model was developed under contract for the Nuclear and Alternate Fuels Division of the Office of Coal, Nuclear, Electric and Alternate Fuels in the Energy Information Administration (EIA).⁴¹ The INM is used to simulate nuclear fuel cycle operations.

The data for the INM include the following general categories:

- **Operating Reactor Data.** This is a list of information on nuclear reactors assumed to be operable during the time period being analyzed. For each reactor, the list includes the name, start and retirement dates, net summer capability, generic category to which the reactor is assigned, indicators of the fuel management plans to be used, and the applicable dates for the fuel management plans.
- **Generic Reactor Data.** Each operating reactor is classified into one of the generic categories, such as boiling-water reactor and pressurized-water reactor. The data for the generic categories of reactors include capacity factors, thermal efficiency, maintenance priority, and a list of allowable fuel management plans.
- **Fuel Management Data.** The data describing a fuel management plan are used to simulate the internal workings of operating reactors. Fuel management data consist of the following: full

power days, capacity factors, kilograms of enriched uranium per megawatt of capacity loaded during each refueling, spent fuel discharged, assays of the fissile isotopes in the fuel loaded and discharged, and fraction of core replaced.

- **Fuel Cycle Parameters.** These data items include lead and lag times from the start of a cycle for the fuel cycle processes (that is, conversion, enrichment, fabrication, spent fuel disposal), tails assays for enrichment services,⁴² process mass-loss factors, and process waste production.
- **Control/Scenario Data.** The user can specify data such as annual capacity factors for all equilibrium cycles.

Annual requirements for uranium concentrate (U_3O_8) and enrichment services, as well as discharges of spent fuel, are a function of the fuel management plan being used by each reactor and the specified tails assay for enrichment services. To calculate the annual requirements, the date for the start of a cycle is determined for each reactor by a formula that uses (a) the number of full power days specified in the fuel management plan and (b) the capacity factor. (A "full-power day" is the equivalent of 24 hours of full-power operation of a reactor.) The length of the cycle can then be determined as follows:

$$\text{Length of cycle} = (\text{number of full-power days}) / (\text{capacity factor}).$$

The length of the cycle includes the time during which electricity is being generated and the time during which the reactor is not operating (such as during refueling).

⁴¹David Andress, System Sciences Inc., *International Nuclear Model*, Vols. I, II, and III (Bethesda, MD, 1985).

⁴²"Tails assay" refers to the concentration of the U-235 isotope in the waste stream from the enrichment process. The higher the concentration of U-235 in the waste, the lower the requirement for enrichment service but the greater the requirement for natural uranium for a given quantity of enriched uranium produced.

The lead times for fuel cycle services must also be incorporated: U_3O_8 is delivered to a conversion plant 15 months before the restart of the nuclear unit, and enrichment services begin 12 months before the restart of the unit. Finally, the quantities of U_3O_8 and enrichment services required are determined from the amount of enriched uranium specified in the fuel management plan and from the enriched product assay and transaction tails assay. For a new reactor, the fuel management data and the lead times for the initial cycles are unique. After a reactor has reached equilibrium, the full-power days in a cycle, the quantity of fuel loaded, and the spent fuel discharged per cycle remain constant for a specific fuel management plan.

The INM is used to produce annual summary reports for generic reactor categories and totals for all reactors. These reports include: annual generation of electricity, annual capacity factors, annual and cumulative requirements for U_3O_8 and enrichment services, annual discharges of spent fuel, and total spent fuel discharges less the spent fuel withdrawn for reprocessing. The uranium concentrate requirements are reported as requirements for U_3O_8 or "yellowcake"; the enrichment service requirements are measured in separative work units; and the discharges of spent fuel are expressed in metric tons of initial heavy metal. The projected discharges of spent fuel exclude discharged fuel that is designated for reinsertion.

Nuclear Fuel Management Plans and Nuclear Fuel Burnup

Fuel management plans for the generic reactor categories were developed from a statistical analysis of historical fuel cycle data. The historical data include the following: capacity, fuel inserted per cycle (U_3O_8 , uranium metal, U-235), requirements for uranium enrichment service, cycle length, capacity factor, full-power days, spent fuel discharges, and fuel burnup.

Nuclear fuel burnup is a measure of the amount of energy produced from each metric ton of enriched uranium. The average discharge burnup levels have been increasing and increases are expected to continue. For boiling-water reactors, the average equilibrium spent fuel discharge burnup in 1992 was approximately 29,000 MWDT/MTIHM. The burnup values ranged from less than 20,000 to more than 37,000 MWDT/MTIHM. The majority of spent fuel discharges (79 percent) were between 26,000 and 35,000 MWDT/MTIHM. For pressurized-water reactors, the average equilibrium spent fuel discharge burnup in 1992 was

about 39,000 MWDT/MTIHM. The values ranged from under 20,000 to 54,000 MWDT/MTIHM, with the majority of spent fuel discharges (74 percent) between 34,000 and 45,000 MWDT/MTIHM. Table H5 shows projected equilibrium discharge burnup levels from 1993 through 2040.

Equilibrium design burnup levels for U.S. commercial nuclear fuel in the early 1980's were around 28,000 and 33,000 MWDT/MTIHM for boiling-water reactors and pressurized-water reactors, respectively. Engineering advances in fuel integrity and improved fuel management techniques were developed through a joint effort by Government and industry, resulting in higher burnups. In this report, fuel with design burnup above 28,000 MWDT/MTIHM for boiling-water reactors and 33,000 MWDT/MTIHM for pressurized-water reactors is referred to as "extended burnup fuel." The following pages of this Appendix describe the procedures used to develop fuel plans associated with extended fuel burnup levels.

A fuel plan consists of:

- Amount of uranium loaded
- Enrichment assay of the uranium loaded
- Planned number of full-power days
- Design burnup level of the discharged spent fuel.

In an ideal equilibrium cycle, any two of the above parameters determine the other two parameters. The equations relating the parameters are:

$$FB = SD \quad , \quad (1)$$

and

$$E = a + bB(1 + F) \quad , \quad (2)$$

where:

- F = fraction of the core being replaced in an equilibrium reloading,
- B = equilibrium discharge batch average burnup (megawattdays thermal per metric ton of initial heavy metal),
- D = equilibrium full-power days (days),
- S = core specific power (megawatts thermal per metric ton of initial heavy metal),
- F = enrichment assay (percent),

and a and b are regression coefficients.

The fraction of the core replaced is functionally equivalent to the amount of enriched uranium loaded. Equation (1) implies that in an equilibrium mode, the core average burnup, SD , equals the discharge batch average burnup, B , times the batch fractional average, F . For example, if $F = 1/3$ and $B = 33,000$ megawattdays thermal per metric ton of initial heavy metal, then the core average burnup is 11,000 megawattdays thermal per metric ton of initial heavy metal. That is, a batch of fuel stays in the core for three cycles, receiving an exposure of 11,000 megawattdays thermal per metric ton of initial heavy metal during each cycle. The core specific power, S , depends on the particular reactor and core configuration being considered. However, there is a high correlation between core specific power and the ratio of the reactor's rated thermal power to core size (uranium content), so that for modeling purposes, S can be considered invariant for an individual reactor.

Equation (2) assumes a linear reactivity model: that is, the rate of change of reactivity with fuel burnup is constant. The parameters a and b are fixed values determined from the analysis of a coupled thermal-hydraulic nuclear fuel cycle; b depends on bundle design, and a depends on leakage. Both a and b can be affected by design variables governing the conversion ratio and change in the slope of reactivity versus burnup. In an ideal equilibrium cycle, Equation (2) may be interpreted as relating enrichment assay to total burnup, where total burnup is defined as the sum of the discharge burnup, B , and the cycle equilibrium burnup, BF . In practice, the assumption of a linear relationship between enrichment assay and total burnup must be tempered because of the incorporation of burnable poisons with the nuclear fuel. Burnable poisons are used in higher burnup fuel to control reactivity and limit power peaking. The addition of burnable poisons to the nuclear fuel requires moderate increases in enrichment assays to obtain a given burnup objective. This additional U-235 requirement introduces an upward concavity in the enrichment-burnup relationship. However, Equation (2) does provide a good estimate of the relationship over a reasonable burnup range.

Under the conditions described above, Equations (1) and (2) provide a reasonable approximation for an ideal equilibrium cycle. To obtain generic parameters characterizing a typical boiling-water reactor and pressurized-water reactor, estimates of the coefficients in Equation (2) are obtained using a regression analysis.

The regression parameters in Equations (3) and (4) were estimated by a regression analysis applied to fuel management projections supplied to DOE by utilities on Form RW-859. Separate estimates were made for boiling-water reactors and pressurized-water reactors. Only fuel with zircalloy cladding was considered. Prior to applying the regression analysis, anomalous data were identified and eliminated from the analysis set. The R-squared values were 0.74 and 0.77 for pressurized-water reactors and boiling-water reactors (Table C1), respectively.

The "t" test was used to test the regression coefficients against the null hypothesis that they were not significantly different from zero. This test produces a statistical measure for determining whether a variable should be included in the model. In all cases, the coefficients were statistically significant at the 0.0001 level (Table C2).

Substituting the results of the regression analysis in Equation (2) yields the following expressions. For boiling-water reactors:

$$E = 1.087 + 0.0000454 B (1 + F) \quad (3)$$

For pressurized-water reactors:

$$E = 1.097 + 0.0000462 B (1 + F) \quad (4)$$

The projected discharge burnup data from Form RW-859, "Nuclear Fuel Data Survey," that was used in this analysis peaked at 39,000 megawattdays thermal per metric ton of initial heavy metal for boiling-water reactors and 48,000 megawattdays thermal per metric ton of initial heavy metal for pressurized-water reactors. Equations (3) and (4) are not applied to

Table C1. Results of the Regression Analysis of the Enrichment Assay Equations

Reactor Type	Independent Variable	Intercept	Burnup x (1 + Core Fraction)	R-squared
Boiling Water Reactor	Assay	1.087	0.0000454	0.77
Pressurized-Water	Assay	1.097	0.0000462	0.74

Table C2. Results of the Regression Coefficient Tests

Parameter	Reactor Type	
	Boiling Water Reactor	Pressurized-Water Reactor
Intercept		
Value from t Test	11.641	11.412
Significance Level	0.0001	0.0001
Burnup x (1 + Core Fraction)		
Value from t Test	21.369	27.389
Significance Level	0.0001	0.0001

burnup levels exceeding these limits, because utilities are only now developing fuel management plans for burnup levels past these limits, and utility-supplied data for fuel management plans associated with these higher burnup goals are not currently available. For higher burnup ranges, the following analysis is used to establish the relationship between burnup, enrichment assay, and core replacement fraction.

Estimates of the technical parameters in Equation (2) were supplied by General Electric Corporation. Equation (2) can be written in the following difference format:

$$\Delta E = b \Delta[B (1 + F)] \quad , \quad (5)$$

where Δ indicates the difference operator. This equation is applied to a given fuel management plan consisting of an assay E_1 , a burnup B , and a core fraction F_1 . If a new fuel management plan has a burnup B_2 and a core fraction F_2 , then

$$\Delta[B (1 + F)] = B_2 (1 + F_2) - B_1 (1 + F_1) \quad . \quad (6)$$

The change in enrichment assay is calculated by $\Delta E = b \Delta[B (1 + F)]$, and the new enrichment assay is given by $E_2 = E_1 + \Delta E$.

General Electric Corporation suggested that an appropriate value of b in the higher burnup ranges is 0.000063. This value of b provides a good approximation for both boiling-water reactors and pressurized-water reactors. Note that the value of the parameter a in Equation (2) depends on the generic reactor type. Using the General Electric Corporation value for b , Equation (5) becomes

$$\Delta E = 0.000063 \Delta[B (1 + F)] \quad . \quad (7)$$

As Equation (1) indicates, for a given discharge burnup and a given number of effective full-power days per cycle, the core fraction depends on the specific power of the reactor. The reactor fuel management plans used in the INM are based on the generic reactor types and implicitly incorporate a mean specific power value for a generic boiling-water and pressurized-water reactors, respectively.

Equation (1) is used to calculate the core fraction of a new fuel diet plan,

$$F = (S D) / B \quad , \quad (8)$$

Utilities typically develop fuel management plans to meet effective full-power days and discharge burnup goals. That is, they specify the amount of energy to be produced during the cycle and the desired discharge burnup of the fuel, and use these objectives to determine the amount and enrichment assay of the fresh uranium loaded. The burnup objectives are generally determined by economic and operational considerations.

Domestic and foreign fuel management plans for extended burnup are developed for generic boiling-water reactors and pressurized-water reactors (Tables C3 and C4). Each plan is based on assumptions for the number of effective full-power days for the cycle and a discharge burnup level. The years the fuel plan is used in the calculation of fuel requirements is noted in Tables C3 and C4. Trends in burnup and number of effective full-power day plans were obtained from utility-supplied data and industry experts.

Table C3. Domestic Fuel Management Plans for Extended Burnup Scenarios

Year Fuel Plan Is Used	Effective Full-Power Days	Core Fraction	Enrichment Assay (percent)	Design Burnup (MWDT/MTU)
Boiling-Water Reactors				
1993	411	0.287	3.02	33,000
1995	450	0.288	3.19	36,000
2002	489	0.289	3.32	39,000
2010	511	0.274	3.55	43,000
Pressurized-Water Reactor				
1993	431	0.380	3.76	42,000
1998	460	0.370	4.01	46,000
2004	485	0.359	4.32	50,000
2007	511	0.344	4.70	55,000

Table C4. Foreign Fuel Management Plans for Extended Burnup Scenarios

Year Fuel Plan Is Used	Effective Full-Power Days	Core Fraction	Enrichment Assay (Percent)	Design Burnup (MWDT/MTU)
Europe				
Boiling-Water Reactors				
1993	300	0.225	2.91	33,000
1995	300	0.206	3.06	36,000
1998	300	0.191	3.15	39,000
2004	300	0.173	3.35	43,000
2009	530	0.266	3.48	46,000
Pressurized-Water Reactor				
1993	281	0.278	3.39	39,000
1994	281	0.258	3.54	42,000
1998	281	0.235	3.72	46,000
2002	281	0.217	3.97	50,000
Far East				
Boiling-Water Reactors				
1993	355	0.256	3.17	33,000
1995	365	0.241	3.32	36,000
2001	395	0.241	3.44	39,000
2006	420	0.232	3.67	43,000
Pressurized-Water Reactor				
1993	355	0.367	3.51	35,000
1997	365	0.338	3.71	39,000
2001	395	0.332	3.94	43,000
2009	420	0.310	4.38	49,000

The following five steps were used to develop fuel models consistent with increases in fuel burnup and the number of effective full-power days per cycle. The procedure was applied separately to generic boiling-water reactors and pressurized-water reactors and for domestic and foreign reactors.

1. The mean core-specific power (ratio of megawatts thermal to core weight in metric tons of uranium) was converted separately for the boiling-water and pressurized-water reactors in the forecast data base.
2. The core fraction associated with a given burnup level and number of effective full-power days was computed by Equation (8).
3. The specified burnup level and the core fraction calculated in step 2 were used to estimate the enrichment assay. In the domestic fuel management plans for years 1991-1994 for BWR's and 1991-2002 for PWR's, Equations (3) and (4) were used to estimate the enrichment assay. For the

remaining years, Equation (7) was used to estimate the change in the enrichment assay, based on the increased burnup and change in core fraction.

4. The amount of uranium to be loaded was calculated as the product of the core fraction computed in step 2 and the total core weight.
5. Two types of adjustments were made to the enrichment assays estimated in step 3: (1) boiling-water reactor enrichments were adjusted downward by a small amount in the post-2000 period, to account for anticipated improvements in fuel utilization; (2) an enrichment adjustment of +0.2 percent was made to the Japanese enrichments. Japanese utilities have been historically very conservative when ordering nuclear fuel and have typically loaded fuel in their reactors with higher reactivity levels than customarily loaded in the West to obtain comparable burnup levels. This phenomenon is also evident in the higher U-235 enrichment content of the discharged fuel.

Appendix D

**U.S. Nuclear Units
Operable as of
December 31, 1992**

North Anna 1 and North Anna 2, located in Mineral, Virginia, has a net capacity of 848 and 909 MWe, respectively.

Appendix D

U.S. Nuclear Units Operable as of December 31, 1992

Table D1. Operable U.S. Nuclear Generating Units as of December 31, 1992

Site	Unit Name	Net Summer Capability ^a (net MWe)	Utility ^b	Reactor ^c		Month Operable ^d
				Type	Supplier	
Region I - New England						
Connecticut:						
Haddam Neck	Haddam Neck	560	Connecticut Yankee Atomic Power Co.	PWR	W	06/67
Waterford	Millstone 1	652	Northeast Nuclear Energy Co.	BWR	GE	10/70
Waterford	Millstone 2	863	Northeast Nuclear Energy Co.	PWR	C-E	09/75
Waterford	Millstone 3	1,137	Northeast Nuclear Energy Co.	PWR	W	01/86
Maine						
Wicasset	Maine Yankee	870	Maine Yankee Atomic Power Co.	PWR	C-E	06/73
Massachusetts						
Plymouth	Pilgrim 1	665	Boston Edison Co.	BWR	GE	09/72
New Hampshire						
Seabrook	Seabrook 1	1,150	Public Service Co. of NH	PWR	W	03/90
Vermont						
Vernon	Vermont Yankee 1	496	Vermont Yankee Nuclear Power Corp.	BWR	GE	02/73
Total Region I		6,393				
Region II - New York/New Jersey						
New Jersey:						
Salem	Hope Creek 1	1,031	Public Service Electric & Gas Co.	BWR	GE	07/86
Forked River	Oyster Creek 1	610	GPU Nuclear Corp.	BWR	GE	08/69
Salem	Salem 1	1,106	Public Serv. Electric & Gas Co.	PWR	W	12/76
Salem	Salem 2	1,106	Public Serv. Electric & Gas Co.	PWR	W	05/81
New York						
Buchanan	Indian Point 2	931	Consolidated Edison Co.	PWR	W	09/73
Buchanan	Indian Point 3	980	Power Authority of the State of New York	PWR	W	04/76
Scriba	James Fitzpatrick 1	800	Power Authority of the State of New York	BWR	GE	10/74

See footnotes at end of table.

Table D1. Operable U.S. Nuclear Generating Units as of December 31, 1992 (Continued)

Site	Unit Name	Net Summer Capability ^a (net MWe)	Utility ^b	Reactor ^c		Month Operable ^d
				Type	Supplier	
New York (Continued)						
Oswego	Nine Mile Point 1	605	Niagara Mohawk Power Corp.	BWR	GE	08/69
Oswego	Nine Mile Point 2	1,045	Niagara Mohawk Power Corp.	BWR	GE	07/87
Rochester	Robert E. Ginna	470	Rochester Gas & Electric Corp.	PWR	W	09/69
Total Region II		8,684				
Region III – Middle Atlantic						
Maryland:						
Lusby	Calvert Cliffs 1	825	Baltimore Gas & Electric Co.	PWR	C-E	07/74
Lusby	Calvert Cliffs 2	825	Baltimore Gas & Electric Co.	PWR	C-E	11/76
Pennsylvania:						
Middletown	3 Mile Island 1	808	GPU Nuclear Corp.	PWR	B&W	06/74
Shippingport	Beaver Valley 1	810	Duquesne Light Co.	PWR	W	07/76
Shippingport	Beaver Valley 2	833	Duquesne Light Co.	PWR	W	08/87
Pottstown	Limerick 1	1,055	Philadelphia Electric Co.	BWR	GE	08/85
Pottstown	Limerick 2	1,055	Philadelphia Electric Co.	BWR	GE	08/89
Lancaster	Peach Bottom 2	1,051	Philadelphia Elec/Public Serv	BWR	GE	12/73
Lancaster	Peach Bottom 3	1,035	Philadelphia Elec/Public Serv	BWR	GE	07/74
Berwick	Susquehanna 1	1,040	Pennsylvania Power & Light Co.	BWR	GE	11/82
Berwick	Susquehanna 2	1,044	Pennsylvania Power & Light Co.	BWR	GE	06/84
Virginia:						
Mineral	North Anna 1	848	Virginia Electric & Power Co.	PWR	W	04/78
Mineral	North Anna 2	909	Virginia Electric & Power Co.	PWR	W	08/80
Surry	Surry 1	781	Virginia Electric & Power Co.	PWR	W	05/72
Surry	Surry 2	781	Virginia Electric & Power Co.	PWR	W	01/73
Total Region III		13,700				
Region IV – South Atlantic						
Alabama:						
Decatur	Browns Ferry 1	1,065	Tennessee Valley Authority	BWR	GE	12/73
Dacatur	Browns Ferry 2	1,065	Tennessee Valley Authority	BWR	GE	08/74
Decatur	Browns Ferry 3	1,065	Tennessee Valley Authority	BWR	GE	08/76
Dothan	Joseph M. Farley 1	815	Alabama Power Co.	PWR	W	06/77
Dothan	Joseph M. Farley 2	826	Alabama Power Co.	PWR	W	03/81
Florida:						
Red Level	Crystal River 3	820	Florida Power Corp.	PWR	B&W	01/77
Ft. Pierce	St Lucie 1	839	Florida Power & Light Co.	PWR	C-E	03/76
Ft. Pierce	St Lucie 2	839	Florida Power & Light Co.	PWR	C-E	06/83
Florida City	Turkey Point 3	666	Florida Power & Light Co.	PWR	W	07/72
Florida City	Turkey Point 4	666	Florida Power & Light Co.	PWR	W	04/73

See footnotes at end of table.

Table D1. Operable U.S. Nuclear Generating Units as of December 31, 1992 (Continued)

Site	Unit Name	Net Summer Capability ^a (net MWe)	Utility ^b	Reactor ^c		Month Operable ^d
				Type	Supplier	
Georgia:						
Baxley	Hatch 1	748	Georgia Power Co.	BWR	GE	10/74
Baxley	Hatch 2	770	Georgia Power Co.	BWR	GE	06/78
Waynesboro	Vogtle 1	1,110	Georgia Power Co.	PWR	W	03/87
Waynesboro	Vogtle 2	1,114	Georgia Power Co.	PWR	W	03/89
Mississippi:						
Port Gibson	Grand Gulf 1	1,143	System Energy Resources, Inc.	BWR	GE	11/84
North Carolina:						
Southport	Brunswick 1	767	Carolina Power & Light Co.	BWR	GE	11/76
Southport	Brunswick 2	754	Carolina Power & Light Co.	BWR	GE	12/74
Cowens Ford	McGuire 1	1,129	Duke Power Co.	PWR	W	07/81
Cowens Ford	McGuire 2	1,129	Duke Power Co.	PWR	W	05/83
New Hill	Shearon Harris 1	860	Carolina Power & Light Co.	PWR	W	01/87
South Carolina:						
Clover	Catawba 1	1,129	Duke Power Co.	PWR	W	01/85
Clover	Catawba 2	1,129	Duke Power Co.	PWR	W	05/86
Hartsville	H.B. Robinson 2	683	Carolina Power & Light Co.	PWR	W	09/70
Seneca	Oconee 1	846	Duke Power Co.	PWR	B&W	02/73
Seneca	Oconee 2	846	Duke Power Co.	PWR	B&W	10/73
Seneca	Oconee 3	846	Duke Power Co.	PWR	B&W	07/74
Jenkinsville	Summer 1	885	South Carolina Electric & Gas Co.	PWR	W	11/82
Tennessee:						
Daisy	Sequoyah 1	1,148	Tennessee Valley Authority	PWR	W	09/80
Daisy	Sequoyah 2	1,148	Tennessee Valley Authority	PWR	W	09/81
Total Region IV		26,850				
Region V – Midwest						
Illinois:						
Braidwood	Braidwood 1	1,090	Commonwealth Edison Co.	PWR	W	07/87
Braidwood	Braidwood 2	1,090	Commonwealth Edison Co.	PWR	W	05/88
Byron	Byron 1	1,120	Commonwealth Edison Co.	PWR	W	02/85
Byron	Byron 2	1,120	Commonwealth Edison Co.	PWR	W	01/87
Clinton	Clinton 1	930	Illinois Power Co.	BWR	GE	04/87
Morris	Dresden 2	772	Commonwealth Edison Co.	BWR	GE	12/69
Morris	Dresden 3	773	Commonwealth Edison Co.	BWR	GE	03/71
Seneca	LaSalle 1	1,048	Commonwealth Edison Co.	BWR	GE	08/82
Seneca	LaSalle 2	1,048	Commonwealth Edison Co.	BWR	GE	03/84
Cordova	Quad Cities 1	769	Commonwealth Edison Co.	BWR	GE	12/72
Cordova	Quad Cities 2	769	Commonwealth Edison Co.	BWR	GE	12/72
Zion	Zion 1	1,040	Commonwealth Edison Co.	PWR	W	10/73
Zion	Zion 2	1,040	Commonwealth Edison Co.	PWR	W	11/73

See footnotes at end of table.

Table D1. Operable U.S. Nuclear Generating Units as of December 31, 1992 (Continued)

Site	Unit Name	Net Summer Capability ^a (net MWe)	Utility ^b	Reactor ^c		Month Operable ^d
				Type	Supplier	
Michigan:						
Charlevoix	Big Rock Point	67	Consumers Power Co.	BWR	GE	08/62
Bridgman	Donald C. Cook 1	1,000	Indiana/Michigan Power Co.	PWR	W	10/74
Bridgman	Donald C. Cook 2	1,060	Indiana/Michigan Power Co.	PWR	W	12/77
Newport	Fermi 2	1,060	Detroit Edison Co.	BWR	GE	07/85
South Haven	Palisades	755	Consumers Power Co.	PWR	C-E	10/72
Minnesota:						
Monticello	Monticello	532	Northern States Power Co.	BWR	GE	01/71
Red Wing	Prairie Island 1	510	Northern States Power Co.	PWR	W	04/74
Red Wing	Prairie Island 2	505	Northern States Power Co.	PWR	W	10/74
Ohio:						
Oak Harbor	Davis-Besse 1	877	Toledo Edison Co.	PWR	B&W	04/77
North Perry	Perry 1	1,169	Cleveland Electric Illum. Co.	BWR	GE	11/86
Wisconsin:						
Carlton	Kewaunee	522	Wisconsin Public Service Corp.	PWR	W	12/73
Two Creeks	Point Beach 1	492	Wisconsin Electric Power Co.	PWR	W	10/70
Two Creeks	Point Beach 2	492	Wisconsin Electric Power Co.	PWR	W	03/73
Total Region V		21,650				
Region VI – Southwest						
Arkansas:						
Russellville	Arkansas Nuclear 1	836	Arkansas Power & Light Co.	PWR	B&W	5/74
Russellville	Arkansas Nuclear 2	858	Arkansas Power & Light Co.	PWR	C-E	12/78
Louisiana:						
St. Francisville	River Bend 1	931	Gulf States Utilities Co.	BWR	GE	11/85
Taft	Waterford 3	1,075	Louisiana Power & Light Co.	PWR	C-E	03/85
Texas:						
Glen Rose	Comanche Peak 1	1,150	Texas Utilities Electric Co.	PWR	W	04/90
Bay City	South Texas 1	1,241	Houston Light & Power Co.	PWR	W	03/88
Bay City	South Texas 2	1,241	Houston Light & Power Co.	PWR	W	03/89
Total Region VI		7,332				
Region VII – Central						
Iowa:						
Palo	Duane Arnold	515	Iowa Electric Light & Power Co.	BWR	GE	02/74
Kansas:						
Burlington	Wolf Creek	1,159	Wolf Creek Nuclear Oper. Corp.	PWR	W	06/85
Missouri:						
Fulton	Callaway 1	1,125	Union Electric Co.	PWR	W	10/84

See footnotes at end of table.

Table D1. Operable U.S. Nuclear Generating Units as of December 31, 1992 (Continued)

Site	Unit Name	Net Summer Capability ^a (net MWe)	Utility ^b	Reactor ^c		Month Operable ^d
				Type	Supplier	
Nebraska:						
Brownville	Cooper 1	778	Nebraska Public Power District	BWR	GE	01/74
Fort Calhoun	Fort Calhoun 1	476	Omaha Public Power District	PWR	C-E	08/73
Total Region VII		4,053				
Region VIII - North Central No Operable Nuclear Generating Units						
Region IX – West						
Arizona:						
Wintersburg	Palo Verde 1	1,270	Arizona Public Service Co.	PWR	C-E	06/85
Wintersburg	Palo Verde 2	1,270	Arizona Public Service Co.	PWR	C-E	04/86
Wintersburg	Palo Verde 3	1,270	Arizona Public Service Co.	PWR	C-E	11/87
California:						
Avila Beach	Diablo Canyon 1	1,073	Pacific Gas & Electric Co.	PWR	W	11/84
Avila Beach	Diablo Canyon 2	1,087	Pacific Gas & Electric Co.	PWR	W	08/85
San Clemente	San Onofre 2	1,070	Southern California Edison Co.	PWR	C-E	09/82
San Clemente	San Onofre 3	1,080	Southern California Edison Co.	PWR	C-E	09/83
Total Region 9		8,120				
Region X – Northwest						
Oregon:						
Prescott	Trojan 1	1,104	Portland General Electric Co.	PWR	W	11/75
Washington:						
Richland	WNP 2	1,100	Washington Public Power Supply System	BWR	GE	04/84
Total Region X		2,204				
Total United States (109 Units)		98,985^e				

^aAs reported to the Energy Information Administration (EIA) Form-860, "Annual Electric Generator Report." MWe = megawatts-electric

^bPrincipal (majority) owner as reported on the EIA Form-860.

^cReactor Type: BWR, boiling-water reactor; PWR, pressurized-water reactor. Reactor Supplier: B&W, Babcock and Wilcox Co.; C-E, Combustion Engineering, Inc.; GE, General Electric; W, Westinghouse Electric Corporation.

^d"Month operable" is the date the unit received its full-power operating. Retired units are not included.

^eThis total is comprised of 37 BWR's (31,849 MWe) and 72 PWR's (67,137 MWe).

^fTotals may not equal sum of components due to independent rounding.

Source: Energy Information Administration Form EIA-860, "Annual Electric Generator Report." Nuclear Regulatory Commission, "Information Digest, 1992 Edition" (NUREG-0380) (May 1980) (for units which started operating after 1978); Program Summary Report (NUREG-1350, Vol. 4)(March 1992) (for units which started operating in 1960-1978).

Appendix E

**U.S. Nuclear
Generating Units
in the Construction
Pipeline as of
December 31, 1992**

Containment building at the North Anna power plant.

Appendix E

U.S. Nuclear Generating Units in the Construction Pipeline as of December 31, 1992

Table E1. Roster of U.S. Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, by Federal Region and State

Site	Unit Name	Net ^a Summer Capability (net MWe)	Utility ^b	Reactor ^c		Status		Estimated Operable Date		
				Type	Sup- plier	% Com- plete ^d	Li- cense ^e	EIA ^f		
								NN	LR	UF
Region I – New England		0								
Region II – New York/New Jersey		0								
Region III – Middle Atlantic		0								
Region IV – South Atlantic										
Alabama:										
Scottsboro	Bellefonte 1	1,212	Tennessee Valley Authority	PWR	B&W	80	C/ID	2001	2001	2000
Scottsboro	Bellefonte 2	1,212	Tennessee Valley Authority	PWR	B&W	45	C/ID	--	--	2002
Tennessee:										
Spring City	Watts Bar 1	1,170	Tennessee Valley Authority	PWR	W	86	C	1995	1994	1994
Spring City	Watts Bar 2	1,170	Tennessee Valley Authority	PWR	W	70	C	1996	1996	1996
Total Region IV		4,764								
Region V – Midwest										
Ohio:										
North Perry	Perry 2	1,169	Cleveland Electric Illuminating Co.	BWR	GE	57	C/ID	--	--	--
Total Region V		1,169								

See footnotes at end of table.

Table E1. Roster of U.S. Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, by Federal Region and State (Continued)

Site	Unit Name	Net ^a Summer Capability (net MWe)	Utility ^b	Reactor ^c		Status		Estimated Operable Date		
				Type	Sup- plier	% Com- plete ^d	Li- cense ^e	EIA ^f		
								NN	LR	UR
Region VI – Southwest										
Texas:										
Glen Rose	Comanche Peak 2	1,150	Texas Utilities Electric Co.	PWR	W	100	C	1993	1993	1993
Total Region VI		1,150								
Region X – Northwest										
Washington:										
Richland	WNP 1	1,250	Washington Public Power Supply System	PWR	B&W	65	C/ID	--	2005	2002
Richland	WNP 3	1,250	Washington Public Power Supply System	PWR	C-E	75	C/ID	--	--	--
Total Region X		2,500								
Total United States (8 Units)		9,583 ^g								

^aAs reported to the Energy Information Administration (EIA) on Form EIA-860, this value is estimated by the utility. MWe = megawatts-electric.

^bPrincipal owner.

^cReactor Type: BWR, boiling-water reactor; PWR, pressurized-water reactor. Reactor Suppliers: B&W, Babcock and Wilcox Co.; C-E, Combustion Engineering, Inc.; GE, General Electric Corporation; W, Westinghouse Corp.

^dLicense Status: C, construction permit issued; C/ID, construction pipeline, but indefinitely deferred.

^eNuclear News, World List of Nuclear Power Plants (March 1993).

^fEIA estimates for the Lower Reference (LR) and Upper Reference (UR) cases, as described in the text.

^gThis total is comprised of 1 BWR (1,169 MWe) and 7 PWR's (8,414 MWe).

Sources: Energy Information Administration (EIA) Form EIA-860 "Annual Electric Generator Report"; Nuclear News, "World List of Nuclear Power Plants (March 1993), pp. 41-60.

Appendix F

**Foreign Nuclear
Units Operable as of
December 31, 1992**

Japan Atomic Power Company, Ltd. currently operates Tsuruga 1 and 2.

Appendix F

Foreign Nuclear Units Operable as of December 31, 1992

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
Argentina	Atucha 1	Lima, Buenos Aires	335	CN	PHWR	SIEM/KWU	1974
	Embalse	Rio Tercero, Cordoba	600	CN	PHWR	AECL	1983
	Total	2 Units	935				
Belgium	Doel 1	East Flanders	392	EL	PWR	ACW	1974
	Doel 2	East Flanders	392	EL	PWR	ACW	1975
	Doel 3	East Flanders	900	EL	PWR	FRAM/ACW	1982
	Doel 4	East Flanders	1,010	EL	PWR	ACW	1985
	Tihange 1	Huy, Leige	£ 70	EL	PWR	ACLF	1975
	Tihange 2	Huy, Leige	900	EL	PWR	FRAM/ACW	1982
	Tihange 3	Huy, Leige	1,020	EL	PWR	ACW	1985
	Total	7 Units	5,484				
Brazil	Angra 1	Itaorna, Rio de Janeiro	626	BZ	PWR	WEST	1982
	Total	1 Unit	626				
Bulgaria	Kozloduy 1	Kozloduy, Vratsa	405	EA	PWR	AEE	1974
	Kozloduy 2	Kozloduy, Vratsa	405	EA	PWR	AEE	1975
	Kozloduy 3	Kozloduy, Vratsa	405	EA	PWR	AEE	1980
	Kozloduy 4	Kozloduy, Vratsa	405	EA	PWR	AEE	1982
	Kozloduy 5	Kozloduy, Vratsa	953	EA	PWR	AEE	1987
	Kozloduy 6	Kozloduy, Vratsa	953	EA	PWR	AEE	1991
	Total	6 Units	3,526				
Canada	Bruce 1	Tiverton, Ontario	769	ON	PHWR	AECL	1977
	Bruce 2	Tiverton, Ontario	769	ON	PHWR	AECL	1976
	Bruce 3	Tiverton, Ontario	769	ON	PHWR	AECL	1977
	Bruce 4	Tiverton, Ontario	769	ON	PHWR	AECL	1978
	Bruce 5	Tiverton, Ontario	860	ON	PHWR	AECL	1984
	Bruce 6	Tiverton, Ontario	860	ON	PHWR	AECL	1984
	Bruce 7	Tiverton, Ontario	860	ON	PHWR	AECL	1986
	Bruce 8	Tiverton, Ontario	860	ON	PHWR	AECL	1987
	Darlington 1	Newcastle Township, Ontario	881	ON	PHWR	AECL	1991
	Darlington 2	Newcastle Township, Ontario	881	ON	PHWR	AECL	1990

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
Canada (continued)	Darlington 3	Newcastle Township, Ontario	881	ON	PHWR	AECL	1992
	Gentilly 2	Becancour, Quebec	638	HQ	PHWR	AECL	1982
	Pickering 1	Pickering, Ontario	515	ON	PHWR	AECL	1971
	Pickering 2	Pickering, Ontario	515	ON	PHWR	AECL	1971
	Pickering 3	Pickering, Ontario	515	ON	PHWR	AECL	1972
	Pickering 4	Pickering, Ontario	515	ON	PHWR	AECL	1973
	Pickering 5	Pickering, Ontario	516	ON	PHWR	AECL	1982
	Pickering 6	Pickering, Ontario	516	ON	PHWR	AECL	1983
	Pickering 7	Pickering, Ontario	516	ON	PHWR	AECL	1984
	Pickering 8	Pickering, Ontario	516	ON	PHWR	AECL	1985
	Point Lepreau	Bay of Fundy, New Brunswick	640	NB	PHWR	AECL	1982
Total		21 Units	14,561				
China	Qinshan 1	Halyan, Zhejiang	300	MI	PWR	CNNC	1991
Total		1 Unit	300				
C.I.S. (Commonwealth of Independent States)							
Kazakhstan	BN 350	Aktau, Mangyshlak	135	KZ	LMFBR	MTM	1973
Total		1 Unit	135				
Russia	Balakovo 1	Balakovo, Saratov	950	UR	PWR	MTM	1985
	Balakovo 2	Balakovo, Saratov	950	UR	PWR	MTM	1987
	Balakovo 3	Balakovo, Saratov	950	UR	PWR	MTM	1988
	Beloyarskiy 3	Zarechnyy, Sverdlovsk	560	UR	LMFBR	MTM	1980
	Bilibino A	Bilibino, Russia	11	UR	LGR	MTM	1974
	Bilibino B	Bilibino, Russia	11	UR	LGR	MTM	1974
	Bilibino C	Bilibino, Russia	11	UR	LGR	MTM	1975
	Bilibino D	Bilibino, Russia	11	UR	LGR	MTM	1976
	Kalinin 1	Udomlya, Tver	950	UR	PWR	MTM	1984
	Kalinin 2	Udomlya, Tver	950	UR	PWR	MTM	1986
	Kola 1	Polyarnyye Zori, Murmansk	411	UR	PWR	MTM	1973
	Kola 2	Polyarnyye Zori, Murmansk	411	UR	PWR	MTM	1974
	Kola 3	Polyarnyye Zori, Murmansk	411	UR	PWR	MTM	1981
	Kola 4	Polyarnyye Zori, Murmansk	411	UR	PWR	MTM	1984
	Kursk 1	Kurchatov, Kursk	925	UR	LGR	MTM	1976
	Kursk 2	Kurchatov, Kursk	925	UR	LGR	MTM	1979
	Kursk 3	Kurchatov, Kursk	925	UR	LGR	MTM	1983
	Kursk 4	Kurchatov, Kursk	925	UR	LGR	MTM	1985
	Novovoronezh 3	Novovoronezhskiy, Voronezh	385	UR	PWR	MTM	1971
	Novovoronezh 4	Novovoronezhskiy, Voronezh	385	UR	PWR	MTM	1972
	Novovoronezh 5	Novovoronezhskiy, Voronezh	950	UR	PWR	MTM	1980
	Smolensk 1	Desnogorsk, Smolensk	925	UR	LGR	MTM	1982
	Smolensk 2	Desnogorsk, Smolensk	925	UR	LGR	MTM	1985
	Smolensk 3	Desnogorsk, Smolensk	925	UR	LGR	MTM	1990
	Sosnovyy Bor 1	Sosnovyy Bor, St. Petersburg	376	UR	LGR	MTM	1973
	Sosnovyy Bor 2	Sosnovyy Bor, St. Petersburg	376	UR	LGR	MTM	1975

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
Russia (continued)	Sosnovyy Bor 3	Sosnovyy Bor, St. Petersburg	925	UR	LGR	MTM	1979
	Sosnovyy Bor 4	Sosnovyy Bor, St. Petersburg	925	UR	LGR	MTM	1981
Total	28 Units^f		17,795				
Ukraine	Chernobyl 1	Prityal, Kiev	925	UK	LGR	MTM	1977
	Chernobyl 2	Prityal, Kiev	925	UK	LGR	MTM	1978
	Chernobyl 3	Prityal, Kiev	925	UK	LGR	MTM	1981
	Khmelnitsky 1	Neteshin, Khmelnitsky	950	UK	PWR	MTM	1987
	Rovno 1	Kuznetsovsk, Rovno	361	UK	PWR	MTM	1980
	Rovno 2	Kuznetsovsk, Rovno	384	UK	PWR	MTM	1981
	Rovno 3	Kuznetsovsk, Rovno	950	UK	PWR	MTM	1986
	South Ukraine 1	Konstantinovka, Nikolaev	950	UK	PWR	MTM	1982
	South Ukraine 2	Konstantinovka, Nikolaev	950	UK	PWR	MTM	1985
	South Ukraine 3	Konstantinovka, Nikolaev	950	UK	PWR	MTM	1989
	Zaporozhye 1	Energodar, Zaporozhye	950	UK	PWR	MTM	1984
	Zaporozhye 2	Energodar, Zaporozhye	950	UK	PWR	MTM	1985
	Zaporozhye 3	Energodar, Zaporozhye	950	UK	PWR	MTM	1986
	Zaporozhye 4	Energodar, Zaporozhye	950	UK	PWR	MTM	1987
	Zaporozhye 5	Energodar, Zaporozhye	950	UK	PWR	MTM	1989
Total	15 Units		13,020				
Czech Republic	Dukovany 1	Třebic, Jihomoravsky	408	CP	PWR	SKODA	1985
	Dukovany 2	Třebic, Jihomoravsky	408	CP	PWR	SKODA	1986
	Dukovany 3	Třebic, Jihomoravsky	408	CP	PWR	SKODA	1987
	Dukovany 4	Třebic, Jihomoravsky	408	CP	PWR	SKODA	1988
Total	4 Units		1,632				
Finland	Loviisa 1	Loviisa, Uusimaa	445	IV	PWR	AEE	1977
	Loviisa 2	Loviisa, Uusimaa	445	IV	PWR	AEE	1980
	TVO 1	Olkiluoto, Turku Pori	710	TV	BWR	A-A	1978
	TVO 2	Olkiluoto, Turku Pori	710	TV	BWR	A-A	1980
Total	4 Units		2,310				
France	Belleville 1	Loire, Cher	1,310	EF	PWR	FRAM	1987
	Belleville 2	Loire, Cher	1,310	EF	PWR	FRAM	1988
	Blayais 1	Blaye, Gironde	910	EF	PWR	FRAM	1981
	Blayais 2	Blaye, Gironde	910	EF	PWR	FRAM	1983
	Blayais 3	Blaye, Gironde	910	EF	PWR	FRAM	1983
	Blayais 4	Blaye, Gironde	910	EF	PWR	FRAM	1983
	Bugey 1	Loyettes, Ain	540	EF	GCR	VAR	1972
	Bugey 2	Loyettes, Ain	920	EF	PWR	FRAM	1978

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
France (continued)	Bugey 3	Loyettes, Ain	920	EF	PWR	FRAM	1978
	Bugey 4	Loyettes, Ain	900	EF	PWR	FRAM	1979
	Bugey 5	Loyettes, Ain	900	EF	PWR	FRAM	1979
	Cattenom 1	Cattenom, Moselle	1,300	EF	PWR	FRAM	1986
	Cattenom 2	Cattenom, Moselle	1,300	EF	PWR	FRAM	1987
	Cattenom 3	Cattenom, Moselle	1,300	EF	PWR	FRAM	1990
	Cattenom 4	Cattenom, Moselle	1,300	EF	PWR	FRAM	1991
	Chinon B1	Chinon, Indre-et-Loire	905	EF	PWR	FRAM	1982
	Chinon B2	Chinon, Indre-et-Loire	870	EF	PWR	FRAM	1983
	Chinon B3	Chinon, Indre-et-Loire	905	EF	PWR	FRAM	1986
	Chinon B4	Chinon, Indre-et-Loire	905	EF	PWR	FRAM	1987
	Creys-Malville	Bouvesse, Isere	1,200	CR	LMFBR	NOVA	1986
	Cruas 1	Cruas, Ardeche	880	EF	PWR	FRAM	1983
	Cruas 2	Cruas, Ardeche	915	EF	PWR	FRAM	1984
	Cruas 3	Cruas, Ardeche	880	EF	PWR	FRAM	1984
	Cruas 4	Cruas, Ardeche	880	EF	PWR	FRAM	1984
	Dampierre 1	Ouzouer, Loiret	890	EF	PWR	FRAM	1980
	Dampierre 2	Ouzouer, Loiret	890	EF	PWR	FRAM	1981
	Dampierre 3	Ouzouer, Loiret	890	EF	PWR	FRAM	1981
	Dampierre 4	Ouzouer, Loiret	890	EF	PWR	FRAM	1981
	Fessenheim 1	Fessenheim, Haut-Rhin	880	EF	PWR	FRAM	1977
	Fessenheim 2	Fessenheim, Haut-Rhin	880	EF	PWR	FRAM	1977
	Flamanville 1	Flamanville, Manche	1,330	EF	PWR	FRAM	1985
	Flamanville 2	Flamanville, Manche	1,330	EF	PWR	FRAM	1986
	Golfech 1	Valence, Tam et Garonne	1,310	EF	PWR	FRAM	1990
	Gravelines B1	Gravelines, Nord	910	EF	PWR	FRAM	1980
	Gravelines B2	Gravelines, Nord	910	EF	PWR	FRAM	1980
	Gravelines B3	Gravelines, Nord	910	EF	PWR	FRAM	1981
	Gravelines B4	Gravelines, Nord	910	EF	PWR	FRAM	1981
	Gravelines C5	Gravelines, Nord	910	EF	PWR	FRAM	1984
	Gravelines C6	Gravelines, Nord	910	EF	PWR	FRAM	1985
	Nogent sur Seine 1	Nogent sur Seine, Aube	1,310	EF	PWR	FRAM	1987
	Nogent sur Seine 2	Nogent sur Seine, Aube	1,310	EF	PWR	FRAM	1988
	Paluel 1	Veulettes, Seine-Maritime	1,330	EF	PWR	FRAM	1984
	Paluel 2	Veulettes, Seine-Maritime	1,330	EF	PWR	FRAM	1984
	Paluel 3	Veulettes, Seine-Maritime	1,330	EF	PWR	FRAM	1985
	Paluel 4	Veulettes, Seine-Maritime	1,330	EF	PWR	FRAM	1986
	Penley 1	St.-Martin-en, Seine-Maritime	1,330	EF	PWR	FRAM	1990
	Penley 2	St.-Martin-en, Seine-Maritime	1,330	EF	PWR	FRAM	1992
	Phenix	Marcoule, Gard	233	CE	LMFBR	CNIM	1973
	Saint-Laurent B1	St-Laurent-des-Eaux, Loir-et-Cher	915	EF	PWR	FRAM	1981
	Saint-Laurent B2	St-Laurent-des-Eaux, Loir-et-Cher	880	EF	PWR	FRAM	1981

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
France (continued)	Saint-Alban 1	Auberives, Isere	1,335	EF	PWR	FRAM	1985
	Saint-Alban 2	Auberives, Isere	1,335	EF	PWR	FRAM	1986
	Tricastin 1	Pierrelatte, Drome	915	EF	PWR	FRAM	1980
	Tricastin 2	Pierrelatte, Drome	915	EF	PWR	FRAM	1980
	Tricastin 3	Pierrelatte, Drome	915	EF	PWR	FRAM	1981
	Tricastin 4	Pierrelatte, Drome	915	EF	PWR	FRAM	1981
Total		56 Units	57,688				
Germany	Biblis A	Biblis, Hessen	1,146	RW	PWR	KWU	1974
	Biblis B	Biblis, Hessen	1,240	RW	PWR	KWU	1976
	Brokdorf	Brokdorf, Schleswig-Holstein	1,307	BK	PWR	KWU	1986
	Brunsbuettel	Brunsbuettel, Schleswig-Holstein	771	KG	BWR	KWU	1977
	Emsland	Lingen, Niedersachsen	1,270	KN	PWR	KWU	1988
	Grafenrheinfeld KKG	Grafenrheinfeld, Bayern	1,235	BY	PWR	KWU	1982
	Grohnde	Emmerthal, Niedersachsen	1,325	GG	PWR	KWU	1984
	Gundremmingen B	Gundremmingen, Bayern	1,240	KB	BWR	KWU	1984
	Gundremmingen C	Gundremmingen, Bayern	1,248	KB	BWR	KWU	1984
	Isar 1	Essenbach, Bayern	870	KI	BWR	KWU	1977
	Isar 2	Essenbach, Bayern	1,285	KI	PWR	KWU	1988
	Kruemmel	Geesthacht, Schleswig-Holstein	1,260	KK	BWR	KWU	1983
	Muelheim-Kaerlich	Rheinland, Pfalz	1,219	RW	PWR	BBR	1986
	Neckarwestheim 1	Neckarwestheim, Baden-Wuerttemberg	785	GK	PWR	KWU	1976
	Neckarwestheim 2	Neckarwestheim, Baden-Wuerttemberg	1,269	GK	PWR	KWU	1989
	Obrigheim	Obrigheim, Baden-Wuerttemberg	340	KO	PWR	SIEM	1968
	Philippsburg 1	Philippsburg, Baden-Wuerttemberg	864	KP	BWR	KWU	1979
	Philippsburg 2	Philippsburg, Baden-Wuerttemberg	1,276	KP	PWR	KWU	1984
	Stade	Stade, Niedersachsen	640	KS	PWR	SIEM	1972
	Unterweser	Rodenkirchen, Niedersachsen	1,230	KU	PWR	KWU	1978
	Wuergassen KWW	Lauenforde, Niedersachsen	640	PR	BWR	AEG	1971
Total		21 Units	22,460				
Hungary	Paks 1	Paks, Tolna	430	HP	PWR	AEE/SKODA	1982
	Paks 2	Paks, Tolna	433	HP	PWR	AEE/SKODA	1984
	Paks 3	Paks, Tolna	433	HP	PWR	AEE/SKODA	1986
	Paks 4	Paks, Tolna	433	HP	PWR	AEE/SKODA	1987
Total		4 Units	1,729				

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
India	Kakrapar 1	Kakrapar, Gujarat	220	IA	PHWR	DAE/NP	1992
	Madras 1	Kalpakkam, Tamil Nadu	220	IA	PHWR	DAE	1983
	Madras 2	Kalpakkam, Tamil Nadu	220	IA	PHWR	DAE	1985
	Narora 1	Narora, Uttar Pradesh	220	IA	PHWR	DAE/NP	1989
	Narora 2	Narora, Uttar Pradesh	220	IA	PHWR	DAE/NP	1992
	Rajasthan 1	Kota, Rajasthan	207	IA	PHWR	CGE	1972
	Rajasthan 2	Kota, Rajasthan	207	IA	PHWR	L-T	1980
	Tarapur 1	Tarapur, Maharashtra	160	IA	BWR	GE	1969
	Tarapur 2	Tarapur, Maharashtra	160	IA	BWR	GE	1969
Total		9 Units	1,834				
Japan	Fugen ATR	Tsuruga, Fukui	148	PF	HWLWR	HIT/MHI	1978
	Fukushima Daiichi 1	Ohkuma, Fukushima	439	TP	BWR	GE	1970
	Fukushima Daiichi 2	Ohkuma, Fukushima	760	TP	BWR	GE	1973
	Fukushima Daiichi 3	Ohkuma, Fukushima	760	TP	BWR	TOS	1974
	Fukushima Daiichi 4	Ohkuma, Fukushima	760	TP	BWR	HIT	1978
	Fukushima Daiichi 5	Ohkuma, Fukushima	760	TP	BWR	TOS	1977
	Fukushima Daiichi 6	Ohkuma, Fukushima	1,067	TP	BWR	GE	1979
	Fukushima Daiichi 1	Naraha, Fukushima	1,067	TP	BWR	TOS	1981
	Fukushima Daiichi 2	Naraha, Fukushima	1,067	TP	BWR	HIT	1983
	Fukushima Daiichi 3	Naraha, Fukushima	1,067	TP	BWR	TOS	1984
	Fukushima Daiichi 4	Naraha, Fukushima	1,067	TP	BWR	HIT	1987
	Genkal 1	Genkal, Saga	529	KY	PWR	MHI	1975
	Genkal 2	Genkal, Saga	529	KY	PWR	MHI	1980
	Hamaoka 1	Hamaoka-cho, Shizuoka	515	CB	BWR	TOS	1975
	Hamaoka 2	Hamaoka-cho, Shizuoka	806	CB	BWR	TOS	1978
	Hamaoka 3	Hamaoka-cho, Shizuoka	1,056	CB	BWR	TOS	1987
	Ikata 1	Ikata-cho, Ehime	538	SH	PWR	MHI	1977
	Ikata 2	Ikata-cho, Ehime	538	SH	PWR	MHI	1981
	Kashiwazaki Karwa 1	Kashiwazaki, Niigata	1,067	TP	BWR	TOS	1985
	Kashiwazaki Karwa 2	Kashiwazaki, Niigata	1,067	TP	BWR	TOS	1990
	Kashiwazaki Karwa 3	Kashiwazaki, Niigata	1,067	TP	BWR	TOS	1992
	Kashiwazaki Karwa 5	Kashiwazaki, Niigata	1,067	TP	BWR	HIT	1989
	Mihama 1	Mihama-cho, Fukui	320	KA	PWR	WEST	1970
	Mihama 2	Mihama-cho, Fukui	470	KA	PWR	MHI	1972
	Mihama 3	Mihama-cho, Fukui	780	KA	PWR	MHI	1976
	Ohi 1	Ohi-cho, Fukui	1,120	KA	PWR	WEST	1977
	Ohi 2	Ohi-cho, Fukui	1,120	KA	PWR	WEST	1978
	Ohi 3	Ohi-cho, Fukui	1,127	KA	PWR	MHI	1991
	Ohi 4	Ohi-cho, Fukui	1,127	KA	PWR	MHI	1992
	Onagawa 1	Onagawa, Miyagi	497	TC	BWR	TOS	1983
	Sendai 1	Sendai, Kagoshima	846	KY	PWR	MHI	1983
	Sendai 2	Sendai, Kagoshima	846	KY	PWR	MHI	1985
	Shimane 1	Kashima-cho, Shimane	439	CK	BWR	HIT	1973
	Shimane 2	Kashima-cho, Shimane	790	CK	BWR	HIT	1988
	Takahama 1	Takahama-cho, Fukui	780	KA	PWR	WEST	1974
	Takahama 2	Takahama-cho, Fukui	780	KA	PWR	MHI	1975

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
Japan (continued)	Takahama 3	Takahama-cho, Fukuoka	830	KA	PWR	MHI	1984
	Takahama 4	Takahama-cho, Fukuoka	830	KA	PWR	MHI	1984
	Tokai 1	Tokai Mura, Ibaraki	159	JP	GCR	GEC	1965
	Tokai 2	Tokai Mura, Ibaraki	1,080	JP	BWR	GE	1978
	Tomari 1	Tomari-mura, Hokkaido	550	HD	PWR	MHI	1988
	Tomari 2	Tomari-mura, Hokkaido	550	HD	PWR	MHI	1990
	Tsuruga 1	Tsuruga, Fukui	341	JP	BWR	GE	1969
	Tsuruga 2	Tsuruga, Fukui	1,115	JP	PWR	MHI	1986
Total		44 Units	34,238				
Korea, South	Kori 1	Kori, Kyongnam	556	KR	PWR	WEST	1977
	Kori 2	Kori, Kyongnam	605	KR	PWR	WEST	1983
	Kori 3	Kori, Kyongnam	895	KR	PWR	WEST	1985
	Kori 4	Kori, Kyongnam	895	KR	PWR	WEST	1985
	Ulchin 1	Ulchin, Kyongbuk	920	KR	PWR	FRAM	1988
	Ulchin 2	Ulchin, Kyongbuk	920	KR	PWR	FRAM	1989
	Wolsong 1	Kyongju, Kyongbuk	629	KR	PHWR	AECL	1982
	Yonggwang 1	Yonggwang, Chonnam	900	KR	PWR	WEST	1986
	Yonggwang 2	Yonggwang, Chonnam	900	KR	PWR	WEST	1987
Total		9 Units	7,220				
Lithuania	Ignalina 1	Snieckus, Lithuania	1,250	ME	LGR	MTM	1983
	Ignalina 2	Snieckus, Lithuania	1,250	ME	LGR	MTM	1987
Total		2 Units	2,500				
Mexico	Laguna Verde 1	Laguna Verde, Veracruz	654	FC	BWR	GE	1989
Total		1 Unit	654				
Netherlands	Borssele	Borssele, Zeeland	452	PZ	PWR	KWU/RDM	1973
	Dordrecht	Dordrecht, Gelderland	55	GN	BWR	GE/RDM	1968
Total		2 Units	507				
Pakistan	Kanupp	Karachi, Sind	125	PA	PHWR	CGE	1971
Total		1 Unit	125				
Slovak Republic	Bohunice 1	Trnava, Zapadoslovensky	408	SP	PWR	AEE	1978
	Bohunice 2	Trnava, Zapadoslovensky	408	SP	PWR	AEE	1980
	Bohunice 3	Trnava, Zapadoslovensky	408	SP	PWR	SKODA	1984
	Bohunice 4	Trnava, Zapadoslovensky	408	SP	PWR	SKODA	1985
Total		4 Units	1,632				

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
Slovenia	Krsko	Krsko, Vrblina	620	SL	PWR	WEST	1981
Total	1 Unit		620				
South Africa	Koeberg 1	Melkbosstrand, Capetown	920	EK	PWR	FRAM	1983
	Koeberg 2	Melkbosstrand, Capetown	920	EK	PWR	FRAM	1985
Total	2 Units		1,840				
Spain	Almaraz 1	Almaraz, Caceres	900	CS	PWR	WEST	1981
	Almaraz 2	Almaraz, Caceres	900	CS	PWR	WEST	1983
	Asco 1	Asco, Tarragona	898	AN	PWR	WEST	1983
	Asco 2	Asco, Tarragona	898	AN	PWR	WEST	1985
	Coferentes	Coferentes, Valencia	958	IB	BWR	GE	1984
	Jose Cabrera	Zorita, Guadalajara	153	UE	PWR	WEST	1968
	Santa Maria de Garona	Santa Maria de Garona, Burgos	440	CD	BWR	GE	1971
	Trillo 1	Trillo, Guadalajara	1,000	CT	PWR	KWU/ENSA	1988
	Vandellors 2	Vandellors, Tarragona	950	AV	PWR	WEST	1987
Total	9 Units		7,097				
Sweden	Barsebaeck 1	Barsebaeck, Malmohus	600	SY	BWR	A-A	1975
	Barsebaeck 2	Barsebaeck, Malmohus	600	SY	BWR	A-A	1977
	Forsmark 1	Forsmark, Uppsala	970	VA	BWR	A-A	1980
	Forsmark 2	Forsmark, Uppsala	970	VA	BWR	A-A	1981
	Forsmark 3	Forsmark, Uppsala	1,155	VA	BWR	A-A	1984
	Oskarshamn 1	Oskarshamn, Kalmar	442	OK	BWR	A-A	1971
	Oskarshamn 2	Oskarshamn, Kalmar	605	OK	BWR	A-A	1974
	Oskarshamn 3	Oskarshamn, Kalmar	1,160	OK	BWR	A-A	1985
	Ringhals 1	Varberg, Halland	795	VA	BWR	A-A	1974
	Ringhals 2	Varberg, Halland	875	VA	PWR	WEST	1974
	Ringhals 3	Varberg, Halland	915	VA	PWR	WEST	1980
	Ringhals 4	Varberg, Halland	915	VA	PWR	WEST	1982
Total	12 Units		10,002				
Switzerland	Beznau 1	Doettingen, Aargau	350	NK	PWR	WEST	1969
	Beznau 2	Doettingen, Aargau	350	NK	PWR	WEST	1971
	Goesgen	Daeniken, Solothurn	920	GP	PWR	KWU	1979
	Leibstadt	Leibstadt, Aargau	990	LK	BWR	GETSCO	1984
	Muehleberg	Muehleberg, Bern	326	BR	BWR	GETSCO	1971
Total	5 Units		2,936				
Taiwan	Chinshan 1	Chinshan, Taipei	604	TW	BWR	GE	1977
	Chinshan 2	Chinshan, Taipei	604	TW	BWR	GE	1978

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
Taiwan (continued)	Kuosheng 1	Kuosheng, Wang-Li, Taipei	948	TW	BWR	GE	1981
	Kuosheng 2	Kuosheng, Wang-Li, Taipei	948	TW	BWR	GE	1982
	Maanshan 1	Heng Chuen	890	TW	PWR	WEST	1984
	Maanshan 2	Heng Chuen	890	TW	PWR	WEST	1985
Total		6 Units	4,884				
United Kingdom	Bradwell 1	Bradwell, Essex	123	NE	GCR	TNPG	1962
	Bradwell 2	Bradwell, Essex	123	NE	GCR	TNPG	1962
	Calder Hall 1	Seascale, Cumbria	50	BF	GCR	UKAE	1956
	Calder Hall 2	Seascale, Cumbria	50	BF	GCR	UKAE	1957
	Calder Hall 3	Seascale, Cumbria	50	BF	GCR	UKAE	1958
	Calder Hall 4	Seascale, Cumbria	50	BF	GCR	UKAE	1959
	Chapelcross 1	Annan, Dumfriesshire	50	BF	GCR	UKAE	1953
	Chapelcross 2	Annan, Dumfriesshire	50	BF	GCR	UKAE	1959
	Chapelcross 3	Annan, Dumfriesshire	50	BF	GCR	UKAE	1959
	Chapelcross 4	Annan, Dumfriesshire	50	BF	GCR	UKAE	1960
	Dounreay PFR	Dounreay, Highland	250	AE	LMFBR	TNPG	1975
	Dungeness A1	Lydd, Kent	212	NE	GCR	TNPG	1965
	Dungeness A2	Lydd, Kent	212	NE	GCR	TNPG	1965
	Dungeness B1	Lydd, Kent	415	NE	AGR	APC	1983
	Dungeness B2	Lydd, Kent	415	NE	AGR	APC	1985
	Hartlepool A1	Hartlepool, Cleveland	510	NE	AGR	NNC	1983
	Hartlepool A2	Hartlepool, Cleveland	510	NE	AGR	NNC	1984
	Heysham A1	Heysham, Lancashire	550	NE	AGR	NNC	1983
	Heysham A2	Heysham, Lancashire	550	NE	AGR	NNC	1984
	Heysham B1	Heysham, Lancashire	615	NE	AGR	NNC	1988
	Heysham B2	Heysham, Lancashire	615	NE	AGR	NNC	1988
	Hinkley Point A1	Hinkley Point, Somerset	235	NE	GCR	EBT	1965
	Hinkley Point A2	Hinkley Point, Somerset	235	NE	GCR	EBT	1965
	Hinkley Point B1	Hinkley Point, Somerset	560	NE	AGR	TNPG	1976
	Hinkley Point B2	Hinkley Point, Somerset	560	NE	AGR	TNPG	1978
	Hunterston B1	Ayrshire, Strathclyde	625	SC	AGR	TNPG	1976
	Hunterston B2	Ayrshire, Strathclyde	625	SC	AGR	TNPG	1977
	Oldbury 1	Oldbury, Avon	217	NE	GCR	TNPG	1967
	Oldbury 2	Oldbury, Avon	217	NE	GCR	TNPG	1968
	Sizewell A1	Sizewell, Suffolk	210	NE	GCR	EBT	1966
	Sizewell A2	Sizewell, Suffolk	210	NE	GCR	EBT	1966
	Torness 1	Dunbar, East Lothian	700	SC	AGR	NNC	1988
	Torness 2	Dunbar, East Lothian	700	SC	AGR	NNC	1989
	Trawsfynydd 1	Gwynedd, Wales	195	NE	GCR	APC	1965
	Trawsfynydd 2	Gwynedd, Wales	195	NE	GCR	APC	1965

See footnotes at end of table.

Table F1. Roster of Nuclear Generating Units Operable as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Reactor Type ^d	Reactor Supplier ^e	Date of Operation
United Kingdom	Wyffa 1	Anglesey, Wales	475	NE	GCR	EBT	1971
(continued)	Wyffa 2	Anglesey, Wales	475	NE	GCR	EBT	1971
Total		37 Units	11,934				
Total Operable Capacity in Foreign Countries (315 Units)			230,224				

^aEIA's review of the latest data sources has resulted in revisions of names, capacities, and grid operation dates.

^bMWe = megawatts-electric.

^cSee Table F2 for key to abbreviations of utility names.

^dReactor Types: AGR, advanced gas-cooled reactor; BWR, boiling-water reactor; GCR, gas-cooled reactor; LGR, light-water cooled, graphite-moderated reactor; HWLWR, heavy-water-moderated, boiling light-water-cooled reactor; LMFBR, liquid metal fast breeder reactor; PHWR, pressurized heavy-water-moderated and cooled reactor; PWR, pressurized-water reactor.

^eSee Table F3 for key to abbreviations of reactor supplier names.

^fThe four Billbino units A through D, located in Russia are 11 MWe each and are primarily used for district water heating.

Sources: *Nuclear News*, "World List of Nuclear Power Plants" (March 1993), pp. 41-60; *Nucleonics Week* (various issues); *Nuclear Engineering International*, "World Nuclear Industry Handbook, 1993," Country-by Country Programme Summary, pp. 26-54; International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1993), pp. 8, 9.

Table F2. Key to Utility Codes for Rosters of Foreign Commercial Nuclear Generating Units

Code	Name of Utility	Country
AE	AEA Technology	United Kingdom
AN	Asociacion Nuclear Asco	Spain
AV	Asociacion Nuclear Vandellos	Spain
BF	British Nuclear Fuels plc	United Kingdom
BK	Kernkraftwerke Brokdorf GmbH	Germany
BR	Bernische Kraftwerke AG	Switzerland
BY	Bayernwerk AG	Germany
BZ	Furnas Centrais Electricas, SA	Brazil
CB	Chubu Electric Power Company	Japan
CD	Centrales Nucleares del Norte, SA	Spain
CE	Commissariat a L'Energie Atomique	France
CK	Chugoku Electric Power Company, Inc.	Japan
CN	Comision Nacional de Energia Atomica (CNEA)	Argentina
CP	Czech Power Board	Czech Republic
CR	Centrale Nucleaire Europeene a Neutrons Rapides, S.A. (NERSA)	France
CS	Central Nuclear de Almaraz	Spain
CT	Central de Trillo	Spain
CU	Ministry of Basic Industries	Cuba
CV	Central Nuclear de Valdecaballeros	Spain
EA	National Electric Company	Bulgaria
EF	Electricite de France	France
EK	Eskom	South Africa
EL	Electrabel	Belgium
FC	Comision Federal de Electricidad	Mexico
GG	Gemeinschaftskernkraftwerk Grohnde GmbH	Germany
GK	Gemeinschaftskernkraftwerk Neckar	Germany
GN	NV Gemeenschappelijke Kernenergiecentrale Nederland	Netherlands
GP	Kernkraftwerk Goesgen-Daeniken AG	Switzerland
GV	Guangdong Nuclear Power Joint Venture Company, Ltd.	China
HD	Hokkaido Electric Power Company, Inc.	Japan
HP	Hungarian Power Companies, Ltd.	Hungary
HQ	Hydro Quebec	Canada
HU	Hokuriku Electric Power Company	Japan
IA	Atomic Energy Commission, Department of Atomic Energy	India
IB	Iberdrola SA	Spain
IV	Imatran Voima Oy (IVO)	Finland
JP	Japan Atomic Power Company, Ltd.	Japan
KA	Kansai Electric Power Company, Inc.	Japan
KB	Kernkraftwerk RWE-Bayernwerk GmbH	Germany
KG	Kernkraftwerk Brunsbittel GmbH	Germany
KI	Kernkraftwerk Isar	Germany
KK	Kernkraftwerk Kruemmel GmbH	Germany
KN	Kernkraftwerk Lippe-Emsland GmbH	Germany
KO	Kernkraftwerk Obrigheim GmbH	Germany
KP	Kernkraftwerk Philippsburg	Germany
KR	Korea Electric Power Company	Korea, South

Table F2. Key to Utility Codes for Rosters of Foreign Commercial Nuclear Generating Units (Continued)

Code	Name of Utility	Country
KS	Kernkraftwerk Stade GmbH	Germany
KU	Kernkraftwerk Unterwasser GmbH	Germany
KY	Kyushu Electric Power Company, Inc.	Japan
KZ	Kazakh State Atomic Power Engineering and Industry Corp.	Kazakhstan
LK	Kernkraftwerk Leibstadt AG	Switzerland
ME	Ministry of Energy	Lithuania
MI	Ministry of Nuclear Industry	China
NB	New Brunswick Electric Power Commission	Canada
NE	Nuclear Electric plc	United Kingdom
NK	Nordostschweizerische Kraftwerk AG	Switzerland
OK	OKG-Aktiebolag	Sweden
ON	Ontario Hydro Corporation	Canada
PA	Pakistan Atomic Energy Commission	Pakistan
PF	Power Reactor and Nuclear Fuel Development Corporation	Japan
PP	National Power Corporation	Philippines
PR	PreussenElektra AG	Germany
PZ	NV Electriciteits-Productiemaatschappij Zuid-Nederland	Netherlands
RE	Romanian Electricity Authority	Romania
RW	RWE Energie Aktiengesellschaft	Germany
SC	Scottish Nuclear Ltd.	United Kingdom
SH	Shikoku Electric Power Company	Japan
SL	Savske Elektrarne Ljubljana	Slovenia
SP	Slovak Power Board	Slovak Republic
SY	Sydkraft AB	Sweden
TC	Tohoku Electric Power Company, Inc.	Japan
TP	Tokyo Electric Power Company	Japan
TV	Teollisuuden Voima Oy (TVO)	Finland
TW	Taiwan Power Company	Taiwan
UE	Union Electrica, SA, and Fuerzas Electricas del Noroeste, SA	Spain
UK	Ukratomenergoprom	Ukraine
UR	Ministry of Atomic Power	Russia
VA	Vattenfall AB	Sweden

Table F3. Key to Reactor Supplier Codes for Rosters of Foreign Commercial Nuclear Generating Units

Code	Name of Supplier	Country
A-A	ASEA-Atom AB	Sweden
ACW	ACEC/COP/Westinghouse	Belgium
ACLF	ACEC/COP/Creusot-Loire/FRAM/WEST	France
AECL	Atomic Energy of Canada, Ltd.	Canada
AEE	Atomenergoexport	Russia
AEG	Allgemeine Elektrizitäts-Gesellschaft, AEG-Telefunken AG	Germany
APC	Atomic Power Construction, Ltd.	United Kingdom
BBR	Babcock/Brown Boveri Reaktor GmbH	Germany
C-E	Combustion Engineering, Inc.	United States
CGE	Canadian General Electric	Canada
CNIM	Constructions Navales et Industrielles de la Méditerranée	France
CNNC	China National Nuclear Corporation	China
COP	Cockeril Ougrée-Providence	Belgium
DAE	Department of Atomic Energy	India
EBT	English Electric Co. Ltd/Babcock and Wilcox Co./Taylor Woodrow Construction Co.	United Kingdom
ENSA	Equipos Nucleares SA	Spain
FECNE	Nuclear Power Plant Equipment Factory	Romania
FRAM	Framatome: Société Franco-Américaine de Constructions Atomiques SA	France
GE	General Electric Company	United States
GEC	General Electric Company	United Kingdom
GETSCO	General Electric Technical Services Company	United States
HIT	Hitachi	Japan
KHIC	Korea Heavy Industries and Construction Company	Korea, South
KWU	Kraftwerk Union AG	Germany
L-T	Larson and Toubro, Ltd.	India
MHI	Mitsubishi Heavy Industries, Ltd.	Japan
MTM	Mintyazhmash	Russia
NNC	National Nuclear Corporation	United Kingdom
NOVA	Novatome	France
NP	Nuclear Power Corporation of India, Ltd.	India
OTH	Utility/Others	India
PPP	PWR Power Projects	United Kingdom
RDM	Rotterdamse Drookdok Maatschappij	Netherlands
SIEM	Siemens AG	Germany
SKODA	SKODA	Czech Republic
TNPG	The Nuclear Power Group, Ltd.	United Kingdom
TOS	Toshiba	Japan
UKAE	United Kingdom Atomic Energy Authority	United Kingdom
VAR	Various suppliers	Various countries
WEST	Westinghouse Corp.	United States

Appendix G

**Foreign Nuclear
Generating Units in
the Construction
Pipeline as of
December 31, 1992**

The Tokai Nuclear Power Station consists of a 159-MW gas cooled reactor (GCR) and a 1,080-MW boiling water reactor (BWR).

Appendix G

Foreign Nuclear Generating Units in the Construction Pipeline as of December 31, 1992

Table G1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, in Foreign Countries

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Type ^d	Reactor Supplier ^e	% Complete	Expected Date of Operation		
								Published ^f	EIA ^g	
									LR	UR
Argentina	Atucha 2	Lima, Buenos Aires	692	CN	PHWR	KWU	80	6/96	2000	1995
Total	1 Unit		692							
Brazil	Angra 2	Itaorna, Rio de Janeiro	1,229	BZ	PWR	KWU	65	5/98	2000	2000
	Angra 3	Itaorna, Rio de Janeiro	1,229	BZ	PWR	KWU	41	C/ID	2010	2005
Total	2 Units		2,458							
Canada	Darlington 4	Newcastle Township, Ontario	881	ON	PHWR	AECL	99	7/93	1995	1995
Total	1 Units		881							
China	Guangdong 1	Shenzhen, Guandong	900	GV	PWR	FRAM	80	1993	1995	1995
	Guangdong 2	Shenzhen, (Guandong)	900	GV	PWR	FRAM	70	1994	2000	2000
	Qinshan 2	Haiyan, Zhejiang	600	NA	PWR	NA	--	--	2005	2005
	Qinshan 3	Haiyan Zhejiang	600	NA	PWR	NA	--	--		2010
Total	4 Units		3,000							
C.I.S. (Commonwealth of Independent States)										
Armenia	Armenia 1	Melsamor	376	NA	PWR	--	--	--	1995	1995
	Armenia 2	Melsamor	376	NA	PWR	--	--	--	2000	2000
Total	2 Units		752							

See footnotes at end of table.

Table G1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Type ^d	Reactor Supplier ^e	% Complete	Expected Date of Operation		
								Published ^f	EIA ^g	
									LR	UR
Russia	Balakovo 4	Balakova, Saralov	950	UR	PWR	MTM	75	C/D	2005	2000
	Balakovo 5	Balakova Saralov	950	UR	PWR	MTM	--	C/D		2005
	Beloyarsky 4	Zarechnyy, Sverdlovsk	750	UR	LMFBR	MTM	--	C/D		
	Kalinin 3	Udomlya, Tver	950	UR	PWR	MTM	70	C/D	2005	2000
	Kostroma 1	Buy, Kostroma	630	UR	PWR	--	--	C/D	2010	2010
	Kostroma 2	Buy, Kostroma	630	UR	PWR	--	--	C/D	2010	2010
	Kursk 5	Kurchatov, Kursk	925	UR	LGR	MTM	--	C/D	2000	2000
	Rostov 1	Volgodonsk, Rostov	950	UR	PWR	MTM	95	C/D		
	Rostov 2	Volgodonsk, Rostov	950	UR	PWR	MTM	30	C/D		
Total	9 Units		7,685							
Ukraine	Khmelnytsky 2	Neteshin, Khmelnytsky	950	UK	PWR	MTM	--	C/D	2000	2000
	Khmelnytsky 3	Neteshin, Khmelnytsky	950	UK	PWR	MTM	--	C/D		2005
	Khmelnytsky 4	Neteshin, Khmelnytsky	950	UK	PWR	MTM	--	C/D		2010
	Rovno 4	Kuznetsovsk, Rovno	950	UK	PWR	MTM	--	C/D		
	South Ukraine 4	Konstantinovka, Nikolaev	950	UK	PWR	MTM	--	C/D		
	Zaporozhye 6	Energodar, Zaporozhye	950	UK	PWR	MTM	--	C/D	2000	2000
Total	6 Units		5,700							
Cuba	Juragua 1	Cienfuegos	417	CU	PWR	AEE	90	1995	2005	2000
	Juragua 2	Cienfuegos	417	CU	PWR	AEE	15	1997	--	2005
Total	2 Units		834							
Czech Republic	Temelin 1	Temelin, Jihocesky	890	CP	PWR	SKODA	65	1995	2000	1995
	Temelin 2	Temelin, Jihocesky	890	CP	PWR	SKODA	45	1997	2005	2000
Total	2 Units		1,780							
France	Chooz B1	Chooz, Ardennes	1,455	EF	PWR	FRAM	85	2/96	2000	2000
	Chooz B2	Chooz, Ardennes	1,455	EF	PWR	FRAM	65	7/96	2000	2000

See footnotes at end of table.

Table G1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Type ^d	Reactor Supplier ^e	% Complete	Expected Date of Operation		
								Published ^f	EIA ^g	
France (continued)	Civaux 1	Civaux, Vienne	1,455	EF	PWR	FRAM	15	4/97		2005
	Civaux 2	Civaux, Vienne	1,455	EF	PWR	FRAM	5	11/98	--	--
	Goffech 2	Valence, Tam et Garonne	1,310	EF	PWR	FRAM	95	7/93	1995	1995
	Le Camel 1	Le Camel	1,455	EF	PWR	FRAM	0	--	--	--
	Le Camel 2	Le Camel	1,455	EF	PWR	FRAM	0	--	--	--
	Penley 3	St. Martin-en, Seine- Maritime	1,390	EF	PWR	FRAM	0	1995	--	--
	Penley 4	St. Martin-en, Seine, Maritime	1,390	EF	PWR	FRAM	0	1997	--	--
Total	9 Units		12,820							
India	Kaiga 1	Kaiga, Karnataka	220	IA	PHWR	NP	47	12/96	2000	2000
	Kaiga 2	Kaiga, Karnataka	220	IA	PHWR	NP	47	6/97	2000	2000
	Kaiga 3	Kaiga, Karnataka	220	IA	PHWR	OTH	0	1998	2010	2005
	Kakrapar 2	Kakrapar, Gujarat	220	IA	PHWR	DAE/NP	85	4/94	1995	1995
	Rajasthan 3	Kota, Rajasthan	220	IA	PHWR	NP	35	5/97	2000	1995
	Rajasthan 4	Kota, Rajasthan	220	IA	PHWR	NP	35	11/97	2000	2000
	Tarapur 3	Tarapur, Maharashtra	470	IA	PHWR	OTH	0	8/2000	2010	2005
	Tarapur 4	Tarapur, Maharashtra	470	IA	PHWR	OTH	0	5/2001	2010	2005
Total	8 Units		2,260							
Japan	Ashihama 1	Ashihama	1,283	CB	ABWR	NA	0	11/2002	--	--
	Ashihama 2	Ashihama	1,283	CB	ABWR	NA	0	2/2003	--	2005
	Ashihama 3	Ashihama	1,283	CB	ABWR	NA	0	6/2006	--	--
	Genkai 3	Genkai, Saga	1,127	KY	PWR	MHI	92	11/93	1995	1995
	Genkai 4	Genkai, Saga	1,127	KY	PWR	MHI	34	9/97	2000	1995
	Hamaoka 4	Hamaoka-cho, Shizuoka	1,092	CB	BWR	TOS	95	4/93	2000	1995
	Hamaoka 5	Hamaoka-cho, Shizuoka	1,092	CB	ABWR	NA	0	2008	--	--
	Higashidori 1	Higashidori	1,067	TC	BWR	NA	0	2/2004	--	--
	Higashidori 2	Higashidori	1,067	TC	BWR	NA	0	2/2005	--	--
	Hohoku 1	Hohoku	1,067	CK	BWR	NA	0	2010	--	--
	Hohoku 2	Hohoku	1,067	CK	BWR	NA	0	2012	--	--
	Ikata 3	Ikata-cho, Ehime	846	SH	PWR	MHI	77	3/95	2000	1995
	Kashiwazaki Kariwa 4	Kashiwazaki, Niigata	1,067	TP	BWR	HIT	83	7/94	2000	1995

See footnotes at end of table.

Table G1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Type ^d	Reactor Supplier ^e	% Complete	Expected Date of Operation		
								Published ^f	EIA ^g	
									LR	UR
Japan (continued)	Kashiwazaki Kariwa 6	Kashiwazaki, Niigata	1,315	TP	ABWR	TOS/GE	27	12/96	2005	2000
	Kashiwazaki Kariwa 7	Kashiwazaki, Niigata	1,315	TP	ABWR	HIT/GE	9	7/97	2005	2000
	Maki 1	Maki, Niigata	796	TC	BWR	NA	0	10/2002	--	--
	Maki 2	Maki, Niigata	1,067	TC	BWR	NA	0	--	--	--
	Monju	Tsuruga, Fukui	280	PF	LMFBR	TOS/HIT	99	1995	1995	1995
	Onagawa 2	Onagawa, Miyagi	796	TC	BWR	TOS	63	7/95	2000	1995
	Oura 1	Oura	1,296	KA	APWR	NA	0	2010	--	2005
	Oura 2	Oura	1,296	KA	APWR	NA	0	2010	--	2005
	Shika 1	Shika-machi, Ishikawa	513	HU	BWR	HIT	96	7/93	1995	1995
	Shika 2	Shika-machi, Ishikawa	796	HU	ABWR	NA	0	2006	--	--
Total		23 Units	23,938							
Korea, South	Ulchin 3	Ulchin, Kyongbuk	950	KR	PWR	KHIC/C-E	18	6/98	2005	2005
	Ulchin 4	Ulchin, Kyongbuk	950	KR	PWR	KHIC/C-E	18	6/99	2005	2005
	Wolsong 2	Kyongju, Kyongbuk	663	KR	PHWR	AECL/KHIC	22	6/97	2005	2000
	Wolsong 3	Kyongju, Kyongbuk	629	KR	PHWR	AECL	0	1998	2010	2005
	Wolsong 4	Kyongju, Kyongbuk	629	KR	PHWR	AECL	0	1999	2010	2005
	Yonggwang 3	Yonggwang, Chonnam	950	KR	PWR	KHIC/C-E	72	3/95	2005	2000
	Yonggwang 4	Yonggwang, Chonnam	950	KR	PWR	KHIC/C-E	72	3/96	2005	2000
Total		7 Units	5,721							
Lithuania	Ingalina 3	Sniekus, Lithuania	1,000	NA	LGR	NA	0	--	--	2005
Total		1 Unit	1,000							
Mexico	Laguna Verde 2	Laguna Verde, Veracruz	654	FC	BWR	GE	82	12/94	2000	1995
Total		1 Unit	654							
Pakistan	Chasnupp	Mianwali, Punjab	300	PA	PWR	CNNC	0	4/99	2010	2005
Total		1 Unit	300							

See footnotes at end of table.

Table G1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Type ^d	Reactor Supplier ^e	% Complete	Expected Date of Operation		
								Published ^f	EIA ^g	
									LR	UR
Philippines	PNPP 1	Morong, Luzon	620	PP	PWR	WEST	98	C/D	2000	1995
Total		1 Unit	620							
Romania	Cemavoda 1	Cemavoda, Constanta	620	RE	PHWR	AECL	62	1994	2000	1995
	Cemavoda 2	Cemavoda, Constanta	620	RE	PHWR	AECL	46	1996	2000	2000
	Cemavoda 3	Cemavoda, Constanta	620	RE	PHWR	FECNE	23	1997	--	2005
	Cemavoda 4	Cemavoda, Constanta	620	RE	PHWR	FECNE	12	1998	--	2010
	Cemavoda 5	Cemavoda, Constanta	620	RE	PHWR	FECNE	8	1999	--	--
Total		5 Units	3,100							
Slovak Republic	Mochovce 1	Mochovce, Zapadoslov- ensky	390	SP	PWR	SKODA	85	12/94	2000	2000
	Mochovce 2	Mochovce, Zapadoslov- ensky	390	SP	PWR	SKODA	65	9/95	2010	2005
	Mochovce 3	Mochovce, Zapadoslov- ensky	390	SP	PWR	SKODA	45	9/96	--	2010
	Mochovce 4	Mochovce, Zapadoslov- ensky	390	SP	PWR	SKODA	20	4/97	--	2010
		4 Units	1,560							
Spain	Regodola	Jove, Lugo	1,000	UE	PWR	KWU	0	C/D	--	--
	Sayago	Sayago, Zamora	1,030	IB	PWR	WEST	0	C/D	--	--
	Trillo 2	Trillo, Guadalejara	997	CT	PWR	KWU/ENSA	0	C/D	--	--
	Valde- caballeros 1	Valdecaballeros Badajoz	975	CV	BWR	GE	71	C/D	--	--
	Valde- caballeros 2	Valdecaballeros Badajoz	975	CV	BWR	GE	58	C/D	--	--
Total		5 Units	4,977							
Taiwan	Yenliao 1	Kungliao	950	TW	PWR	NA	0	2000	2005	2000
	Yenliao 2	Kungliao	950	TW	PWR	NA	0	2001	2010	2005
Total		2 Units	1,900							

See footnotes at end of table.

Table G1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1992, in Foreign Countries (Continued)

Country	Unit Name ^a	Location	Capacity (net MWe) ^b	Utility ^c	Type ^d	Reactor Supplier ^e	% Complete	Expected Date of Operation		
								Published ^f	EIA ^g	
									LR	UR
United Kingdom	Sizewell B	Sizewell, Suffolk	1,188	NE	PWR	PPP	85	1994	2005	2000
Total		1 Unit	1,188							
Total Capacity in the Construction Pipeline in Foreign Countries (97 Units)			83,820							

^aEIA's review of the latest data sources has resulted in revisions of names, capacities, and grid operation dates.

^bMWe = megawatts-electric

^cSee Table F2 for key to abbreviations of utility names.

^dReactor Types: ABWR advanced boiling-water reactor; APWR advanced pressurized-water reactor; BWR, boiling-water reactor; LMFBR, liquid metal fast breeder reactor; FBR, fast breeder reactor; LGR, light-water-cooled, graphite-moderated reactor; PHWR, pressurized heavy-water-moderated and cooled reactor; PWR, pressurized-water reactor.

^eSee Table F3 for key to abbreviations of supplier names.

^fPublished date is the estimated date of commercial operation.

^gEIA projections in the Lower Reference (LR) and Upper Reference (UR) cases, as described in the text, refer to the preceding 5-year period during which a nuclear unit is estimated to become operable. Units operable for all foreign countries are those that have generated electricity to the grid. A dash (--) indicates that the estimated year of operability is beyond 2010.

Note: NA = not available; C = construction permit issued; (--) = unknown; C/ID = construction pipeline, but indefinitely deferred.

Sources: *Nuclear News*, "World List of Nuclear Power Plants" (March 1993), pp. 41-60. *Nucleonics Week* (various issues). International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1993), pp. 8, 9. Information for Japan was derived from consultation with the DOE Office of Uranium Enrichment.

Appendix H

Annual Capacity, Generation, Spent Fuel, and Fuel Burnup Projections for U.S. Nuclear Power Supply Scenarios

Spent fuel storage pool at Brown's Ferry Nuclear Plant.

Appendix H

Annual Capacity, Generation, Spent Fuel, and Fuel Burnup Projections for U.S. Nuclear Power Supply Scenarios

Table H1. Annual Projections of U.S. Operable Nuclear Capacity at Year End, 1992-2040
(Net Gigawatts-Electric)

Year	Scenario ^b			
	No New Orders Case		Lower Reference Case	Upper Reference Case
	Base Case	30-Percent Life Extension		
1992 ^a	99.0	99.0	99.0	99.0
1993	99.0	99.0	99.0	99.0
1994	99.0	99.0	100.2	100.2
1995	100.2	100.2	100.2	100.2
1996	101.4	101.4	101.4	101.4
1997	101.4	101.4	101.4	101.4
1998	101.4	101.4	101.4	101.4
1999	101.4	101.4	101.4	101.4
2000	101.4	101.4	101.4	102.6
2001	102.6	102.6	102.6	102.6
2002	102.5	102.5	102.5	105.0
2003	102.5	102.5	103.1	105.6
2004	101.9	102.5	103.1	105.6
2005	101.9	102.5	104.4	105.6
2006	101.1	102.5	104.4	105.6
2007	98.5	101.9	104.4	105.6
2008	94.0	97.3	104.4	105.6
2009	91.9	94.4	103.2	104.4
2010	88.5	91.4	102.4	104.8
2011	87.7	90.7	105.6	110.7
2012	84.2	86.9	107.2	115.0
2013	74.0	78.2	106.3	116.9
2014	64.5	70.9	103.5	116.7
2015	63.7	70.9	108.0	124.0
2016	57.4	66.3	105.4	123.6
2017	54.7	64.4	106.2	126.6
2018	52.2	62.8	107.3	129.9
2019	52.2	62.8	110.0	134.8
2020	49.0	60.6	112.8	139.8
2021	46.0	59.4	113.4	142.6
2022	41.8	56.2	115.0	146.4
2023	37.7	54.1	116.7	150.3
2024	29.9	49.6	116.2	152.0
2025	24.4	45.2	115.8	153.8
2026	14.8	42.0	119.0	159.2
2027	9.3	37.0	118.7	161.1
2028	8.0	35.7	120.6	165.2
2029	5.9	33.1	119.8	166.6

See footnotes at end of table.

Table H1. Annual Projections of U.S. Operable Nuclear Capacity at the End of the Year, 1992-2040 (Continued)

Year	Scenario ^b			
	No New Orders Case		Lower Reference Case	Upper Reference Case
	Base Case	30-Percent Life Extension		
2030	4.7	31.5	118.8	167.8
2031	4.7	31.5		
2032	4.7	30.8		
2033	3.6	28.1		
2034	2.4	24.3		
2035	2.4	23.4		
2036	1.2	21.4		
2037	1.2	19.8		
2038	1.2	18.9		
2039	1.2	18.9		
2040	1.2	18.0		

^aActual.

^bValues may not equal referenced tables due to rounding.

Note: Projections for the Lower Reference and Upper Reference Cases were made through 2030.

Sources: **Capacity Data**—Energy Information Administration, Form EIA-860, "Annual Electric Generator Report" (1992). **Status Data**—Energy Information Administration, *Monthly Energy Review*, April 1993, DOE/EIA-0035(93/04) April 1993.

Table H2. Annual Projections of U.S. Nuclear Generation, 1992-2040
(Net Terawatt-hours)

Year	Scenario			
	No New Orders Case		Lower Reference Case	Upper Reference Case
	Base Case	30-Percent Life Extension		
1992 ^a	619	619	619	619
1993	605	605	605	605
1994	610	610	611	611
1995	611	611	615	615
1996	620	620	620	620
1997	623	623	625	625
1998	624	624	624	624
1999	626	626	626	626
2000	626	626	626	632
2001	632	632	632	632
2002	632	632	632	644
2003	634	634	637	650
2004	632	634	637	651
2005	630	634	641	654
2006	627	634	644	654
2007	620	631	644	654
2008	604	623	646	654
2009	577	595	644	652
2010	558	580	637	651
2011	547	565	642	663
2012	539	560	660	698
2013	503	526	664	715
2014	440	475	651	720
2015	405	450	659	745
2016	387	446	672	775
2017	360	423	672	790
2018	343	414	684	818
2019	333	405	692	839
2020	325	400	711	873
2021	303	390	721	898
2022	288	381	729	920
2023	247	354	742	947
2024	208	336	749	969
2025	168	308	743	977
2026	115	282	750	999
2027	76	261	761	1025
2028	54	239	768	1046
2029	43	228	771	1064
2030	33	214	768	1075
2031	30	209		
2032	30	207		
2033	29	198		
2034	21	176		
2035	16	159		
2036	8	143		
2037	8	134		
2038	8	126		
2039	8	124		
2040	8	122		

^aActual

Sources: 1992 Generation Data—Energy Information Administration, *Monthly Energy Review*, April 1993, DOE/EIA-0035 (93/04)(April 1993), Projected Generation—International Nuclear Model, File CN6933.PRJ.IMN93.OUTPUT, June 1993.

Table H3. Projected Annual U.S. Spent Fuel Discharges, 1992-2040
(Thousand Metric Tons of Initial Heavy Metal)

Year	Scenario			
	No New Orders Case		Lower Reference Case	Upper Reference Case
	Base Case	30-Percent Life Extension		
1992 ^a	2.3	2.3	2.3	2.3
1993	2.4	2.4	2.4	2.4
1994	1.6	1.6	1.6	1.6
1995	2.4	2.4	2.4	2.4
1996	1.9	1.9	1.9	1.9
1997	2.1	2.1	2.1	2.1
1998	2.1	2.1	2.0	2.0
1999	1.8	1.8	1.9	1.9
2000	2.1	2.1	2.1	2.1
2001	1.9	1.9	1.9	1.9
2002	2.0	2.0	1.9	1.9
2003	2.1	2.1	2.2	2.2
2004	1.7	1.7	1.7	1.8
2005	2.0	2.0	2.0	2.0
2006	2.1	2.0	2.0	2.0
2007	1.9	1.8	1.8	1.9
2008	2.3	2.3	1.9	1.9
2009	1.8	2.1	2.0	2.1
2010	1.8	1.9	1.8	1.8
2011	1.6	1.7	1.9	2.0
2012	2.0	2.1	2.0	2.0
2013	2.2	2.1	2.4	2.6
2014	2.0	2.0	2.4	2.5
2015	1.3	1.3	1.9	2.1
2016	1.6	1.7	2.1	2.5
2017	1.0	1.0	1.8	2.0
2018	1.2	1.4	2.0	2.5
2019	0.9	1.0	1.8	2.1
2020	0.9	1.0	1.7	2.2
2021	1.2	1.3	2.3	2.6
2022	1.1	1.2	1.8	2.3
2023	1.0	1.2	2.0	2.4
2024	1.2	1.3	2.5	3.1
2025	0.9	1.1	2.1	2.7
2026	1.0	1.0	1.9	2.6
2027	0.6	1.0	2.3	3.0
2028	0.2	0.7	2.1	2.8
2029	0.3	0.8	2.3	3.1
2030	0.2	0.8	2.5	3.2
2031	0.1	0.5		
2032	0.1	0.6		
2033	0.1	0.7		
2034	0.1	0.8		
2035	0.0	0.4		
2036	0.1	0.4		
2037	0.0	0.5		
2038	0.0	0.4		
2039	0.0	0.3		
2040	0.0	0.3		

^aActual.

Sources: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993, and Form RW-859, "Nuclear Fuel Data" (1992).

Table H4. Projected Total U.S. Spent Fuel Discharges, 1992-2040
(Thousand Metric Tons of Initial Heavy Metal)

Year	Scenario			
	No New Orders Case		Lower Reference Case	Upper Reference Case
	Base Case	30-Percent Life Extension		
1992 ^a	25.9	25.9	25.9	25.9
1993	28.3	28.3	28.3	28.3
1994	29.9	29.9	29.9	29.9
1995	32.3	32.3	32.3	32.3
1996	34.2	34.2	34.2	34.2
1997	36.2	36.2	36.3	36.3
1998	38.3	38.3	38.3	38.3
1999	40.1	40.1	40.2	40.2
2000	42.3	42.3	42.3	42.3
2001	44.1	44.1	44.1	44.2
2002	46.1	46.1	46.1	46.1
2003	48.2	48.2	48.2	48.3
2004	50.0	49.9	49.9	50.1
2005	51.9	51.9	51.9	52.1
2006	54.1	53.9	54.0	54.1
2007	56.0	55.7	55.7	56.0
2008	58.2	57.9	57.6	57.8
2009	60.0	60.0	59.7	59.9
2010	61.9	61.9	61.5	61.7
2011	63.5	63.5	63.4	63.7
2012	65.5	65.6	65.4	65.8
2013	67.7	67.7	67.8	68.3
2014	69.7	69.7	70.2	70.9
2015	71.0	71.0	72.1	73.0
2016	72.7	72.7	74.3	75.5
2017	73.7	73.7	76.0	77.5
2018	74.8	75.0	78.0	79.9
2019	75.8	76.1	79.8	82.0
2020	76.7	77.1	81.5	84.2
2021	77.9	78.4	83.8	86.9
2022	78.9	79.6	85.5	89.2
2023	80.0	80.8	87.6	91.6
2024	81.2	82.1	90.0	94.7
2025	82.1	83.2	92.1	97.4
2026	83.1	84.2	94.0	100.0
2027	83.8	85.2	96.3	103.0
2028	84.0	85.9	98.4	105.8
2029	84.3	86.7	100.7	108.9
2030	84.5	87.4	103.2	112.1
2031	84.5	87.9		
2032	84.6	88.5		
2033	84.7	89.2		
2034	84.8	90.0		
2035	84.9	90.4		
2036	85.0	90.8		
2037	85.0	91.4		
2038	85.0	91.8		
2039	85.0	92.1		
2040	85.0	92.4		

^aActual.

Note: Spent fuel discharges are cumulative from 1957.

Sources: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993, and Form RW-859, "Nuclear Fuel Data" (1992).

Table H5. Projected Average Annual Burnup of Spent Fuel Discharges by U.S. Nuclear Power Plants for Equilibrium Cycles, 1993-2040
(Megawattdays Thermal per Metric Ton of Uranium)

Year	Scenario							
	No New Orders				Lower Reference Case		Upper Reference Case	
	Base Case		30-Percent Life Extension					
	BWR ^a	PWR ^a	BWR	PWR	BWR	PWR	BWR	PWR
1993	32,372	39,510	32,372	39,510	32,372	39,510	32,372	39,510
1994	33,568	41,345	33,568	41,345	33,568	41,345	33,568	41,345
1995	33,723	40,960	33,723	40,960	33,723	40,960	33,723	40,960
1996	35,459	42,423	35,459	42,423	35,459	42,423	35,459	42,423
1997	34,339	41,915	34,339	41,915	34,339	41,915	34,339	41,915
1998	35,964	42,192	35,964	42,192	35,964	42,189	35,964	42,189
1999	34,653	43,043	34,653	43,043	34,653	42,849	34,653	42,849
2000	36,374	42,713	36,374	42,713	36,374	42,726	36,374	42,718
2001	36,508	44,409	36,508	44,409	36,508	44,470	36,508	44,401
2002	35,567	43,481	35,570	43,481	35,570	43,474	35,570	43,378
2003	36,929	44,108	36,939	44,108	36,939	44,146	36,939	44,174
2004	37,804	45,234	37,910	45,242	37,910	45,245	37,910	44,944
2005	39,522	44,356	39,409	44,393	39,408	44,430	39,408	44,527
2006	38,393	46,657	38,431	46,836	38,042	47,059	38,042	46,982
2007	39,015	46,895	38,855	46,878	39,251	47,354	39,251	47,132
2008	37,890	47,740	37,654	47,850	37,580	48,207	37,580	48,328
2009	38,655	49,693	38,722	49,709	39,305	49,700	39,305	49,645
2010	37,798	50,649	37,792	50,678	37,604	50,837	37,604	50,694
2011	38,103	50,319	38,220	50,523	39,132	50,871	39,132	50,930
2012	37,746	51,301	37,724	51,432	38,403	52,247	38,403	52,506
2013	39,849	51,895	39,948	52,100	40,115	52,843	40,115	52,588
2014	38,988	52,535	38,934	52,871	38,593	52,987	38,593	52,998
2015	40,868	52,188	40,885	52,765	41,108	52,694	41,108	52,665
2016	39,976	52,517	40,211	53,510	38,870	53,092	38,032	52,768
2017	41,863	50,336	41,715	51,382	40,316	51,998	40,316	51,753
2018	41,052	53,442	40,984	53,890	39,666	53,182	39,258	53,094
2019	42,845	53,219	43,076	53,469	41,714	52,824	40,777	52,333
2020	40,058	51,445	40,017	52,283	40,397	52,324	40,511	52,345
2021	42,189	52,843	42,186	53,694	42,262	53,269	41,550	53,195
2022	40,034	51,238	40,832	52,350	40,833	52,801	40,556	52,627
2023	40,586	52,606	41,286	52,840	42,049	52,962	41,878	53,001
2024	37,617	50,693	38,590	52,121	40,890	52,988	40,841	53,231
2025	37,883	52,191	40,028	53,442	40,561	53,621	40,365	53,366
2026	0	51,966	38,678	52,445	42,073	53,230	42,240	53,396
2027	42,108	51,918	49,889	53,250	42,555	53,502	41,975	53,654
2028	0	49,506	41,861	53,412	41,639	53,326	41,478	53,177
2029	0	45,438	40,856	51,138	42,191	52,717	42,387	53,085
2030	0	47,443	41,889	52,331	42,063	53,594	41,736	53,707
2031	0	49,979	40,508	52,155	41,770	52,932	41,723	53,090
2032	0	47,292	44,179	52,548	41,647	53,422	41,943	53,541
2033	0	43,900	42,349	51,721	42,302	53,084	42,034	53,501
2034	0	0	42,699	52,575	41,738	53,402	41,673	53,345
2035	0	50,778	42,490	52,608	42,394	53,792	42,519	53,974
2036	0	50,778	44,814	53,562	42,432	54,099	42,593	54,298
2037	0	0	39,373	52,159	42,873	53,716	42,847	53,815
2038	0	50,778	43,303	52,581	42,943	54,671	42,987	54,821
2039	0	50,778	0	53,085	42,958	54,236	43,025	54,525
2040	0	0	0	51,696	42,970	54,165	42,999	54,360

^aBWR = Boiling water reactor; PWR = Pressurized water reactor.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993, and Form RW-859, "Nuclear Fuel Data" (1992).

Table H6. Projected Average Annual Burnup of Spent Fuel Discharges by U.S. Nuclear Power Plants for All Cycles, 1993-2040
(Megawattdays Thermal per Metric Ton of Uranium)

Year	Scenario							
	No New Orders							
	Base Case		30-Percent Life Extension					
	BWR ^a	PWR ^a	BWR	PWR	BWR	PWR	BWR	PWR
1993	31,799	39,510	31,799	39,510	31,799	39,510	31,799	39,510
1994	33,568	41,345	33,568	41,345	33,568	41,345	33,568	41,345
1995	33,723	40,558	33,723	40,558	33,723	40,558	33,723	40,558
1996	35,459	41,845	35,459	41,845	35,459	41,259	35,459	41,259
1997	34,339	41,399	34,339	41,399	34,339	41,625	34,339	41,625
1998	35,964	41,352	35,964	41,352	35,964	41,641	35,964	41,641
1999	34,653	42,663	34,653	42,663	34,653	42,484	34,653	42,483
2000	36,374	42,713	36,374	42,713	36,374	42,726	36,374	42,718
2001	36,508	44,409	36,508	44,409	36,508	44,470	36,508	43,852
2002	35,220	43,032	35,223	43,032	35,223	43,015	35,223	43,093
2003	36,929	43,816	36,939	43,816	36,939	43,861	36,939	43,722
2004	36,160	45,234	37,910	45,242	37,910	44,851	37,910	43,502
2005	39,522	44,356	39,409	44,393	39,408	44,205	39,408	43,848
2006	35,932	46,657	38,431	46,836	38,042	46,363	38,042	46,982
2007	39,015	43,846	38,855	46,343	39,251	47,354	39,251	47,132
2008	35,717	45,527	35,478	45,673	37,580	47,596	37,580	48,328
2009	37,680	48,529	34,563	49,133	37,028	49,700	37,028	49,645
2010	35,168	48,424	35,156	49,081	34,902	50,837	34,902	50,694
2011	34,970	50,319	35,053	50,523	34,980	50,871	34,980	50,100
2012	32,324	50,393	33,024	48,513	34,896	49,522	34,896	49,737
2013	35,984	43,526	36,053	44,810	33,807	47,538	32,080	46,451
2014	30,831	46,127	31,076	49,342	30,753	46,648	30,753	45,164
2015	40,868	51,251	40,885	52,765	35,326	49,024	32,411	46,729
2016	34,507	48,128	34,681	51,146	31,799	48,236	29,806	47,392
2017	41,863	47,526	41,715	49,131	34,091	46,285	32,916	44,366
2018	37,926	50,986	38,022	52,759	34,230	50,516	32,146	49,035
2019	42,845	53,219	43,076	53,469	36,454	51,784	34,485	50,147
2020	40,058	48,674	40,017	50,418	38,543	48,908	37,620	47,753
2021	42,189	48,825	42,186	52,794	37,993	49,985	35,503	48,844
2022	31,609	48,993	31,776	52,350	36,932	49,135	35,817	48,723
2023	33,519	47,703	34,192	52,840	40,216	49,057	39,003	47,985
2024	29,861	44,143	34,892	48,715	35,524	49,519	34,782	49,056
2025	30,507	43,947	32,334	48,260	35,027	50,893	34,526	50,238
2026	25,659	37,311	33,765	50,035	40,197	50,512	39,585	49,682
2027	42,108	40,339	49,889	46,838	35,049	49,968	34,238	49,485
2028	0	39,458	41,861	49,911	39,350	49,747	38,439	49,471
2029	26,567	44,501	33,892	49,064	36,043	48,775	36,947	48,705
2030	0	39,027	41,889	49,330	37,503	48,492	36,234	48,339
2031	0	49,979	40,508	52,155	38,320	50,394	38,204	50,382
2032	0	47,292	44,179	51,114	36,361	50,392	36,978	49,694
2033	0	34,025	35,441	45,819	39,691	46,805	39,513	47,861
2034	0	31,588	42,699	45,250	38,928	49,280	39,677	50,330
2035	0	50,778	42,490	51,092	42,394	53,263	42,519	53,591
2036	0	36,276	44,814	46,861	40,572	51,153	41,238	52,122
2037	0	0	39,373	49,811	42,873	52,782	42,847	53,148
2038	0	50,778	43,303	50,492	42,943	53,934	42,987	54,295
2039	0	50,778	0	53,085	42,958	54,236	43,025	54,525
2040	0	0	0	49,678	42,970	53,510	42,999	53,165

^aBWR = Boiling water reactor; PWR = Pressurized water reactor.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUT,PUT, June 1993, and Form RW-859, "Nuclear Fuel Data" (1992).

Appendix I

**World Nuclear Fuel
Cycle Facilities that
Prepare Fuel for
Nuclear Power Plants**

The handling of plutonium in a glove box.

Appendix I

World Nuclear Fuel Cycle Facilities that Prepare Fuel for Nuclear Power Plants

Table 11. World Nuclear Fuel Cycle Facilities That Prepare Fuel for Nuclear Power Plants

Country	Owner/Controller	Plant Name/Location	Capacity ^a
Uranium Hexafluoride Conversion Facilities^b			
United States	Allied Corporation	Metropolis, Illinois	12,700 MTu/year
Canada	CAMECO	^c Port Hope, Ontario	9,000 MTu/year
	CAMECO	^d Blind River, Ontario	18,000 MTu/year
China ^e	CNNC		600 MTu/year
France	COMURHEX	^f Malvesi	14,000 MTu/year
	COMURHEX	^g Pierrelatte 1	14,000 MTu/year
	COMURHEX	^h Pierrelatte 2	350 MTu/year
Japan	PNC	Ningyo Toge	200 MTu/year
South Africa	AEC	Pelindaba	750 MTu/year
United Kingdom	British Nuclear Fuels, Ltd.	Springfields, Lancashire	5,500 MTu/year
C.I.S.	Techsnabexport	--	14,000 MTu/year
India	DAE	Trombay	185 MTu/year
	DAE	Hazira	110 MTu/year
Uranium Enrichment Facilitiesⁱ			
United States	U.S. Department of Energy	Oak Ridge, Tennessee ^j	--
	U.S. Department of Energy	Paducah, Kentucky ^k	11,300 MTSWU/year
	U.S. Department of Energy	Portsmouth, Ohio ^l	8,000 MTSWU/year
France	EURODIF	Tricastin	10,800 MTSWU/year
West Germany	Urenco	Gronau	520 MTSWU/year
Japan	PNC	Ningyo Toge	260 MTSWU/year
	JNFI	Rokkashomura	150 MTSWU/year
Netherlands	Urenco	Almelo	1,410 MTSWU/year
South Africa	AEC	Pelindaba	300 MTSWU/year
United Kingdom	Urenco	Capenhurst	820 MTSWU/year
C.I.S.	Techsnabexport	--	12,000 MTSWU/year
Peoples Republic of China	China Nuclear Energy Industry Corporation	--	500 MTSWU/year

See footnotes at end of table.

Table 11. World Nuclear Fuel Cycle Facilities That Prepare Fuel for Nuclear Power Plants (Continued)

Country	Owner/Controller	Plant Name/Location	Capacity ^a
Uranium Fuel Fabrication Facilities¹			
United States	Babcock & Wilcox	Lynchburg, Virginia	400 MTu/year
	Combustion Engineering	Windsor, Connecticut	300 MTu/year
	Siemens	Richland, Washington	700 MTu/year
	Westinghouse	Columbia, South Carolina	1,150 MTu/year
	General Electric	Wilmington, N.C.	1,100 MTu/year
Belgium	FBFC	Dessel	400 MTu/year
Brazil	FEC	Rensende	100 MTu/year
Canada	Canadian General Electric	Peterborough, Ontario	1,000 MTu/year
	Westinghouse of Canada, Ltd.	Port Hope, Ontario	900 MTu/year
	Westinghouse of Canada, Ltd.	Carences, Quebec	200 MTu/year
C.I.S.	Elektrostal	Elektrostal	500 MTu/year
	Novosibirsk	Novosibirsk	500 MTu/year
France	FBFC	Romans	600 MTu/year
	FBFC	Pierelatte	500 MTu/year
West Germany	Advanced Nuclear Fuels	Lingen	300 MTu/year
	RBU-1 (PWR)	Hanau	600 MTu/year
India	Nuclear Fuel Complex	Hyderabad	25 MTu/year
Italy	Fab. Nuc.	BOSCO	200 MTu/year
Japan	Japan Nuclear Fuels	Yokosuka City	750 MTu/year
	Mitsubishi Nuclear Fuel	Tokai Mura	440 MTu/year
	Nuclear Fuels Industries	Kumatori	265 MTu/year
	Nuclear Fuels Industries	Tokai Mura	200 MTu/year
Korea	KNFC	Seoul	200 MTu/year
Spain	ENUSA	Juzbado	200 MTu/year
South Africa	AEC	Pelindaba	100 MTu/year
Sweden	AABB-ATOM	Vasteras	400 MTu/year
United Kingdom	British Nuclear Fuels, Ltd.	Springfields, Lancashire	200 MTu/year

Note: This table includes the main facilities that prepare fuel for power plants. It does not include auxiliary facilities or plants that support those main facilities.

^aStatus as of December 1992. MTU, metric tons of uranium; MTSWU, metric tons of separative work units.

^bNuclear Assurance Corporation, *Fuel-Trac Reports*, "UF₆ Status Report" (Atlanta, GA, March 1993), pp. 2-4.

^cUO₃ to UF₆.

^dU₃O₈ to UO₃.

^eNAC's estimate based on domestic fuel-cycle industry.

^fU₃O₈ to UF₆.

^gUF₆ to UF₆.

^hConversion of reprocessed (irradiated) UO₃(NO₃)₂ to UF₆.

ⁱNuclear Assurance Corporation, *Fuel-Trac Reports*, "Enrichment Status Report" (Atlanta, GA, February 1993), pp. 2-3.

^jThis facility, which had been on standby since 1986, was closed on December 15, 1987.

^kU.S. Department of Energy, Office of the Assistant Secretary of Nuclear Energy.

^lNuclear Assurance Corporation, *Fuel-Trac Reports*, "LWR Fabrication Status Report" (Atlanta, GA, February 1993), pp. 5-10.

Appendix J

**Projected Uranium
Requirements in
Metric Tons**

ENERGY EQUIVALENT

**ONE TON
URANIUM**

=

**12,000,000
BARRELS OF OIL
OR
3,000,000
TONS OF COAL**

One ton of uranium is equivalent to 12 million barrels of oil and to 3 million tons of coal.

Appendix J

Projected Uranium Requirements in Metric Tons

Table J1. Projected Average Annual Uranium Requirements for Nuclear Power Plants in the World, 1993-2010
(Thousand Metric Tons of Uranium)

Year	United States	Canada	Eastern Europe	China	CIS	Western Europe	Far East	Other	Total
1993-1995									
Lower Reference Case	17.0	1.6	2.4	0.3	4.6	19.0	8.4	0.5	53.8
Upper Reference Case	17.0	1.7	2.7	0.3	4.6	19.0	10.3	0.8	56.4
1996-2000									
Lower Reference Case	17.4	1.9	2.5	0.4	4.9	18.6	9.7	0.9	56.3
Upper Reference Case	17.7	1.9	2.8	0.4	5.1	18.7	10.8	1.0	58.5
2001-2005									
Lower Reference Case	17.1	2.0	2.7	0.5	5.3	18.4	10.1	1.1	57.3
Upper Reference Case	17.3	2.5	3.5	0.5	6.1	19.0	11.1	1.5	61.5
2006-2010									
Lower Reference Case	16.7	2.0	2.9	0.6	5.2	16.7	11.5	1.4	57.1
Upper Reference Case	17.7	2.9	4.3	0.8	6.9	20.1	14.7	2.0	69.3

Note: Totals may not equal sum of components due to independent rounding. The conversion factor used to convert million pounds U₃O₈ to thousand metric tons U is 0.384645.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Table J2. Projected Cumulative Uranium Requirements for Nuclear Power Plants in the World, 1993-2010
(Thousand Metric Tons of Uranium)

Year	United States	Canada	Eastern Europe	China	CIS	Western Europe	Far East	Other	Total
1995									
Lower Reference Case	50.9	4.9	7.1	0.9	13.7	57.1	25.1	1.5	161.3
Upper Reference Case	50.9	5.0	8.0	1.0	13.8	57.1	30.9	2.4	169.1
2000									
Lower Reference Case	137.9	14.3	19.8	2.8	38.3	149.9	73.3	6.3	442.7
Upper Reference Case	139.3	14.4	22.2	2.9	39.4	150.6	85.0	7.5	461.4
2005									
Lower Reference Case	223.2	24.4	33.3	5.6	64.9	242.0	123.8	11.7	729.0
Upper Reference Case	225.6	26.7	39.7	5.6	70.1	245.7	140.6	15.0	768.9
2010									
Lower Reference Case	307.0	34.5	47.8	8.5	91.0	325.5	181.5	18.5	1,014.4
Upper Reference Case	313.9	41.0	61.2	9.8	104.4	346.1	214.2	25.0	1,115.6

Note: Totals may not equal sum of components due to independent rounding. The conversion factor used to convert million pounds U₃O₈ to thousand metric tons U is 0.384645.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Table J3. Projected Average Annual Natural Uranium Requirements for U.S. Nuclear Power Plants, 1993-2030
(Thousand Metric Tons Uranium)

Year	No New Orders Case	Lower Reference Case	Upper Reference Case
1993-1995	17.1	17.0	17.0
1996-2000	17.3	17.4	17.7
2001-2005	16.8	17.1	17.3
2006-2010	14.2	16.7	17.6
2011-2015	10.8	17.6	20.5
2016-2020	7.9	18.6	23.3
2021-2025	4.8	19.8	26.2
2026-2030	1.0	19.6	27.6

Note: Totals may not equal sum of components due to independent rounding. The conversion factor used to convert million pounds U₃O₈ to thousand metric tons U is 0.384645.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Table J4. Projected Cumulative Natural Uranium Requirements for U.S. Nuclear Power Plants, 1993-2030
(Thousand Metric Tons Uranium)

Year	No New Orders Case	Lower Reference Case	Upper Reference Case
1995	51.4	50.9	50.9
2000	138.1	137.9	139.3
2005	222.2	223.2	225.6
2010	293.2	307.0	313.9
2015	347.1	395.1	416.3
2020	386.8	487.9	532.6
2025	410.8	586.9	663.7
2030	416.8	685.1	801.7

Note: Totals may not equal sum of components due to independent rounding. The conversion factor used to convert million pounds U_3O_8 to thousand metric tons U is 0.384645.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File CN6933.PRJ.INM93.OUTPUT, June 1993.

Glossary

Glossary

Baseload Plant: A plant, usually housing high-efficiency steam-electric units, which is normally operated to take all or part of the minimum load of a system, and which consequently produces electricity at an essentially constant rate and runs continuously. These units are operated to maximize system mechanical and thermal efficiency and minimize system operating costs.

Boiling-Water Reactor (BWR): A light-water reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine.

Breeder Reactor: A reactor that both produces and consumes fissionable fuel, especially one that creates more fuel than it consumes. The new fissionable material is created by a process known as breeding, in which neutrons from fission are captured in fertile materials.

Burnup: A measure of the amount of energy obtained from fuel in a reactor. Typically, burnup is expressed as the amount of energy produced per unit weight of fuel irradiated or "burned." Burnup levels are generally measured in units of megawattdays thermal per metric ton of initial heavy metal (MWDT/MTIHM).

Canadian Deuterium-Uranium Reactor (CANDU): Uses heavy water or deuterium oxide (D_2O), rather than light water (H_2O) as the coolant and moderator. Deuterium is an isotope of hydrogen that has a different neutron absorption spectrum from that of ordinary hydrogen. In a deuterium-oxide-moderated reactor, fuel made from natural uranium (0.71 U-235) can sustain a chain reaction.

Capacity: The load for which a generating unit is rated, either by the user or by the manufacturer. In this report, "capacity" refers to the utility's design electrical rating (see below).

Capacity Factor: The ratio of the electricity produced by a generating unit, for the period of time considered, to the energy that could have been produced at continuous full-power operation during the same period.

Commercial Operation: The phase of reactor operation that begins when power ascension ends and the operating utility formally declares to the NRC that the nuclear power plant to be available for the regular production of electricity. This declaration is usually related to the satisfactory completion of qualification tests on critical components of the unit.

Construction Pipeline: The various stages involved in the acquisition of a nuclear reactor by a utility. The events that define these stages are the ordering of a reactor, the licensing process, and the physical construction of the nuclear generating unit. A reactor is said to be "in the pipeline" when the reactor is ordered and "out of the pipeline" when it completes low-power testing and begins operation toward full power. (See Operable).

Criticality: The condition in which a nuclear reactor is just self-sustaining (i.e., the rate at which fissioning remains constant.)

Design Electrical Rating (capacity), Net: The nominal net electrical output of a nuclear unit, as specified by the utility for the purpose of plant design.

Discharged Fuel: Irradiated fuel removed from a reactor during refueling. (See Spent Nuclear Fuel.)

Enrichment Tails Assay: A measure of the amount of fissile uranium (U-235) remaining in the waste stream from the uranium enrichment process. The natural uranium "feed" that enters the enrichment process generally contains 0.711 percent (by weight) U-235. The "product stream" contains enriched uranium (greater than 0.711 percent U-235) and the "waste" or "tails" stream contains depleted uranium (less than 0.711 percent U-235). At the historical enrichment tails assay of 0.2 percent, the waste stream would contain 0.2 percent U-235. A higher enrichment tails assay requires more uranium feed (thus permitting natural uranium stockpiles to be decreased), while increasing the output of enriched material for the same energy expenditure.

Equilibrium Cycle: An analytical term which refers to fuel cycles that occur after the initial one or two cycles of a reactor's operation. For a given reactor, equilibrium cycles have similar fuel characteristics.

Fast Breeder Reactor (FBR): A reactor in which the fission chain reaction is sustained primarily by fast neutrons rather than by thermal or intermediate neutrons. Fast reactors require little or no moderator to slow down the neutrons from the speeds at which they are ejected from fissioning nuclei. This type of reactor produces more fissile material than it consumes.

Fertile Material: Material that is not itself fissionable by thermal neutrons but can be converted to fissile material by irradiation. The two principal fertile materials are uranium-238 and thorium-232.

Fissile Material: Material that can be caused to undergo atomic fission when bombarded by neutrons. The most important fissionable materials are uranium-235, plutonium-239, and uranium-233.

Fission: The process whereby an atomic nucleus of appropriate type, after capturing a neutron, splits into (generally) two nuclei of lighter elements, with the release of substantial amounts of energy and two or more neutrons.

Forward Costs: The operating and capital costs (in current dollars) still to be incurred in the production of uranium from estimated reserves; such costs are used in assigning the uranium reserves to cost categories. Forward costs include labor, materials, power and fuel, royalties, payroll and production taxes, insurance, and general and administrative costs. Expenditures prior to reserve estimates—e.g., for property acquisition, exploration, mine development, and mill construction—are excluded from forward cost determinations. Income taxes, profit, and the cost of money are also excluded. Thus, forward costs are neither the full costs of production nor the market price at which the uranium will be sold.

Full-Power Day: The equivalent of 24 hours of full power operation by a reactor. The number of full power days in a specific cycle is the product of the reactor's capacity factor and the length of the cycle.

Gas-Cooled Fast Breeder Reactor (GCFR): A fast breeder reactor that is cooled by a gas (usually helium) under pressure.

Generation (Electricity): The process of producing electric energy from other forms of energy; also, the amount of electric energy produced, expressed in watthours (Wh).

Gross Generation: The total amount of electric energy produced by the generating units at a generating

station or stations, measured at the generator terminals.

Net Generation: Gross generation less the electric energy consumed at the generating station for station use.

Gigawatt-Electric (GWe): One billion watts of electric capacity.

Heavy Water: Water containing a significantly greater proportion of heavy hydrogen (deuterium) atoms to ordinary hydrogen atoms than is found in ordinary (light) water. Heavy water is used as a moderator in some reactors because it slows neutrons effectively and also has a low cross-section for absorption of neutrons.

Heavy-Water-Moderated Reactor: A reactor that uses heavy water as its moderator. Heavy water is an excellent moderator and thus permits the use of inexpensive natural (unenriched) uranium as fuel.

Kilowatt-Electric (kWe): One thousand watts of electric capacity.

Kilowatthour (kWh): One thousand watthours.

Light Water: Ordinary water (H_2O), as distinguished from heavy water or deuterium oxide (D_2O).

Light-Water Reactor (LWR): A nuclear reactor that uses water as the primary coolant and moderator, with slightly enriched uranium as fuel. There are two types of commercial light-water reactors—the boiling-water reactor (BWR) and the pressurized-water reactor (PWR).

Liquid Metal Fast Breeder Reactor (LMFBR): A nuclear breeder reactor, cooled by molten sodium, in which fission is caused by fast neutrons.

Load Following: Regulation of the power output of electric generators within a prescribed area in response to changes in system frequency, tie-line loading, or the relation of these to each other, so as to maintain the scheduled system frequency and/or the established interchange with other areas within predetermined limits.

Low-Power Testing: The period of time between a plant's initial fuel loading date and the issuance of its operating (full-power) license. The maximum level of operation during this period is 5 percent of the unit's design electrical rating.

MAGNOX: A gas-cooled power reactor that uses graphite as the moderator and carbon dioxide gas as the coolant.

Megawatt-Electric (MWe): One million watts of electric capacity.

Megawatthour (MWh): One million watthours of electric energy.

Metric tons of Initial Heavy Metal (MtIHM): The weight of the initial fuel loading (in metric tons) used in an assembly.

Metric tons Uranium (MTu): A measure of weight equivalent to 2,204.6 pounds of uranium and other fissile and fertile materials that are loaded into an assembly during fabrication of the assembly.

Moderator: A material such as ordinary water, heavy water, or graphite, used in a reactor to slow down high-velocity neutrons, thus increasing the likelihood of further fission.

Net Summer Capability: The steady hourly output which generating equipment is expected to supply to a system load exclusive of auxiliary power as demonstrated by testing at the time of summer peak demand.

Nuclear Power Plant: A single- or multi-unit facility in which heat produced in a reactor by the fissioning of nuclear fuel is used to drive a steam turbine(s).

Nuclear Reactor: An apparatus in which the nuclear fission chain can be initiated, maintained, and controlled so that energy is released at a specific rate. The reactor apparatus includes fissionable material (fuel) such as uranium or plutonium; fertile material; moderating material (unless it is a fast reactor); a heavy-walled pressure vessel; shielding to protect personnel; provision for heat removal; and control elements and instrumentation.

Plutonium (Pu): A heavy, fissionable, radioactive, metallic element (atomic number 94). Plutonium occurs in nature in trace amounts. It can also be produced as a byproduct of the fission reaction in a uranium-fueled nuclear reactor and can be recovered for future use.

Power Ascension: The period of time between a plant's initial fuel loading date and its date of first commercial operation (including the low-power testing period). Plants in the first operating cycle (the time from initial fuel loading to the first refueling), which lasts approx-

imately 2 years, operate at an average capacity factor of about 40 percent.

Pressurized-Water Reactor (PWR): A nuclear reactor in which heat is transferred from the core to a heat exchanger via water kept under high pressure, so that high temperatures can be maintained in the primary system without boiling the water. Steam is generated in a secondary circuit.

Reasonably Assured Resources (RAR): Resource category that refers to uranium that occurs in known mineral deposits of such size, grade, and configuration that it could be recovered within the given production cost ranges, with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. The RAR category corresponds to the U.S. Department of Energy (DOE) Reserves category.

Reinserted Fuel: Irradiated fuel that is discharged in one cycle and inserted in the same reactor after sitting in the storage pool for at least one subsequent refueling. In a few cases, fuel discharged from one reactor has been used to fuel a different reactor.

Separative Work Unit (SWU): The standard measure of enrichment services. The effort expended in separating a mass F of feed of assay x_f into a mass P of product of assay x_p and waste of mass W and assay x_w is expressed in terms of the number of separative work units needed, given by the expression $SWU = WV(x_w) + PV(x_p) - FV(x_f)$, where $V(x)$ is the "value function," defined as $V(x) = (1 - 2x) \ln[(1-x)/x]$.

Spent Nuclear Fuel: Irradiated fuel that is permanently discharged from a reactor at the end of a fuel cycle. Spent or irradiated fuel is usually discharged from reactors because of chemical, physical, and nuclear changes that make the fuel no longer efficient for the production of heat, rather than because of the complete depletion of fissionable material. Except for possible reprocessing, this fuel must eventually be removed from its temporary storage location at the reactor site and placed in a permanent repository. Spent nuclear fuel is typically measured either in metric tons of heavy metal (i.e., only the heavy metal content of the spent fuel is considered) or in metric tons of initial heavy metal (essentially, the initial mass of the uranium before irradiation). The difference between these two quantities is the weight of the fission products.

Terawatthour (TWh): One trillion (10^{12}) watthours of electric energy.

Uranium (U): A heavy, naturally radioactive, metallic element (atomic number 92). Its two principally occurring isotopes are uranium-235 and uranium-238. Uranium-235 is indispensable to the nuclear industry, because it is the only isotope existing in nature, to any appreciable extent, that is fissionable by thermal neutrons. Uranium-238 is also important, because it

absorbs neutrons to produce a radioactive isotope that subsequently decays to plutonium-239, an isotope that also is fissionable by thermal neutrons.

Uranium Oxide (U_3O_8): Uranium concentrate or yellowcake.

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