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World Nuclear Outlook 1995

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Contains information on commercial nuclear capacity, fuel requirements, spent fuel and the uranium and enrichment markets.

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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 through 2015 of nuclear capacity, generation, and fuel cycle requirements for all countries in the world using nuclear power to generate electricity for commercial use. It also contains information and forecasts of developments in the uranium market. Long-term projections of U.S. nuclear capacity, generation, and spent fuel discharges for two different scenarios through 2040 are developed for the Department of Energy's Office of Civilian Radioactive Waste Management (OCRWM). In turn, the OCRWM provides partial funding for preparation of this report. The projections of uranium requirements 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.*

Some long-term nuclear capacity projections that required modeling of macroeconomic parameters were obtained from the Office of Integrated Analysis and Forecasting, Energy Information Administration. 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 PC version (PCINM) used for calculating the electricity generation values and fuel cycle requirements in this report, is documented in the International Nuclear Model Personal Computer Model Documentation. The Uranium Market Model (UMM) was used to project uranium prices, production, imports and inventories. Its documentation can be found in *Model Documentation of the Uranium Market Model* (prepared by the Oak Ridge National Laboratory).

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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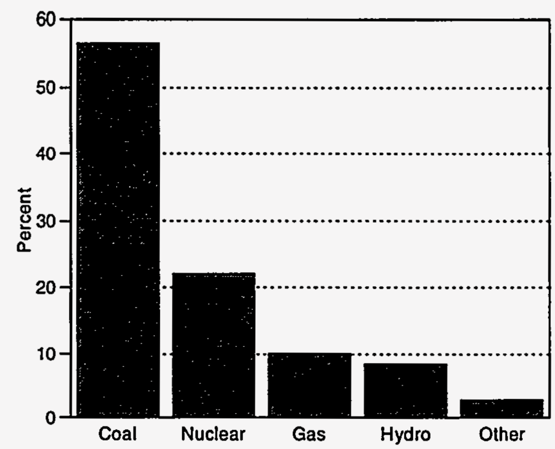
Worldwide Status of Nuclear Power

Nuclear power continues to be an important source of electricity, accounting for 23 percent of total electricity generation worldwide. World nuclear-generated electricity equaled 2,131 net terawatthours (TWh), a 1.8 percent increase over the 2,093 net TWh in 1993. At the end of 1994, there were 432 commercial nuclear reactors operating in 30 countries throughout the world, with a total capacity of 340.7 GWe. During the year, four nuclear units were connected to the grid in four countries while two were retired. One unit each was connected to the grid in the following countries: China, Japan, Mexico, and South Korea.

Worldwide, there are 98 nuclear units under construction. The Far East region has 37 units, more than any other region in the world. South Korea started constructing 5 units in 1994. The United States, as well as most Western European countries, has very few reactors under construction.

U.S. nuclear utilities continued putting forth a united effort to maintain a prominent role as a supplier of baseload power. Once again, the nuclear industry achieved a record capacity factor of 73.8 percent, the fourth record high in the past five years. In 1994, nuclear power plants in the United States produced 22 percent of utility-generated electricity, second only to coal-fired plants (Figure ES1).

Figure ES1. Percent Net U.S. Utility Electricity Generation by Fuel Type, 1994



Note: Other includes wood, waste, wind, photovoltaic, geothermal, and solar thermal energy sources connected to electric utility distribution systems.

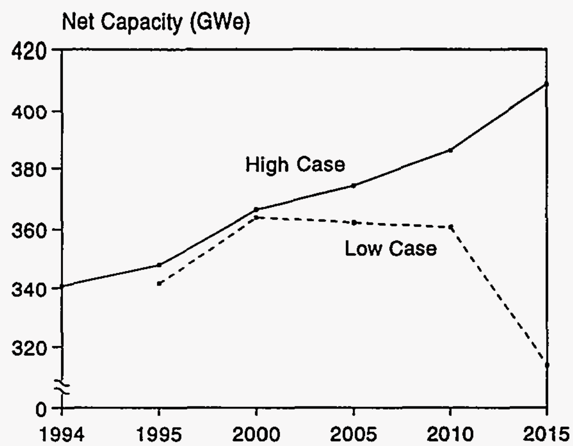
Source: Energy Information Administration, *Monthly Energy Review June 1995*, DOE/EIA-0035(95/06).

Worldwide Nuclear Capacity Projections

By the year 2015, worldwide nuclear capacity is projected to be between 313.9 GWe and 409.7 GWe (Figure ES2). The wide range in the projections indicates the uncertainty of nuclear power's future. At the low end of the range, the projected decline assumes that Western Europe and the United States choose alternatives to nuclear power for electricity generation, and fewer new nuclear plants will be constructed to replace the retiring units. On the other hand, countries in the Far East are expected to have an increase in nuclear power. China and South Korea are experiencing a tremendous increase in energy demand, and they, as well as Japan, have chosen nuclear power, at least in part, to meet this demand. In Eastern Europe, an increase in nuclear power may occur, but the costly upgrading of existing nuclear plants to meet Western safety standards is perhaps the major issue at this point.

The U.S. nuclear capacity is projected to decline from 99.1 GWe in 1994 to be between 61.4 GWe and 76.0 GWe by 2015. Today the United States has only one nuclear unit actively under construction. Although seven units are listed in the construction pipeline, six units are classified as indefinitely deferred with very little likelihood of ever being completed. The Tennessee Valley Authority (TVA) canceled plans to complete the Bellefonte 1 and 2, and Watts Bar 2 units, but they will complete Watts Bar 1, and should receive a full-power operating license in early 1996.

Figure ES2. 1994 World Nuclear Capacity and Projected Capacity, 1995-2015



Sources: **1994**—United States, Nuclear Regulatory Commission, "Information Digest, 1995 Edition" (NUREG-1357) (March 1995): Foreign, International Atomic Energy Agency (IAEA), "Nuclear Power Reactors in the World" (Vienna, Austria, April 1995). **Projections**—The projections are based on a critical assessment of detailed country-specific nuclear power plans. For some countries, the "World Integrated Nuclear Evaluation System," (WINES, June 1995 run) was used to supplement the 2015 capacity projection.

Uranium Market

Lingering oversupply fed by the drawdown of commercial inventories and imports from the republics of the Former Soviet Union (FSU) continued to push uranium market prices down in 1994. Meanwhile, overall world demand has been relatively flat in recent years, with little prospect for sustained growth over the next 20 years. Reflecting these conditions, the average uranium price, as indicated by the Nuexco spot price for the unrestricted market declined to $7.05 per pound U_3O_8 in 1994, compared to $7.12 per pound U_3O_8 in 1993. In the restricted U.S. market, where FSU imports have been limited, the average Nuexco spot price declined to $9.31 per pound U_3O_8 in 1994 from $9.98 per pound U_3O_8 in 1993.

Annual worldwide demand for U_3O_8 from 1995 through 2015 is projected to range from 119 million to 174 million pounds. Although the growth in nuclear power in Western Europe is not as high as other regions of the world, reactors in the Western Europe region account for 32 percent of this demand, the largest share of any region. Mixed-oxide fuel is being used in modest amounts in Western Europe and Japan, but will not affect significantly the use of uranium.

Despite the weakness in uranium spot prices in 1994, the market showed indications of tightening supply in the near-term. Persistent weak prices have depressed world production to levels well below Western demand. Also, excess commercial inventories in the West have been substantially reduced, while imports from the FSU have been limited. Influenced by these conditions, prices are expected to rise sharply over the next few years and then remain relatively stable as uranium becomes available from new U_3O_8 production and the liquidation of Russian and U.S. government inventories. In the longer term, prices are expected to rise more sharply as lower cost reserves become depleted. The spot price (in constant 1994 dollars) is projected to be $16.56 per pound U_3O_8 by 2010.

The United States produced 3.4 million pounds of U_3O_8 in 1994, up slightly from 3.1 million pounds in 1993. Production was from nonconventional operations, chiefly through in situ leaching and byproduct recovery from the mining of phosphate. Reflecting the persistent trend of low prices, more costly conventional underground and open pit mines have been closed since 1992.

Between 1995 and 2015, the United States is projected to account for 27 percent of cumulative world demand. Because U.S. uranium resources are of lower quality than those in Australia, Canada, and other countries, a large share of projected U.S. demand is likely to be met by less costly imports. Projected price increases should stimulate U.S. production to rise to 9.2 million pounds U_3O_8 by 2006. As lower cost reserves are depleted, production is projected to decline to 6.2 million pounds in 2010.

Enrichment Market

Excess inventories of enriched uranium in the Western world have largely been liquidated, while at the same time imports from the Russian Federation continue to be limited by the suspension agreements. As a result, the average spot price for the restricted U.S. enrichment market, as indicated by the Nuexco SWU Value, increased to $85.63 per SWU in 1994 from $78.42 per SWU in 1993. Russian-origin material was sold on the unrestricted market at an average Nuexco SWU Value of $67.58 per SWU in 1994, a slight increase from $67.25 per SWU in 1993. These increases in price have occurred despite the fact that annual demand of 26 million to 38 million SWU projected for 1995-2015 is less than the current worldwide enrichment capacity of 49 million SWU.

Over 90 percent of the volume of SWU purchased by domestic and foreign utilities in 1994 was through long-term contracts. The average duration of these contracts was 5 years. Due to significant excess enrichment capacity, utilities have been able to negotiate more flexible contract terms and conditions. As a means to improve their competitive position, enrichers have begun to market enriched uranium product, which includes the sale of the uranium feed component as well as the enrichment service.

Commercial Spent Fuel

Spent fuel management continues to be one of the most important tasks in the nuclear fuel cycle. Some countries are having successes while other countries are experiencing problems with the satisfactory implementation of short and long-term disposal. For example, Sweden has been successfully shipping spent fuel to an interim storage facility since 1982. But Japan is running out of storage space and will need to build additional storage facilities before 2010. In the United States, major legislative initiatives (both House and Senate versions) that would refocus the U.S. Department of Energy's (DOE) spent fuel storage program are pending in Congress. These bills recommend developing a centralized interim spent fuel storage facility to be used until a final repository is available. Meanwhile, U.S. nuclear reactors discharged 1,883 metric tons of uranium (MTU) in 1994. The spent fuel inventory stands at 29.8 thousand MTU. EIA projects that the United States will generate about 42 thousand MTU from 1995 through 2015. Cumulative spent fuel discharges worldwide for 1995 to 2015 are projected to be 217 to 226 thousand MTU.

1. Introduction

The use of nuclear power for electricity generation is increasing significantly in some regions of the world, while in others, it is projected to remain stable or decrease. For example, South Korea has an ambitious plan to expand the role of nuclear power. On the other hand, electric utilities in the United States have no immediate plans for constructing nuclear power plants.

This report presents the status of nuclear power at the end of 1994 for all countries with commercial nuclear power programs. The report contains projections of nuclear capacity, electricity generation, nuclear fuel requirements, and spent fuel discharges throughout the world. Sections covering current U.S. uranium market developments, projections of uranium prices, imports, inventories and production, and the uranium enrichment are also included. A review of the operating performance of U.S. reactors and issues affecting reactor lifetimes is also presented.

The U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) 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 preparing an annual report to Congress. Also, the DOE's Assistant Secretary for Policy uses the report for information on the status and outlook of nuclear power worldwide. Projections of nuclear capacity, fuel requirements and uranium production contained in this report are provided to the Organization for Economic Cooperation and Development and the International Atomic Energy Agency.

Chapter 2 of this report focuses on the status of nuclear power in the world by regional breakdown, including a detailed presentation of nuclear capacity projections through 2015, followed by a summary of important events that occurred in the regions in 1994 and the early months of 1995. Nuclear capacity projections are developed for two scenarios, a Low Case and a High Case. These scenarios are developed from an analysis of nuclear reactor construction schedules and retirements for each country, supplemented with computer model projections, as deemed appropriate.

Chapter 3 contains worldwide projections of reactor requirements for uranium and enrichment services for the Low and High Cases. These requirements 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. Projections of spent fuel discharges worldwide are discussed along with a presentation of the status of the spent fuel program in the United States. Also, in Chapter 3, is a discussion of world uranium market developments, with an emphasis on the U.S. market. Projections of uranium prices, U.S. imports, uranium inventories, and uranium production are discussed. Highlights of the uranium enrichment industry are also presented in this Chapter.

Chapter 4 contains a discussion on the performance of U.S. nuclear plants and issues related to U.S. reactor life times. It includes an update on capacity factors and operating and maintenance costs. Prospects for and issues of operating license renewal are addressed followed by a discussion on issues concerning the possibility of early shut down by some nuclear units.

Chapter 5 contains a comparison of EIA's projections with those of other organizations involved in the evaluation, analysis, and reporting of information on the nuclear and uranium industries.

Appendix A briefly describes nuclear power technology and the nuclear fuel cycle. Appendix B contains a discussion of the computer models and input assumptions used for the analysis and projections in this report. Appendices C and D are lists of nuclear reactors that were in operation and under construction at the end of 1994. Appendix E includes projections of nuclear capacity, generation, and spent fuel for two nuclear supply scenarios in the United States through 2040. Appendix F lists nuclear fuel cycle facilities that convert, enrich, and fabricate fuel for use in nuclear units. Appendix G contains a discussion of the uncertainties regarding uranium supplies. Appendix H shows selected tables in metric units.

2. Nuclear Capacity Status and Projections

Nuclear power programs have slowed in many countries in recent years because of a lower than expected growth rate of electricity consumption, lack of funding in developing countries, and public concerns regarding nuclear safety and radioactive waste disposal. This chapter concentrates chiefly on the status of the nuclear industry in 1994 and the first quarter of 1995. In particular, it tracks the progress of nuclear reactors under construction and the potential development of new nuclear generating capacity along with the status of current operating units. It also presents worldwide nuclear power capacity projections by the Energy Information Administration (EIA) from 1995 through 2015. Following a summary of the methodology used to make the projections, the discussion of nuclear power development focuses on the following regions: (1) United States, (2) Canada, (3) Western Europe, (4) Eastern Europe, (5) Far East, and (6) Other. Some country discussions have been omitted because little significant development occurred in 1994. Readers are advised to review *World Nuclear Outlook 1994* for a discussion of countries omitted here.

Information contained in this chapter as to nuclear units ordered and their status may differ from that in Appendix D. The material in Appendix D was obtained from various sources, but developed by EIA and is primarily based upon official utility project information; however, some units may be omitted from Appendix D because they were deemed unlikely to be built within the projected timeframe. In contrast, various sources were consulted for this chapter to permit analysis of the status of individual projects.[1]

World Nuclear Power

Current Status

At the end of 1994, 432 commercial nuclear units were operating in 30 countries throughout the world, with a total capacity of 340.7 net gigawatts-electric (GWe) (Table 1). A net increase of two units (2.6 GWe) occurred in 1994. A total of four nuclear units were in fact connected to the electrical grid; they were located in four countries on two continents. One unit was connected to the grid in China: Guangdong 2, a 906 net-megawatt-electric (MWe) pressurized light-water-cooled and moderated reactor (PWR). The unit, which is located in Shenzhen, Guangdong, completes the Guangdong two-unit station. Japan, which added four units in 1993, connected only one unit in 1994: Ikata 3, a 846-MWe PWR. Mexico added its second nuclear unit, Laguna Verde 2, a 654-MWe boiling light-water-cooled and moderated reactor (BWR), located in Laguna Verde, Veracruz. South Korea also connected one unit to the electrical grid, Yonggwang 3, a 950-MWe PWR, located in Yonggwang, Chonnam.

Two nuclear units were officially retired in 1994: Bugey 1 and Dounreay PFR. The Bugey 1 unit, located in Loyettes, Ain, in France, is the first of a five-unit station to be retired. The unit, a 540-MWe gas-cooled, graphite-moderated reactor (GCR), had operated for 22 years. In the United Kingdom, Dounreay PFR, a 234-MWe fast breeder reactor (FBR), had operated for 20 years.

Once again in 1994, the United States led all countries in nuclear capacity with 99.1 GWe, followed by France (58.5 GWe), Japan (38.9 GWe), Germany (22.7 GWe), Russia (19.8 GWe), Canada (15.8 GWe), and Ukraine (12.7 GWe) (Figure 1). Combined, these seven countries accounted for 79 percent of the world's capacity for generating electricity. World nuclear-generated electricity equaled 2,131.2 net terawatthours (TWh), a 1.8 percent increase over the 2,093.4 net TWh in 1993.

As of December 31, 1994, the "construction pipeline" consisted of 98 units with a total capacity of 85.3 GWe in various stages of construction (Table 2). Reactors in the construction pipeline vary from being actively under construction to being only in the planning stages. The decision about whether to include a reactor in the

[1]Primary sources of information in this chapter include various issues of *Nuclear Engineering International* (Surry, United Kingdom: Business Press, Ltd.); *Nuclear News* (LaGrange, Illinois: American Nuclear Society); Nuexco, *1995 Annual Nuexco Review* (Denver, CO, 1993); *NUKEM Market Report* (Stamford, CT); *Nuclear Fuel and Nucleonics Week* (New York: McGraw-Hill). Most of the sources reflect information reported through April 30, 1995, but a few sources include information reported through May 1995.

Table 1. Operable Nuclear Power Plant Statistics, 1993 and 1994

Country	Number of Operable Units[a]		Net Capacity (MWe)[b]		Amount of Electricity from Nuclear Units			1994
					Net TWh[b]		Percent Change	Share[c] (percent)
	1993	1994	1993	1994	1993	1994		
United States	109	109	99,041	99,148	610.3	640.4	4.9	[d]19.7
Canada	22	22	15,755	15,755	88.6	101.7	14.8	19.1
Western Europe								
Belgium	7	7	5,527	5,527	39.5	38.2	-3.3	55.8
Finland	4	4	2,310	2,310	18.8	18.3	-2.5	29.5
France	57	56	59,033	58,493	350.2	341.8	-2.4	75.3
Germany	21	21	22,657	22,657	145.0	143.0	-1.4	29.3
Netherlands	2	2	504	504	3.7	3.7	0.0	4.9
Slovenia	1	1	632	632	3.8	4.4	15.5	38.0
Spain	9	9	7,105	7,105	53.6	52.8	-1.5	35.0
Sweden	12	12	10,002	10,002	58.9	70.2	19.2	51.1
Switzerland	5	5	2,985	2,985	22.0	23.0	4.5	36.8
United Kingdom	35	34	11,909	11,720	79.8	79.4	-0.5	25.8
Subtotal:	153	151	122,664	121,935	775.3	774.8	-0.1	42.6
Eastern Europe								
Bulgaria	6	6	3,538	3,538	14.0	15.3	9.5	45.6
CIS/Kazakhstan	1	1	70	70	0.4	0.4	0.0	0.6
CIS/Russia	29	29	19,843	19,843	119.2	97.8	-18.0	11.4
CIS/Ukraine	15	15	12,679	12,679	75.2	68.9	-8.4	34.2
Czech Republic	4	4	1,648	1,648	12.6	12.1	-3.7	28.2
Hungary	4	4	1,729	1,729	13.0	13.2	1.8	43.7
Lithuania	2	2	2,370	2,370	12.3	6.6	-46.1	76.4
Slovak Republic	4	4	1,632	1,632	11.0	12.1	10.3	49.1
Subtotal	65	65	43,509	43,509	257.7	226.6	-12.1	17.9
Far East								
China	2	3	1,194	2,100	2.5	13.5	440.0	1.5
Japan	48	49	38,029	38,875	246.3	258.3	4.9	30.7
Korea, South	9	10	7,220	8,170	55.4	55.9	0.9	35.5
Taiwan	6	6	4,890	4,890	33.0	33.5	1.5	31.7
Subtotal	65	68	51,333	54,035	337.2	361.2	7.1	18.0
Other								
Argentina	2	2	935	935	7.2	7.7	6.7	13.8
Brazil	1	1	626	626	0.4	0.0	-90.0	0.0
India	9	9	1,593	1,493	5.4	4.3	-20.0	1.4
Mexico	1	2	654	1,308	3.7	4.3	15.7	3.2
Pakistan	1	1	125	125	0.4	0.5	25.0	1.0
South Africa	2	2	1,842	1,842	7.2	9.7	34.6	5.7
Subtotal	16	17	5,775	6,329	24.3	26.5	9.1	3.7
Total World	430	432	338,077	340,711	2,093.4	2,131.2	1.8	23.0

[a]For 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.

[b]MWe = megawatt-electric; TWh = terawatthours.

[c]Each country's net electricity generated from nuclear power generating units as a percentage of net electricity generated from all sources by utilities and nonutilities. The source for non-U.S. nuclear generation data is the International Atomic Energy Agency (IAEA). The nuclear share of utility-generated electricity for the United States was 22.0 percent.

[d]1994 utility generation was obtained from the Energy Information Administration, *Monthly Energy Review, June 1995.* DOE/EIA-0035(95/06) (Washington, DC, June 95). Forecasted 1994 gross nonutility generation data was obtained from the Energy Information Administration, Projection for the Short-Term Energy Outlook Memorandum, June 29, 1995.

Source: 1993-International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1994). 1994-International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1995).

Table 2. Status of Commercial Nuclear Generating Units in the Construction Pipeline as of December 31, 1994

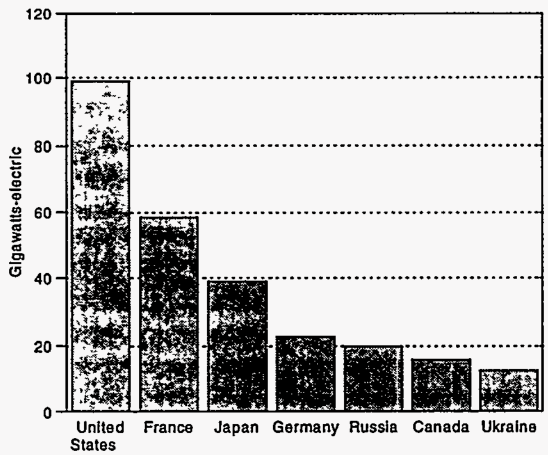
Country	Percentage of Construction Completed									
	0 to 25		26 to 50		51 to 75		76 to 100		Total	
	No. of Units	Net MWe[a]	No. of Units	Net MWe	No. of Units	Net MWe	No. of Units	Net MWe	No. of Units	Net MWe
United States	0	0	1	1,212	4	4,839	2	2,382	7	8,433
Western Europe										
France	4	5,755	2	2,905	0	0	2	2,910	8	11,570
United Kingdom	1	1,188	0	0	0	0	1	1,188	2	2,376
Subtotal	5	6,943	2	2,905	0	0	3	4,098	10	13,946
Eastern Europe										
CIS/Armenia	1	370	0	0	0	0	1	[b]370	2	740
CIS/Russia	7	5,325	1	950	1	950	1	950	10	8,175
CIS/Ukraine	3	2,850	1	950	1	950	2	1,900	7	6,650
Czech Republic	0	0	0	0	2	1,824	0	0	2	1,824
Romania	3	1,890	1	630	0	0	1	635	5	3,155
Slovak Republic	1	388	1	388	1	388	1	388	4	1,552
Subtotal	15	10,823	4	2,918	5	4,112	6	4,243	30	22,096
Far East										
China	4	3,170	0	0	0	0	0	0	4	3,170
Japan	13	1,4540	0	0	3	3,757	2	1,042	18	19,339
Korea, North	1	200	0	0	0	0	0	0	1	200
Korea, South	7	5,750	3	2,570	0	0	1	950	11	9,270
Philippines	0	0	0	0	0	0	1	620	1	620
Taiwan	2	1,800	0	0	0	0	0	0	2	1,800
Subtotal	27	25,460	3	2,570	3	3,757	4	2,612	37	34,399
Other										
Argentina	0	0	0	0	0	0	1	692	1	692
Brazil	0	0	1	1,229	1	1,245	0	0	2	2,474
Cuba	2	816	0	0	0	0	0	0	2	816
India	3	1,160	2	404	2	404	1	202	8	2,170
Pakistan	1	300	0	0	0	0	0	0	1	300
Subtotal	6	2,276	3	1,633	3	1,649	2	894	14	7,452
Total World	53	45,502	13	11,238	15	14,357	17	14,229	98	85,326

[a]MWe = megawatt-electric.
[b]Although the exact stage of construction for the Medzamor 2 reactor is unknown, the Medzamor 2 unit was reconnected to the grid in June 1995.
Source: "World List of Nuclear Power Plants," *Nuclear News* (March 1995), pp. 27-42. *Nucleonics Week* (various issues).

construction pipeline is based on an assessment of a given country's desire to build a nuclear reactor and the financial constraints involved in purchasing one. A total of 20 countries have been identified as having nuclear units currently in the construction pipeline. Of the 98 units, 53 are less than 25 percent complete.[2] The Far East region's nuclear construction program far surpasses that of any other region, with 37 units in the construction pipeline for a total capacity of 34.4 GWe. During 1994, nine reactors were added to the construction pipeline list, five of them in South Korea.

[2]The 53 units that were listed as being less than 25 percent complete include those units whose percent completion is unknown.

Figure 1. Nations with the Largest Nuclear Generating Capacity, 1994



Source: See Table 1.

Outlook

Methodology

In general, EIA uses three different approaches to develop nuclear generating capacity for individual countries. The first approach projects nuclear capacity by estimating completion dates for units under construction in each country.[3] If a country's construction pipeline is exhausted before the end of the projection period, a second approach, the World Integrated Nuclear Evaluation System (WINES) model, may be used to supplement the capacity projection. The WINES model develops long-term projections of nuclear generating capacity for each country using assumptions about its economic growth, its energy consumption, and the proportion of energy to be supplied by nuclear power. For countries that have no units in the construction pipeline, a third approach is used. These projections were based on an assessment of detailed country-specific nuclear power plant information provided by the countries at the 1995 Consultancy Meeting on International Nuclear Capacity Forecasting held by the International Atomic Energy Agency (IAEA) in March 1995.

This year's projections include two scenarios, the High Case and the Low Case, for the United States and other countries. The two cases were developed to show the effects of different assumptions on projected nuclear generating capacity. The U.S. scenarios are also called the "**No New Orders**" and "**License Renewal**" cases. In the "No New Orders" case, it is assumed that no new advanced light-water reactors (ALWR) will become operational before the year 2015 and all current nuclear units are retired on the dates their initial license-terms expire. In the "License Renewal" case, it is assumed that half the current nuclear units renew their licenses for additional 20-year terms. However, the additional capacity shown by this scenario could occur for other reasons. For example, it could result if less than half the nuclear units renewed their licenses, while some new ALWRs came online. The "License Renewal" case serves as a reasonable surrogate for this and other possible outcomes.

The **Low Case (Foreign)** capacity projections are based solely on units in the construction pipeline, which are listed in Appendix D, along with their estimated dates of operation (in the "Published" column). Expected retirement dates for existing reactors are incorporated in the projections.

The **High Case (Foreign)** is an accelerated growth case, which assumes that each country's unfinished nuclear units are completed but not necessarily operational by 2015. Estimates of operation dates for nuclear units in the construction pipeline are based on analysis of historical construction performance, regulatory issues, financial constraints, and regional electricity demand considerations. Projections based on these methods were supplemented by use of the WINES model for the 2015 High Case projection for the following countries: Argentina, Belgium, Canada, Finland, France, Germany, Mexico, Spain, Sweden, Taiwan, and United Kingdom. Note that neither the U.S. nor foreign scenarios should be interpreted as exhausting the range of possible nuclear supply futures.

Projections and Regional Developments

A slowdown in the construction of nuclear power plants is currently in effect in Belgium, Bulgaria, Canada, Cuba, Finland, Germany, Italy, Lithuania, Netherlands, Philippines, Spain, Sweden, Switzerland, United Kingdom, and the United States. In these countries, there are few prospects for any significant change in nuclear power development.

[3]As noted earlier, the construction pipeline was developed by EIA, which may omit some units discussed in the text if analyst deems that unit unlikely to be built within the projection timeframe.

By the year 2015, the worldwide installed nuclear capacity is projected to be between 313.9 and 409.7 GWe, compared to the current total of 340.7 net GWe (Table 3). The decline in capacity in the Low Case assumes that few new nuclear baseload electricity generation plants will be commissioned in Western Europe and the United States, as these countries look at alternative fuel sources such as natural gas. For these regions, the focus is on extending the operation of existing plants. For the countries of the Former Soviet Union and Eastern Europe, some growth in nuclear power is projected; however, adding safety features and upgrades to western standards are the current major issues. In fact, Asia may be the only region of the world with significant growth of nuclear generating capacity. Countries like China, South Korea, Taiwan, Indonesia, and Thailand are experiencing a tremendous increase in energy consumption. In some of these countries, nuclear power has been chosen to satisfy at least partially the demand. In the other regions of the world, nuclear power will remain a relatively small contributor to electricity supply.

The following overview examines current developments in nuclear power in the five regions listed at the beginning of the chapter, describing the current status and highlighting important events during the year. The projections result from of a review carried out yearly by EIA to develop plausible scenarios for nuclear generating capacity developments.

United States

As of December 31, 1994, the list of operable nuclear power plants in the United States included 109 nuclear units (Figure 2) with a total net capacity of 99.1 net GWe. In 1994, U.S. plants reached the highest capacity factor ever, achieving an average value of 73.8 percent and topping the 1992 value of 70.9 percent.[4] As would be expected, total nuclear generation also reached its highest point, 640.4 net TWh. This total was 21.7 TWh more than the previous high of 618.8 net TWh set in 1992.

U.S. utilities generated 22.0 percent of their electricity from nuclear plants in 1994, compared with 21.2 percent in 1993—a 3.8 percent increase that was largely attributable to improved performance. Utilities in six of the 10 Federal regions in the United States generated more than 20 percent of their electricity from nuclear power plants, led by New England (50.9 percent) and New York/New Jersey (37.9 percent) (Table 4).

The 1994 EIA projection indicates that with only one nuclear unit actively under construction, the United States is likely to have a nuclear capacity of between 61.4 GWe (Low Case) and 76.0 GWe (High Case) by 2015. Although seven units are listed in the construction pipeline, six units are classified as indefinitely deferred and have very little hope of ever being completed. All units officially remain in the construction pipeline, however, until the Nuclear Regulatory Commission receives a formal letter from the utility stating that the unit will not be constructed.

The Tennessee Valley Authority (TVA) is the only U.S. utility still building nuclear plants. In 1994, however, it decided to cancel plans to finish its Bellefonte unit 1 and 2 station and the Watts Bar 2 unit. Originally, the utility decided to rely on nuclear generation to supply a major portion of its commitments; however, the recent policy change has shifted the TVA away from using nuclear generating units to meet future power demand. The utility is now looking at demand-side management, independent power producers, and new technology to meet future power needs. Originally, an announcement of the units' future was to be outlined in TVA's draft Integrated Resource Plan (IRP), which was due to be completed in July 1995; however, the fate of the units apparently was unavoidable and the utility decided to announce its plans earlier.

The TVA had invested billions of dollars in the Bellefonte and Watts Bar stations, in addition to amassing large debts in fixing other operating units and continuing construction on the other plants. TVA is about $4 billion under its federally mandated $30 billion debt ceiling and finishing the three nuclear units would have cost about $9 billion. The decision to cancel Bellefonte 1 and 2 and Watts Bar 2 left the units 80, 45, and 70 percent complete, respectively.

Until TVA finalizes its IRP sometime in late 1995 or early 1996, the utility will maintain the three units in their current condition and then decide whether to restart its Brown's Ferry 1 nuclear unit. The utility is exploring ways to convert the Bellefonte station to another technology utilizing pulverized coal or integrated coal gasification. In addition, the utility is considering a partnership with other utilities to carry out the pending Brown's Ferry 1 restart. Brown's Ferry

[4]In 1993, U.S. plants recorded a capacity factor of 70.5 percent.

Table 3. 1994 Operable Nuclear Capacities and Projected Capacities for 1995, 2000, 2005, 2010, and 2015
(Net Gigawatts-Electric)

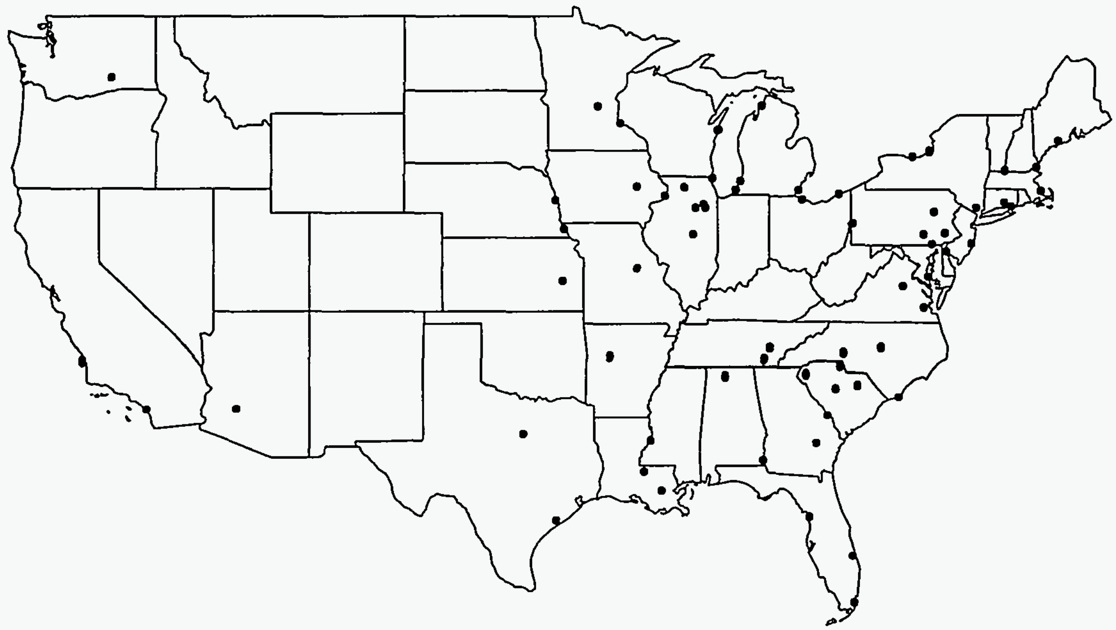
Country	1994[a]	1995		2000		2005		2010		2015	
		Low	High	Low	High	Low	High	Low	High	Low	High
United States	99.1	99.1	99.1	100.3	100.3	100.3	100.3	91.1	95.0	61.4	76.0
Canada	15.8	14.9	14.9	14.1	14.1	14.1	14.1	12.0	12.0	12.0	15.3
Western Europe											
Belgium	5.5	5.5	5.5	5.5	5.5	4.7	4.7	3.9	3.9	3.9	4.8
Finland	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.7
France	58.5	58.5	59.9	64.3	64.3	62.9	62.9	62.9	64.3	60.5	72.8
Germany	22.7	22.7	22.7	22.0	22.0	21.4	21.4	21.4	21.4	20.2	23.6
Italy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Netherlands	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	1.4
Slovenia	0.6	0.6	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	7.0	7.1	7.0	7.0	6.5	7.0	6.5	9.4
Sweden	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	6.7	10.5
Switzerland	3.0	3.0	3.0	3.0	3.0	2.3	2.3	1.9	1.9	1.9	2.6
United Kingdom	11.7	12.4	12.4	11.8	11.8	10.5	10.5	9.5	10.7	7.2	12.4
Subtotal	121.9	122.7	124.1	127.0	127.1	121.7	121.7	119.1	122.1	109.8	141.4
Eastern Europe											
Bulgaria	3.5	3.5	3.5	2.7	2.7	1.9	2.9	1.9	3.8	1.9	3.8
CIS/Armenia	0.0	0.0	0.4	0.4	0.7	0.4	0.7	0.4	0.7	0.4	0.7
CIS/Kazakhstan	0.1	0.1	0.1	0.1	0.1	0.0	0.6	0.0	0.6	0.0	1.2
CIS/Russia	19.8	19.8	21.7	23.6	23.6	20.1	20.9	17.5	24.5	12.9	27.1
CIS/Ukraine	12.7	12.7	13.6	15.5	14.1	14.1	15.1	15.6	16.6	11.4	15.2
Czech Republic	1.6	1.6	1.6	2.6	3.5	3.5	3.5	3.5	3.5	3.1	5.1
Hungary	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	2.3	2.1	3.3
Lithuania	2.4	2.4	2.4	2.4	2.4	2.4	2.4	1.2	2.4	1.2	1.2
Romania	0.0	0.0	0.6	0.6	1.3	1.3	1.9	1.9	2.5	2.5	3.2
Slovak Republic	1.6	1.6	1.6	2.0	1.6	1.6	1.6	1.6	1.6	0.8	1.4
Subtotal	43.5	43.5	47.3	51.6	51.7	47.0	51.2	45.3	58.5	36.2	62.1
Far East											
China	2.1	2.1	2.1	2.1	2.1	3.3	5.3	5.3	5.3	5.3	8.2
Japan	38.9	39.9	39.9	43.7	43.7	45.8	46.1	51.1	52.3	52.6	57.7
Korea, North	0.0	0.0	0.0	0.2	0.0	0.2	1.9	0.2	1.9	0.2	1.9
Korea, South	8.2	8.2	9.1	13.0	13.0	13.9	14.9	17.4	17.4	17.4	19.3
Philippines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.6
Taiwan	4.9	4.9	4.9	4.9	4.9	6.7	6.7	6.7	6.7	6.7	8.5
Subtotal	54.0	55.1	56.0	63.9	63.7	69.9	74.9	80.7	84.2	82.2	96.2
Other											
Argentina	0.9	0.9	0.9	0.9	1.6	1.6	1.6	1.3	1.3	1.3	1.5
Brazil	0.6	0.6	0.6	0.6	1.9	1.9	1.9	1.9	3.1	1.9	3.1
Cuba	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.8
India	1.5	1.5	1.7	2.3	2.5	2.2	3.6	3.3	3.5	3.3	5.1
Iran	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.3
Israel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Mexico	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.9
Pakistan	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.7	0.3	0.6
South Africa	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Turkey	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	2.0
Subtotal	6.3	6.3	6.5	7.1	9.6	9.3	12.1	12.4	14.1	12.3	18.7
Total World	**340.7**	**341.6**	**348.1**	**363.9**	**366.4**	**362.1**	**374.1**	**360.6**	**386.0**	**313.9**	**409.7**

[a]Status as of December 31, 1994.

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

Source: 1994—United States, Nuclear Regulatory Commission, "Information Digest, 1995 Edition" NUREG-0380 (March 1995); Foreign International Atomic Energy Agency (IAEA), "Nuclear Power Reactors in the World"] (Vienna, Austria, April 1995); Projections—The projections are based on a critical assessment of detailed country-specific nuclear power plans. For some countries, the "World Integrated Nuclear Evaluation System," (WINES) (WINES June 1995 run) was used to supplement the 2015 capacity projection.

Figure 2. Location of Operable Nuclear Power Plants in the United States



Note: Plants at some locations have more than one unit.
Source: Energy Information Administration.

Table 4. U.S. Nuclear Capacity and Generation as of December 31, 1994, by Federal Region

Federal Region[a]	Capacity (net MWe)[b]	Actual 1994 Generation (net TWh)[b]	Percent Share[c]
I New England	6,375	41,169,782	50.9
II New York/New Jersey	8,693	51,360,769	37.9
III Middle Atlantic	13,812	103,871,079	29.5
IV South Atlantic	26,860	174,448,190	25.4
V Midwest	21,676	121,491,116	22.3
VI Southwest	8,482	55,447,810	12.9
VII Central	4,044	28,988,206	19.0
VIII North Central	0	0	0.0
IX West	8,120	56,923,131	25.4
X Northwest	1,086	6,739,749	5.1
Total	**99,148**	**640,439,832**	**22.0**

[a]**Region I:** Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, and Connecticut; **Region II**, New York and New Jersey; **Region III:** Pennsylvania, Delaware, District of Columbia, Maryland, Virginia and West Virginia; **Region IV:** Kentucky, Tennessee, North and South Carolina, Mississippi, Alabama, Georgia, and Florida; **Region V:** Minnesota, Wisconsin, Michigan, Illinois, Indiana, and Ohio; **Region VI:** New Mexico, Oklahoma, Arkansas, Texas, and Louisiana; **Region VII:** Nebraska, Iowa, Kansas, and Missouri; **Region VIII:** Montana, North and South Dakota, Wyoming, Utah, and Colorado; **Region IX:** California, Nevada, Arizona, and Hawaii; **Region X:** Washington, Oregon, Idaho, and Alaska.

[b]MWe = megawatt-electric; TWh = terawatthours.

[c]*Nuclear-generated electricity as a percentage of utility-generated electricity.* Nonutility generated electricity is not included.

Note: • Totals may not equal sum of components due to independent rounding. • One TWh is equivalent to one billion kilowatthours.

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

1 still retains a full operating license from the NRC that is valid through 2013. Due to Federal borrowing limits, TVA may need outside financing to help cover the estimated $1.5 billion to $2 billion in restart cost.

Canada

Ontario Hydro, Canada's largest utility, manages 20 of the country's 22 operable reactors (Figure 3). The other Canadian reactors are the 640-MWe Gentilly 2 reactor operated by Hydro-Quebec and the 635-MWe Point Lepreau 1 operated by the New Brunswick Electric Power Company. All of the country's nuclear plants are Canadian deuterium-uranium or CANDU reactors (PHWRs) supplied by Atomic Energy of Canada, Ltd. Net generation for Canada's operable nuclear units totalled 101.7 TWh, a substantial increase over the 1993 figure of 88.6, due in large part to increases in efficiency at a number of plants. As a result, nuclear power accounted for 19.1 percent of the total electric generation, compared to the 1993 share of 17.3 percent.

In 1993, Ontario Hydro announced that it would reduce its surplus generating capacity by almost 3.0 GWe, because of declining energy sales in the previous 4 years. As a result, several power plants are scheduled to be shut down. The shutdown includes two oil-fired plants at the Lennox power station, two coal-fired units at the Lambton station, and one nuclear unit, Bruce 2. Currently, the Bruce 2 unit is scheduled to be shutdown in September 1995, but not decommissioned; instead, the unit will be preserved in such a way that it can be brought back into service if needed. To continue

Figure 3. Location of Operable Nuclear Power Plants in Canada

Note: Plants at some locations have more than one unit.
Source: Plant location was obtained from the International Atomic Energy Agency.

operating, the Bruce 2 unit would have required large-scale maintenance work, including replacing 480 fuel-carrying pressure tubes, over the next few years.

Much like the U.S. outlook, Canada's prospects for new nuclear capacity in the near-term are unfavorable. The country has no units in the construction pipeline and the nuclear industry's primary concern has become maintaining reliable operation of existing plants.

Western Europe

The Western European region comprises 10 countries with a total capacity of 121.9 net GWe from 151 nuclear units (Table 5; Figure 4), with nuclear-generated electricity accounting for 43 percent of total electricity generation. The region accounts for 36 percent of the world's total commercial nuclear power capacity and is projected to account for 35 percent in both the High and Low Cases, by 2015. Many countries in Western Europe have been affected by economic recession, but their governments are predicting increased electricity demand in the future. Nuclear power does not appear, however, to be the fuel of choice for these countries. In 2010, the difference between the Low and High Cases is 3.1 GWe. By 2015, the difference is 31.6 GWe, indicating the uncertainty of nuclear power's role in contributing to the energy mix in Western Europe. Nearly all countries except France are experiencing a slowdown in nuclear-generated capacity. As in the United States, economics, public perception, and the back end[5] of the nuclear fuel cycle have made nuclear power's future uncertain. In Belgium, Germany, Netherlands, Spain, Sweden, Switzerland, and the United Kingdom, nuclear capacity is projected to decline by 2015 in the Low Case.

In 1994, Finland's few reactors generated 30 percent of the electricity used in the country. In September 1993, however, the Finnish parliament had vetoed plans for a fifth nuclear reactor. The decision leaves the country with few alternatives to meet the estimated additional baseload power needs of 3.5 GWe by 2005. Industry and utility representatives hope to reintroduce the reactor proposal after parliamentary elections, but it is unlikely that the antinuclear Center and Green parties, which have the controlling vote, will allow such a proposal to pass. The Social Democrats are believed to be more favorable to nuclear power.

Table 5. Power Plant Statistics for the Western European Region, 1994

Country	Number of Operable Reactors	Operable Capacity (net MWe)[a]	Number of Reactors in Construction	Construction Capacity (net MWe)[a]	1994 Capacity Factor (Percent)	Amount of Electricity from Nuclear Units in 1994 (net TWh)[a]	1994 Percent Nuclear Share[b]
Belgium	7	5,527	0	0	81.1	38.2	55.8
Finland	4	2,310	0	0	90.0	18.3	29.5
France	56	58,493	8	11,570	67.1	341.8	75.3
Germany	21	22,657	0	0	71.8	143.0	29.3
Netherlands	2	504	0	0	84.6	3.7	4.9
Slovenia	1	632	0	0	79.2	4.4	38.0
Spain	9	7,105	0	0	77.2	52.8	35.0
Sweden	12	10,002	0	0	76.0	70.2	51.1
Switzerland	5	2,985	0	0	89.4	23.0	36.8
United Kingdom	34	11,720	2	2,376	72.4	79.4	25.8
Total	**151**	**121,935**	**10**	**13,946**	**--**	**774.8**	**42.6**

[a]MWe = megawatt electric; TWh = terawatthours.
[b]Net electricity generated from nuclear power generating units as a percentage of net electricity generated from utilities and nonutilities.
-- = Not applicable.
Source: **1994 Capacity Factor:** *Nucleonics Week* (New York, McGraw-Hill) (February 9, 1995). p.8.

[5]"Back end" refers to the steps necessary to manage the spent radioactive nuclear fuel, as opposed to the "front end," which comprises the steps necessary to prepare nuclear fuel for reactor operation.

Figure 4. Location of Operable Nuclear Power Plants in the Western Europe Region

Note: Plants at some locations have more than one unit.
Source: Plant location was obtained from the International Atomic Energy Agency.

Regardless of the country's decision about nuclear power, some form of baseload power must be built to meet electricity needs in the 21st century. The country's four operating reactors generated 18.3 net TWh of electricity in 1994. Electricity consumption increased by 4 percent in 1994, signaling an economic recovery.

Finnish utilities have been moving to coal-fired plants, but the carbon dioxide (CO_2)taxes are so high that the coal-fired plants are not as competitive as nuclear power. Imatran Voima Oy (IVO), the state-owned utility, is studying the viability of a 600-MWe coal-fired plant, as well as the possibility of a gas-fired plant, at a site with three existing units.

IVO and Russia have signed a new contract continuing the transportation of spent nuclear fuel from the Finnish Loviisa nuclear power plant to Russia. Finnish authorities, however, believe that the country should store its own nuclear waste. Currently, IVO plans to increase its capacity for interim storage of spent fuel at Loviisa in anticipation of an amendment to the Finnish nuclear energy law that would require final disposal of high-level waste within Finnish territory. Presently, Loviisa's reactor storage pools have capacity for only 5 years' worth of spent fuel. IVO and Teollisuuden Voima Oy, a privately owned utility, are searching for a suitable site for a final repository in Finnish bedrock, but the plans do not envision making a repository available before 2020.

In 1994, France's 56 nuclear reactors generated 75 percent of the total electricity produced in the country, second only to Lithuania's 76-percent share. Currently, nuclear power enjoys a 25-percent edge in electricity generation cost over coal and gas-fired power in France and has produced over 100,000 direct jobs for its citizens. The country expects nuclear power to retain its cost advantage even as its plants age and replacement of major components increases. Electricité de France (EDF), the country's national utility, expects nuclear power to keep its cost advantage as units move to longer operating cycles and as higher burnups of fuel are introduced.

EDF likely will not need any new reactor orders until the next century. Domestic demand is not growing substantially, and EDF does not expect to export more than 70 billion KWh of electricity by 2000, a level it can meet with present capacity. In 1994, France's nuclear plants generated 342 net TWh, with a capacity factor of 67.1 percent. EDF has set the goal of an 85-percent capacity factor by 2000. For any new capacity, the French government is encouraging the development of cogeneration and independent power production.

EDF, however, has taken some criticism for its energy development by environmentalists and other opponents. The perceived lack of fairness in developing renewable energy sources and energy conservation, the over-use of electricity as an energy source, and the underestimation of nuclear cost—most notably, the back end of the fuel cycle—are some of the concerns raised by detractors.

Like utilities in the United States and many other countries around the world, the French are considering plant life extension, which would replace aging components such as steam generators, reactor vessel heads, and primary system piping.

Although EDF has not placed any new reactor orders, it will proceed with plans to complete its series of N4 1,455-MWe PWRs, beginning with Chooz B1 and B2, to be completed between 1995 and 1996, and Civaux 1 and 2, which received final authorization from the government early in 1994.

Germany's 21 nuclear units continue to be some of the world's most productive reactors, despite the Social Democratic Party's opposition to nuclear power and seemingly endless court cases to close them down. Talks aimed at developing a comprehensive German energy policy regarding nuclear power are scheduled to resume in 1995. In 1993, the German government energy talks addressed CO_2 emissions and the role nuclear power should play in the country's energy mix. The Christian Democrats, who have support in the Federal Government, continue to support the use of nuclear power, but the Social Democrats, who have the majority of support in the state governments, are generally committed to phasing out nuclear power and, in several state governments, want nuclear power to close down as soon as possible. Recommendations regarding nuclear power were omitted from the final energy policy report in order to gain agreement on the report.

In the absence of a political consensus regarding nuclear power, the Federal Government passed two amendments to the atomic energy act in 1994. The first amendment leaves open the option of building a new nuclear power plant, with the caveat that the reactor be designed and operated in such a way as to eliminate the possibility of a serious offsite accident. The second amendment removes a previous requirement for operators of nuclear power plants to make arrangements for reprocessing of spent fuel as an essential part of the back end of the fuel cycle. Now the utilities have the option of interim storage and final direct disposal of spent fuel. Most utilities have indicated that they do not wish to pull out of earlier contracts for reprocessing services in France because of the heavy penalties that would be involved, but they may well opt out of some later contracts that offer them more flexibility. Some utilities, however, have canceled their reprocessing contracts with British Nuclear Fuels (BNF) and are in the process of renegotiating contracts with Cogema and BNF.

The Dutch government and the NV Electriciteits-Producktiemaatschappij Zuid-Nederland (PZ) utility agreed in December 1994 to shut down at the end of 2003 the Borssele 449-MWe PWR, which was set to operate until 2007. Borssele is the only commercial-size reactor in the Netherlands. In exchange for the early shutdown, the utility will receive about $40 million, allowing it to proceed with a safety-related backfit program at the Borssele reactor. The utility has already spent $91 million for backfits required by the safety authority to extend the operating license, from 2004 to 2007, an arrangement that has now been revoked by the 1994 agreement.

Meanwhile, the Dutch government is preparing a new nuclear energy white paper to be presented to Parliament in the second half of 1995. Preliminary reports indicate that the revised energy policy will emphasize research and development of passively safe nuclear power plants if new reactors are ordered.

Fifteen years after Sweden's historic vote to shut down all its nuclear plants by 2010, the country is no closer to phasing out nuclear power. Today, roughly 50 percent of the country's electricity comes from nuclear power; however, the new prime minister has expressed commitment to the original 2010 shutdown date and interest in eventually replacing nuclear power with natural gas. Such a policy would set in motion the decommissioning of the country's 12 reactors, which produced more than 70 net TWh of electricity in 1994.

Sweden's antinuclear Green Party proposes to replace the lost power with biofuel, wind, and solar energy combined with more efficient production and energy conservation. Both union and industry leaders have campaigned against a shutdown, arguing that inexpensive nuclear power gives them leverage in the world market from industries such as mining, steel, and paper, which require abundant power. Current Swedish law states that reactors can be shut down only for safety reasons, but must shut down by 2010. The Greens advocate starting Ringhals 2 decommissioning now because its license is up for renewal at the end of 1995.

Despite the retirement of one reactor, Dounreay PFR, a 234-MWe unit located in Dounreay, Highland, the United Kingdom's (U.K.) remaining 34 operating reactors generated 79.4 net TWh of electricity in 1994. Nuclear power accounted for 26 percent of the total electricity generated in the country. With a total nuclear generating capacity of 11.7 net GWe, the U.K.'s reactors are operated by three utilities, British Nuclear Fuels, Nuclear Electric (NE), and Scottish Nuclear Limited.

In 1994, NE reported that nuclear operating cost per kilowatthour generated had decreased significantly since the U.K.'s electricity industry was privatized in 1989. At the time, the nuclear sector was to be commercialized too; however, that plan was abandoned due to investors' concerns about decommissioning costs.

In May 1995, the U.K. government concluded that the privatization of the advanced gas-cooled and PWR nuclear stations, together with a significant level of their associated liabilities, is feasible. As a result, the government intends to privatize parts of Nuclear Electric and Scottish Nuclear Fuels as a subsidiary of a single holding company during the course of 1996. The government, however, concluded that the older magnox stations would be best kept in the public sector since the magnox stations will not generate enough money over their remaining lives to meet all their accrued liabilities.

The government also concluded that it currently would not assist NE financially in its quest to build a new nuclear power station as it would constitute a significant intervention in the electricity market when current circumstances do not warrant such an intervention.

Eastern Europe

The 65 nuclear units in Eastern Europe region (Table 6; Figure 5) had a total capacity of 43.5 net GWe at year-end 1994. Russia and Ukraine accounted for three-quarters of the capacity within the region. Most of Eastern Europe's gains in nuclear capacity (High Case) will come from Russia, Romania, and Ukraine. These countries are in a difficult transition period from centralized to market economies and nuclear power plant construction is capital intensive. The projection assumes that financing will be available through international lending institutions or the economies of these countries will improve enough to make nuclear construction a viable option. At the end of 1994, there continued to be a great deal of uncertainty surrounding the continued operation of first-generation VVER-440 (model 230) and RBMK reactors in Eastern Europe. Different countries in the region have discussed the possibility of retiring some of these units early; however, due to the energy shortage in Eastern Europe, no country has implemented such a plan.

The two-unit PWR Medzamor nuclear plant was shut down in 1988 after Armenia experienced a devastating earthquake. Although the quake did not harm the plant, it raised public concerns, and the plant was retired from service in 1989. Following the breakup of the former Soviet Union, the Armenian government was forced to institute daily brownouts to conserve energy. Armenia is inhabited by about 3 million people and relies heavily on inadequate hydroelectric power and imported fuel to produce its electricity. These imports, which used to come primarily from neighboring Azerbaijan, were interrupted because Armenia has been at war with that country. As a result, the Armenian government decided in 1994 to restart the Medzamor 2 unit.

In the early 1990's, various expert groups from the Russian Ministry of Atomic Energy, as well as specialists from Framatome Electricité de France and the International Atomic Energy Agency defined all the work needed to put the nuclear plant back into service. The Armenian parliament resolved all of the safety upgrade issues in April 1994, and an agreement was made with the Armenian Regulatory Agency to allow the restart of Medzamor 2 without many upgrades that western experts believed were needed. As of late 1994, the country was inspecting the reactor pressure vessel, steam generator, and primary circulation pumps, Russia was scheduled to send reactor fuel for the unit in June 1995, and the unit was scheduled to restart shortly after. Even with the pending restart of Medzamor 2, Armenia is hoping for western assistance for further upgrades, but the Group of 7 and the European Bank of Reconstruction and Development appear willing only to help finance building a new oil-fired plant.

In the Czech Republic, the Ceske Energeticke Zavody (CEZ) utility operates four 408-MWe VVER-440s (model 213), which have a combined capacity of 1.6 net GWe, at the Dukovany station. Nuclear-generated electricity represents about 28 percent of total electricity generation. After official protest by the Austrian

Table 6. Power Plant Statistics for the Eastern Europe Region, 1994

Country	Number of Operable Reactors	Operable Capacity (net MWe)[a]	Number of Reactors in Construction	Construction Capacity (net MWe)[a]	1994 Capacity Factor (Percent)	Amount of Electricity from Nuclear Units in 1994 (net TWh)[a]	1994 Percent Nuclear Share[b]
Bulgaria	6	3,538	0	0	42.6	15.3	45.6
CIS/Armenia	0	0	2	740	0.0	0.0	0.0
CIS/Kazakhstan	1	70	0	0	NA	0.4	0.6
CIS/Russia	29	19,843	10	8,175	52.8	97.8	11.4
CIS/Ukraine	15	12,679	7	6,650	61.8	68.9	34.2
Czech Republic	4	1,648	2	1,824	NA	12.1	28.2
Hungary	4	1,729	0	0	87.2	13.2	43.7
Lithuania	2	2,370	0	0	NA	6.6	76.4
Romania	0	0	5	3,155	0.0	0.0	0.0
Slovak Republic	4	1,632	4	1,552	NA	12.1	49.1
Total	**65**	**43,509**	**30**	**22,096**	**--**	**226.6**	**15.3**

[a]MWe = megawatt electric; TWh = terawatthours.
[b]Net electricity generated from nuclear power generating units as a percentage of net electricity generated from all sources by utilities and nonutilities.
NA = Not available.
-- = Not applicable.
Source: **1994 Capacity Factor:** *Nucleonics Week* (New York, McGraw-Hill) (February 9, 1995).

Figure 5. Location of Operable Nuclear Power Plants in the Eastern Europe Region

Note: Plants at some locations have more than one unit.
Source: Plant location was obtained from the International Atomic Energy Agency.

government and debate in the U.S. Congress, the U.S. Export-Import Bank in March 1994 approved over $300 million in commercial loans to the CEZ utility to finance U.S. goods and services from Westinghouse to complete construction of the two-unit Temelin nuclear plant. Prior to the loan, construction of the Temelin VVER-1000 reactors had been suspended while the CEZ tried to secure financing for safety, instrumentation, and control upgrades.

The continuing debate over Temelin comes at a time when the Czech Republic is seeking to reduce the enormous amounts of air pollution brought about by burning soft lignite coal. Currently, the CEZ plans to close its dirtiest coal-fired electric power plants and invest several billion dollars in controlling pollution from remaining coal plants and in modernizing its nuclear plants.

In early 1995, Westinghouse completed fuel design and nearly completed core safety analysis for the Temelin plant. The company is now set to design fuel, instrument, and control systems and provide initial cores and four reloads for each of the two units. The first unit is projected to come online in 1997 and the second unit in 1998.

Although Russia has 29 operating plants with a total capacity of 19.8 net GWe, generation has been declining since 1991. In 1994 Russia produced 18 percent less nuclear power than in 1993, in part because customers were not paying for the electricity and because the plants were operated at lower power for safety reasons. Nuclear power, however, was still contributing about 12 percent of the Russian share of electricity production, because fossil-fueled power plants were also producing less power than in 1993 during the continuing depression of the Russian economy.

As of the end of 1994, Rosenergoatom, the Russian Federation's nuclear power generation organization, was owed 1.6 trillion rubles by the state electricity supply enterprise (ROA), which runs most of Russian's large nonnuclear plants as well as the national grid. The lack of cash payments forced Rosenergoatom to delay scheduled reactor repairs, but there were no power shortages because ROA runs its own plants. Notwithstanding scarce funding, energy demand uncertainties, and some opposition to nuclear expansion, Minatom, the Ministry of Atomic Energy for the Russian Federation, still planned to add 15 GWe of nuclear power by 2010.[6] The plan was approved in 1992 by President Boris Yeltsin, but little or no progress had been made by the end of 1994 except for work on units already under construction.

Minatom is now nearing completion on five nuclear power plants. These include three VVER-1000's—Kalinin 3, Rostov 1 and Balakova 5—plus Kursk 5, a RBMK 1000, and two smaller nuclear district heating units, Voronezh 1 and 2. Six regional governments—Voronezh, Chelyabinsk, Sverdlovsk, Kostroma, Murmansk and the Far East—have declared they are willing to site more reactors for Minatom's expansion plans.

Despite safety related cutbacks in output, Lithuania's nuclear plant produced the highest share of electric power for the country at 76 percent. In 1994, Lithuania's authorities continued to focus on safety issues at its Ignalina station. A 3-year probabilistic safety analysis (PSA) of Ignalina conducted by Sweden's Nuclear Inspectorate (SKI), the Russian Research and Engineering Institute of Power Engineering, and the Lithuanian Energy Institute was completed over the summer, and the results of the PSA have been incorporated into the plant's safety improvement program.

In order to obtain hard currency, Lithuania would like to export more electricity; however, export potential is limited. The Ignalina plant is currently competing with Russia's three-unit Smolensk station, and so far the Lithuanian plant has no grid connection to Western Europe. The country used to export to Russia, Belarus, and Latvia, but the Russian exports have ceased, and Belarus has stopped buying power because Lithuania raised its price.

In the Slovak Republic, Slovensky Energeticky Podnik is responsible for operating the four 408-MWe VVERs at Bohunice station (two VVER-440 model 213 and two VVER-440 model 230) and for constructing the four-unit Mochovce nuclear station. Unfortunately, the decision about whether or not to fund the completion of the first two Mochovce units remained unsettled at the end of 1994 because Austria threatened to leave the European Bank for Reconstruction and Development (EBRD) if funding were approved.

The EBRD's decision about financing the project hinges primarily on whether the Slovak government will close the two old model-230 units at its Bohunice station that are deemed "unsafe" by western safety standards. The Slovaks contend that those units cannot be shutdown

[6]The Russian government's plan to add 15 GWe exceeds EIA's construction pipeline of 8.1 GWe. Some of the government's planned reactors have not been sited and are unlikely to be built.

until the Mochovce reactors come online. For now, the Slovak government has requested that the EBRD postpone a vote on financing Mochovce's completion as the Slovaks are now considering changing suppliers and rejecting the Electricité de France proposal, which depends on EBRD financing, in favor of an offer, said to be 30 percent cheaper, from Skoda Prague and Russia's Minatom.

Ukraine's primary concern in 1994, as it has been for the past 9 years, was the fate of the Chernobyl reactors. The Ukrainian leadership continues to work with the international community on developing a decommissioning schedule for Chernobyl by the year 2000. Since the 1986 accident at Chernobyl 4, the safety of the other RBMK reactors at the Chernobyl nuclear complex has been an international concern. In part because of world opinion, Chernobyl 1 and 3 have received safety upgrades, and Chernobyl 2, which remains closed following a fire in 1991, is also undergoing upgrades prior to its anticipated restart in 1996. To replace the power generated by the reactors, the government wants western countries to help build a 3,000-MWe gas-fired combined-cycle plant near the Chernobyl site.

The Ukrainian government, however, has set a list of conditions that they believe should be met before decommissioning takes place. One critical issue yet to be settled is the amount of money needed to close the plant. The other conditions include: stabilization of the power supply; construction of storage facilities for radioactive waste and spent fuel; resolution of the problems of Chernobyl 4's entombment shelter; and last but not least, employment for Chernobyl workers. In order to decommission the entire facility in the future, a decommission fund would be established with profits from future sales of electricity.

Meanwhile, the United States, France, and Germany also continue to assist in improving fire protection and operation procedures for responding to accidents at the Rovno nuclear station, which hosts two VVER-440 and two VVER-1000 reactors.

Although Ukraine has not added a new nuclear unit since 1989, the country is nearing completion of several reactors in the construction pipeline. The Zaporozhye 6 unit is scheduled to be connected to the grid in 1995. The Zaporozhye station, located in the town of Energodar in southern Ukraine near the Black Sea, has been operating for 9 years. In addition, the Chernobyl 2 unit is scheduled to be reconnected by 1996, Khmelnitski 2 in 1997, and Rovno 4 by 1998.

Far East

In 1994, the Far East region accounted for 16 percent of the total world nuclear capacity, up one percentage point from the previous year. Except China, most of the countries lack indigenous natural resources, and therefore are dependent on imports from other countries to fuel their economies. The oil shocks of the 1970's led Japan, Taiwan, and South Korea to develop nuclear power as a means to spur economic growth and decrease dependence on imported fuels. As a result, these countries have been rapidly developing economically despite their lack of domestic resources.

The region's 68 operable units have a total capacity of 54.0 GWe (Table 7; Figure 6). With an additional 34.4 GWe of capacity in the construction pipeline, the region is projected by 2015 to add 28.2 GWe in the Low Case and 42.2 GWe in the High Case. In 1994, three units began operation in three countries—one unit located in China (Guangdong 2), one unit in Japan (Ikata 3), and one unit in South Korea (Yonggwang 4).

Electricity consumption has more than doubled in China in the past 10 years, and the government aims to increase the country's generating capacity by 15 GWe per year before the year 2000. This ambitious program envision an expansion of nuclear generating capacity to 50 GWe by 2020. China has indicated that it will make use of both indigenously developed PWRs and imported plants from international vendors in its quest for nuclear power.

China, which had no nuclear power plants until 1991, connected its third nuclear unit to the grid when the Guangdong 2 unit became commercially operational in 1995. Guangdong 1, China's second nuclear unit, was connected to the grid in September 1993. Seventy percent of the Guangdong stations output will be exported to Hong Kong and the remaining 30 percent used in Guangdong.

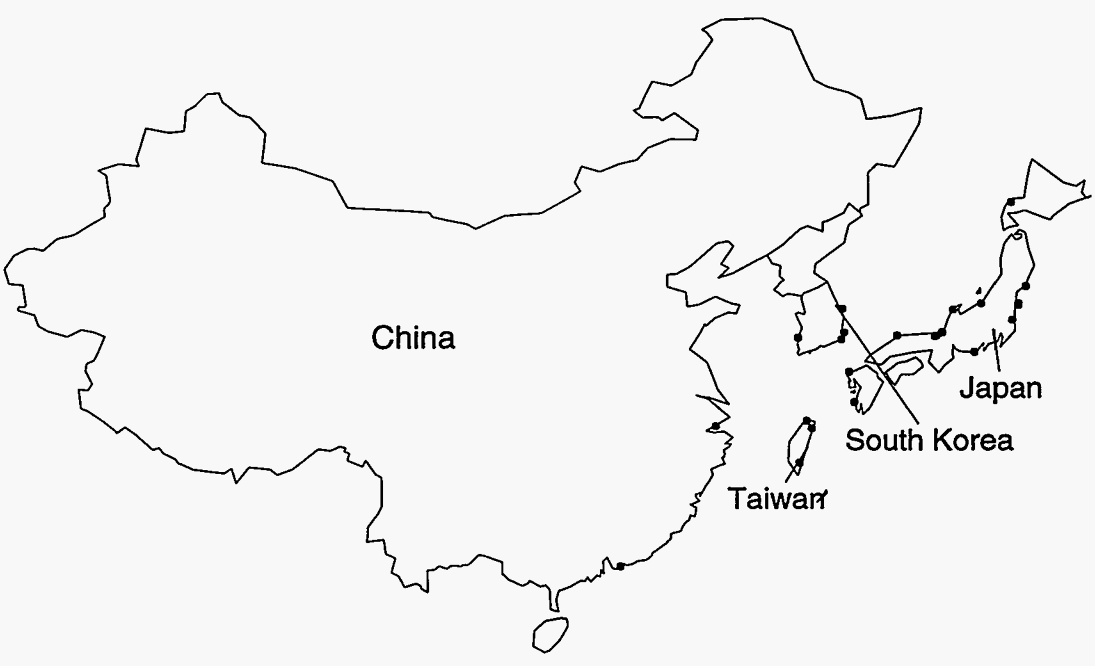
In February 1995, Westinghouse Electric Corporation signed an agreement with China's Nuclear Energy Industry Corporation to deliver two steam turbines to be used at the Qinshan 2 and 3 nuclear power plants, located next to Qinshan 1, a 288-MWe Chinese-designed PWR. The Westinghouse contract represents an important foothold in the expanding Chinese energy market, and it also complies with the current U.S. policy of exporting nonnuclear components only.

Table 7. Power Plant Statistics for the Far East Region, 1994

Country	Number of Operable Reactors	Operable Capacity (net MWe)[a]	Number of Reactors In Construction	Construction Capacity (net MWe)[a]	1994 Capacity Factor (Percent)	Amount of Electricity from Nuclear Units in 1994 (net TWh)[a]	1994 Percent Nuclear Share[b]
China	3	2,100	4	3,170	0.0	13.5	1.5
Japan	49	38,875	18	19,339	73.7	258.3	30.7
Korea, North	0	0	1	200	0.0	0.0	0.0
Korea, South	10	8,170	11	9,270	86.4	55.9	35.5
Philippines	0	0	1	620	0.0	0.0	0.0
Taiwan	6	4,890	2	1,800	76.7	33.5	31.7
Total	68	54,035	37	34,399	--	361.2	18.0

[a]MWe = megawatt electric; TWh = terawatthours.
[b]Net electricity generated from nuclear power generating units as a percentage of net electricity generated from utilities and nonutilities.
-- = Not applicable.
Source: **1994 Capacity Factor:** *Nucleonics Week* (New York, McGraw-Hill) (February 9, 1995), p.8.

Figure 6. Location of Operable Nuclear Power Plants in the Far East Region



Note: Plants at some locations have more than one unit.
Source: Plant location was obtained from the International Atomic Energy Agency.

On January 15, 1995, Framatome and the China Guangdong Nuclear Power Company signed an agreement for Framatome to supply two 985-MWe reactors. The plant will be built at Lin-ao in the Guangdong Province, only a few kilometers from Daya Bay. The agreement includes engineering services and training at a total cost of $1.6 billion.

Along with the nuclear plant expansion program, China is embarking on a policy of reprocessing spent fuel and recycled plutonium in both fast reactors and light-water reactors. China is building a pilot reprocessing plant to handle civilian reactor fuels and plans to have a larger plant operational by 2010. In the meantime, spent fuel is being stored at the reactor site and will be transported to the Lanzhou Nuclear Fuel Complex, which is scheduled to be completed in 1998 and is designed to hold 550 metric tons of initial heavy metal.

Japan has 49 operable reactors. One unit was connected to the grid in 1994, adding 0.8 GWe of capacity and bringing Japan's total installed nuclear capacity to 38.9 GWe. Tepco, Japan's largest utility, accounted for the majority of the country's total nuclear capacity. The country generated 258.3 net TWh of electricity with an average capacity factor of 74 percent in 1994, an increase of 1.4 percent over 1993. Japan's ambitious nuclear power program was established to achieve energy independence. According to the Atomic Basic Law, Japan's goal is "to secure energy resources in the future . . . and thereby contribute to the welfare of mankind and to elevation of the national living standard." Japan's long-term nuclear power program includes the construction and operation of reprocessing and recycling facilities to reduce its dependence on foreign energy resources. It is the first country in the Far East to begin operating a commercial-scale uranium enrichment plant. However, problems of future plant siting could constitute a hindrance to Japan's nuclear program.

Japan currently relies on nuclear energy for about 32 percent of its power generation. The Japanese government has set new energy supply targets for the year 2010 in which nuclear's share will remain at just over 30 percent of the anticipated 220 GWe of generating capacity from all energy sources. This target means that total nuclear generating capacity will have to exceed 70 GWe, but that is roughly 10 GWe less than planned in 1986. The downsizing of the country's nuclear projection is due, in part, to lower electricity demand as well as difficulty in locating and licensing sites for new nuclear units.

The Korean Electric Power Corporation (KEPC) connected its 10th nuclear unit with the addition of Yonggwang 3, a 950-MWe PWR, in 1994. KEPC has 11 units in the construction pipeline, seven more than the previous year. The 11 units total 9.3 GWe of capacity and are projected to come online between 1995 and 2015. Korea has chosen its first waste site on an island called Kuropdo, located about 65 km off the western coast of the industrial port city of Inchon. Construction is planned to start in 1996 and be completed in 2001.

Taiwan's rapid industrialization has brought growth in energy demand, but new generating capacity has not kept pace. The country's reserve margin has plummeted from more than 40 percent in 1985 to roughly 4 percent today. The state-owned utility, Taipower, has been forced to ration electricity to industrial customers during the hot summer months when demand is very high. Taipower expects electricity demand to increase at an average of 5.6 percent annually through 2001.

Taipower intends to nearly double its installed electric generating capacity of 19 MWe by 2000, bringing its reserve margin to about 20 percent. A total of 17 GWe of capacity is planned, with 2.5 GWe coming from nuclear power. Because Taiwan's energy demand is increasing, and because limited natural resources require the country to import the bulk of its energy supplies, the ruling Kuomintang party is committed to pushing ahead with new nuclear capacity despite efforts of antinuclear groups that have made siting the new reactors very difficult.

The planned nuclear station, Yenliao 1 and 2, also known as the Lungman project, will be located on the northeast tip of the island and will have a combined capacity of 1.8 GWe. Choosing a vendor for the Yenliao plant was delayed in 1994; Framatome withdrew its bid because it was unable to reach agreement with Taipower on several issues. At present, Taipower operates six nuclear power units located at three stations. The Kuosheng station in northern Taiwan consists of two 950-MWe BWR units; the Chinshan station, also in the north, includes two 600-MWe BWRs; and on the southern tip of the island, the Maanshan station contains two 890-MWe PWRs. Total net capacity was 4.9 GWe, with an average capacity factor of 77 percent.

At the beginning of 1994, the Democratic People's Republic of Korea was constructing a 200-MWe reactor at Taechon and a 50-MWe reactor at Yongbyon. Initially, the United States thought the Taechon 1 reactor was intended to produce weapons grade plutonium. In October 1994, the United States and North Korea signed an "Agreed Framework." Under the terms of the accord, the United States will to build two PWRs in return for North Korea's agreement to halt its domestic nuclear development program. The units will be similar to the Ulchin 3 and 4 plants in South Korea, which use a 960-MWe System 80+ reactor design by General Electric. After issuance of a construction permit, actual construction could start in May 1997, and service could begin in December 2002, with the second unit coming online one year later. The station is projected to cost $3.8 billion. In addition, North Korea must accept IAEA inspection of its facilities, as well as put its spent fuel rods into dry storage, uphold its obligation as a signatory to the Non-Proliferation Treaty, and recommence its dialogue with South Korea. The accord, however, faces stiff opposition from some members of Congress as well as from North Korea.

Other

Accounting for 2 percent of the world's total nuclear capacity, the "other" countries have relatively small nuclear power programs in contrast to the major regions. There are 17 operable units divided among the six countries with a total capacity of 6.3 GWe (Table 8; Figure 7). The capacity of this region is projected to increase threefold by 2015 in the High Case.

Brazil's only operable unit, Angra 1, a 626-MWe PWR located in Itarona, Rio de Janeiro, has operated for 13 years. When Angra 2 is completed later in the decade, the station will account for approximately 40 percent of all the electricity consumed by Rio de Janeiro.

On December 8, 1994, the Brazilian Congress decided to transfer more than $400 million from the deferred Angra 3 to the Angra 2 nuclear unit. The Angra nuclear plant is approximately 13 years behind schedule and has already cost the country $6 billion for the two unfinished units, compared with the original $2 billion budget. The original July 1976 contract for Angra 2 and 3 was the first part of a program of nuclear power plant construction that envisaged as many as eight units. The program fell through, however, due to a massive debt crisis of the 1980's, and any available money went to the completion of Angra 1.

Currently, unit 2 is scheduled to start up in 1998 at an additional cost of $1.5 billion. Much of the money will come from German banks ($300 million) and the state utility Electrobras, which is contributing $800 million. Little work had been done on the Angra 2 unit since 1988, but in 1994 work resumed on the unit with the installation of the first major component, the pressurizer.

The completion and grid connection of Mexico's Laguna Verde nuclear unit marks the end of the country's current nuclear-generated capacity expansion. The General Electric 654-MWe BWR was connected in November 1994, 17 years after construction started.

Table 8. Power Plant Statistics for the Other Region, 1994

Country	Number of Operable Reactors	Operable Capacity (net MWe)[a]	Number of Reactors in Construction	Construction Capacity (net MWe)[a]	1994 Capacity Factor (Percent)	Amount of Electricity from Nuclear Units in 1994 (net TWh)[a]	1994 Percent Nuclear Share[b]
Argentina	2	935	1	692	91.9	7.7	13.8
Brazil	1	626	2	2,474	0.0	0.0	0.0
Cuba	0	0	2	816	0.0	0.0	0.0
India	9	1,493	8	2,170	27.8	4.3	1.4
Mexico	2	1,308	0	0	71.7	4.3	3.2
Pakistan	1	125	1	300	48.8	0.5	1.0
South Africa	2	1,842	0	0	60.8	9.7	5.7
Total	**17**	**6,329**	**14**	**6,452**	**--**	**26.5**	**3.7**

[a]MWe = megawatt electric; TWh = terawatthours.
[b]Net electricity generated from nuclear power generating units as a percentage of net electricify generated from utilities and nonutilities.
-- = Not applicable.
Source: **1994 Capacity Factor:** *Nucleonics Week* (New York, McGraw-Hill) (February 9, 1995). p. 8.

Figure 7. Location of Operable Nuclear Power Plants in the Other Region

Note: Plants at some locations have more than one unit.
Source: Plant location was obtained from the International Atomic Energy Agency.

Mexico's demand for energy is expected to increase substantially as the country continues its industrial expansion. With the Laguna Verde plant now at full capacity, the plant is expected to provide more than 5 percent of the country's electricity. In 1994, the plant provided more than 4 percent of the country's electricity.

Although Turkey plans to expand its hydroelectric resources further, this power source will not fill the demand created by increased industrialization and population growth. The Turkish Electricity Generation and Transmission Company expects electricity demand to increase to about 270 TWh by 2010, and its long-term plan is to add about 40 GWe of additional generating capacity by 2010. The projected capacity includes 34 hydroelectric plants (12.8 GWe), 33 lignite and coal plants (9.1 GWe), 14 natural gas plant (9.5 GWe), 12 coal plants (6 GWe), and 2 nuclear power plants (2.0 GWe).

Turkey has considered nuclear power for some time as it aims to reduce import dependency. Nuclear is attractive because economical, reliable, and clean energy production has been recognized as necessary for achieving Turkey's ambitious energy development goals. In the mid-1980's, negotiations with two reactor vendors for the construction of a two-unit plant at Akkuyu on the southern coast had reached an advanced stage; however, a lack of export financing prevented placement of an order. In 1994, plans to award a consultancy contract to Korea Atomic Energy Research Institute for Turkey's first nuclear power plant were delayed because an of antinuclear protest by Greenpeace. Although the protest slowed down the country's movement toward nuclear power, it is believed that nuclear power will play a role in the country's future energy mix. The government's aim is for its first plant to be built on a build-operate-transfer agreement,[7] although other creative financing options are also being reviewed. The reactor is expected to be operational by 2003.

[7]The build-operate-transfer agreement requires that the nuclear power plant suppliers build and operate the plant for 15 years through a joint venture utility (JVU) established by the Turkish Electric Authority and the suppliers. The plant owner, JVU, will be responsible for the construction, operation, and financing of the plant. The energy produced will be purchased and distributed by the Turkish Electric Authority.

3. Nuclear Fuel Cycle

The term "nuclear fuel cycle" applies to the steps necessary to prepare new nuclear fuel and manage spent fuel (Appendix A). Recent developments in the nuclear fuel cycle regarding the availability of supply and the storage of spent fuel are being closely followed by the industry. The availability of uranium to produce nuclear fuel had been a concern in the 1970's, but this issue has waned as optimistic forecasts for nuclear power generation have not been realized. While adequate supplies of natural and enriched uranium exist in the world, recent political and trade issues could make their availability in the world market less certain. Meanwhile, the costs and logistical problems of spent fuel management are intensifying, especially as space for storage of spent fuel at some U.S. nuclear plants is running low.

In addition to topics on the recent developments of the uranium and enrichment markets and spent fuel management, Chapter 3 contains nuclear fuel cycle projections. The projections are of worldwide uranium and enrichment requirements and spent fuel discharges through 2015 and projections of uranium spot prices, imports, inventories and production through 2010. Nuclear fuel requirements are highly dependent upon projections of nuclear capacity (Chapter 2) and expected fuel cycle operating characteristics. The International Nuclear Model PC Version (PCINM) and the Uranium Market Model (UMM), both discussed in Appendix B, were used to derive these projections.

Uranium Market Developments

Overview of the World Market

The world uranium market in 1994 continued to be affected by lingering oversupply fed by the drawdown of excess commercial inventories in Western countries[8] and exports from the republics of the Former Soviet Union (FSU).[9] Demand for uranium has been relatively flat in recent years, with little prospect for sustained growth over the next 20 years (projections of uranium requirements are presented later in this chapter). Reflecting these conditions, the average unrestricted Nuexco spot price declined to $7.05 per pound U_3O_8 in 1994 from $7.12 per pound in 1993.[10] The average spot price for the restricted U.S. market,[11] also declined in 1994; it retreated to $9.31 per pound U_3O_8 from $9.98 per pound in 1993. In comparison, the average spot price reached its high of $43.23 per pound U_3O_8 (in nominal dollars) in 1978.

Despite the weakness in spot prices during 1994, the uranium market showed indications of tightening supply in the near term. Persistent weak prices have forced the closure of higher cost production capacity and postponed the start of planned production projects. As a result, world U_3O_8 production has fallen to levels well below Western reactor fuel requirements (Figure 8). Meanwhile, excess commercial inventories of natural and enriched uranium in the Western world have been substantially reduced. At the end of 1994, the quantity of these inventories was estimated to be sufficient to cover less than 3 years of reactor requirements.[12] Since many non-U.S. utilities typically hold between 2 and 3 years of inventory as a hedge against possible supply disruptions, it appears unlikely that the drawdown of Western commercial inventories will continue to be a major source of supply in the future.

Imports from the FSU have augmented supply in the face of declining Western production and the drawdown of commercial inventories. The FSU had become an important source of supply to the West since the late 1980's, as the government sought to gain foreign exchange. Historically, levels of uranium output were based more on government-planned objectives than

[8]Western refers to the countries of the world outside of the current and former centrally planned economies.

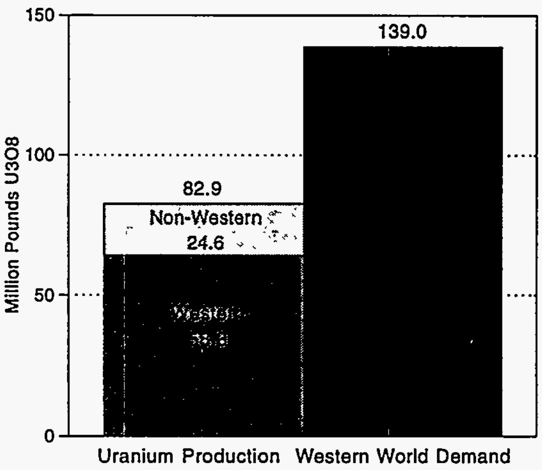
[9]The republics of the FSU are also referred to as the Commonwealth of Independent States (CIS) and the Newly Independent States (NIS).

[10]TradeTech, *Nuexco Review* (Denver, CO, May 1995), p. 25.

[11]A two-tier market developed at the end of 1992 as a result of the suspension agreements that restrict U.S. imports from the republics of the Former Soviet Union.

[12]Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), p. ES-2.

Figure 8. Comparison of World Uranium Production and Western World Demand, 1994



Source: *Nukem Market Report*, (May 1995), p. 19.

than the market considerations faced by Western producers.[13] In recent years, however, more costly production facilities were closed or replaced by less costly recovery methods. As a result, estimated production in the republics of the FSU has declined from 30.7 million pounds U_3O_8 in 1990 to 18.8 million pounds in 1994.[14,15] Recent production has come from Kazakhstan, Russian Federation, Ukraine, and Uzbekistan.

Despite the decline in uranium production, the republics of the FSU, principally the Russian Federation, hold large civilian and military inventories of natural and enriched uranium. These inventories have been estimated at over 1 billion pounds of U_3O_8 equivalent.[16] Since the end of the Cold War, the commercial disposition of these inventories has become inevitable. The United States and the Russian Federation signed an agreement in January 1994 by which the United States will pay to acquire at least 500 metric tons of highly enriched uranium (HEU) over a 20-year period. The HEU, coming from the dismantling of nuclear weapons held by the Russian Federation, would be converted to low enriched uranium (LEU) suitable for fueling commercial nuclear power reactors. The HEU conversion is expected to produce 15,259 metric tons of LEU (assuming a 90 percent enrichment level for the HEU), an amount equivalent to about 398 million pounds of U_3O_8.[17] The first shipment of LEU from Russian HEU that met the specifications stipulated by the agreement was delivered to the United States in June 1995.[18]

Introduction of potentially large quantities of uranium materials contained in FSU inventories could have a major impact on the world market for many years. In order to mitigate the potentially negative impact of this source on the uranium industries of their respective countries, the United States and the European Union, beginning in 1991, took steps to limit FSU imports. In October 1992, agreements suspending antidumping investigations by the U.S. Department of Commerce (suspension agreements) were signed between the United States and the successor states of the FSU. These agreements linked imports from the FSU to a price schedule. However, imports were effectively halted because the prices did not reach their expected levels. In order to provide more realistic quotas, the suspension agreements with the Russian Federation and Kazakhstan were renegotiated and amended in 1994 and 1995, respectively. As a result of the amended agreement with the Russian Federation, the U.S. Department of Commerce announced the completion of 14 "matched-sales" contracts in 1994, whereby quantities of Russian imports were matched with newly produced U.S.-origin U_3O_8 and enriched uranium.[19] It should be noted that under current law the uranium feed component in the LEU to be sold to the United States under the HEU agreement would also count against the quotas specified under the Russian amendment.[20]

[13]A wholly commercial uranium market was established in the United States when the Federal Government ended its procurement program in 1970. In contrast, the uranium and nuclear power fuel industries of the FSU have been closely integrated with military programs until the establishment of independent republics in 1991.

[14]Energy Information Administration, "The Uranium Industry of the Commonwealth of Independent States," *Uranium Industry Annual 1991*, DOE/EIA-0478(91) (Washington, DC, October 1992), Table FE-5.

[15]Nukem, *Nukem Market Report*, (May 1995), pp. 23-24.

[16]Energy Information Administration, *World Nuclear Outlook 1994*, DOE/EIA-0436(94) (Washington, DC, December 1994), p. 27.

[17]Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), pp. 4-17, 4-18.

[18]Timbers, William, testimony presented at hearings on the privatization of the U.S. Enrichment Corporation, conducted by the Senate Energy and Resources Committee (June 13, 1995).

[19]R.L. MacDonald, "U.S. Policy Toward Trade with the C.I.S.," paper presented at the Fuel Cycle 95 conference (Coronado, CA, April 1995), pp. 3-4.

[20]As this report went to press, proposals were being considered by both the U. S. Administration and Congress to better facilitate the HEU agreement, including a waiver of pertinent antidumping laws.

Uranium contained in U.S. HEU stockpiles is also a potential entrant into the marketplace. The amount of U.S. HEU inventory deemed as excess has been estimated between 50 and 120 metric tons.[21] Because the excess U.S. HEU is reported to be less enriched than Russian HEU, its conversion to LEU would have less impact on the market. It is estimated to contain 22.5 million pounds U_3O_8, assuming a 50-percent enrichment level for the HEU and use of a 1.5-percent enrichment for the blendstock.[22]

Uncertainties about the availability of supply have been introduced by recent developments regarding quotas on FSU imports, delays in the introduction of Russian HEU, and the default of a major trading firm. These factors, described more fully in Appendix G, have contributed to a reversal of declining prices. By the end of the first quarter 1995, spot prices for the restricted U.S. market exceeded $11.00 per pound U_3O_8.[23]

Domestic Uranium Production

The United States produced 3.4 million pounds U_3O_8 in 1994, an increase of about 9 percent from the 1993 production of 3.1 million pounds.[24] This increase was the first since 1989. Due to protracted weakness in prices, however, much higher cost capacity in the United States has been closed or placed on standby. Thus, recent levels of domestic output are well below the record 43.7 million pounds achieved in 1980.[25] Production in 1994 came from nonconventional sources: in situ leaching (ISL) and as a byproduct recovered from the processing of phosphate ore.[26] Since mid-1992 only nonconventional production facilities have operated in the United States.[27] Production in 1995 will continue to come principally from less costly nonconventional methods. Some conventional production could be resumed in 1995, probably from milling ore stockpiled in previous years rather than from new mine production.

Domestic Utility and Supplier Transactions

Domestic utilities loaded 39.0 million pounds U_3O_8 equivalent into U.S. reactors in 1994. Much of this demand was met by the sales and purchases of uranium from imports and domestic inventories (Table 9). This section provides a summary of the transactions carried out by suppliers and U.S. utilities in the domestic market. For this discussion, "suppliers" are defined as U.S. or foreign firms that exchange, loan, purchase, or sell uranium in the domestic market, but are not U.S. utilities. They include brokers, converters, enrichers, fabricators, producers, and traders.

Direct import purchases totaled 36.6 million pounds U_3O_8 in 1994, 15.5 million pounds by utilities and 21.1 million pounds by suppliers.[28] Import commitments of utilities and suppliers from 1995 through 2005 total 124.8 million pounds.[29] In 1993, direct purchases of imports by suppliers and U.S. utilities totaled 21.0 million pounds U_3O_8.[30] Their contract commitments at the end of 1993 were 111.3 million pounds.[31]

Chief origins for import purchases in 1994 were Canada (32 percent), Uzbekistan (22 percent), Kazakhstan (11 percent), and Australia (9 percent).[32] The significant quantities of U_3O_8 originating from Uzbekistan and Kazakhstan appear to contradict the import restrictions stipulated by the suspension agreements signed between the United States and the republics of the FSU (see Appendix G for a discussion on import restrictions). This apparent contradiction can be explained by differences in the ultimate destination for the import purchases reported to the EIA. Examples include purchases by U.S. utilities of foreign-origin U_3O_8 for feed

[21]U.S. Department of Energy, presentation at public meeting on the disposition of U. S. HEU (Oak Ridge, TN, November 1994).
[22]Ibid.
[23]TradeTech, *Nuexco Review* (Denver, CO, May 1995), p. 25.
[24]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. xviii.
[25]Energy Information Administration, *Uranium Industry Annual 1993*, DOE/EIA-0478(93) (Washington, DC, September 1994), p. 17.
[26]In situ leaching is the recovery of valuable components of a mineral deposit by a process of leaching without physical extraction of the mineralized rock from the ground (also referred to as "solution mining"). Uranium is also commercially recovered as a byproduct during the production of phosphoric acid from phosphate ore. The uranium content is too low for the phosphate ore to be economically mined solely for the uranium.
[27]Minor quantities of uranium were recovered at conventional mills by processing waters from inactive mines.
[28]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 29.
[29]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 29.
[30]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. xviii.
[31]Energy Information Administration, *Uranium Industry Annual 1993*, DOE/EIA-0478(93) (Washington, DC, September 1994), p. 36.
[32]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 33.

Table 9. U.S. Uranium Market Data, 1993-1994

	1993	1994
	(Million Pounds U_3O_8 equivalent)	
Demand and Uranium Production		
Uranium used by domestic utilities in fuel assemblies	45.1	39.0
Domestic concentrate production	3.1	3.4
Utility and Supplier Transactions		
Deliveries by domestic utilities to U.S. and foreign enrichment plants	35.1	37.6
Deliveries to U.S. utilities by domestic suppliers	15.5	22.7
Direct import purchases by utilities	15.7	15.5
Direct import purchases by suppliers	5.3	21.1
Inventories		
Utility inventory, natural uranium	R57.9	42.5
Utility inventory, enriched uranium	R23.3	24.2
Supplier inventory, natural uranium	R19.1	15.5
Supplier inventory, enriched uranium	R5.4	4.0
Total Inventories	R105.7	86.3
	(Dollars per Pound U_3O_8 equivalent)	
Contract and Spot Market Prices		
Quantity-weighted average price of deliveries to U.S. utilities under domestic purchase contracts	13.14	10.30
Quantity-weighted average price of deliveries to U.S. utilities and suppliers under foreign purchase contracts	10.53	8.95
Average spot-market price (unrestricted market)	7.12	7.05
Average spot-market price (restricted U.S. market)	9.98	9.31

R=Revised

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

Sources: **1993**—Energy Information Administration, *Uranium Industry Annual 1993*, DOE/EIA-0478(93) (Washington, DC, September 1993), pp. xxviii, 33, 36, 42, 44-45. **1994**–Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), pp. xviii, 29, 31, 35, 37. **1993-1994**–Spot-Market Prices (NUEXCO Exchange Values)—TradeTech, *NUEXCO Review* (Denver, CO, May 1995), p. 25.

to foreign enrichment suppliers, and purchases by producers, brokers, and traders to fill export delivery commitments. As such, not all U_3O_8 purchased by U.S. companies from foreign countries was actually delivered to the United States.[33]

Suppliers have contracted to import uranium to fill a portion of both domestic and export delivery commitments in order to take advantage of less costly foreign-origin uranium (Table 9). Domestic uranium producers, for example, could benefit by acquiring uranium to meet delivery commitments at costs less than their marginal costs of production. Of the 22.7 million pounds U_3O_8 that U.S. utilities purchased from domestic suppliers in 1994, 15 million pounds or 66 percent of these purchases were of foreign origin.[34] At the end of 1994, utility contract commitments with domestic suppliers totaled 61.4 million pounds for 1995 through 2002.[35]

[33]See Appendix G for a discussion of transactions made by U. S. utilities whereby U_3O_8 purchased from the FSU is subsequently enriched in a third country prior to delivery to the United States.

[34]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 25.

[35]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 24.

Import purchases were also the major component of deliveries made to enrichment suppliers. A more detailed discussion of the enrichment services market is presented later in this chapter.[36] U.S. utilities shipped 29.1 million pounds U_3O_8 equivalent of foreign-origin uranium to enrichment suppliers in 1994.[37] These shipments represented 77 percent of the total feed deliveries of 37.6 million pounds made by U.S. utilities to domestic and foreign enrichment suppliers. It should be noted, however, that the foreign-origin feed deliveries to domestic enrichment plants in any given year do not necessarily reflect imports for that year, since some of the material may have already been in the United States prior to the beginning of the year. Both U.S.- and foreign-origin uranium shipments increased slightly in 1994, by 0.7 and 1.8 million pounds, respectively, from 1993.[38,39] U.S. enrichment plants received 33.5 million pounds U_3O_8, and foreign enrichment plants received 4.1 million pounds. The foreign uranium shipped to domestic plants came mostly from Canada (55 percent), Australia (12 percent), and Kazakhstan (8 percent).[40]

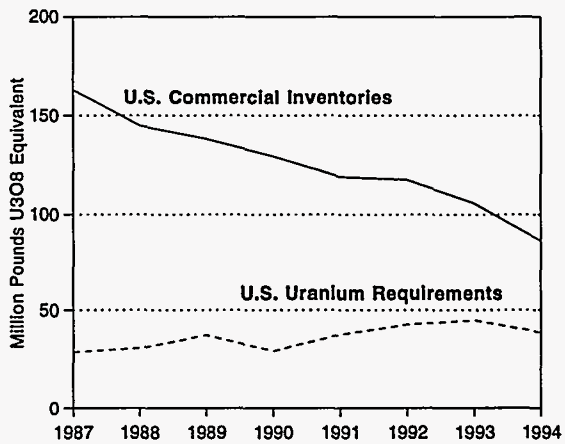
Domestic Inventories

As orders for new nuclear power plants were canceled in the late 1970's, U.S. utilities under contract obligations to purchase uranium began accumulating large excess inventories. U.S. commercial inventories of natural and enriched uranium held by utilities and suppliers reached their peak at around 192 million pounds of U_3O_8 equivalent in 1983.[41] With less concern about the interruption of supply, utilities found it no longer necessary to hold large quantities of natural and enriched uranium for strategic reasons. A secondary market was created to accommodate the trading of excess inventories.[42]

In more recent years, shareholders and public utility commissions have demanded improved financial performance from U.S. utilities. The utilities have responded by adopting leaner management policies favoring less inventory holdings, while seeking more flexible delivery arrangements. Such policies have become attractive with the availability of various forms of relatively low-cost uranium on the secondary market, including supply from the FSU. As a result, commercial inventories held by utilities and suppliers have steadily declined since the mid-1980's (Figure 9). Thus, inventory drawdowns have become an important source of supply in the world market.

Total U.S. commercial inventories of natural and enriched uranium were 86.3 million pounds U_3O_8 equivalent at the end of 1994.[43] This quantity is equivalent

Figure 9. Comparison of U.S. Commercial Inventories and U.S. Uranium Requirements, 1987-1994



Note: U.S. Commercial inventories are quantities of natural uranium (U_3O_8) and enriched uranium held by U.S. utilities and suppliers other than the U.S. Department of Energy or the U.S. Enrichment Corporation.

Sources: **U.S. Commercial Inventories:** Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), Table ES1. **U.S. Uranium Requirements:** Energy Information Administration, 1987-1991-*Domestic Uranium Mining and Milling Industry: 1992 Viability Assessment*, DOE/EIA-0477(92) (Washington, DC, December 1993), Table 30; 1992-1993-*Uranium Industry Annual 1993*, DOE/EIA-0478(93) (Washington, DC, September 1994), uranium used in fuel assemblies, p. 45; 1994-*Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), uranium used in fuel assemblies, p. 37.

[36]Although the uranium enrichment services market is described in a later section, the enriched component of the commercial uranium inventory is considered in this section since it takes into account the equivalent natural uranium that served as feedstock.

[37]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 35.

[38]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 35.

[39]Energy Information Administration, *Uranium Industry Annual 1993*, DOE/EIA-0478(93) (Washington, DC, July 1995), p. 37.

[40]Form EIA-858, "Uranium Industry Annual Survey."

[41]Energy Information Administration, *Domestic Mining and Milling Industry: 1991 Viability Assessment*, DOE/EIA-0477(91) (Washington, DC, December 1992), p. 73.

[42]Secondary market transactions include sales, exchanges and loans of uranium other than direct sales by suppliers to U.S. utilities or direct purchases of imports by U.S. utilities.

[43]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. xviii.

to just over 2 years of forward reactor requirements,[44] down from over 4 years in the mid-1980's (Figure 9). Inventories held by U.S. utilities at the end of 1994 totaled 66.7 million pounds U_3O_8 equivalent, a decline of 14.5 million pounds from the 1993 end-of-year inventory (Table 9). As of December 31, 1994, domestic uranium suppliers held 19.5 million pounds U_3O_8 equivalent, 5.0 million pounds less than the previous year. In comparison, total U.S. commercial inventories were 105.7 million pounds held at the end of 1993 (Table 9).[45] Utilities had 81.2 million pounds of natural and enriched uranium at year end 1993, while suppliers had 24.5 million pounds in their inventories.

It should be noted that the quantities of commercial inventories listed above do not include material held as "government" inventories by the U.S. Department of Energy (DOE) and the U.S. Enrichment Corporation (USEC), a government-owned corporation. As of December 31, 1994, U.S. government inventories were 74.3 million pounds U_3O_8 equivalent.[46] Although USEC is currently a government-owned corporation, it has the authority to choose whether the inventory it holds can be used for commercial reasons. Current legislative proposals, discussed later in this chapter, regarding the disposition of DOE inventories and the privatization of the USEC could make the inventories currently held by the DOE also available to the commercial market in the coming years.

Projections of World Uranium Requirements

Uranium requirements are defined as the amount of uranium needed to fuel reactors. The requirements do not include the purchase of uranium to be held as inventory for later use. From 1995 through 2015, reactors worldwide are projected to need between 3.1 billion to 3.3 billion pounds of U_3O_8 for fuel (Table 10). Annual uranium requirements are projected to range between 119 million pounds and 174 million pounds of U_3O_8 (Table 11). For the Low Case, annual requirements trend downward starting in 2011, reflecting a decrease in nuclear capacity. On the other hand, annual uranium requirements remain fairly stable through 2015, in parallel with nuclear capacity projection for the High Case.

For the Low Case, Western Europe accounts for 32 percent of total uranium requirements from 1995 through 2015, followed by the United States at 27 percent (Figure 10). The Far East and Eastern Europe account for 22 percent and 14 percent, respectively, of uranium requirements, with Canada and other countries accounting for the remaining amount.

Through 2015, mixed-oxide fuel (MOX) will displace some of the demand for uranium, but not a significant amount. Belgium, France, Germany, Japan, and Switzerland currently have MOX programs. For the short term, the use of MOX fuel is constrained by available MOX fabrication capacity, which is about 65 metric tons heavy metal per year (Appendix F). MTHM of MOX is equivalent to about 1.5 million pounds of U_3O_8. MOX production in 1994 is estimated to have been about 1.3 million pounds U_3O_8 equivalent.[47] In 1995 MOX production will increase to about 2 million pounds U_3O_8 equivalent, rising to around 4 million pounds U_3O_8 equivalent per year by the turn of the century. The displacement of demand for U_3O_8 will be around 3 to 6 million pounds U_3O_8 equivalent per year through the turn of the century, and will increase to almost 9 million pounds U_3O_8 equivalent per year by 2015 (Table 12). This projection assumes that all operators of reactors applying for a MOX license will receive them, that all will chose to use MOX fuel in about 30 percent of the reactor's core and that once the reactor retires, it will be replaced with another reactor using MOX fuel. Even though reactor operators have licenses to use MOX fuel, they may not always do so.

U.S. Uranium Industry Projections

Introduction

Projections of spot-market prices, domestic production, net imports, and domestic inventories developed for 1995 through 2010 are based on certain assumptions, some of which relate to world demand for uranium, the existing supply sources (i.e., production centers), and production from future production centers as a function of future market requirements (see Appendix B for details). These assumptions also reflect information on the quality of reserves and associated economic costs of mining, milling, and marketing; the levels of current

[44]The annual quantity of forward reactor requirements is estimated by assuming that approximately the same amount of uranium required in 1994 will be required in future years.
[45]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 37.
[46]Ibid.
[47]NAC International, *An Analysis of MOX Fuel Utilization* (Norcross, GA, January 1995).

Table 10. Projected Cumulative Uranium Requirements for World Nuclear Power Plants, 1995-2015
(Million Pounds U_3O_8)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1995	47.1	47.1	4.0	4.0	20.8	24.1	55.5	56.6	23.6	23.0	3.1	2.9	154.1	157.8
1996	92.0	92.2	8.3	8.5	46.4	51.1	101.9	102.9	51.0	52.5	5.8	5.3	305.6	312.6
1997	136.3	136.3	12.5	12.7	70.7	76.6	155.9	157.0	79.7	82.2	7.9	9.6	463.1	474.5
1998	182.3	182.3	17.1	17.5	95.2	99.6	205.7	207.9	109.5	110.5	10.6	12.8	620.4	630.7
1999	223.6	223.6	21.4	21.8	118.2	121.6	252.3	255.0	138.5	141.7	15.0	16.5	769.0	780.2
2000	269.3	269.3	25.0	25.4	142.2	143.7	302.4	305.6	166.4	169.2	17.8	19.7	923.1	932.8
2001	317.3	317.3	29.3	29.7	167.9	167.8	350.8	354.8	194.6	205.7	21.7	23.1	1,081.5	1,098.4
2002	358.7	358.7	33.4	33.8	188.9	191.0	400.5	404.7	224.8	241.1	24.7	26.8	1,231.0	1,256.1
2003	404.8	404.8	37.9	38.3	211.1	222.3	449.9	454.6	257.4	274.2	27.6	32.5	1,388.7	1,426.6
2004	451.6	451.6	41.8	42.2	232.7	246.4	496.9	502.6	285.6	304.5	31.2	36.5	1,539.8	1,583.9
2005	498.0	498.0	45.6	46.1	254.7	270.3	541.4	547.2	315.2	338.3	35.6	40.8	1,690.5	1,740.7
2006	535.7	536.3	48.6	49.0	277.3	293.5	588.2	594.9	350.0	368.9	40.0	45.1	1,839.8	1,887.7
2007	578.2	578.8	52.7	53.1	299.3	316.8	635.8	643.2	388.3	412.5	44.2	49.7	1,998.4	2,054.0
2008	623.2	624.7	56.2	56.6	316.6	343.0	680.7	691.4	422.7	448.7	49.4	55.9	2,148.9	2,220.2
2009	660.3	665.1	59.5	60.0	336.1	370.9	725.8	737.1	452.8	479.6	53.5	61.0	2,288.0	2,373.7
2010	700.1	707.2	63.2	63.8	352.5	395.9	771.9	790.2	490.3	523.4	58.1	66.8	2,436.0	2,547.4
2011	731.6	742.9	65.9	67.0	370.4	423.4	816.3	838.9	525.6	561.1	61.9	72.2	2,571.7	2,705.5
2012	763.5	781.7	69.7	71.2	387.7	447.4	859.1	889.2	555.9	600.8	65.8	78.0	2,701.7	2,868.3
2013	788.3	811.3	73.7	75.8	404.0	475.9	901.6	942.9	593.7	641.9	70.9	86.0	2,832.2	3,033.8
2014	814.0	845.0	76.8	79.7	417.6	499.5	941.5	993.0	628.5	681.1	74.5	91.2	2,953.0	3,189.4
2015	838.7	876.1	80.1	83.8	429.8	523.1	981.4	1034.2	663.3	720.4	78.4	98.1	3,071.7	3,335.8

Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

domestic and foreign inventories, and potential future additions to or withdrawal from inventory.

Spot-Market Price

Over the forecast period, spot-market prices are likely to rise in response to the continued decline in Western commercial inventories and restrictions on imports from the republics of the FSU. New uranium production is expected to be undertaken to meet demand. After an initial sharp increase, prices are projected to gradually rise as new sources of uranium from the liquidation of Russian and U.S. government inventories are made available to the market. In the longer term, however, prices are expected to rise more sharply late next decade as reserves become depleted for many of the currently operating low-cost production centers. The spot price in constant 1994 dollars is projected to be $16.56 per pound by 2010 (Table 13).

Production

Because of the higher costs of current and projected domestic operations than those of other countries, along with the availability of supplies from the Former Soviet Union, China, and Mongolia, a large share of domestic demand is met by imports. However, an overall increase in uranium prices should induce domestic production to rise gradually to 9.2 million pounds in 2006 (Table 14). Domestic production is projected to supply about 22 percent of domestic requirements in 2006, up from 9 percent in 1995. As lower cost reserves are depleted, production is expected to decline to 6.2 million pounds in 2010.

Net Imports

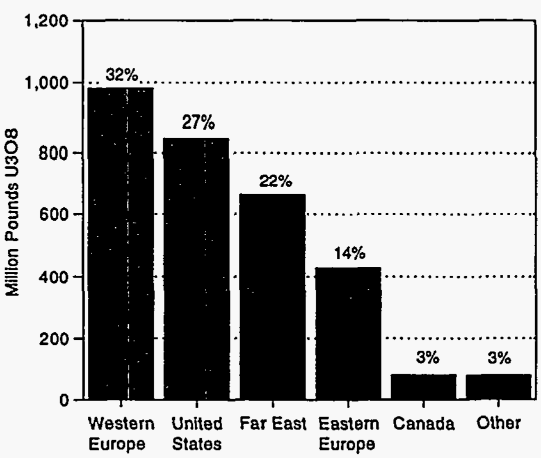
Even though domestic production is projected to rise in the coming years, a large portion of the aggregate

Table 11. Projected Annual Uranium Requirements for World Nuclear Power Plants, 1995-2015
(Million Pounds U_3O_8)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1995	47.1	47.1	4.0	4.0	20.8	24.1	55.5	56.6	23.6	23.0	3.1	2.9	154.1	157.8
1996	45.1	45.1	4.3	4.5	25.6	27.0	46.3	46.3	27.4	29.5	2.7	2.4	151.5	154.8
1997	44.1	44.1	4.2	4.2	24.3	25.5	54.0	54.1	28.8	29.7	2.1	4.3	157.5	161.0
1998	45.9	45.9	4.6	4.8	24.5	23.0	49.8	50.9	29.8	28.4	2.7	3.2	157.3	156.3
1999	41.3	41.3	4.3	4.3	23.0	21.9	46.6	47.1	29.0	31.1	4.3	3.7	148.6	149.5
2000	45.7	45.7	3.6	3.6	23.9	22.1	50.1	50.5	27.9	27.5	2.9	3.2	154.1	152.6
2001	48.0	48.0	4.4	4.4	25.8	24.2	48.4	49.2	28.2	36.5	3.8	3.4	158.4	165.6
2002	41.4	41.4	4.1	4.1	21.0	23.1	49.7	50.0	30.3	35.4	3.1	3.7	149.5	157.7
2003	46.1	46.1	4.5	4.5	22.2	31.3	49.4	49.8	32.6	33.2	2.9	5.7	157.7	170.6
2004	46.8	46.8	3.9	3.9	21.6	24.1	46.9	48.0	28.1	30.3	3.6	4.1	151.1	157.3
2005	46.4	46.4	3.8	3.8	22.0	23.9	44.5	44.6	29.7	33.7	4.3	4.3	150.7	156.8
2006	37.7	38.3	3.0	3.0	22.6	23.2	46.8	47.7	34.7	30.6	4.4	4.3	149.3	147.1
2007	42.5	42.5	4.1	4.1	21.9	23.3	47.6	48.3	38.3	43.6	4.2	4.5	158.6	166.3
2008	45.0	45.9	3.5	3.5	17.3	26.2	44.9	48.2	34.5	36.2	5.2	6.2	150.5	166.2
2009	37.1	40.4	3.3	3.3	19.5	28.0	45.0	45.7	30.0	30.9	4.0	5.1	139.1	153.5
2010	39.8	42.1	3.6	3.9	16.4	24.9	46.1	53.1	37.6	43.8	4.6	5.8	148.0	173.7
2011	31.5	35.8	2.7	3.1	17.9	27.5	44.4	48.7	35.3	37.7	3.8	5.4	135.7	158.2
2012	31.9	38.7	3.8	4.2	17.4	24.0	42.7	50.3	30.2	39.8	3.9	5.8	130.0	162.7
2013	24.7	29.7	4.0	4.6	16.3	28.5	42.6	53.7	37.9	41.1	5.1	7.9	130.6	165.6
2014	25.7	33.6	3.1	3.9	13.6	23.6	39.9	50.1	34.8	39.2	3.6	5.3	120.7	155.6
2015	24.7	31.2	3.3	4.2	12.2	23.6	39.9	41.2	34.8	39.3	3.9	6.9	118.8	146.4

Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Figure 10. Total Uranium Requirements by Region, 1995-2015, Low Case Projections



Source: Energy Information Administration, Office of Coal, Nuclear and Electric Fuels, International Nuclear Model, File INM95.WK3.

domestic demand will continue to be met by imports as supply from inventory drawdown declines (Table 14). Over the forecast period, net imports are projected to supply more than 70 percent of domestic requirements. Such levels contrast sharply with domestic production, which is projected to supply no more than 22 percent of domestic requirements. Net imports are projected to rise toward the end of the decade, providing 81 percent of the requirements in 2010.

Inventories

The level of inventories deemed optimal by U.S. utilities will be dependent on many factors, including cost considerations of operating in newly deregulated electric power markets and perceptions of the magnitude and availability of uranium supplies, especially from the FSU. U.S. inventories are projected to gradually fall below their current estimated level of just over 2 years of reactor requirements. They should stabilize in the later half of the decade at a level deemed

Table 12. Projected Uranium Requirements for the Low Case With and Without MOX Fuel, 1995-2015
(Million Pounds U_3O_8 Equivalent)

Year	Western Europe		Far East		Total		Percent Savings
	Without MOX	With Mox	Without MOX	With Mox	Without MOX	With Mox	
1995	55.5	52.6	23.6	23.6	79.1	76.2	3.6
1996	46.3	43.1	27.4	27.2	73.7	70.2	4.7
1997	54.0	50.0	28.8	28.6	82.8	78.6	5.0
1998	49.8	45.5	29.8	29.4	79.6	74.9	6.0
1999	46.6	41.4	29.0	28.4	75.6	69.8	7.7
2000	50.1	44.9	27.9	27.1	78.0	71.9	7.8
2001	48.4	42.8	28.2	27.4	76.6	70.2	8.4
2002	49.7	43.7	30.3	29.5	80.0	73.2	8.5
2003	49.4	43.1	32.6	31.6	82.0	74.7	9.0
2004	46.9	40.4	28.1	26.9	75.0	67.3	10.3
2005	44.5	38.0	29.7	28.3	74.2	66.3	10.7
2006	46.8	40.3	34.7	33.1	81.5	73.4	10.0
2007	47.6	41.1	38.3	36.5	85.9	77.6	9.7
2008	44.9	38.4	34.5	32.5	79.4	70.9	10.8
2009	45.0	38.5	30.0	27.8	75.0	66.3	11.7
2010	46.1	39.6	37.6	35.1	83.7	74.8	10.7
2011	44.4	37.9	35.3	32.8	79.7	70.8	11.2
2012	42.7	36.2	30.2	27.7	72.9	64.0	12.3
2013	42.6	36.1	37.9	35.4	80.5	71.6	11.1
2014	39.9	33.4	34.8	32.3	74.7	65.8	12.0
2015	39.9	33.4	34.8	32.3	74.7	65.8	12.0
Total	**981.1**	**860.4**	**663.5**	**633.4**	**1,644.6**	**1,493.8**	**9.2**

Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

reasonably adequate to satisfy annual reactor requirements (Table 14).

World Uranium Resources

Introduction

As discussed earlier in this chapter, uranium imports are projected to continue to be important in supplying the uranium requirements of U.S. nuclear reactors. These projections take into account the availability of supply throughout the world, including the quality of resources and the associated economic costs of mining, milling, and processing of existing and future production centers. For a better understanding of the outlook for world uranium supply, this section provides data and analysis on U.S. and foreign uranium resources.

In the 1970's, optimistic projections of nuclear power growth stimulated intensive uranium resource appraisal activities in much of the world. Annual world uranium exploration expenditures (excluding the Former Soviet Union, Eastern Europe, China, and Mongolia) peaked at $756 million in 1979.[48] In contrast, cumulative world exploration expenditures recorded for all years prior to 1975 were $790 million.[49] These exploration efforts were very successful and contributed to increased discoveries of uranium deposits. Higher quality deposits were discovered in other countries, notably Australia and Canada, that could be mined at lower costs than deposits found in the United States. Realizing their competitive position, foreign uranium producers have

[48]OECD Nuclear Energy Agency and International Atomic Energy Agency, *Uranium: Resources, Production and Demand* (Paris, France, 1986), Table 10. Expenditures in nominal U.S. dollars.

[49]OECD Nuclear Energy Agency and International Atomic Energy Agency, *Uranium: Resources, Production and Demand* (Paris, France, 1979), Table 11. Expenditures in nominal U.S. dollars.

Table 13. Projected U.S. Spot-Market Prices for Uranium Under Current Market Conditions, 1995-2010
(Constant 1994 Dollars per Pound U_3O_8)

Year	Price
1995	11.49
1996	12.12
1997	12.14
1998	12.03
1999	12.39
2000	12.69
2001	12.83
2002	13.01
2003	13.20
2004	13.57
2005	14.16
2006	14.88
2007	15.12
2008	15.92
2009	16.16
2010	16.56

Note: Adjusted by three-point smoothing.
Source: Energy Information Administration, Uranium Market Model run no. 1995_12.DAT, July 28, 1995.

Table 14. Projected U.S. Uranium Requirements, Net Imports, Commercial Inventories, and Production of Uranium, 1995-2010
(Million Pounds U_3O_8 Equivalent)

Year	Requirements[a]	Net Imports[a,b]	Commercial Inventories[a]	Production[a]
1995	45.4	33.5	76.9	4.3
1996	45.0	32.2	69.5	5.3
1997	43.8	32.0	63.5	5.7
1998	44.3	33.2	58.5	6.1
1999	45.0	34.8	54.9	6.0
2000	45.0	35.6	52.2	6.3
2001	45.2	35.9	50.2	6.8
2002	44.8	35.7	48.6	7.4
2003	46.4	37.4	47.2	7.7
2004	43.6	34.5	46.2	8.1
2005	42.2	32.3	45.2	8.9
2006	41.7	31.7	44.4	9.2
2007	41.5	32.3	43.7	8.6
2008	40.6	31.9	43.2	8.3
2009	36.1	28.5	42.7	7.1
2010	34.4	27.7	42.2	6.2

[a]Adjusted by three-point smoothing.
[b]Net imports = total imports less exports.
Source: **Requirements**—Energy Information Administration, International Nuclear Model, File INM95.WK3. **Net Imports, Inventories and Production**—Energy Information Administration, Uranium Market Model run no. 1995_12.DAT, July 28, 1995.

become more important than domestic sources in supplying the uranium requirements of U.S. nuclear reactors.

Uranium resources are classified on the basis of the level of confidence by which they are estimated (see glossary for a description of uranium resource categories). The following discussion will focus on the resource categories of the highest level of confidence: (1) U.S. reserves, and (2) Reasonably Assured Resources (RAR) reported for foreign countries. Reserves are mineral deposits for which the size, configuration, and production costs have been determined based on direct radiometric and chemical measurements gathered from drill holes and other types of sampling techniques. They correspond to RAR as used by the International Atomic Energy Agency and the Nuclear Energy Agency. Uranium resources are further categorized by forward costs, based on the operating and capital costs (in current dollars) yet to be incurred in producing uranium from known deposits.[50]

U.S. Uranium Resources

Most of the major uranium deposits in the United States were identified prior to 1980. Since 1980, however, additional deposits that led to production were discovered in northwest Nebraska and northern Arizona.[51] Due to the market conditions described earlier in this chapter, U.S uranium exploration expenditures have decreased dramatically from the high of $316 million in 1979.[52] In 1994, uranium exploration expenditures were $4 million, a decrease of 68 percent from $11.27 million expended in 1993. Exploration activities in recent years have been directed toward reevaluating and extending known deposits, especially in the context of recovering uranium by lower-cost ISL.

Low-cost U.S. reserves are defined as having forward costs of $30 per pound U_3O_8 or less. As of December 31, 1994, they are estimated to be 294 million pounds of U_3O_8.[53] Medium-cost reserves with forward costs of $50 per pound are estimated to be 953 million pounds of U_3O_8. These estimates do not include uranium recoverable as a byproduct from phosphate or copper mining. The average grade of low-cost U.S. reserves is 0.18 percent U_3O_8, while individual deposits typically contain less than 50 million pounds U_3O_8. U.S. deposits are of lower quality and, therefore, more costly to produce from than the significant foreign deposits described below. The United States also contains considerable potential for additional resources that could be discovered and developed into reserves. Estimated Additional Resources are used to describe estimates of additional uranium deposits expected to occur as extensions of known deposits in well-defined geological trends; they are estimated at 2.2 billion pounds U_3O_8 at forward costs up to $30.[54]

Foreign Uranium Resources

As of December 31, 1992, foreign RAR of 3.7 billion pounds of U_3O_8 were estimated to be available at a cost of $30 per pound, and RAR of 4.8 billion pounds U_3O_8 were estimated at up to $50 per pound.[55] RAR are concentrated in comparatively few countries, with Australia, Brazil, Canada, Niger, and South Africa containing 85 percent of the reported $30 per pound RAR; the RAR in these countries is estimated to be significantly greater than those in the United States. At the end of 1992, Australian RAR at $30/lb were 1.2 billion pounds U_3O_8, more than double the reported RAR of any other country except Canada.

Of the countries listed above, Australia and Canada have the highest quality of significant deposits amenable to low-cost production. In the Athabasca basin of Canada, several large deposits under consideration for development are estimated to contain reserves of at least 100 million pounds U_3O_8 each, with average grades in excess of 4 percent.[56] The Olympic Dam project in Australia currently realizes significant economies of scale from producing copper and uranium as coproducts; its reserves are sufficient to support production of 3.3 million pounds U_3O_8 in 1995, expanding to 7.7 million pounds by 2000.[57]

[50]A more detailed discussion of uranium resources and reserves is provided in Appendix B of the *Uranium Industry Annual 1994*.
[51]Geidl, John, and Szymanski, William, "United States Uranium Reserves and Production," *Proceedings of the American Nuclear Society's International Conference and Technology Exposition on Future Nuclear Systems: Emerging Fuel Cycles and Waste Disposal Options Global '93*, (Seattle, WA, September 1993), p. 1187.
[52]Data for U.S. exploration expenditures are reported in nominal dollars.
[53]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 10.
[54]Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 8.
[55]OECD Nuclear Energy Agency and International Atomic Energy Agency, *Uranium 1993: Resources, Production and Demand* (Paris, France, 1994), Table 1.
[56]Natural Resources Canada, *Uranium in Canada: 1994 Assessment of Supply and Requirements* (Ottawa, Canada, 1994), p. 5.
[57]*The U_x Report*,"Olympic Dam Expansion Status," (December 12, 1994), p. 3.

China, Eastern Europe, and the former Soviet Union are known to contain considerable uranium resources of uncertain extent. Historically, the civilian and military nuclear programs of these countries were closely linked and were operated in an environment of secrecy. Resources were developed to meet domestic requirements with excess production earmarked for exports to gain much needed foreign exchange. With the breakup of the Former Soviet Union and increased cooperation with Western countries, information on uranium resources and current production is gradually becoming available. Because the accounting methods of these countries differ from practices generally used in Western countries, however, reliable official data regarding the forward production costs of resources are not available.[58] As these countries implement aspects of a market economy many resources could be deemed no longer feasible to exploit. Economic reality has already been felt in Eastern Europe, where production centers are either being closed or heavily subsidized by governments to support domestic nuclear power requirements.

Table 15. Foreign Production Capability at $30 per Pound U_3O_8
(Thousand Pounds U_3O_8)

Country or Region	1995	2000	2005
Canada	21,578	30,678	16,639
Australia	10,919	15,339	15,339
Namibia	9,099	9,099	9,099
Niger	8,839	8,839	8,839
S. Africa	4,940	4,940	4,940
Gabon	3,900	3,900	3,900
Europe	9,619	4,940	4,680
S. America	1,495	1,495	1,417
Asia	598	650	780
Total	**70,987**	**79,880**	**65,633**

Note: Capability is for existing and committed production centers.
Source: OECD Nuclear Energy Agency and International Atomic Energy Agency, *Uranium 1993: Resources, Production and Demand* (Paris, France, 1994), Table 12.

Foreign Uranium Production Capability

Based on the assessment of uranium resources presented above, estimates were made of foreign production capability at $30 per pound U_3O_8 from centers considered to be existing or committed at the beginning of 1994 (Table 15). Australia and Canada have the largest share of foreign production capability and also account for many of the export commitments to the United States over the next decade. As previously discussed, uranium exports to the United States are restricted from certain republics of the Former Soviet Union. After all current supply commitments have been accounted for, the remaining low-cost foreign production capability is more than adequate to meet future customer needs in the United States. This section provides an analysis of the key trends that are expected to affect foreign production capabilities.

Output from large low-cost deposits in the Athabasca basin of Saskatchewan has made Canada the world's premier uranium producer since 1984. For example, Key Lake alone produced nearly 14 million pounds U_3O_8 in 1993.[59] A continued dominance is projected for Canadian exports as several significant mining projects are planned in the Athabasca Basin that could offset the depletion of reserves currently under production. In March 1995, Cogema Resources Inc. announced the beginning of construction at McClean Lake, the first new uranium mine-mill complex to open in the world since 1988. The project was approved in 1994 by the Federal and Provincial governments over the recommendations of an environmental review panel to further evaluate the project's impact.

While Australia contains abundant low-cost resources, the capability to produce from these resources has been limited by government policy. In 1983, the Australian government passed a law known as the "Three-Mine Policy" which restricted uranium production to three specifically named sites-Nabarlek and Ranger, which were already in production, and Olympic Dam which was under development. The law in effect has become a two-mine policy when the government did not approve of an additional mining site after Nabarlek was closed in 1988. The government, however, is expected to allow the development of Jabiluka as reserves from the nearby Ranger mine become depleted. Further relaxation of the Three-Mine Policy could allow Australia to increase its share of the U.S. market.

The lack of reliable forward production cost data for China, Mongolia, and the Former Soviet Union, as discussed in the previous section, adds considerably to the

[58]Energy Information Administration, "The Uranium Industry of the Commonwealth of Independent States," *Uranium Industry Annual 1991*, DOE/EIA-0478(91) (Washington, DC, October 1992), pp. 3-4.
[59]Natural Resources Canada, *Uranium in Canada: 1994 Assessment of Supply and Requirements* (Ottawa, Canada, 1994), p. 4.

uncertainties in projecting the future supply capabilities of these countries. Recent trends, however, indicate that these countries intend to pursue a significant role in the export market for many years. For example, Western firms have recently entered into joint venture agreements to develop and market production in Mongolia and the republics of the Former Soviet Union, especially the Russian Federation, Kazakhstan, and Uzbekistan. These joint ventures are looking at resources amenable to low-cost production methods such as ISL. China has also been recently developing projects with the emphasis on low-cost production methods.

Enrichment Market Developments

Overview

Utilities historically have filled the majority of their enrichment service requirements through long-term contracts. This trend continued in 1994, as domestic and foreign utilities awarded 28 long-term contracts for about 24 million separative work units (SWU).[60] The average duration of these contracts was 5 years. In contrast, spot purchases for the year totaled just over 1 million SWU.

Spot prices in recent years have risen in response to declining Western inventories and the restriction on imports from the Russian Federation. These factors are discussed in more detail in the section on uranium market developments in this chapter. The average spot price for the restricted market, as indicated by the average Nuexco SWU Value, increased to $85.63 per SWU in 1994 from $78.42 per SWU in 1993.[61] Due to the availability of Russian-origin material, the average SWU Value showed little change for the unrestricted market; $67.58 per SWU in 1994 compared with $67.25 per SWU in 1993. However, the 1994 unrestricted SWU Value is significantly higher than its low of about $50.00 per SWU (in nominal dollars) in 1990.

Unlike U_3O_8 producers, the enrichment service industry holds substantial excess capacity. In 1994, requirements were about 68 percent of the world's available enrichment capacity.[62] Projections indicate only marginal increases in requirements over the next decade (projections are presented later in this chapter). As a result, enrichers have found themselves operating in an extremely competitive business environment. Customers have benefitted by receiving more favorable contract terms and conditions, including contract extension or termination provisions, quantity flexibilities, reduced lead times in which customers are required to deliver feed to enrichers, and choice in selecting the level of enrichment tails assay.

Besides offering more flexible contracts, enrichers have been enhancing their competitive position by marketing enriched uranium product (EUP). EUP transactions differ from traditional enrichment service arrangements, in that the customer purchases a product, rather than just a service. The purchase price of the EUP includes the feed component as well as the enrichment service. The customer, however, does not procure the feed and deliver it to the enricher. As such, the enricher becomes a seller of nuclear fuel material. The quantity of EUP in which an enricher is able to supply depends on its access to competitively priced feed.

A significant recent development is the U.S. Congress' move to privatize the United States Enrichment Corporation (USEC).[63] The Energy Policy Act of 1992 provides legal authority for the privatization initiative. Two bills, H.R. 1216 (passed by the House on March 15, 1995) and S. 755, regarding privatization were introduced in 1995. The proposed legislation strives to make the USEC attractive to private investors while at the same time considering a rational disposition of LEU from the HEU agreement with Russia (USEC was named the U.S. agent for this material). Proposals were considered to increase the value of USEC by transferring surplus uranium from the DOE and covering certain liabilities associated with contracts formerly held by the DOE.

The enrichment market faces many of the same uncertainties as described for the uranium market. These uncertainties, described more fully in Appendix G, have contributed to a further strengthening of spot prices. By the end of the first quarter 1995, the average SWU Value for the restricted U.S. market exceeded $90.00 per SWU.

[60]Uranium Exchange Company, "The Enrichment Market Outlook- March 1995 Quarterly Update," (Danbury, CT, March 1995), pp. 4.1, 2.1.

[61]TradeTech, *Nuexco Review* (Denver, Colorado, May 1995), p. 28.

[62]NAC International, *Nuclear Industry Status Report on Enrichment, A Fuel-Trac Product* (Norcross, Georgia, February 1995), Table 3.1 (capacity); Section G, p. 1 (requirements).

[63]The United States Enrichment Corporation (USEC) was created as a separate government corporation in 1993 to carry out the enrichment services formerly provided by the U.S. Department of Energy.

Current Enrichment Services Profile

The current worldwide installed enrichment capacity of 48.7 million SWU is available from 13 plants in 8 countries.[64] A detailed listing of facilities and their capacities and ownership is presented in Appendix F. USEC, with plants in Portsmouth, Ohio and Paducah, Kentucky, holds 39 percent of this capacity. Russia and France also have significant capacity with shares of 29 and 22 percent, respectively.

Two types of enrichment plants are currently operating in the world: gaseous diffusion and centrifuge.[65] Gaseous diffusion technology has been used in large scale enrichment operations in the United States since the early 1950's. The U.S. plants were built by the Government to meet military requirements but later handled all of the enrichment services required by the Western world's commercial nuclear power industry. In 1979, the Triscastin gaseous diffusion plant in France became the first western commercial enrichment plant to operate outside the United States.[66] The plant's construction was stimulated in part by the U.S. Government decision to restrict new orders for services. Gaseous diffusion plants in the United States, France, and China make up 63 percent of currently available enrichment capacity.

The centrifuge technology was first demonstrated on a large-scale in the former Soviet Union during the 1950's.[67] The centrifuge plants currently operating in Russia have replaced earlier gaseous diffusion plants. The technology was later applied to plants constructed in Western Europe and Japan. Centrifuge plants in Russia, Germany, Netherlands, United Kingdom, and Japan make up 37 percent of currently available enrichment capacity (Appendix F).

Projections of Uranium Enrichment Services Requirements

Total worldwide enrichment service requirements from 1995 through 2015 are projected at 665 million to 718 million SWU (Table 16). Projections on an annual basis range from 26 million to 38 million SWU (Table 17). For the Low Case, Western Europe accounts for 34 percent of the total projected enrichment service requirements through 2015 (Figure 11). The United States and the Far East follow with shares of 28 percent and 22 percent, respectively. For the High Case projections of total enrichment service requirements, these regions increase share by 1 to 2 percent points at the expense of the Other region. It should be noted that while Canada requires natural uranium, the Candu-type reactors operating in that country do not require enrichment services.[68]

The use of MOX fuel in Western Europe and the Far East also replaces some enriched uranium with plutonium, resulting in lower enrichment service requirements. Based on the MOX fuel assumptions used in this report, total cumulative enrichment requirements in Europe and the Far East from 1995 through 2015 will be 8.5 percent less (Table 18). The use of MOX fuel is discussed more thoroughly in the previous section on uranium requirements.

Enrichment Capability

Current enrichment capacity exceeds the annual requirements projected through 2015 (Table 20). As such, enrichers will be forced to improve operating efficiencies. USEC's older gaseous diffusion plants could be particularly susceptible to competitive pressures. The gaseous diffusion process is highly energy intensive, therefore, it incurs higher operating costs than centrifuge plants. For example, approximately 60 percent of USEC's current production cost is for the purchase of electric power.[69] Future power costs are uncertain. However, the expected increase in USEC's power costs as its suppliers comply with provisions of the Clean Air Act[70] could be somewhat offset by the opportunity availed by deregulation to access more competitively priced power from other suppliers.

In response to the high costs of power, gaseous diffusion plants in France and the United States are operated to take advantage of lower off-peak rates.

[64]Available capacity does not include plants in Argentina and Pakistan that are believed to have capacities of less than 100 metric tons SWU.

[65]See glossary for definitions of gaseous diffusion and centrifuge technologies.

[66]*NuclearFuel,* "DOE's SWU Competitors Profiled in Recent Smith Barney Report," (June 25, 1990), p. 3.

[67] *NuclearFuel,*"DOE's SWU Competitors Profiled in Recent Smith Barney Report," (June 25, 1990), p. 6.

[68]Candu reactor is a type of heavy-water-moderated reactor in which heavy water is used as a moderator, thereby allowing natural uranium (in the form of UO_2) to be used in place of enriched uranium as a fuel.

[69]Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), p. 6-8.

[70]Provisions of the "Clean Air Act Amendment of 1990" seek to limit the emission of gases that contribute to acid rain.

Table 16. Projected Cumulative Enrichment Service Requirements for World Nuclear Power Plants, 1995-2015
(Million Separative Work Units)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1995	10.2	10.2	0.0	0.0	4.6	4.3	11.3	11.1	5.6	5.4	0.4	0.2	32.1	31.2
1996	20.1	20.1	0.0	0.0	9.4	9.8	21.8	22.2	10.8	11.1	0.7	0.5	63.0	63.6
1997	29.9	29.9	0.0	0.0	14.0	14.4	33.4	34.0	16.3	16.9	0.9	0.8	94.5	95.9
2998	39.6	39.6	0.0	0.0	18.3	19.3	45.2	45.8	22.8	23.0	1.3	1.4	127.2	128.9
1999	50.3	50.3	0.0	0.0	23.7	24.1	56.4	57.1	28.7	29.1	1.6	1.8	160.8	162.2
2000	59.4	59.4	0.0	0.0	28.9	29.1	68.2	69.1	34.9	35.4	2.1	2.1	193.6	195.0
2001	70.3	70.3	0.0	0.0	34.1	34.1	79.8	80.6	41.0	41.9	2.3	2.5	227.7	229.3
2002	78.7	78.7	0.0	0.0	38.6	38.6	90.7	91.7	47.0	48.6	2.8	3.0	258.0	260.6
2003	90.0	90.0	0.0	0.0	43.7	43.7	102.2	103.5	53.6	55.7	3.1	3.3	292.9	296.3
2004	98.0	98.0	0.0	0.0	48.7	51.6	112.1	113.4	60.2	62.5	3.5	4.0	322.8	329.5
2005	109.1	109.1	0.0	0.0	53.2	56.5	123.5	124.9	67.8	70.5	3.8	4.3	357.6	365.5
2006	119.2	119.3	0.0	0.0	57.8	61.3	134.8	136.4	74.5	77.8	4.2	4.9	390.8	399.8
2007	129.4	129.5	0.0	0.0	62.2	66.3	146.3	148.1	83.2	86.3	4.9	5.69	426.4	436.0
2008	138.6	138.9	0.0	0.0	66.3	70.9	157.4	159.3	90.8	94.3	5.3	6.2	458.6	469.7
2009	147.9	148.9	0.0	0.0	70.7	76.8	168.5	171.1	98.7	102.7	6.1	7.0	492.1	506.7
2010	156.9	158.2	0.0	0.0	74.0	84.1	179.2	182.8	107.2	111.4	6.5	7.6	524.1	544.2
2011	165.3	167.9	0.0	0.0	77.9	90.1	189.4	194.2	115.3	120.0	7.1	8.5	555.3	580.8
2012	172.1	175.7	0.0	0.0	81.7	95.6	199.6	205.9	121.8	127.9	7.6	9.2	583.1	614.4
2013	178.2	183.1	0.0	0.0	85.1	101.1	209.2	217.0	130.5	137.8	8.1	10.0	611.5	649.3
2014	183.9	191.0	0.0	0.0	88.7	107.4	218.9	229.3	138.6	146.7	8.5	10.9	639.0	685.5
2015	189.1	197.3	0.0	0.0	91.4	112.5	228.6	239.6	146.8	157.1	8.9	11.7	665.4	718.3

Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Overfeeding is another possible strategy to reduce power costs. Since USEC holds inventories of natural uranium, it is in a position to "overfeed" its operation by using more relatively less expensive uranium to produce the same quantity of enriched product with less relatively more expensive power. In this process, the actual enrichment tails assay would be higher than the contracted transaction tails assay.[71] USEC could also close some its capacity by replacing this foregone capability with LEU purchased through the HEU agreement with the Russian Federation.

Centrifuge plants, besides incurring lower operating costs, offer the following advantages over gaseous diffusion plants: (1) capacity can be increased or decreased more easily through a modular approach, and (2) centrifuges are amenable to specific work such as enriching reprocessed spent fuel. To take advantage of these competitive benefits, additional centrifuge plant capacity is planned for Western Europe, Japan, and the United States. Depending on market conditions, an additional 5 million SWU of centrifuge plant capacity could become available in Western Europe, Japan, and the United States by 2000.[72]

The last phase of public hearings on licensing was completed in March 1995 for the Louisiana Energy Services' (LES) planned centrifuge plant site in Claiborne Parish, Louisiana.[73] Ownership of LES is held between a supplier of enrichment services (Urenco), utilities (Duke Power and others), and the firm involved in the plant construction (Fluor Daniel Corp.). The plant's planned 1.5 million SWU capacity could be available by 2000. If completed, the Claiborne facility would be the

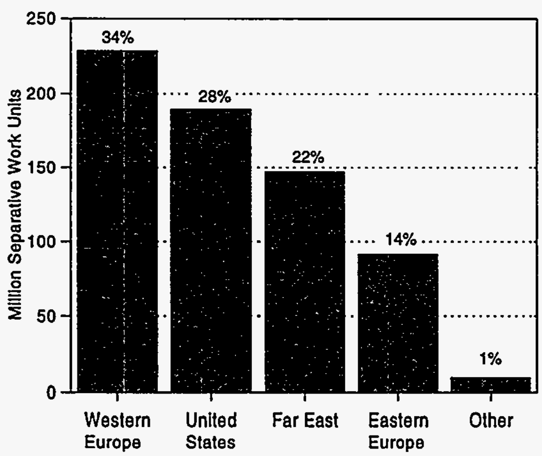
[71]Tails assay refers to the amount of the U-235 isotope that is left in the depleted natural uranium feedstock after the enriched product is removed.
[72]Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), Table 6-5.
[73]Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), p. 6-32.

Table 17. Projected Annual Enrichment Service Requirements for World Nuclear Power Plants, 1995-2015
(Million Separative Work Units)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1995	10.2	10.2	0.0	0.0	4.6	4.3	11.3	11.1	5.6	5.4	0.4	0.2	32.1	31.2
1996	9.9	9.9	0.0	0.0	4.8	5.5	10.5	11.1	5.3	5.7	0.4	0.3	30.9	32.4
1997	9.8	9.8	0.0	0.0	4.6	4.6	11.5	11.8	5.4	5.9	0.1	0.3	31.5	32.3
2998	9.7	9.7	0.0	0.0	4.3	5.0	11.8	11.8	6.5	6.1	0.4	0.6	32.7	33.0
1999	10.7	10.7	0.0	0.0	5.4	4.8	11.2	11.4	5.9	6.1	0.3	0.4	33.6	33.2
2000	9.1	9.1	0.0	0.0	5.3	5.0	11.8	11.9	6.2	6.4	0.5	0.4	32.8	32.8
2001	10.9	10.9	0.0	0.0	5.2	5.0	11.5	11.6	6.2	6.4	0.2	0.4	34.1	34.4
2002	8.4	8.4	0.0	0.0	4.5	4.6	10.9	11.1	6.0	6.7	0.5	0.5	30.3	31.3
2003	11.3	11.3	0.0	0.0	5.1	5.1	11.5	11.8	6.6	7.1	0.3	0.3	34.9	35.7
2004	8.0	8.0	0.0	0.0	5.0	7.8	9.9	9.9	6.6	6.8	0.4	0.7	29.9	33.2
2005	11.1	11.1	0.0	0.0	4.5	4.9	11.4	11.6	7.5	8.0	0.2	0.4	34.8	36.0
2006	10.1	10.2	0.0	0.0	4.6	4.8	11.3	11.5	6.7	7.3	0.5	0.5	33.2	34.3
2007	10.2	10.2	0.0	0.0	4.5	5.0	11.6	11.7	8.7	8.5	0.7	0.8	35.6	36.2
2008	9.2	9.4	0.0	0.0	4.0	4.6	11.1	11.2	7.6	7.9	0.4	0.6	32.2	33.7
2009	9.3	10.0	0.0	0.0	4.4	5.9	11.1	11.8	7.9	8.5	0.8	0.8	33.5	37.0
2010	9.0	9.3	0.0	0.0	3.4	7.4	10.7	11.6	8.5	8.7	0.4	0.5	32.0	37.5
2011	8.4	9.7	0.0	0.0	3.9	5.9	10.2	11.4	8.1	8.6	0.6	0.9	31.2	36.6
2012	6.8	7.8	0.0	0.0	3.8	5.5	10.2	11.7	6.5	7.9	0.4	0.7	27.8	33.6
2013	6.1	7.4	0.0	0.0	3.4	5.5	9.6	11.3	8.7	9.9	0.6	0.8	28.4	34.9
2014	5.7	7.9	0.0	0.0	3.6	6.3	9.7	12.1	8.2	8.9	0.4	0.9	27.5	36.2
2015	5.2	6.3	0.0	0.0	2.7	5.0	9.7	10.3	8.2	10.4	0.4	0.8	26.2	32.8

Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Figure 11. Total Enrichment Requirements by Region, 1995-2015, Low Case Projections



Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

first new enrichment plant in the United States since the mid-1950's.

Spent Fuel Disposal

Spent fuel management continues to be one of the most important tasks in the nuclear fuel cycle. The U.S. Nuclear Waste Policy Act of 1982 (NWPA) assigned the responsibility to DOE to select and characterize potential sites for geologic repositories, recommend sites for repositories and develop a spent fuel repository. The NWPA established the Office of Civilian Radioactive Waste Management within DOE to conduct the federal waste management program. Many utilities believe that the Act established 1998 as the target year for the government to begin accepting spent fuel from utilities, but the DOE has made it known that "it does not have a statutory obligation to accept spent nuclear fuel in 1998 in the absence of an operational repository or other facility constructed under the Act."[74] The Secretary of Energy has indicated an intent to explore

[74]*Federal Register,* Vol. 59, No. 100, (May 25, 1994), pp. 27008-27009.

Table 18. Projected Annual Enrichment Requirements for Western Europe and the Far East With and Without MOX Fuel, Low Case, 1995-2015
(Million Separative Work Units)

Year	Western Europe		Far East		Total		Percent Savings
	Without MOX	With MOX	Without MOX	With MOX	Without MOX	With MOX	
1995	11.3	10.7	5.6	5.6	16.9	16.3	3.6
1996	10.5	9.8	5.3	5.3	15.8	15.1	4.6
1997	11.5	10.7	5.4	5.4	16.9	16.0	5.2
1998	11.8	10.9	6.5	6.4	18.3	17.3	5.5
1999	11.2	10.1	5.9	5.8	17.1	15.9	7.3
2000	11.8	10.7	6.2	6.0	18.0	16.7	7.1
2001	11.5	10.3	6.2	6.0	17.7	16.3	7.7
2002	10.9	9.6	6.0	5.8	16.9	15.5	8.5
2003	11.5	10.2	6.6	6.4	18.1	16.5	8.6
2004	9.9	8.5	6.6	6.3	16.5	14.9	9.9
2005	11.4	10.0	7.5	7.2	18.9	17.2	8.9
2006	11.3	9.9	6.7	6.3	18.0	16.3	9.6
2007	11.6	10.2	8.7	8.3	20.3	18.5	8.7
2008	11.1	9.7	7.6	7.2	18.7	16.9	9.7
2009	11.1	9.7	7.9	7.4	19.0	17.1	9.8
2010	10.7	9.3	8.5	8.0	19.2	17.3	9.9
2011	10.2	8.8	8.1	7.6	18.3	16.4	10.4
2012	10.2	8.8	6.5	6.0	16.7	14.8	11.4
2013	9.6	8.2	8.7	8.2	18.3	16.4	10.4
2014	9.7	8.3	8.2	7.7	17.9	16.0	10.7
2015	9.7	8.3	8.2	7.7	17.9	16.0	10.7
Total	**228.5**	**202.9**	**146.9**	**140.4**	**375.4**	**343.3**	**8.5**

Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Table 19. U.S. Utilities with Dry Storage Capacities

Utility Name	Reactor	Storage Type
Arkansas Power and Light Co.	Arkansas Nuclear 1 & 2	Concrete Cask
Baltimore Gas and Electric	Calvert Cliffs 1 & 2	Concrete Module
Carolina Power and Light	Robinson 2	Concrete Module
Consumers Power Co.	Palisades	Concrete Cask
Duke Power Co.	Oconee 1, 2, & 3	Concrete Module
GPU Nuclear Corp.	Oyster Creek	Concrete Module
Northern States Power Co.	Prairie Island 1 & 2	Concrete Cask
Pennsylvania Power & Light Co.	Susquehanna 1 & 2	Concrete Module
Public Service Co. of Colorado	Fort St. Vrain	Modular Dry Storage
Sacramento Municipal Utility District	Rancho Seco	Concrete Module
Toledo Edison Co.	Davis-Besse	Concrete Module
Virginia Power	Surry 1 & 2	Metal Cask

Source: Energy Information Administration, *Spent Nuclear Fuel Discharges from U.S. Reactors 1993*, SR/CNEAF/95-01, (Washington, DC, February 1995), pp. 52-53.

Table 20. Projected Cumulative Discharges of Spent Fuel from World Nuclear Power Plants, 1995-2015
(Thousand Metric Tons of Uranium)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1995	2.4	2.4	1.8	1.8	1.2	1.2	4.5	4.5	1.3	1.3	0.5	0.5	11.6	11.6
1996	4.6	4.6	3.4	3.4	2.4	2.5	7.9	7.9	2.7	2.7	0.9	0.9	22.0	22.1
1997	6.6	6.6	4.9	5.0	3.8	4.1	11.4	11.5	4.1	4.2	1.4	1.4	32.2	32.7
1998	8.5	8.5	6.5	6.5	5.2	5.3	14.6	14.7	5.5	5.6	1.8	1.8	42.1	42.4
1999	10.6	10.6	8.3	8.4	6.4	6.7	17.8	18.0	7.1	7.4	2.4	2.4	52.6	53.4
2000	12.6	12.6	10.0	10.1	7.9	8.7	21.3	21.5	8.7	9.2	2.9	3.1	63.4	65.2
2001	14.5	14.5	11.5	11.7	9.4	10.2	25.0	25.3	10.5	10.9	3.4	3.8	74.4	76.4
2002	16.4	16.4	12.9	13.1	10.9	11.8	28.3	28.4	12.2	12.6	4.0	4.6	84.7	86.9
2003	18.3	18.3	14.6	14.8	12.5	13.4	31.1	31.3	13.8	14.2	4.7	5.4	95.1	97.4
2004	20.2	20.2	16.2	16.4	14.5	14.9	34.7	34.9	15.6	16.2	5.6	6.1	106.8	108.8
2005	22.3	22.3	17.8	18.0	16.3	16.7	36.9	37.2	17.1	18.2	6.4	6.8	116.8	119.2
2006	24.3	24.2	19.3	19.5	17.8	18.1	40.0	40.3	19.0	20.4	7.1	7.8	127.6	130.3
2007	26.3	26.2	20.7	20.8	19.1	19.6	42.9	43.2	20.7	22.3	7.8	8.8	137.6	141.0
2008	28.3	28.1	22.0	22.1	20.4	21.0	45.2	45.6	22.7	24.5	8.8	9.7	147.4	151.1
2009	30.1	30.0	23.4	23.6	22.1	22.6	47.4	47.8	24.5	26.8	9.7	10.7	157.2	161.4
2010	32.2	32.0	25.1	25.2	23.7	24.1	49.6	50.0	26.3	29.0	10.7	11.6	167.6	171.9
2011	33.9	33.7	26.3	26.4	25.0	25.8	52.1	52.7	28.6	31.2	11.6	12.4	177.4	182.2
2012	35.9	35.5	27.5	27.6	26.4	27.6	54.4	55.0	30.6	33.3	12.5	13.5	187.2	192.5
2013	38.3	37.7	28.7	28.9	27.8	29.2	56.6	57.4	32.3	35.4	13.3	14.5	196.9	203.0
2014	40.7	40.1	30.2	30.5	29.2	31.4	58.8	60.0	34.3	37.9	14.2	15.8	207.4	215.7
2015	41.6	41.3	31.5	32.1	30.9	33.2	60.9	62.3	36.3	40.2	15.0	17.0	216.3	226.1

Note: Totals may not equal sum of components due to independent rounding. Spent fuel projections in the Low Case are sometimes larger than spent fuel projections in the High Case due to more reactors retiring in the Low Case and consequently discharging the entire reactor core.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

various options for sharing the costs related to the financial burden associated with continued on-site storage of spent nuclear fuel. A number of bills have been introduced in the U.S. Senate and House of Representatives that, if passed and signed into law, could make significant changes in the nuclear waste disposal program.

Some countries do not share the problems of the United States concerning spent fuel disposal. For example, under Swedish law, the plant owners are responsible for the safe handling and disposal of all radioactive wastes. The Swedish Nuclear Fuel and Waste Management Company (SKB) sends spent nuclear fuel to a central interim storage facility.[75] About 2000 tons of spent fuel have been shipped there since 1982. The SKB is in the process of performing research and choosing sites for a deep geologic repository for the permanent disposal of spent fuel and other long-lived wastes. This repository is expected to be available in 2015.

In the United Kingdom, the Nuclear Industry Radioactive Waste Executive (Nirex) is responsible for providing and operating a repository for the disposal of radioactive wastes. Their plan is to construct a deep underground disposal which uses multi-barrier containments and natural barriers provided by the geological environment. Investigations are being conducted to determine an appropriate site. If suitable, Nirex would place the wastes in caverns 2100 feet below the surface in a hard rock formation. The goal is to have a repository in operation by 2010.

However, there is political resistance to spent fuel storage projects in other countries. Projects requiring relicensing have experienced delays and some away-from-reactor facility schedules have slipped. A spent fuel storage problem is developing in Japan. According to an article in Nuclear Engineering International, new storage facilities estimated to hold about 13,000 tons will be necessary before 2010.[76] Taiwan has a similar

[75]P.E. Ahlstrom and C. Thegerstrom, "The Swedish Route to Final Disposal," *Nuclear Europe Worldscan*, (January/February 1994).
[76]C.K. Anderson, "Interim Spent Fuel Management: 1995 Update," *Nuclear Engineering International* (March 1995).

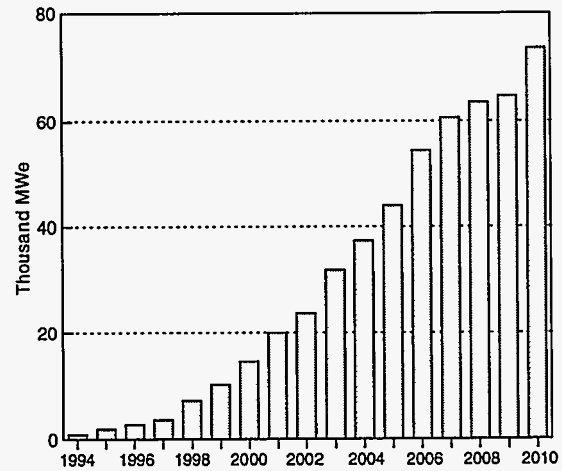
storage problem and Korea will need to solve their storage problem just after 2000. Russia, the Czech Republic, Hungary, Bulgaria, Slovakia, Lithuania and the Ukraine are all developing at-site dry storage facilities.

Utility At-reactor Dry Storage

Some U.S. nuclear units are running out of space in their spent fuel pools. The options available are reracking the existing spent fuel storage pools, rod consolidation and dry storage. According to data collected for the Office of Civilian Radioactive Waste Management, by 2010 about 80 reactors will not have any additional space to store spent fuel if DOE does not begin accepting discharged spent fuel. This would amount to a loss of about 74 thousand MWe (Figure 12). It also shows the amount of generating capacity affected by this decision. Of course the dates of a possible shutdown will change as utilities construct interim spent fuel storage facilities, change fuel management plans, and possibly ship spent fuel away from the reactor. A temporary solution to the spent fuel disposal problem is dry storage in NRC approved casks.[77] The first license for a U.S. spent fuel storage and transport cask was issued to the Nuclear Assurance Corporation International in September 1994. The license was a transportation certificate of compliance for the NAC-STC dual-purpose cask. The cask is now licensed as a full-time transportation package for spent fuel that has been cooled for more than six years.

U.S. utilities may obtain site-specific or general licenses to store spent fuel in Independent Spent Fuel Storage Installations (ISFSI).[78] Thirteen utilities have decided to increase their spent fuel storage capacity by using dry storage techniques (Table 19).[79] The different techniques include metal storage casks, concrete storage casks, metal canisters housed in concrete modules, and concrete storage vaults. Dry metal cask storage technology is being developed in Japan to solve the spent fuel storage problem.[80]

Figure 12. Possible Loss of Generating Capacity as of December 31, 1993



Source: Energy Information Administration, Spent Nuclear Fuel Discharges from U.S. Reactors 1993, SR/CNEAF/95-01 (Washington, DC, February 1995).

Spent Fuel Projections

In 1994, U.S. nuclear reactors discharged 1,883 metric tons of uranium (MTU). This brings the nuclear spent fuel inventory to 29.8 thousand MTU. The United States is projected to discharge around 42 thousand MTU from 1995 to 2015 (Table 20). For the same time period, it is projected that Western Europe will discharge between 61 and 62 thousand MTU. These two country groups are projected to generate almost one-half of the worldwide spent nuclear fuel by 2015. The Far East countries are projected to contribute about 17 percent to the worldwide total by 2015. Total spent fuel discharges worldwide from 1995 to 2015 are projected to be 217 to 226 thousand metric tons uranium.

[77]Ivan Stuart, "The First Licensed U.S. Dual-purpose Cask," *Nuclear Engineering International* (March 1995).
[78]Eileen M. Supko, "Utility At-reactor Spent Fuel Storage Plans," paper presented at the Fuel Cycle '95 Conference (Coronado, CA, April 1995).
[79]Energy Information Administration, *Spent Nuclear Fuel Discharges from U.S. Reactors 1993*, SR/CNEAF/95-01 (Washington, DC, February 1995), pp. 52-53.
[80]C.K. Anderson, "Interim Spent Fuel Management: 1995 Update," *Nuclear Engineering International* (March 1995).

4. U.S. Nuclear Power Plant Performance And Operating Lifetime Issues

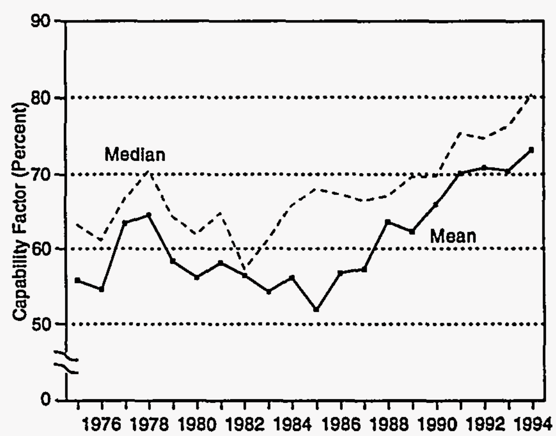
Because of deregulation of the electric power industry, existing nuclear plants are facing new economic challenges. Improvement in operating performance and lowering of operating costs are important for the long term survival of some nuclear power plants. Reactor performance will affect decisions regarding reactor operating lifetimes. On the one hand, reactors with good performance records are in a better position to extend their operating license. Some utilities are actively pursuing that option. On the other hand, poor performing reactors are more likely not to seek license renewal, and in certain instances, they may be likely candidates for premature shutdown. This has already occurred, and given the competitive environment of the electric industry, additional early retirements might be possible.

This chapter presents information on plant utilization and electricity production costs of nuclear power plants. It then addresses plant license extension, a topic affecting the level of nuclear capacity in the United States into the next century, followed by a discussion of reactor retirement issues.

U.S. Capacity Factors

The improvement in plant utilization that began in the late eighties continued through 1994 as the U.S. nuclear industry's average capacity factor reached an all-time high of 73.8 percent (Figure 13), an increase of 2.8 percentage points over the previous record of 70.9 percent set in 1992.[81] Average capacity factors have been in the seventies since 1991, in contrast to the 8 years following the Three Mile Island unit 2 accident, when they hovered in the mid-to-upper fifties. The median reactor capacity factor in 1994 was 80.4 percent, an increase of 4.0 percentage points over the previous record of 76.4 set in 1993. The top 25 percent of the reactors in 1994 achieved capacity factors above 91.1 percent, and 75 percent of the reactors had capacity factors above 64.6 percent, which by comparison was close to the median capacity factor in the early-to-mid eighties (Figure 13).

Figure 13. U.S. Nuclear Power Plant Capacity Factors, 1975-1994



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

The increase in capacity factors that began in the late eighties is due to a number of factors including improvements in utility management and worker moral, abatement of new NRC requirements, improved outage management, longer fuel cycles, and technical advancements in reactor components and materials. The industry recognized the importance of plant performance, and a number of efforts specifically aimed at improving performance were established. For example, there was considerable variation in performance among individual reactors and it was recognized that transferring knowledge from the good performers to the poor performers was one way to help the plants.[82]

[81]Average annual capacity factor statistics were computed as capacity-weighted averages.

[82]For an in depth discussion of these factors 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)*.

Reactor Outage Management

Reactor outage management, as noted above, is one of the key reasons for the continued improvement in capacity factors. The outage rate of a nuclear reactor is the percent of time the unit is not generating electricity. Total outages declined from a record high of 37.4 percent in 1983 to a record low of 23.0 percent in 1994 (Figure 14). Both the refuelling and duty cycle outages have been decreasing since the later 1980's, but the bulk of reduction in total outages after 1987 is attributable to reductions in refuelling time. In 1994, the duty and refuelling cycle outage were 8.1 and 14.9 percent, respectively.

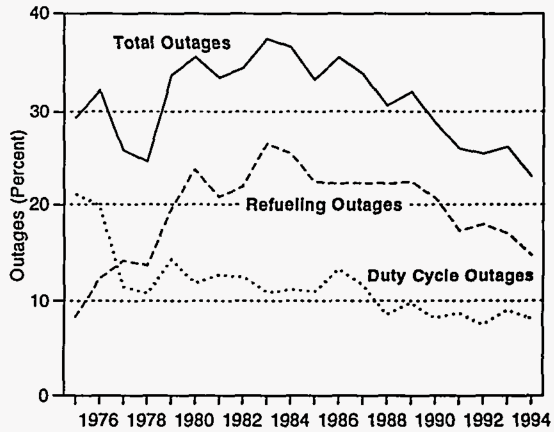
Long outages are caused by major equipment problems, regulatory-related actions, and administrative decisions. Reduction in the number of units with extended outages, defined as an outage length greater than 6 months, has had a beneficial impact on the industry capacity factor. In the past 4 years, the percent of capacity with long outages has leveled off to about 5 percent, a significant drop from a high of 14 percent in 1983 and 1984 (Figure 15). It should be noted that in the past 4 years approximately 2 percent of long-outage capacity is attributable to Browns Ferry units 1 and 3, which have been shutdown since 1986.

Fuel Cycles vs. Reactor Performance

Longer fuel cycles have also contributed to improvements in capacity factors. Utilities have a variety of reasons for increasing cycle length, most of which are related to plant availability, generating costs, and the regulatory system. Reducing the frequency of refueling saves money, reduces personnel radiation exposure, and can increase revenues through higher availability and capacity factors. Overall per unit generating costs are reduced by increasing output (i.e., increased capacity factor), combined with real costs savings such as reduced replacement power needs.

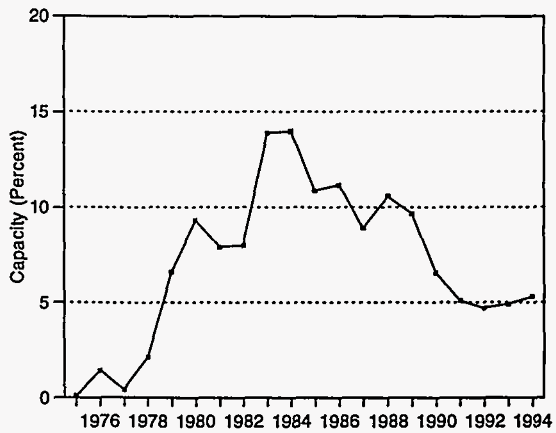
When nuclear power was first commercialized, most reactors operated on planned annual cycles, which meant they had to be shut down each year for refuelling. Utilities recognized that they could reduce relative down time for refuelling and boost capacity factors by extending cycle lengths. With a two month refuelling outage, for example, the relative outage time is 16.7 percent for an annual cycle versus 11.1 percent for an 18 month cycle. Theoretically, this difference translates into a potential improvement in the capacity factor of over 5 percentage points. Today, the majority of the reactors in the United States are operating on 18 month cycles, with a growing number changing to 24 month cycles.[83]

Figure 14. U.S. Nuclear Power Plant Annual Outages, 1975-1994



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

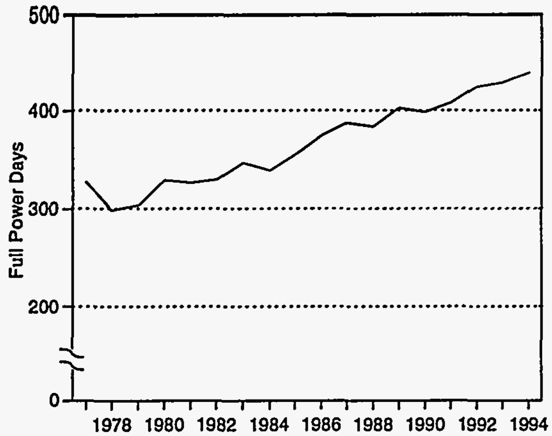
Figure 15. Percent of U.S. Nuclear Capacity with Extended Outages, 1975-1994



Note: Extended outages are defined as outages greater than six months.
Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (NUREG-0020).

[83]Utilities generally plan to refuel their reactors in the spring and fall when electricity demand is at seasonal lows. Consequently, extensions to cycle lengths are normally made in 6 months increments.

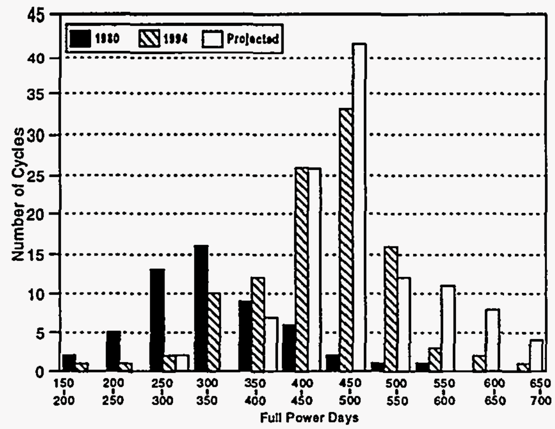
Figure 16. Average Number of Full Power Days per Fuel Cycle for U.S. Nuclear Reactors, 1977-1994



Note: Full power days are the number of days in which a reactor operates at full capacity in order to generate the amount of electricity that is actually produced during the cycle. The first two fuel cycles of each reactor are not included.

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

Figure 17. Distribution of Number of Fuel Cycles Operated at Different Full Power Days, 1980, 1994, and Projected for 2000



Note: Number of cycles for 1980 are tabulated from the last cycle completed for each reactor through 1980. The number of cycles for 1994 are tabulated from the last cycle completed for each reactor through 1994. Projected cycles include five projected cycles for each reactor, approximately through the year 2000.

Sources: **1980 and 1994:** Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (NUREG-0020), **Projected:** Energy Information Administration, Nuclear Fuel Data, Form RW-859, 1994.

When looking at actual trends in cycle length (expressed as full power days (FPD)) over the last 2 decades, the industry has had a significant increase in FPD's. In the late seventies, the average number of FPD's per cycle was about 330 (Figure 16).[84] From those levels, the average number of FPD's increased, at a fairly steady rate, to approximately 440 in 1994.

There is some variation among reactors in the actual number of FPD's achieved. By 1980, the majority of reactors operated with FPD's between 250 and 400, although a few were operating as low as 150 to 200 FPD's per cycle, and some as high as 550 to 600 FPD's per cycle (Figure 17). By 1994, the distribution had shifted considerably. The majority of reactors were between 400 and 500, and a few were as high as 650 to 700 FPD's per cycle.

It is expected that utilities, in order to benefit from longer fuel cycles, will continue to stretch-out the fuel cycle in the future. By 2000 the majority of reactors are expected to operate between 450-500 FPD's, with a significant number operating above 500 FPD's per cycle. There appears to be a good possibility of a continued improvement in capacity factors through longer fuel cycles.

Reactor Performance Levels[85]

Although capacity factors for the industry as a whole continue to get better, operating performance is not

[84]When analyzing industry trend, full power days (FPD) are a better indicator than actual cycle lengths. Long outages for major equipment repair or other problems cause actual cycle lengths to deviate from planned cycle lengths and distort the statistics. For example, a planned annual cycle which happened to have a long outage that extended the cycle length to 18 months would be classified as an 18 month cycle rather than an annual cycle. As a rough rule of thumb, a nominal cycle length can be approximated by dividing the full power days by 75 percent; so 300 full power days translates into approximately 13 months and 440 full power days translates into approximately 19 months. This shows a progression from 12 to 18 month cycles.

[85]In this analysis, data are segmented into four three-year periods from 1983 through 1994. Only units that have operated past their first cycle for the full three years of a given period are included in this analysis.

uniform across all units. When comparing the performance of reactor groups based on size, there is a fairly wide discrepancy.[86] Only a little improvement was made by the small units for the years 1983 through 1988 (Table 21). In contrast, mid-size reactors showed a significant improvement, while the performance of large units deteriorated over the same period. However, from 1989 through 1994 significant improvements were made by small, mid-size, and large reactors. From 1992 through 1994, the best performing group was the 19 small units with an average capacity factor of 80.8 percent, an increase of 14.4 percentage points over their capacity factor in 1989 through 1991. Capacity factors for the 41 mid-sized and 48 large units were 72.6 and 70.3 percent, increases of 1.5 and 5.0 percentage points, respectively, from 1989 through 1991. Mid-sized reactors were the best performers in 1989 through 1991.

It is instructive to further categorize each size group by age.[87] From 1992 through 1994, newer units had a better performance record than older units (Table 22). The 42 new units achieved an average capacity factor of 76.4 in 1992 through 1994, versus 68.5 for the 66 older units. Although as a group, the newer units had better performance records then older units, it is interesting to note that the reactors with the highest capacity factors were the small, older units. In some ways, the data suggest that operating performance is related to size of the units, not age. However the results are mixed. For the large reactors, the newer units clearly out performed the older units, suggesting an age-related degradation in performance. Perhaps a combinations of age related and size related factors are at work.

The category of large, old units contains a number of problem plants which account for the relatively low capacity factor of the group.[88] The Tennessee Valley Authority (TVA) operates 5 out of the 13 large old units, and all the TVA reactors have had problems. The Browns Ferry units 1 and 3 have been out of service since 1986, and consequently drag the average down since they are counted in the capacity, but are not generating electricity. Browns Ferry unit 3 is currently scheduled to come online in 1996. When or if Browns Ferry unit 1 will be restarted is speculative. TVA has not yet begun work on refurbishing the unit; moreover, they recently canceled three reactors that were under construction. TVA also operates the 2 unit Sequoyah Nuclear Plant. Performance at this plant has been improving, but unit 1 has been inconsistent over the last 3 years.

Commonwealth Edison Company (CECO), operates two of the old large reactors, Zion units 1 and 2. The average capacity factor for the Zion Nuclear Plant over the last 3 years was below 60 percent. As most of CECO's electricity is generated from nuclear power, some of its reactors may be used in a load-following

Table 21. U.S. Nuclear Power Plant Average Capacity Factors, by Size, 1983-1994

Size	Average Capacity Factor			
	1983-1985	1986-1988	1989-1991	1992-1994
Small (<= 700 MWe)	62.2	65.6	66.4	80.8
	(22)	(21)	(20)	(19)
Mid-Size (701-1000 MWe)	60.6	67.5	70.1	72.6
	(35)	(37)	(38)	(41)
Large (> 1000 MWe)	47.6	42.6	65.3	70.3
	(10)	(17)	(37)	(48)
All Units	59.1	59.5	67.3	72.2
	(67)	(75)	(95)	(108)

Note: Number of reactors is in parentheses.
Source: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (NUREG-0020).

[86]Large units are defined as those with capacities greater than 1000 megawatts electric (MWe); mid-sized units are greater than 700 MWe and not more than 1000 MWe; and small units are 700 MWe or less. It should be noted that no statistical tests were performed to determine whether differences between groups are real or due to random error.

[87]Young units are defined as those 12 years old or less at the end of 1994, and old units are greater than 12 year old.

[88]The analysis of individual plants is based on data obtained from the Nuclear Regulatory Commission, "Licensed Operating Reactors: Status Summary Report," (NUREG-0020), and the Federal Energy Regulatory Commission, Form 1.

Table 22. U.S. Nuclear Power Plant Average Capacity Factors, by Age and Size, 1992-1994

	Mean Capacity Factor			
	Small (<=700 MWe)	Mid-Size (701-1000 MWe)	Large (> 1000 MWe)	All Units
New (<12 years)	--	74.3 (7)	76.7 (35)	76.4 (42)
Old (>=12 years)	80.8 (19)	72.2 (34)	52.3 (13)	68.5 (66)
All Units	80.8 (19)	72.6 (41)	70.3 (48)	72.2 (108)

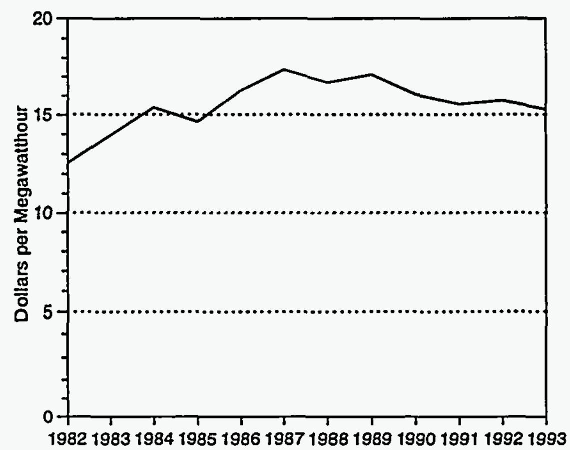
-- = Not applicable.
Note: Number of reactors is in parentheses.
Source: Nuclear Regulatory Commission, *Licensed Operating Reactors, Status Summary Report* (NUREG-0020).

mode, and it appears that the older reactors may be down on the dispatch list, which would lower utilization.

The two Salem units, operated by Public Service Electric and Gas, have had a mixed operating history and recently have had a number of equipment problems that have contributed to poor performance. Over the past 3 years the Salem Nuclear Plant's capacity factor has averaged below 60 percent.

On the positive side, the two Peach Bottom units have recovered from their regulatory-mandated outage and are now performing well. Philadelphia Electric Company (PECO) is placing a lot of emphasis on performance; their Limerick plant is operating very well, and PECO plans to apply the lessons learned at their Limerick plant to their Peach Bottom plant.

Figure 18. Average Operating and Maintenance Costs for U.S. Nuclear Power Plants, 1982-1993



Notes: Costs are in 1993 dollars. Fuel costs are excluded.
Source: Federal Energy Regulatory Commission, Form 1 (data obtained from the Utility Data Institute).

Operating and Maintenance Costs[89]

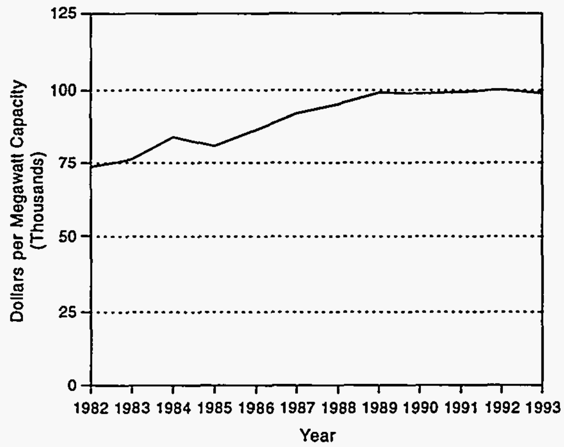
Industry-wide average O&M costs per MWh (expressed in 1993 dollars) have remained relatively stable from 1991 through 1993, reflecting the stability of capacity factors for the same years (Figure 18). On average, O&M costs in 1993 were $15.50 per MWh, or slightly above one and half cents per KWh. Adding fuel costs, which averaged $6.02 per MWh in 1993, gives a total production costs of $21.52 per MWh in 1993. In comparison, 1993 production costs for fossil steam plants was $21.81 per MWh, or roughly equal to the costs of running a nuclear plant.[90] In general, it appears that from a total industry perspective, nuclear power's production costs per unit of output are currently competitive with fossil steam plants.[91]

[89]Costs data presented in this section are from the Federal Energy Regulatory Commission, FERC Form 1, "Annual Report of Major Electric Utilities, Licensees and Others," September 1994. O&M costs do not include the costs of fuel. When used, the term production costs includes O&M costs plus fuel costs.

[90]Calculated from data obtained from the Federal Energy Regulatory Commission, Form 1.

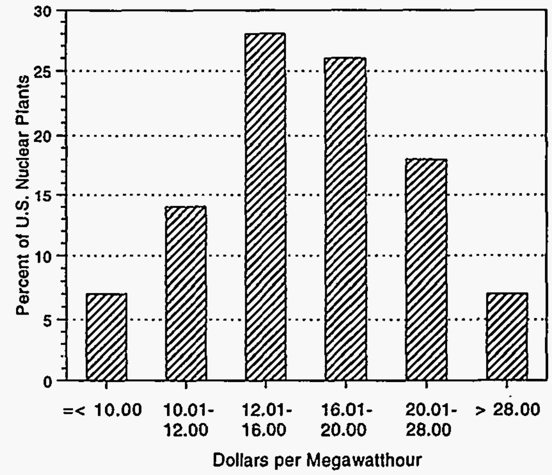
[91]It is important to note that when evaluating the competitiveness of nuclear plants vis-a-vis fossil fuel plants, projected capital expenditures, which may be high for some nuclear plants, must be factored into the analysis.

Figure 19. Average Annual Operating and Maintenance Costs per Megawatt-electric of U.S. Nuclear Capacity, 1982-1993



Notes: Costs are in 1993 dollars. Fuel Costs are excluded.
Source: Federal Energy Regulatory Commission, Form 1 (data obtained from the Utility Data Institute).

Figure 20. Variation in Operating and Maintenance Data Costs for U.S. Nuclear Power Plants, 1991-1993



Notes: Costs are in 1993 dollars. Fuel Costs are excluded.
Source: Federal Energy Regulatory Commission, Form 1 (data obtained from the Utility Data Institute).

Industry-wide O&M costs per megawatt of capacity have also remained stable for the last 5 years, 1989 through 1993 (Figure 19). O&M costs per unit of capacity is a measure of the utilities ability to control costs of the plant, independent of output. Although these costs have stabilized, because of the expected increase in competition they probably need to decrease in the future for the industry to remain competitive with other sources of fuel.

O&M Cost Structure

Although the nuclear industry as a whole appears to be cost competitive currently, there is wide variance in the distribution of O&M costs. Some units are doing very well, while others operate at a relatively high costs. In 1991 through 1993 over 50 percent of the nuclear plants had an average O&M costs greater than $16.00 per MWh (Figure 20). On the low side, 21 percent had costs less than $12.00 per MWh and on the high side 7 percent had costs greater than $28.00 per MWh. Causes of this large difference in O&M costs among plants are many. Differences in management and operating practices, variation in plant size and design, and possibly other factors all play a role.

Size of the nuclear plant clearly has an effect on O&M costs. In 1991 through 1993, the average O&M costs for small plants (less than 800 MWe) were $20.97 per MWh (Table 23).[92] For very large plants (greater than 2000 MWe), average O&M costs were only $13.74 per MWh, a fairly significant difference. Perhaps the reason for this difference is through efficiencies achieved from economies of scale. For example, it has been estimated that approximately two thirds of the O&M costs are labor related and manpower requirements for larger plants are proportionately less than those of smaller plants.[93]

When the plants are categorized by age, it appears that the newer plants are less expensive to operate. O&M costs for very large new plants were $12.87, compared with $15.79 for older plants of similar size. A similar situation exists between new and older plants for the other size categories, although the spread between new and old is smaller. The data suggest that both age and size are factors affecting the O&M costs of nuclear plants, but plant size appears to be a more important determinant of O&M costs.

[92]Because cost data are recorded at the plant level and not at the individual reactor level, the size classification used in this section is slightly different from that used previously.

[93]H.I. Bower, et al., "Cost Estimating Relationships for Nuclear Power Plant Operation and Maintenance," ORNL/TM-10563 (ORNL, Nov. 1987).

Table 23. Comparison of Average U.S. O&M Costs by Age and Plant Size, 1991-1993
(Dollars per Megawatthour)

Age Group (Years)	Plant Size Groupings (Megawatt-electric)				
	Small (< 800)	Mid-Size (800 to < 1,200)	Large (1,200 to < 2,000)	Very Large (>= 2,000)	All Sizes
New (≤ 12)	--	15.90	15.36	12.87	13.14
		(7)	(10)	(14)	(31)
Old (> 12)	20.97	16.76	16.89	15.79	17.41
	(12)	(11)	(14)	(7)	(44)
All Ages	20.97	16.39	16.36	13.74	15.48
	(12)	(18)	(24)	(21)	(75)

-- = Not applicable.
Notes: Costs are in 1993 dollars. Fuel costs are excluded. Number of nuclear plants is in parentheses.
Source: Federal Energy Regulatory Commission, Form 1 (data obtained from the Utility Data Institute).

Prospects for Reductions in Costs

Faced with pressure to make nuclear plants more competitive, utilities are joining together to share information and techniques to help reduce operating costs. Information sharing is nothing new to the industry, but now the utilities are being more open about sharing cost data and resources. In 1994 two alliances were formed; the Utilities Service Alliance (USA), consisting of nine nuclear utilities, and the Utility Business Opportunities Exchange (UBOE), consisting of four southern utilities. Both alliances have similar cost reduction goals, but their makeup and approaches are different. USA is more oriented toward single unit plants, while UBOE members are multi-unit plants. Examples of activities to help reduce costs are the sharing of equipment and tools, and sharing of training and purchasing activities.

More recently, the Nuclear Energy Institute has started a program aimed at helping the nuclear industry develop standard ways of measuring the cost of specific activities. In the past, nuclear plants have found it difficult to compare costs because of different accounting systems. Also, most of the cost data collected and reported by the industry is by functional area (i.e. maintenance, operations, engineering, etc.), actual plant operations overlap or go beyond these functional boundaries. It seems reasonable that from better economic benchmarking of plant activities, efficiency improvements can be more focused on high cost activities.

Whether or not these and other programs reduce costs over the long term remain to be seen. But it is fairly clear that the nuclear industry is initiating programs to meet the economic challenge they now face.

Nuclear Power Plant License Extension

Because orders for new nuclear plants in the United States are unlikely over the next decade or so, nuclear power's share of the energy mix in the early years of the next century will depend on decisions about license extension made in the near future. Between now and 2015, 51 reactors, consisting of 39 GWe of capacity (about 47 percent of active units and 38 percent of nuclear capacity), are scheduled to retire (Table 24). This amount may be reduced slightly if some utilities choose to recapture construction times.[94] Nonetheless, decisions to extend or not to extend the operating license will have to be made for 51 reactors over the next 20 years.[95]

Most nuclear utility officials believe it is technically feasible to keep today's nuclear units operating safely

[94]Recapture of construction time means that the 40 year operating license date starts when the reactor becomes operable, not when the construction permit was issued. For plants affected, some, but not all, have applied to the NRC to recapture the construction time.
[95]Under current NRC rules, a utility cannot apply for license renewal prior to 20 years from the expiration date of the current license.

well beyond their 40-year license. That number was set in law before the first commercial plant was built and was based on financial considerations.[96] However, as aging effects begin to take a toll, there are concerns that components such as the reactor vessel, the containment, and major piping and supports may have degraded over time. Plant life extension and the Nuclear Regulatory Commission's (NRC) license renewal process will depend on a review of the plant's structures and components to determine the affects of aging beyond 40 years.

NRC License Renewal Program

The original license renewal program was adopted by the Nuclear Regulatory Commission in December 1991. Although expiration of operating licenses is not an immediate concern for most plants, no utility has yet submitted an application for license renewal. Under a joint U.S. Department of Energy and industry program, two "lead plants" were selected to test the process of preparing license renewal applications. Yankee Rowe, a PWR whose operating license was to expire in 2000, was scheduled to be the first plant to apply for life extension. However, reactor pressure vessel (RPV) embrittlement was found, and in February 1992, Yankee Atomic Electric Company (YAEC) voted to permanently close the unit instead of correcting the problems. Yankee's RPV design made it extremely expensive to answer the technical questions posed by the NRC. YAEC even briefly considered replacing the RPV, but for economic reasons, permanent shutdown was chosen.

Monticello, a BWR operated by Northern States Power (NSP), was the other plant selected for the lead plant initiative. Monticello's operating license expires in 2010. In 1992 NSP decided to postpone its application, citing regulatory uncertainty. NSP expressed concern that the amount, cost, and extent of testing and backfits that will eventually be required by the NRC were unknown. NSP estimated that the number of systems to be reviewed was at least 104, up from the original 74, with no indication of where it might go from there.

The NRC recognized the uncertainty and confusion surrounding the license renewal program and in May 1995 issued a final revised nuclear power plant license renewal ruling.[97] The new procedures are suppose to reduce the uncertainty with the license renewal process and help clarify what is expected by the NRC to extend an operating license.

The effects of plant and equipment aging is a major concern of license renewal. Addressing that concern, the revised procedure will focus on the adverse effects of aging rather than identification of all aging mechanisms. What this means is that, unlike the old rule which was an open-ended research project to identify and evaluate how aging of equipment occurs, the new rule focuses on the effects of aging by monitoring performance of equipment in a manner that allows for timely identification and correction of problems.

In order to give credit to existing programs that manage the effects of aging, and by appropriately crediting the continuing regulatory process, the revised rule limits the aging management review for license renewal to "passive" structures and components.[98] Existing regulatory activities and the maintenance rule provide the basis for generically excluding structures and components that perform active functions from the aging management review.[99]

Finally, additional record keeping and updating requirements for a final safety analysis report have been simplified and made less prescriptive. In conclusion, if the economics of the plant are favorable, the revised rule should make it easier for the utility to extend the operating life of the plant.

Reactor Pressure Vessel Integrity[100]

The integrity of the reactor pressure vessel (RPV) is essential in assuring long term operation of nuclear power plants. However, through continued use, RPV's become embrittled from neutron irradiation. Radiation embrittlement is a concern because it causes a reduction

[96]*Nucleonics Week*, "Outlook On Life Extension," March 31, 1994, p. 4.

[97]Information on revision to the license renewal program was obtained from the NRC, Document 7590-01-P, Washington DC.

[98]Passive structures and components for which aging degradation is not readily monitored are those that perform an intended function without moving parts or without a change in configuration or properties.

[99]The maintenance rule requires the utility to monitor the performance of systems, structure, and components, within its scope against established goals. This rule, which will become effective July 1996, is the NRC's first performance based rule.

[100]Information on reactor pressure vessel problems was obtained from the U.S. Nuclear Regulatory Commission, Regulatory Information Conference (May 9-10, 1995, Rockville Maryland), Personal Conversations with Mr Dennis Harrison, Office of Nuclear Energy, U.S. Department of Energy, May 26, 1995, and Nucleonics Week, Special Report, *Outlook on Life Extension*, March 31, 1994.

in the capability of the RPV material to withstand the presence of cracks and a reduction in the fracture toughness of the material.[101] RPV's constructed of materials with high traces of copper and nickel in the weld areas are especially susceptible to this phenomena.

Utilities contemplating continued operation of their PWR's beyond a 40 year life will have to solve the RPV embrittlement problem. The NRC requires utilities to conduct ongoing analysis of their RPV's and to submit information on the status of there vessels. Two reactors, Beaver Valley 1 and Palisades, have been projected to potentially exceed the pressurized thermal shock (PTS) screening criteria before the end of license.[102] Beaver Valley 1 is projected to exceed the PTS screening criteria in 2012, four years before end of license. Palisades is projected to exceed the PTS screening criteria in 2004, two years prior to end of license. The NRC notes that the results of their findings are based on the information currently reported by the utilities and are subject to change. The date when these plants are projected to reach the screening criteria may change as a results of new surveillance data and additional analysis. More plants may also be affected. On the other hand, by implementing different fuel management techniques and inserting special neutron-absorbing material in the reactor core, nuclear units may be able to reduce the irradiation levels sufficiently to stay below the screening criteria. In addition, utilities can anneal the RPV to restore the material properties to near original unirradiated condition.

In support of developing annealing techniques in the United States, the U.S. Department of Energy is conducting a three-phase reactor pressure vessel (RPV) annealing research program. Annealing is the process of heating the RPV to an extremely high heat, around 850 degrees F, for about 1 to 2 weeks. This heating restores the metal's crystalline structure and consequently changes the embrittled metal back to normal. No RPV has been annealed in the United States. Russia has experience in annealing 13 reactor vessels, but because of different RPV designs, their techniques cannot be utilized directly in the U.S.

The three-phase DOE program started in 1995 and is expected to run to about 2002. Phase I, which is the only phase currently funded, consists of two parts; Part A involves conducting demonstration projects on two unirradiated reactor vessels. The purpose of the demonstration projects is to test two technologies for heating the RPV's, an electric furnace employing resistant heating, and a hot air gas fired furnace. In Part B, the results of the demonstration projects will be analyzed, focusing on what affects extreme heat have on the pressure vessel material. For example, after extreme heat, does the pressure vessel return to its original size? Phase II involves defining the regulatory requirements for reactor annealing and setting the stage for an application from the commercial nuclear power industry. Phase III is the commercialization of the process and implementation of the program. A lead plant concept will probably be used. It is interesting to note that Consumer Power Company, owner of Palisades nuclear plant plans to anneal the unit's embrittled RPV, and perhaps will participate in DOE's program.

Prospects for License Renewal[103]

Because the license renewal procedures have been simplified, and the industry as a whole seems to favor them, it is expected that utilities interested in license renewal will go forward. It is recognized, however, that the first plant or group of plants to go through the procedures will bear the brunt of unanticipated costs and public scrutiny. In other words, they will iron out the bugs in the process.

The Virginia Power Company is interested in renewing the operating license of its nuclear units and, up until recently, has been actively pursuing this option. They originally planned to submit an application for license renewal for the North Anna and Surry Nuclear plants in early 1995, but decided to wait until the revised license renewal rule was complete. Surry units 1 and 2 are scheduled for retirement within 20 years, while each unit at North Anna has over 20 years remaining on its operating license. Their original plan was to seek a 5-year license extension, but have since decided that

[101]Fracture toughness is a material property that defines a components's capability to carry load in the presence of a crack. When the fracture toughness is exceeded, an existing crack is predicted to propagate.

[102]Unanticipated accidents in a PWR could result in a rapid and significant decrease in the reactor coolant temperature, concurrent with or followed by repressurization. These events are often referred to as "overcooling or pressurized thermal shock (PTS) events. In these PTS events, rapid cooling of the reactor vessel internal surface results in thermal stress, which if severe enough, can result in the propagation of cracks in a reactor vessel weakened from embrittlement.

[103]Information on utilities interested in license renewal was obtained from *Nucleonics Week*, "Outlook on Life Extension," Special Report, March 1994; Batchlor, Derek, "License Renewed at Wisconsin Electric," Wisconsin Electric Power Company, 1994; and various editions of *Nucleonics Week*, June 1994 through March 1995.

the time, effort, and costs of a 5-year extension is the same as a 20-year extension. The company plans to wait until the 1997-1998 period to submit an application. By then, they expect the Westinghouse Owners Group will have concluded the studies they are conducting on key life extension issues affecting Westinghouse PWR's and that this may help facilitate the application process.

Wisconsin Electric Power Company, owner of the Westinghouse designed Point Beach Nuclear Plant, has also expressed an interest in license renewal. Point Beach 1 is scheduled for retirement in 2010 and unit 2 is scheduled for retirement in 2013.

Baltimore Gas and Electric, owner of the Calvert Cliffs plant, is another utility actively interested in license renewal, although they have not announced plans for submitting. Calvert Cliffs unit 1 is scheduled for retirement in 2014. The company has spent over $8 million on life extension work including the evaluation of components to see if they can operate an additional 20 years.

It is interesting to note that the plants expressing an interest in license renewal have relatively high capacity factors and low O&M costs. Both the Surry plant and Point Beach have produced electricity from 1991 through 1993 at a cost of less than $0.02 per kWh (Table 24).

Older, smaller plants which will reach retirement age in about 15 years are considered less likely to be economically attractive candidates for license extension. Some of these plants have relatively high operating costs, and questionable performance records. For example, Big Rock Point, Dresden 2, Haddam Neck, and Oyster Creek, all scheduled to retire by 2010, have high production costs relative to coal fired plants within their region (Table 24). Coupled with high operating costs is the possibility that as plants become older, capital expenditures for age related problems may increase. Unless production costs can be reduced, major capital expenditures can not be justified, thus license renewal is not a viable option.

In conclusion, it seems probable that some of these plants approaching the end of their operating license, who have had poor performance records will not seek to renew their license. This needs to be caveated with the statement that a detailed economic analysis is required to arrive at a firm conclusion.

Reactor Retirement Issues

The closings of Yankee Rowe in 1991 and Trojan and San Onofre 1 in 1992 coupled with the movement towards deregulation and competition in the electricity industry have raised concerns that additional nuclear plants may be retired prior to their license expiration date. Although some plants have been discussed as early retirement candidates, there is no consensus on which plants, nor the total number of plants that may retire early. Estimates vary on exactly how many will be shut down before their 40-year operating license expire--some say just a couple, other forecast around 20.[104] Typically, a reviewable basis for arriving at such estimates are not presented, so that the validity of these claims can not be evaluated.

Economic Factors[105]

While the general factors affecting the decision to retire a plant before its license expires can be identified, the final decision depends on a utilities specific circumstances. Regional variations in fuel costs, for example, may show that a coal plant as an alternative is more economical in one area of the country, but not so in another.

An analysis of the early retirement option should look at the operating costs of the nuclear plant compared to the operating costs of a replacement power plant during the remainder of the existing license period. Included in the operating costs are the cost of capital additions, which may be small for a coal-fired plant, for example, but significant for a nuclear plant.

Major plant repairs, such as steam generator replacement or fixing pressure vessel embrittlement problems, add to the cost of operation, and can have a significant impact on the early retirement decision. For major plant repairs, the issues of early retirement and license renewal can be related, depending on the age of the plant when repairs are needed. The utility may need license renewal for the repairs to be economical.

Major capital expenditure for replacement capacity will occur for normal retirement, but will be accelerated by early retirement. There can be a significant benefit from postponing this expenditure, if the utility can earn a return on the funds over and above the increasing costs

[104]*Nucleonics Week*, "Moody's Says High-Cost Producers Face The Abyss in New Environment," November 10, 1994, p. 3-4.

[105]Major economic factors to consider for early retirement were reported in a paper developed by Edward D. Lee, *Economic Shut-Down of Nuclear Plants: Recent Case Studies and Industry Outlook*, Charles River Associates, (Washington, DC, 1992). Also, additional analysis can be found in a paper prepared by James Hewlett, "The Operating Cost and Longevity of U.S. Nuclear Plants," *Energy Policy*, July 1992.

Table 24. U.S Nuclear Power Operating License Expiration Date, 2000-2015

Retirement Year	Reactor Name	Retirement Year Assuming Construction Recapture	Capacity (net MWe)	1992-94 Capacity Factor (percent)	Electricity Production Costs ($/MWh)[a] 1991-93 Nuclear Plant	1991-93[b] Coal Plants Within Reactor's Utility	1991-93[c] Coal Plants Within Reactor's Region	1991-93[d] Gas Plants Within Reactor's Utility
2000	Big Rock Point	--	67.0	62.9	63.6	20.4	20.5	--
2006	Dresden 2	--	772.0	55.7	30.0	44.0	27.2	--
2007	Haddam Neck	--	560.1	77.6	31.7	--	22.6	--
	Palisades**	2011	755.0	67.3	23.5	20.4	20.5	--
2008	Maine Yankee	2012	870.0	78.4	16.0	--	22.6	--
	Diablo Canyon 1	2021	1073.0	84.5	19.1	--	18.4	34.5
2009	Nine Mile Point 1	--	605.0	82.1	28.4	21.6	22.6	32.9
	Oyster Creek 1	--	610.0	78.7	36.4	--	26.3	--
	Robert E. Ginna*	--	470.0	83.8	24.0	--	22.6	--
2010	H.B. Robinson 2**	--	683.0	71.8	23.8	21.8	20.3	--
	Millstone 1	--	641.0	72.2	33.9	--	22.6	--
	Monticello	--	539.0	87.0	20.4	16.8	17.0	--
	Diablo Canyon 2	2025	1087.0	87.2	19.1	--	18.4	34.5
	Point Beach 1**	--	492.0	88.7	14.7	20.7	27.2	--
2011	Dresden 3	--	773.0	47.5	30.0	44.0	27.2	--
2012	Vermont Yankee 1	--	496.0	86.2	24.4	--	22.6	--
	Surry 1**	--	781.0	79.5	16.2	20.9	20.3	--
	Turkey Point 3**	--	666.0	79.9	32.8	--	20.3	29.5
	Pilgrim 1	--	665.4	73.2	29.4	--	22.6	31.7
	Quad Cities 1	--	769.0	53.8	26.3	44.0	27.2	--
	Quad Cities 2	--	769.0	52.3	26.3	44.0	27.2	--
2013	Surry 2**	--	781.0	83.9	16.2	20.9	20.3	--
	Oconee 1	--	846.0	84.9	14.6	20.0	20.3	--
	Oconee 2	--	846.0	82.3	14.6	20.0	20.3	--
	Peach Bottom 2	--	1051.0	72.4	28.1	42.3	26.3	--
	Point Beach 2*	--	482.0	88.3	14.7	20.7	27.2	--
	Prairie Island 1	--	510.0	85.9	15.1	16.8	17.0	--
	Fort Calhoun 1	--	476.0	77.6	34.0	13.6	17.0	--
	Indian Point 2	--	931.0	85.7	26.0	--	22.6	46.9
	San Onofre 2	2022	1070.0	91.5	24.2	19.4	18.4	36.3
	San Onofre 3	2022	1080.0	81.3	24.2	19.4	18.4	36.3
	Turkey Point 4**	--	666.0	81.2	32.8	--	20.3	29.5
	Zion 1*	--	1040.0	55.9	21.7	44.0	27.2	--
	Zion 2	--	1040.0	61.4	21.7	44.0	27.2	--
	Browns Ferry 1[e]	--	1065.0	0.0	--	16.6	20.3	--
	Kewaunee	--	522.0	87.2	21.1	21.5	27.2	--
2014	Cooper 1	--	778.0	60.5	19.6	13.7	17.0	--
	Duane Arnold	--	515.0	79.5	23.8	12.5	17.0	--
	Arkansas Nuclear 1	--	836.0	87.1	20.9	21.6	22.6	20.6

See footnotes at end of table.

Table 24. U.S. Nuclear Power Operating License Expiration Date, 2000-2015 (continued)

Retirement Year	Reactor Name	Retirement Year Assuming Construction Recapture	Capacity (net MWe)	1992-94 Capacity Factor (percent)	Electricity Production Costs ($/MWh)[a]			
					1991-93 Nuclear Plant	1991-93[b] Coal Plants Within Reactor's Utility	1991-93[c] Coal Plants Within Reactor's Region	1991-93[d] Gas Plants Within Reactor's Utility
	3 Mile Island 1	--	786.0	94.3	20.3	--	17.0	--
	Oconee 3	--	846.0	83.2	14.6	19.9	20.3	--
	Calvert Cliffs 1	--	830.0	73.5	21.7	23.4	26.3	--
	Browns Ferry 2	--	1065.0	76.7	35.0	16.6	20.3	--
	James Fitzpatrick 1	--	800.0	47.7	57.9	--	22.6	44.7
	Donald C. Cook 1	--	1000.0	74.2	19.7	16.1	20.5	--
	Hatch 1	--	740.1	85.3	22.3	21.7	20.3	--
	Peach Bottom 3	--	1035.0	82.1	28.1	42.3	26.3	--
	Prairie Island 2	--	505.0	85.5	15.1	16.8	17.0	--
	Brunswick 2	--	754.0	50.6	48.8	21.8	20.3	--
2015	Indian Point 3**	--	980.0	23.5	29.8	--	22.6	44.7
	Millstone 2**	--	873.1	55.1	33.9	--	22.6	--

[a]Includes operating, maintenance and fuel costs. Costs are computed at the plant level.
[b]This is the average cost for coal plants (greater than 400 MW capacity) owned by the same utility owning the reactor.
[c]This is the average cost for all coal plants within the same NERC region as the reactor.
[d]This is the average cost for all gas plants (greater than 400 MW capacity) owned by the same utility owning the reactor.
[e]Unit has been shut down for an extended time.
MWe = Megawatt-electric.
-- = Not applicable.
* Utility has plans to replace the steam generator.
** Utility has replaced the steam generator.
Note: Construction recapture refers to adding the time between issuance of construction license and operating license to the reactor's operating license expiration date.
Sources: Nuclear Regulatory Commission, *Licensed Operating Reactors: Status Summary Report* (NUREG-0020), and Federal Energy Regulatory Commission, Form 1 (obtained from the Utility Data Institute).

of replacement capacity during the remaining life of the plant. However, in cases where there is excess capacity, replacement capacity may not be needed for years, reducing the cost of accelerated replacement capacity investments.

Similarly, major capital expenses for decommissioning are accelerated in an early retirement plan. The lost return on that capital can be costly if the return on the funds is greater than the real increase in decommissioning costs over the same period.

The purchase of temporary replacement power is another consideration. Unless a utility has extra capacity to see it through the loss of a baseload nuclear power plant, it is likely that it will have to purchase power to make up for the loss in the short run. The short-term cost of this purchase may likely be higher than the O&M cost of the nuclear plant. If this is the case, potential costs saving from premature retirement will be reduced.

Perhaps the major reason for more early shutdowns will be the occurrence of a technical problem, like a steam generator replacement, where the repair costs cannot be recovered in the remaining time of the operating license, and license renewal is not economical over the longer-term because of high operating costs (more on this point later in the chapter).

After all the cost-benefit analysis is done and all the numbers are run, the early retirement of a nuclear plant may be the result of political or regulatory actions. More specifically, nuclear power plants are very capital intensive, and if retired early, there may be significant undepreciated capital. If the regulators disallow the utility to recover the costs of the undepreciated assets, the decision to shutdown, at least from the utility owners point of view, becomes less clear. However, this may not be a significant factor in the future. The recovery of capital costs was allowed for the three most recent early retirements: San Onofre 1, Trojan, and Yankee Rowe.

Review of Nuclear Power Plant Closing[106]

Since 1987, seven nuclear plants have been permanently retired from service prior completing their 40-year licensed term (Table 25). While economics played a major role in some plant closing, regulatory, political, and technical issues were also factors.

The 436 MWe San Onofre 1 unit was retired on November 30, 1992, after a contentious review of the cost-benefits of keeping the unit running. The review was precipitated by plans for a $135 million capital expense for steam generator repairs and concerns about the unit's low lifetime capacity factor of 46 percent. Southern California Edison (SCE) conducted a parametric analysis based on a number of uncertainties such as future capacity factors and natural gas prices. The results were mixed and dependent upon which assumptions were adopted. SCE felt that San Onofre 1 could be operated at a 70 percent capacity factor and that the cost benefits weighed in favor of keeping the plant operating. However, the California Public Utilities Commission Division of Ratepayer Advocates (DRA) reached an opposite conclusion, and SCE acquiesced to the Commission rather than face a protracted battle in a hostile environment. SCE also declined to pursue a proposal to develop a plan in which it would assume the economic risks and rewards of operating San Onofre 1.

On August 10, 1992, the Portland General Electric (PGE) Company decided to permanently shutdown the 1,095 MWe Trojan nuclear power plant in 1996 in lieu of replacing the plants four steam generators. But, when the plant was taken off line for refuelling on November 9, 1992, PGE decided not to return Trojan to service because of tube leaks in one of the steam generators and concerns about the regulatory treatment of tubular microflaws. The original decision to permanently retire Trojan was based on a requirement for least-cost electricity generation, and it was determined that demand-side management and alternate sources such as hydroelectric, natural gas, and cogeneration were more cost effective. Hydroelectric power is abundant in the Pacific Northwest and is the least cost source of power when there is ample water. Public pressure may also have contributed to PGE's decision to retire Trojan, as opponents of the plant were successful in placing state-wide referenda on the ballot. Although the referenda were soundly defeated, the resolve of the plant's opponents remained. Trojan had a lifetime capacity factor of about 53 percent.

The 167 MWe Yankee Rowe plant, whose operating license was to expire in 2000, had been scheduled to be the first plant to apply for license renewal. However, when the NRC raised questions concerning potential vessel embrittlement problems, the Yankee Atomic Electric Company decided not to restart the plant after its 1991 shutdown for refuelling. Although there were no physically identifiable indicators of actual embrittlement problems which could endanger the safe operation of the plant and Yankee Atomic believed that the plant was safe to operate, the utility could not justify the expenditures to demonstrate to the NRC that no problems actually existed. Vessel embrittlement is a new area for the NRC and few guidelines and procedures have been developed. There was also the possibility that a hidden problem might have been uncovered in an in-depth inspection. Although the vessel embrittlement issue was the primary reason for retiring Yankee Rowe, reduced electricity demand projections and the availability of inexpensive power from Canada mitigated the need for the capacity supplied by Yankee Rowe. The plant had a relatively good performance record with a lifetime capacity factor around 74 percent, but, because of its small size, had high O&M costs.

Fort St. Vrain was the only high temperature gas reactor (HTGR) to operate commercially in the United Sates. The 330 MWe unit was constantly plagued with design and operating problems during its 10 years of operation, and Public Service Company of Colorado permanently retired the plant in 1989. Fort St. Vrain had a lifetime capacity factor of just under 15 percent and had relatively high operating costs.

The 819 MWe Shoreham plant was plagued by cost overruns, delays, and legal and political battles during its protracted construction period. Although Shoreham was operated for low power testing between 1985 and 1987, and finally received a full power license from the NRC on April 21, 1989, it was never put into

[106]Information from this section was obtained from the Office of Technology Assessment, "Aging Nuclear Power Plants: Managing Plant Life and Decommissioning," (Washington, DC, September 1993); and Decision Analysis Corp., "Nuclear Unit Retirements," unpublished report (Vienna, VA, December 1991).

commercial operation. The State of New York would not accept the emergency evacuation plan submitted by Long Island Lighting Co. (LILCO) and maintained no plan would be acceptable because the affected area was too populous. To end this impasse, LILCO finally agreed to sell Shoreham to the State of New York for decommissioning, at a transaction price of $1. As part of the settlement, LILCO received a tax writeoff of $2.8 billion, 5 percent annual rate increase for three years, and targeted rate increases in a range of 4.5 to 5 percent for an additional 7 years.

Rancho Seco had high operating costs and a poor operating history throughout most of its life, with a lifetime capacity factor of only 39 percent. Because of high costs, a public referendum was passed setting performance standards for the unit to continue operating. The 873 MWe plant failed to meet the criteria set forth by the referendum and the Sacramento Municipal Utility District permanently removed Rancho Seco from service on June 7, 1989. Rancho Seco, along with the other Babcock & Wilcox (B&W) reactors as a group, suffered from poor performance in the early to mid eighties following the Three Mile Island 2 accident. Most of the remaining B&W reactors seem to have recovered from their earlier problems and have achieved the highest capacity factor of any vendor group in the last several years.

The 48 MWe La Crosse plant was the smallest commercial nuclear power plant in operation when it was retired in 1987 for economic reasons. The plant was too small to absorb the fixed costs (regulatory and security concerns, design engineering, etc.) of operating in nuclear environment. La Crosse had a lifetime capacity factor of 50.7 percent.

Four other units, Indian Point 1, Dresden 1, Humboldt Bay, and Three Mile Island 2, were retired prior to completion of their 40-year lives, all before 1980. Indian Point 1, Humboldt Bay, and Dresden 1 were early vintage reactors. The 200 MWe Indian Point 1 unit was retired in 1974; the 63 MWe Humboldt Bay plant was retired in 1976; and the 197 MWe Dresden 1 unit was retired in 1978. In 1979, after only a few months of operation, the Three Mile Island unit 2 experienced a devastating accident that culminated in a core melt down which made the unit inoperable.

Prospects for More Retirement of Reactors

No utility, at this time, has publicly announced plans to retire a currently operating nuclear unit before the license expires. Some currently operating plants have experienced technical or other problems, over recent times, and the option of early retirement was considered. For example, due to poor performance, excess capacity in the region, and low costs competition from independent power producers, Niagara Mohawk Power Corporation struggled with the potential closure of Nine Mile Point 1, which had been considered a possibility to retire as early as 1995, 14 years before expiration of its operating license.[107] However, the unit has performed very well over the last several years, and Niagara Mohawk decided that continued operation of the plant was beneficial, especially in light of the Clean Air Act's requirements to reduce emissions.

Another example, The Wisconsin Public Service Commission recently concluded that it is more economical to replace Wisconsin Electric Power Company's, Point Beach 2 steam generators and build a temporary storage facility to supplement the currently crowded spent fuel pool, than to shut down the plant in 1998.[108] Other reactors reported in the trade and industry literature have been mentioned, but nothing conclusive with respect to early shutdown.[109]

Although articles in the trade press discuss this issue, projecting early retirements is a highly risky, and in some sense, a speculative endeavor. Each utility has different conditions that may influence their decision to shut down a unit early. It is unlikely that analysts, journalists, and other observers of the industry, have all the information needed to make a truly informed analysis. Given that, there are certain indicators that perhaps can provide some insight into the issue.

Lessons learned from units that shut down early indicate clearly that the need for a major capital expenditure played a big role. The last three units to shut down all needed major repairs. San Onofre 1 and Trojan needed steam generator replacement, and Yankee Rowe needed RPV work, although the extent and costs of this work was never established. The

[107]*Nuclear News*, "NIMO Backs Unit 1 Until 1995, Maybe Not Later," (January 1993), p. 21.

[108]*Nucleonics Week*, "Hearing Conclude on WEPCO Plan to Keep Point Beach-2 Operating," November 3, 1994, p. 6.

[109]Rochester Gas and Electric's Ginna plant, Southern California Edison's San Onofre plant, and Northern State Power's Prairie Island plant have also been mentioned.

operating performance and/or O&M costs of the units were also similar among the units. San Onofre 1 and Trojan were poor performers with very low lifetime capacity factors (Table 25). Yankee Rowe's lifetime capacity factor was good, but its O&M costs for the last 3 years were high, $0.041 per KWh. Trojan's O&M costs were somewhat high at $0.032 per KWh. Based on these units, pending major repairs, combined with poor performance, and relatively high O&M costs seem to be good indicators of a potential early shut down.

Although steam generator problems played a major role in the past, this may change in the future. Techniques for solving steam generators problems are improving, and replacement time and costs are decreasing.[110] Many utilities with problems are planning to either replace the steam generators or perform some corrective action. There are 10 utilities with plans for steam generator replacements in the United States. Other solutions are being sought as well. For example, Maine Yankee, a 22 year old PWR scheduled to retire in 2008, is currently undergoing a massive steam generator sleeving project. The point is that steam generator replacement may have been a big factor in previous decision for early shut down, but because of industry experience, improvement in techniques for correcting the problems, and lower costs, it may be less of a consideration in the future.

RPV embrittlement is another area to watch. Embrittlement played a role in the Yankee Rowe early shut down decision, and as of now, there are 2 currently operating reactors at risk. As mentioned previously, Palisades and Beaver Valley 1 are expected to exceed the PTS screening limit before end of license, but that could change. NRC's ongoing surveillance program could result in more RPV problems in other reactors.

On the positive side, efforts to solve the RPV embrittlement problem have been started. The U.S. DOE's annealing program may result in a solution to this important problem. However, because there are significant economic, and regulatory uncertainties in this area, it is not clear what influence RPV problems will have, if any, on reactor retirement decisions in the future.

Table 25. Retired U.S. Commercial Nuclear Reactors Greater than 45 Megawatts-electric

Unit	Date Shutdown	Date Commercial Operation	Capacity (MDC Net)	Capacity Factor (Lifetime / Last 3 Years)	O&M Costs Last 3 Years ($/MWh) / ($/MW)
Indian Point 1	10/31/74	10/1/62	200	NA	NA
Humboldt Bay	7/2/76	8/1/63	63	NA	NA
Three Mile Island 2	3/28/79	12/30/78	880	NA	NA
Dresden 1	10/31/78	8/1/60	197	46.3 / 45.0	NA
La Crosse	4/3/87	11/1/69	48	50.7 / 64.5	25.70 / 137,018
Rancho Seco	6/7/89	4/17/75	873	39.1 / 17.2	147.00 / 151,067
Shoreham	6/28/89	None	819	--	--
Fort St. Vrain	8/18/89	7/1/79	330	14.7 / 15.3	267.84 / 247,004
Yankee Rowe	10/1/91	7/1/61	167	74.2 / 73.8	40.64 / 230,165
Trojan	11/10/92	5/26/76	1095	52.8 / 46.1	31.85 / 105,741
San Onofre 1	11/30/92	1/1/68	436	46.0 / 58.1	NA

MDC = Maximum dependable capacity.
NA = Data not available.
-- = Not applicable.
Notes: •O&M costs are in 1993 dollars. •O&M costs do not include fuel costs. •Cost data is for last three full calendar years of operation, except for Yankee Rowe and Trojan where it is last three years of operation (they were shut down near the end of the year). •Capacity factor data is last 3 years of operation, from month of shutdown.
Sources: Nuclear Regulatory Commission (NRC), "Licensed Operating Reactors: Status Summary Report (NUREG-0020), NRC, "Information Digest, 1995 Edition," and Federal Energy Regulatory Commission, Form 1 (obtained from the Utility Data Institute).

[110]Energy Information Administration, "Steam Generator Degradation and Its Impact on Continued Operation of Pressurized Water Reactors in the United States," *Electric Power Monthly*, (Washington, DC, August, 1995).

When looking at electricity production costs of units retiring in the next 20 years, all but a few units appear to be comparable to the average costs of plants using alternative fuels, such as coal and gas (Table 24)[111]. Plants with relatively high production costs include Big Rock Point, Dresden, Haddam Neck, Oyster Creek, Millstone, Turkey Point, Fort Calhoun, Browns Ferry, Fitzpatrick, and Brunswick.[112] Some of these plants have good operating performance, and with the current emphasis on cost reduction in the industry, one would expect to see improvements in production costs.

This is but a rough sketch of the prospects of early retirement. A complete analysis is beyond the scope of this report. However, some general observations can be made. Most nuclear units scheduled to retire in the next 20 years appear to be competitive. With decreased regulation and more competition, the situation could change over the next few years. For example, new low cost gas fired plants could put competitive pressure on nuclear plants. On the other hand, managers of nuclear plants have, over the past few years, emphasized cost reduction, and have achieved relatively good results in this area. Additional costs reduction probably will be needed. Major capital expenditures, such as steam generator repairs, have played a significant role in previous early retirements, but this may change with new techniques and increased industry experience.

[111]It is important to note that this Table includes plants that are scheduled to retire in the next 20 years only. It is assumed that plants with a remaining scheduled lifetime of 20 years or more, are not subject to early retirement at this time.

[112]These plants have electricity production costs $0.30 per KWh or higher, and the average costs of alternative plants with the utility or region are lower.

5. Comparison with Other Projections

This chapter contains a comparison of EIA projections and projections made by other organizations. The projections compared are nuclear capacity, uranium requirements, enrichment service requirements and spent fuel discharges. Nuclear capacity is given for 1995, 2000, 2005, and 2010, while the other projections are presented for 1995 through 2010. Appendix E contains annual projections of capacity and fuel cycle requirements through 2040 for the United States.

Recognizing the uncertainties associated with making long term projections, the EIA has developed two scenarios for projecting U.S. nuclear capacity and fuel cycle requirements, the No New Orders Case (Low Case) and the License Renewal Case (High Case). The No New Orders Case (Low Case) corresponds to a scenario where no new orders for nuclear units are placed, i.e., no new advanced light-water reactors will become operational before the year 2015. The retirement dates for currently operating reactors are determined by the expiration dates of their licenses as granted by the U.S. Nuclear Regulatory Commission. The License Renewal Case (High Case) is identical to the No New Orders Case (Low Case) with the exception that 55 of the 109 operable U.S. reactors will renew their licenses for additional 20-year terms. The reactors were selected by analyzing and ranking nuclear reactors according to their likelihood for life-extension. Factors affecting life-extension decisions include economics, reactor performance, public acceptance, environmental considerations, and utility planning. Both the No New Orders Case (Low Case) and the License Renewal Case (High Case) have only one reactor, Watts Bar 1, beginning operation during the projection period. Construction has been halted on the other three Tennessee Valley Authority units (Watts Bar 2, Bellefonte 1 and 2) and they are not, therefore, included in these projections.

For foreign countries, the two scenarios modeled are the Low Case and the High Case. The Low Case has current reactors operating for about 30 years with some new capacity being added based on reactors in the construction phase coming online. The High Case has a more optimistic schedule with reactors in construction being completed sooner than in the Low Case and for countries like Japan, France, and Germany, EIA projects growth beyond the capacity of the identified nuclear power plants. The World Integrated Nuclear Evaluation System (WINES) model was used to determine these capacity additions. See Appendix B for a discussion of WINES.

In this chapter, EIA's License Renewal Case (High Case) is compared with the High Case projections of the other organizations.

Comparison of Actual Versus EIA Forecasts

EIA's projections of cumulative spent fuel discharges and worldwide nuclear capacity made in 1994 are almost equal to the actual 1994 value (Table 26). The projection made in 1994 of U.S. nuclear electric generation is almost 5 percent less than the actual. Projections of electricity generation are heavily influenced by capacity factors and EIA's projection of the annual average U.S. capacity factor for 1994, 70.0 percent, was much lower than the actual value of 73.8 percent.[113] The projections of cumulative spent fuel discharges, worldwide nuclear capacity and U.S. nuclear electric generation made in earlier reports are less than 5 percent different from the actual values.

Comparison with Last Year's EIA Report

Domestic Projections

EIA's domestic capacity projections differ from last year's because three of the four TVA reactors that were being constructed have been removed from the current projection. Also, TVA's Watts Bar 1 is projected to be completed in 1996 whereas it was projected to come on line in 1995 in last year's report. For the Low and High Case, EIA is projecting nuclear capacity to increase

[113]Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(95/07) (Washington, DC, July 1995), p. 105.

Table 26. Comparison of Historical Data and EIA Forecasts

Year	Status	U.S. Cumulative Spent Fuel Discharges (Thousand Metric Tons Uranium)				
		Year Forecast was Made				
		1991	1992	1993	1994	Actual
1991	Projected Data	24.0	NA	NA	NA	23.6
1992	Projected Data	25.9	25.9	NA	NA	25.9
1993	Projected Data	27.9	28.1	28.3	NA	28.0
1994	Projected Data	29.7	30.0	29.9	29.9	29.8

Year	Status	Worldwide Nuclear Capacity (Net Gigawatts-Electric)			
		Year Forecast was Made			
		1992	1993	1994	Actual
1992	Projected Data	324-325	NA	NA	331
1993	Projected Data	326-327	326-327	NA	338
1994	Projected Data	327-329	327	340-342	341

Year	Status	U.S. Nuclear Electric Generation (Net Terawatthours)			
		Year Forecast was Made			
		1992	1993	1994	Actual
1992	Projected Data	610	NA	NA	619
1993	Projected Data	612	605	NA	610
1994	Projected Data	618	610	611	640

NA = Not applicable.

Sources: Energy Information Administration, *World Nuclear Fuel Cycle Requirements 1991*, DOE/EIA-0436(91) (Washington, DC, October 1991), p. 61; *World Nuclear Fuel Cycle Requirements 1992*, DOE/EIA-0436(92) (Washington, DC, December 1992), pp. 108, 110; *World Nuclear Fuel Cycle Requirements 1993*, DOE/EIA-0436(93) (Washington, DC, November 1993), pp. 141-143; *World Nuclear Outlook 1994*, DOE/EIA-0436(94) (Washington, DC, December 1994), pp. 106, 107; *Spent Nuclear Fuel Discharges from U.S. Reactors 1992*, SR/CNEAF/94-01 (Washington, DC, May 1994), p. 20.

from 99 net gigawatts (net GWe) in 1995 to 100 net GWe in 2000 and 2005 (Table 27). In the Low Case, the capacity drops to 91 net GWe in 2010 and in the High Case, to 95 net GWe. In last year's report, the projected nuclear capacity for 1995 was 100 net GWe for the Low Case increasing to 103 net GWe in 2000. The capacity continued to increase to 104 net GWe in 2005 before dropping to 91 net GWe in 2010. In last year's High Case, the capacity was projected to be 100 in 1995. It rose to 103 net GWe in 2000 and 104 net GWe in 2005. In 2010, the capacity fell to 95 net GWe. The High Case capacity projection in last year's report reflected a more optimistic view of the U.S. nuclear power option than the current High Case.

Conversely, EIA's projections of domestic capacity factors are higher this year than last year because of the anticipation of continual improvement in reactor performance as shown over the last few years. The average annual capacity factor for U.S. reactors for 1994 was 73.8 percent.[114] The EIA is projecting capacity factors around 74 percent through 2010 whereas last year the

[114]Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(95/07) (Washington, DC, July 1995), p. 105.

Table 27. Comparison of Projections for U.S. Nuclear Capacity at Year End, 1995, 2000, 2005, and 2010

Source	Capacity (Net GWe)[a]			
	1995	2000	2005	2010
Energy Information Administration				
World Nuclear Outlook 1995				
No New Orders (Low Case)	99	100	100	91
Fifty Percent License Renewal (High Case)	99	100	100	95
World Nuclear Outlook 1994				
Low Case	100	103	104	91
High Case	100	103	104	95
Energy Resources International	100	100	101	105
NUEXCO	97	95	94	88
NAC International	99	100	99	86

[a]Capacity values are based on net summer capability ratings. GWe = gigawatts-electric.

Sources: Energy Information Administration, International Nuclear Model, File INM95.WK3; Energy Information Administration, *World Nuclear Outlook 1994*, DOE/EIA-0436(94) (Washington, DC, December 1994); Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), p. 3-39; NUEXCO Report, 1994-1995 (Denver, CO), p. 9; and NAC International, *Nuclear Megawatt Generation Status Report* (Norcross, GA, February 1995), p. C-43.

projections were more conservative at 72 and 73 percent. This increase in capacity factors has a significant impact on uranium requirements, enrichment service requirements and spent fuel discharge projections. See chapter four for a more detailed description of domestic capacity factors.

Comparing the high cases for both EIA reports, the current U.S. uranium requirement projections for 1995 through 2010 is less than 1 percent lower at 707.2 million pounds U_3O_8 than last year's projection of 712.0 million pounds (Table 28). EIA is projecting higher burnups than last year based on the nuclear utilities burnup projections, and the lower uranium projection is due to higher burnup. The enrichment service requirement projection for 1995 through 2010 is less than 1 percent higher than last year's projection. For 1995 through 2010, EIA projects enrichment service requirements to be 158.4 million separative work units (SWU) and last year the projection was 158.0 million SWU. The projection for spent fuel discharges is 32.0 thousand metric tons of initial heavy metal (MTIHM) and last year the projection was 32.2 thousand MTIHM. Even though the nuclear capacity projections are lower this year, the increase in projected capacity factors is causing the enrichment service requirements and spent fuel discharges to remain at about the same level as they were last year.

Foreign Projections

EIA is projecting foreign nuclear capacity in 1995 to be 249 net GWE, increasing to 266 net GWe by 2000 and 274 net GWe in 2005 before reaching 291 in 2010 (Table 29). The 2010 projection is 9 percent below last year's projection of 316 net GWe because of lower capacity projections in Canada and Western Europe.

Total uranium requirements for the period 1995 through 2010 for foreign countries are projected to be 1840 million pounds U_3O_8 (Table 30), 2 percent more than last year's projection. Projected total enrichment service requirements for 1995 through 2010 for foreign countries are 386 million SWU, slightly more than last year's projection. Total spent fuel discharges from foreign reactors for 1995 through 2010 are projected to be 140 thousand MTIHM. Last year's projection was 3 percent lower at 135 thousand MTIHM. The differences in projected fuel cycle requirements are due to minor adjustments to foreign fuel diets and to updating reactor capacity factors. As in the case of U.S. reactors, projected capacity factors this year are generally higher than those projected last year. This accounts for the slightly higher projections of fuel cycle requirements.

Table 28. Comparison of Selected Forecasts of Fuel Cycle Requirements for the United States, 1995 Through 2010

Source	Projection Period 1995	1996-2000	2001-2005	2006-2010	Total 1995-2010
	Total Uranium Requirements (million pounds U_3O_8)				
Energy Information Administration					
1995 Report	47.1	222.2	228.7	209.2	707.2
1994 Report	49.3	225.4	232.0	205.3	712.0
Energy Resources International, Inc.	47.3	234.0	232.4	251.2	764.9
NUEXCO	42.0	204.3	195.0	186.2	627.5
NAC International	47.5	240.1	248.0	230.4	766.0
	Total Enrichment Service Requirements (million separative work units)				
Energy Information Administration					
1995 Report	10.2	49.2	49.8	49.2	158.4
1994 Report	8.9	50.7	49.4	49.0	158.0
Energy Resources International, Inc.	10.3	51.3	50.3	53.6	165.5
NUEXCO	9.4	46.4	44.9	43.0	143.7
NAC International	9.6	55.0	53.2	49.8	167.7
	Total Spent Fuel Discharges (thousand metric tons of initial heavy metal)				
Energy Information Administration					
1995 Report	2.4	10.2	9.7	9.7	32.0
1994 Report	2.3	9.9	9.7	10.3	32.2
Energy Resources International, Inc.	2.3	9.5	9.1	9.0	29.9
NAC International	2.1	10.4	10.5	10.9	33.9

Sources: Energy Information Administration, International Nuclear Model, File INM95.WK3; Energy Information Administration, *World Nuclear Outlook 1994*, DOE/EIA-0436(94) (Washington, DC, December 1994); Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), pp. 4-55, 6-66, and 8-37; NUEXCO Report, 1994-1995 (Denver, CO), pp. 3 and 21; and NAC International, *U_3O_8 Status Report*; *Enrichment Status Report*; and *Discharge Fuel/Reprocessing Status Report* (Norcross, GA, February 1995), pp. F-1; F-39; D-39.

Comparison with Other Reports

EIA's projections are compared with the projections of the following organizations:

- Energy Resources International, Inc. (ERI)
- NUEXCO
- NAC International (NAC).

Each organization makes assumptions about the expected completion of nuclear units in the construction pipeline, about expected capacity factors, nuclear fuel management plans and a number of other factors. The projections made by EIA are comparable to those made by the other organizations. The differences can be attributed to dissimilar assumptions.

EIA uses techniques similar to those used by the other organizations referenced in this report to project uranium requirements and enrichment service requirements. Uranium and enrichment service requirements are a function of five major, interrelated variables concerning the fuel management and operating characteristics of the reactor. In computing the uranium and enrichment service requirements, values for these five must be estimated. The variables are:

- Capacity factor—a measure of capacity utilization
- Uranium enrichment product assay—percent of U-235 in the enriched product
- Tails assay used—a measure of the amount of U-235 remaining in the waste stream
- Fuel burnup—the amount of energy generated from the fuel
- The length of the fuel cycle—the length of time the reactor operates before refueling.

In order to obtain these values, EIA performs statistical analyses of historical reactor operating data from the Form RW-859 and from data collected by the U.S. Nuclear Regulatory Commission.

Comparison to Energy Resources International

ERI assumes that after the year 2000, there will be a need for new baseload generation capacity in the United States which would require new nuclear plant orders.[115] This accounts for the nuclear capacity growth in the High Case. EIA's projection of additional capacity comes from operating reactors whose life has been extended by 20 years. Also, ERI's nuclear capacity differs from EIA's because ERI measures reactors connected to the grid where EIA considers reactors which have begun commercial operation. The tails assay in ERI's assumptions are set to 0.30 percent everywhere except in the United States where tails assay increases to 0.31 beginning in 1999. France, Belgium, the Netherlands, Spain and the United Kingdom have their tails assay increase gradually from 0.25 in 1995 to 0.29 in 2000. EIA's tails assay is held to a constant 0.30 in the United States and to 0.28 in other countries. ERI assumes that plutonium and uranium are recycled in some Western European countries and Japan, whereas EIA assumes no recycling.

ERI's domestic nuclear capacity for 1995 and 2000 is 100 net GWe and its projection of domestic nuclear capacity for 2005 is 101 net GWe and for 2010, 105 net GWe (Table 27). This is a reflection of the new baseload generation expected by ERI. EIA projects that only 1.2 net GWe come online between 1995 and 2010. Consequently, ERI's projection by 2010 is 10 percent greater than EIA's. For 2010, ERI's projection of foreign capacity, 382 net GWe, is 31 percent greater than EIA's (Table 29).

ERI is projecting domestic uranium requirements to be 765 million pounds U_3O_8 for 1995 through 2010, 8 percent more than EIA's projection (Table 28). Its projection of foreign uranium requirements for 1995 through 2010 is 1976 million pounds U_3O_8, 7 percent more than EIA's (Table 30). ERI projects that the domestic enrichment service requirements for 1995 through 2010 will be 165 million SWU. EIA's projection of 158 million SWU is about 4 percent lower. Looking at foreign enrichment service requirements, ERI's projection of 400 million SWU for 1995 through 2010 is

Table 29. Comparison of Projections of Foreign Nuclear Capacity at Year End, 1995, 2000, 2005, and 2010

Source	Capacity (Net GWe)			
	1995	2000	2005	2010
EIA—1995 Report	249	266	274	291
EIA—1994 Report	248	269	283	316
ERI	245	277	327	382
NUEXCO	242	263	283	290
NAC International	249	273	312	306

GWe = Gigawatts-electric.
Sources: Energy Information Administration, International Nuclear Model, File INM95.WK3; Energy Information Administration, *World Nuclear Outlook 1994*, DOE/EIA-0436(94) (Washington, DC, December 1994); Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), p. 3-39; NUEXCO Report, 1994-1995, (Denver, CO), p. 9; and NAC International, *Nuclear Megawatt Generation Status Report* (Norcross, GA, February 1995), p. C-1.

[115]Energy Resources International, Inc., *1995 Nuclear Fuels Cycle Supply and Price Report,* (Washington, DC, May 1995), p. 3-12.

Table 30. Comparison of Selected Forecasts of Fuel Cycle Requirements for Foreign Countries, 1995 Through 2010

Source	Projection Period: 1995	1996-2000	2001-2005	2006-2010	Total 1995-2010
	Total Uranium Requirements (million pounds U_3O_8)				
EIA 1995 Report	110.7	552.8	579.2	597.5	1,840.2
EIA 1994 Report	105.2	535.0	562.0	596.6	1,798.8
ERI	110.3	540.5	612.5	712.6	1,975.9
NUEXCO	104.3	530.3	561.5	567.6	1,763.7
NAC International	96.1	503.9	649.7	675.9	1,925.6
	Total Enrichment Service Requirements (million separative work units)				
EIA 1995 Report	21.0	114.7	120.6	129.5	385.8
EIA 1994 Report	21.1	109.1	120.6	127.7	378.5
ERI	21.8	110.0	124.2	144.2	400.2
NUEXCO	20.1	104.5	111.6	113.4	349.6
NAC International	23.5	117.4	137.3	142.5	420.7
	Total Spent Fuel Discharges (thousand metric tons of initial heavy metal)				
EIA 1995 Report	9.3	43.4	44.2	43.0	139.9
EIA 1994 Report	8.3	41.6	42.1	43.0	135.0
NAC International	7.8	43.5	44.0	48.3	143.7

Sources: Energy Information Administration, International Nuclear Model, File INM95.WK3; Energy Information Administration, *World Nuclear Outlook 1994*, DOE/EIA-0436(94) (Washington, DC, December 1994); Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), pp. 4-55, 6-66; NUEXCO Report, 1994-1995, (Denver, CO), pp. 3, 21; and NAC International, *U_3O_8 Status Report; Enrichment Status Report*; and *Discharge Fuel/Reprocessing Status Report* (Norcross, GA, February 1995), pp. F-1, F-46; F-1, F-39; D-1, D-39.

4 percent more than EIA's. ERI is projecting domestic spent fuel discharges to be 30 thousand MTIHM for 1995 through 2010; this is 6 percent less than EIA's projection. There is no projection for foreign spent fuel discharges. ERI's projected fuel cycle requirements are generally higher than EIA's and correspondingly its capacity projections are also higher.

Comparison to NUEXCO

NUEXCO bases their projections on material collected from literature and from information from utilities.[116] They also use their own judgement in making assumptions when reliable data are not available. As does EIA, NUEXCO considers the following factors in their determination of nuclear fuel requirements: nuclear capacity, nuclear plant design characteristics, nuclear plant operating characteristics, fuel assembly characteristics and fuel cycle characteristics. NUEXCO assumes that capacity factors increase as a ramp function. EIA uses throughout the projection period, a capacity factor that is representative of the performance of the reactor.

NUEXCO projects the U.S. capacity in 1995 to be 97 net GWe (Table 27). The projection falls steadily until it reaches 88 net GWe in 2010. NUEXCO's domestic capacity projections are about 7 percent lower than EIA's for 2010. As for foreign nuclear capacity, NUEXCO shows a 1.2 percent annual growth rate from 1995 to 2010, 242 net GWe to 290 GWe (Table 29). The EIA's annual growth rate for this time period amounts to 1.0 percent. Capacity projections are somewhat

[116]*NUEXCO Report*, 1994-1995 (Denver, CO).

subjective. The dissimilarities are attributable to different estimates of startup and retirement dates for some reactors.

NUEXCO projects that about 627 million pounds of U_3O_8 will be needed in the United States for 1995 through 2010 (Table 28). This is 11 percent lower than EIA's projection. NUEXCO also projects foreign uranium requirements for 1995 through 2010 to be about 1764 million pounds U_3O_8, 4 percent less than EIA's projection for that time period (Table 30). Likewise, NUEXCO's projections of domestic enrichment service requirements, 144 million SWU, is 9 percent less than EIA's projection of 158 million SWU. NUEXCO projects foreign enrichment service requirements to be 350 million SWU, 4 percent less than EIA's projection.

Comparison to NAC International

NAC's data base contains detailed information on utility operating and fuel management plans which enables individual utility requirements to be closely reproduced.[117] EIA's data base has some specific data but it utilizes generic fuel management plans of country groupings. NAC modifies the utilities' commercial operating date to take into account other known information that may indicate dates later than those officially formulated. Some of these factors are financial information, regulatory ranking, construction progress and load growth projections. EIA may have different reactor operating dates as EIA uses official commercial operating dates from the Nuclear Regulatory Commission and the International Atomic Energy Agency. This contributes to some of the differences in projected fuel cycle requirements.

NAC projects domestic nuclear capacity to be 99 net GWe in 1995 and 100 net GWe in 2000 (Table 27). The capacity is projected to drop to 99 net GWe in 2005 and to 86 net GWe in 2010. Although NAC's domestic nuclear capacity projections are lower than EIA's, NAC projects higher domestic uranium requirements, enrichment service requirements, and spent fuel discharges over the 1995 to 2010 period.

Uranium requirements of 766 million pounds are projected for domestic reactors for 1995 through 2010, 8 percent more than EIA's projection (Table 28). NAC projects that domestic enrichment service requirements will be 168 million SWU, 6 percent more than EIA. Its projection for domestic spent fuel discharges from 1995 through 2010 is 34 thousand MTIHM whereas EIA's projection is 32 thousand MTIHM. NAC's projection for 1995 through 2010 of foreign uranium requirements is 1926 million pounds U_3O_8 EIA's projection is 5 percent less (Table 30). NAC's projection of foreign enrichment service requirements is 9 percent greater than EIA's and its projection of foreign spent fuel discharges is 144 thousand MTIHM, 3 percent greater than EIA's projection.

Summary

The EIA and the three organizations mentioned above make different assumptions about variables such as capacity factors, date of operation, on-line capacity, and tails assay. They also use different methods for arriving at their projections. EIA's projection of nuclear capacity for 1995 through 2010 falls within the range of the others with ERI having the highest capacity projection for both the United States and foreign countries. NUEXCO's projection for 1995 through 2010 for nuclear capacity and all of the fuel cycle requirements are lower than EIA's. Whereas, the projections made by NAC are all higher than those made by EIA.

[117]NAC International, *U_3O_8 Status Report* (Norcross, GA, February 1995), Appendix 1, pp. 1-3.

Appendix A

Nuclear Power Technology and 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.[118] 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

[118]Atomic 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 between 3 and 5 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 or lost 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 nuclear 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.

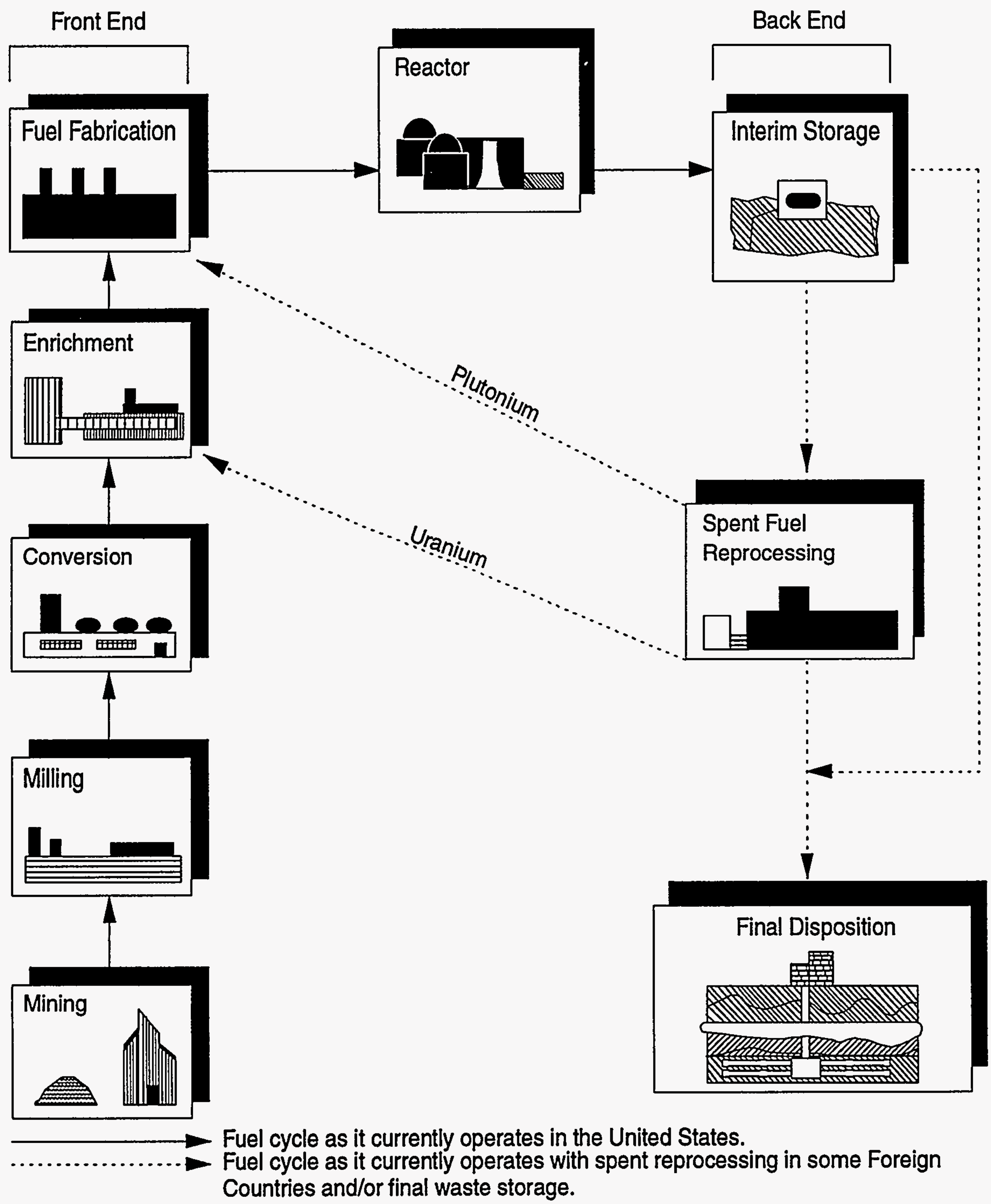
- **Mining.** Uranium-bearing ore is mined by methods similar to those used for other metal ores. The uranium content of ores in the United States typically ranges from 0.05 to 0.3 percent uranium oxide (U_3O_8). In foreign countries the uranium content of ores varies widely, from 0.035 percent in South 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.

- **Enrichment.** Natural uranium cannot be used as fuel in light-water reactors because its content of

Figure A1. The Nuclear Fuel Cycle



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 Europe. 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. Currently, plants in Europe are reprocessing spent fuel from utilities in Europe and Japan.

- **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

The Analysis Systems

Appendix B

The Analysis Systems

Economic and Energy Parameter Input Assumptions for Projecting Nuclear Capacity

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

Tables B1 through B3 present economic and energy parameter inputs to the model for countries that are projected to have nuclear power plants by 2015. Within the model framework, economic (gross national product or 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 WINES model was not used to forecast U.S. nuclear capacity.

For the countries listed in Table B1, labor-age population growth rates are derived from the World Bank population projections. The labor force participation fraction rate range from 0 percent to as high as 2.5 percent. Labor productivity is assumed to grow at a rate from 1 percent to as high as 4 percent per year (Table B1).

The function describing growth in demand for delivered 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 an average annual rate of 1.5 percent in the Far East (Table B2).

Table B1. WINES Economic Parameter Values Assumptions for the High Case
(Percent)

Country	Labor Force Participation Annual Growth Rate	Labor Productivity Annual Growth Rate
Canada[a]	1.0	2.0
Western Europe[b]		
Belgium	0.0	3.0
Finland	0.2	3.0
France	0.1	2.5
Germany	0.0	3.0
Spain	0.1	3.2
Sweden	0.2	2.0
Switzerland	0.1	2.0
United Kingdom	0.3	2.0
Eastern Europe		
Russia	1.0	1.5
Far East		
China	2.5	4.0
Taiwan	0.6	3.0
Other		
Argentina	0.4	1.0
Mexico	0.8	2.0

[a]Member country of the Organization for Economic Cooperation and Development (OECD).

[b]All countries listed for the Western Europe region are members of the OECD.

Note: WINES = World Integrated Nuclear Evaluation System. Values are indicated for those countries where WINES was used to develop the forecasts. In the High Case, WINES was used for all countries except Armenia, Brazil, Bulgaria, Cuba, Czech Republic, Hungary, India, Italy, Japan, Kazakhstan, Lithuania, Netherlands, North Korea, Philippines, Romania, Slovenia, Slovak Republic, South Africa, South Korea, Ukraine, and the United States.

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.

Table B2. WINES Energy Assumptions for the High Case
(Percent)

Country	Aggregate Delivered Energy Real Annual Price Growth Rate	Price Elasticity of Aggregate Delivered Energy Demand	Income Elasticity of Aggregate Delivered Energy Demand
Canada[a]	1.0	-0.3	0.6
Western Europe[b]			
Belgium	0.5	-0.3	0.6
Finland	0.5	-0.3	0.6
France	1.0	-0.3	0.6
Germany	1.0	-0.3	0.6
Spain	0.5	-0.3	0.6
Sweden	2.0	-0.3	0.6
Switzerland	0.5	-0.3	0.6
United Kingdom	0.5	-0.3	0.6
Eastern Europe			
Russia	1.5	-0.3	0.6
Far East			
China	1.5	-0.3	0.6
Taiwan	1.5	-0.3	0.6
Other			
Argentina	1.5	-0.3	0.6
Mexico	1.5	-0.3	0.6

[a]Member country of the Organization for Economic Cooperation and Development (OECD).

[b]All countries listed for the Western Europe region are members of the OECD.

Note: WINES = World Integrated Nuclear Evaluation System. Values are indicated for those countries where WINES was used to develop the forecasts. In the High Case, WINES was used for all countries except Armenia, Brazil, Bulgaria, Cuba, Czech Republic, Hungary, India, Italy, Japan, Kazakhstan, Lithuania, Netherlands, North Korea, Philippines, Romania, Slovenia, Slovak Republic, South Africa, South Korea, Ukraine, and the United States.

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.

Price elasticity of aggregate energy demand is assumed to be -0.3 (Table B2) for all countries. The elasticity value is 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 thando countries with relatively lower incomes. Income elasticity of aggregate energy demand for all countries is assumed to be 0.6 (Table B2). The elasticity is consistent with the income elasticity of 0.6 computed with data for the period 1970 to 1987.

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 High case is 2010. The asymptotic electrical share of delivered energy range from 10 to 35 percent (Table B3). The assumption is based on an analysis of the historical penetration of electricity in the individual countries and by fitting the best logistic curve to the historical data. The electrical halving factor range from 10 to 20 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.

The asymptotic nuclear share of electrical generation, derived in a manner similar to that used for the asymptotic electrical share range from 10 to 50 percent

Table B3. WINES Electrical and Nuclear Share Parameter Values Assumed for the High Case

Country	Asymptotic Electrical Share of Total Delivered Energy (percent)	Asymptotic Nuclear Share of Total Electricity (percent)	Halving Factor (years)	
	High Case	High Case	Electrical	Nuclear
Canada[a]	35	17	10	15
Western Europe[b]				
Belgium	20	55	10	20
Finland	27	35	15	20
France	30	85	10	15
Germany	20	27	10	20
Spain	30	33	10	15
Sweden	33	50	15	20
Switzerland	35	40	10	15
United Kingdom	22	20	10	15
Eastern Europe				
Russia	10	13	20	11
Far East				
China	20	10	20	30
Taiwan	25	50	15	15
Other				
Argentina	15	25	15	25
Mexico	15	15	15	25

[a]Member country of the Organization for Economic Cooperation and Development (OECD).
[b]All countries listed for the Western Europe region are members of the OECD.
Note: WINES = World Integrated Nuclear Evaluation System. Values are indicated for those countries where WINES was used to develop the forecasts. In the High Case, WINES was used for all countries except Armenia, Brazil, Bulgaria, Cuba, Czech Republic, Hungary, India, Italy, Kazakhstan, Lithuania, Netherlands, North Korea, Philippines, Romania, Slovenia, Slovak Republic, South Africa, Ukraine, and the United States.
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.

in the Far East (Table B3). Countries in Western Europe 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 20 to 35 percent for the countries in Western Europe, while the asymptotic nuclear shares of electrical generation range from 20 to 85 percent. For countries grouped under "other," the asymptotic electrical shares of delivered energy is assumed to be 15 percent, while the asymptotic nuclear share of electrical generation range from 15 to 25 percent. The 1994 average domestic nuclear share of utility-electrical generation was 17.9 percent. Because Far East countries are committed to nuclear power as a means of baseload power, waste disposal and licensing should not create as much a problem as in other countries. Therefore, the nuclear halving factor is assumed to be 15 years; execpt for China, with 30 years, where financing nuclear projects might require more time (Table B3).

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 1994 was approximately 33,000 megawattdays thermal per metric ton of initial heavy metal (MWDT/MTIHM).[119] The burnup values ranged from less than 20,000 to 47,000 MWDT/MTIHM. The majority of spent fuel discharges (82 percent) were between 27,000 and 38,000 MWDT/MTIHM. For pressurized-water reactors, the average equilibrium spent fuel discharge burnup in 1994 was about 41,000 MWDT/MTIHM. The values ranged from under 22,000 to 55,000 MWDT/MTIHM, with the majority of spent fuel discharges (83 percent) between 34,000 and 47,000 MWDT/MTIHM.

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 the following:

- 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:

$$FB = SD \quad , \tag{1}$$

and

$$E = a + bB\,(1 + F) \tag{2}$$

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),
E = 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, for example gadolinium, 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.

[119]Form RW-859, "Nuclear Fuel Data."

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 0.76 and 0.70 for pressurized-water reactors and boiling-water reactors (Table B4), 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 B5).

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

$$E = 1.411 + 0.0000386\, B\,(1 + F) \quad . \qquad (3)$$

For pressurized-water reactors:

$$E = 0.852 + 0.0000505\, B\,(1 + F) \quad . \qquad (4)$$

The projected discharge burnup data from Form RW-859, "Nuclear Fuel Data Survey," that was used in this analysis peaked at 55,000 megawattdays thermal per metric ton of initial heavy metal for boiling-water reactors and 64,000 megawattdays thermal per metric ton of initial heavy metal for pressurized-water reactors. Equations (3) and (4) are not applied to 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.[120] Equation (2) can be written in the following difference format:

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

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

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

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 (BWR) and pressurized-water reactors (PWR). 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

$$\Delta E = 0.000063\, \Delta[B\,(1 + F\,)] \qquad (7)$$

Table B4. 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	1.411	0.0000386	0.70
Pressurized-Water	Assay	0.852	0.0000505	0.76

Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, Analysis and Systems Division, working papers, March 1995.

[120]Conversation with Mr. Ray Schmidt, Engineer at General Electric Corp.

Table B5. Results of the Regression Coefficient Tests

Parameter	Reactor Type	
	Boiling Water Reactor	Pressurized-Water Reactor
Intercept		
Value from t Test	11.581	7.574
Significance Level	0.0001	0.0001
Burnup x (1 + Core Fraction)		
Value from t Test	14.913	26.344
Significance Level	0.0001	0.0001

Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, Analysis and Systems Division, working papers, March 1995.

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 International Nuclear Model, PC Version 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,

$$F = (S\ D)\ /\ B\ , \tag{8}$$

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 B6 and B7). 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 B6 and B7. Trends in burnup and number of effective full-power day plans were obtained from utility-supplied data and industry experts.

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 1994-2004 for BWR's and 1994-2002 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

Table B6. 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/MTIHM)[a]
Boiling-Water Reactors				
1993	450	0.288	3.20	36,000
1998	500	0.288	3.35	40,000
2006	511	0.274	3.50	43,000
2018	530	0.266	3.67	46,000
Pressurized-Water Reactor				
1993	450	0.397	3.81	42,000
1998	470	0.378	4.06	46,000
2004	500	0.370	4.38	50,000
2008	511	0.344	4.72	55,000
2018	511	0.315	5.03	60,000

[a]MWDT/MTIHM = Megawattdays thermal per metric ton initial heavy metal.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, Analysis and Systems Division, working papers, May 1995.

Table B7. 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/MTIHM)[a]
Europe				
Boiling-Water Reactors				
1995	300	0.206	3.09	36,000
1998	300	0.191	3.15	39,000
2004	300	0.173	3.35	43,000
2009	300	0.161	3.49	46,000
Pressurized-Water Reactor				
1994	300	0.275	3.56	42,000
1998	300	0.251	3.76	46,000
2002	300	0.231	4.01	50,000
2007	300	0.210	4.33	55,000
Far East				
Boiling-Water Reactors				
1995	365	0.241	3.34	36,000
2001	395	0.241	3.43	39,000
2006	420	0.232	3.67	43,000
2012	445	0.230	3.84	46,000
Pressurized-Water Reactor				
1997	365	0.338	3.69	39,000
2001	395	0.332	3.95	43,000
2009	420	0.310	3.38	49,000
2015	445	0.293	4.82	55,000

[a]MWDT/MTIHM = Megawattdays thermal per metric ton initial heavy metal.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, Analysis and Systems Division, working papers, May 1995.

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. Historically, Japanese utilities have been very conservative when ordering nuclear fuel and have typically loaded fuel with higher reactivity levels in their reactors than the fuel customarily loaded in the West to obtain comparable burnup levels. The evidence of this is reflected in the higher U-235 enrichment content of the discharged fuel.

The Models

International Nuclear Model PC Version

The estimates of the nuclear fuel cycle requirements in this report were produced with the International Nuclear Model PC Version (PCINM). This model was developed under contract for the Office of Coal, Nuclear, Electric and Alternate Fuels in the Energy Information Administration (EIA).[121] The PCINM is used to simulate nuclear fuel cycle operations.

The data for the PCINM 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, enriched uranium, spent fuel discharges, 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), enrichment tails assays, 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:

Length of cycle = (number of full-power days) / (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).

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 PCINM 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

[121] Z. Incorporated, *International Nuclear Model, Personal Computer (PCINM)* (Silver Spring, MD, 1992).

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.

EIA uses the spent fuel projections from PCINM as input into a disaggregate spent fuel forecasting program, DISAG. DISAG is used to calibrate the reactor-specific projections made by utilities, and collected on Form RW-859, to the aggregate PCINM spent fuel projections. The calibration methodology preserves the PCINM aggregate projections of spent fuel discharges and electricity generation by adjusting the utilities' reactor-specific projections of spent fuel and fuel burnup levals. The methodology also preserves the nature and shape of the burnup distributions projected by the utilities. For information on DISAG see "Disaggregate Spent Fuel Forecasting Model Documentation-DISAG", Washington Consulting Group, Inc., July 1992.

Uranium Market Model

Overview

The Uranium Market Model (UMM), which was used for most of the uranium projections in this report, is a microeconomic model in which uranium supplied by the mining and milling industry is used to meet the demand for uranium by electric utilities with nuclear power plants. Uranium is measured on a U_3O_8 concentrate equivalent basis. The input data encompass every major production center and utility on a worldwide basis. The model provides annual projections for each major uranium production and consumption region in the world. Sixteen regions were used in this study: (1) the United States, (2) Canada, (3) Australia, (4) South Africa, (5) Other Africa, (6) Western Europe, (7) Latin America, (8) the East, (9) Other, (10) Eastern Europe, (11) Russia, (12) Kazakhstan, (13) Uzbekistan, (14) Ukraine, (15) Kyrgyz Republic, and (16) Other Former Soviet Union. Production centers and utilities were identified as being in one of the 16 regions.

Uranium Demand

Uranium demand is assumed to equal near-term unfilled requirements on the part of utilities. Unfilled requirements are determined by subtracting current contract commitments at firm (non-spot) prices and inventory drawdown from total reactor requirements plus any assumed inventory buildup. Contract commitments calling for price to equal the future spot prices with no firm floor price are thus included in the calculation of uranium demand. In this way, demands may be placed on the market by uranium producers with such contracts when the spot price falls below the production costs of these producers.

The demand for uranium by electric utilities with nuclear power plants is a key parameter. Annual projections of reactor requirements are from EIA forecasts (see Chapter 3 for domestic forecasts). In the model, individual utility requirements were combined into regional totals. These projections are assumed to be inelastic with respect to uranium prices, separative work unit prices, and tails assays. Scenarios with varying demands can be determined by using alternative inputs for projected reactor requirements.

In addition to reactor requirements, most utilities also maintain a uranium inventory as a contingency against possible disruptions in supply. The desired degree of forward inventory coverage varies by countries, due to such factors as national policies, contracting approaches, and regulatory treatment of inventory costs. These variations are incorporated in the model. Inventory demand is a function of future reactor requirements and future uranium prices which change from year to year. This demand is elastic with respect to the spot price and, in line with market behavior, decreases as the price falls and increases as the price rises.

Contract commitments, between both producers and electric utilities and between utilities and enrichment suppliers, are taken into account exogenously. Commitments between producers and electric utilities are considered in two ways. The first is an estimate of the overcommitments by utilities to purchase uranium in excess of their annual reactor requirements. The second represents producer-utility contracts by specifying the commitments made by producers to deliver uranium from a specific production center to a particular utility. Contracts between utilities and enrichment suppliers can also lead to overcommitments in terms of the utility buying uranium for committed deliveries to enrichment plants that exceed the utility's reactor requirements.

Uranium Supply

Uranium supply is represented by an annual short-run supply curve consisting of increments of potential production and the supply of excess inventories which are assumed to be available at different market prices. Production centers are defined as mine-mill combinations, if there is conventional production, and as processing facilities for nonconventional production. Also included are producers in Western countries, Eastern Europe, the Former Soviet Union, and China that are potential net exporters. In general, production centers come on line, produce uranium, and deplete their reserves depending on a number of geologic, engineering, market, and political conditions. Producers that are able to produce and sell uranium most cheaply generally occupy the lower portions of the supply curve. Production costs are estimated exogenously, taking the following into account: the size of the reserves; annual production capacity; ore grade; type of production; capital, labor, and other costs; and taxes and royalty requirements. A fair market rate of return is also assumed. Government subsidies, variations in exchange rates, floor prices, supply disruptions, or other factors may affect the shape of the supply curve each year.

Some excess utility inventories are also treated as sources of potential supply that may be drawn down or sold in the secondary market. The size of these yearly drawdowns and sales depends on the utility's desired level of contingency stocks, spot-market prices, and the utility's general propensity to draw down its stocks or to sell uranium in the secondary market. Thus, each utility's inventory level varies annually depending on its projected reactor requirements, its contract commitments with producers and enrichment suppliers, the trend in market prices, its own inventory planning strategy, and the sales of excess inventories held by suppliers and governments.

Market-Clearing Conditions

Equilibrium is achieved in the forecasts when the supply of uranium meets the demand for uranium. Supply comes from production centers; utilities' inventories, which may already be at levels sufficient to satisfy inventory demand; excess inventories held by suppliers and governments; and utilities' excess inventories which are drawn down or sold in the secondary market.[122] Demand consists of utility reactor requirements, contingency inventory demand, and any additional market demand resulting from contract overcommitments with either producers or enrichment facilities.

The market projections in any given year are determined by activities in previous years, such as market prices and decisions to defer production of reserves; the demand levels for projection years are affected by reactor requirements in future years. Unanticipated changes in future demand may be introduced exogenously so that market activities in any forecast year may be constrained by actions taken in previous years.

Under free-market conditions with a single world market, utilities may draw down their inventories either for their own use or for sale in the secondary market; production is allocated to satisfy contract commitments; and remaining demand is met by producers with uncommitted reserves and by other suppliers with holdings of uranium. The intersection of this supply curve with the unfilled demand identifies the particular production and other supply increments that are sold in the market and defines the equilibrium spot-market price for that year. These sales, together with those from contract commitments, are tabulated to give projections of production in the United States and in other regions.[123] The equilibrium spot-market price and the 1-year lagged spot-market price are used to compute a projected spot-market price. Projected prices for new contracts are estimated as a function of the projected spot-market price. The net imports of a country are calculated from its utilities' reactor requirements, contingency inventory demand, contract commitments, inventory use, and its producers' sales.

[122]Loans of uranium among the various suppliers and users are not modeled as such. Borrowing and lending activities do not alter the total inventories of uranium, but they do delay the purchase of newly produced uranium. This effect can be modeled by assuming that the inventories of uranium that are not held by utilities or producers remain constant at their current level.

[123]In projecting production in the United States and other regions, the modeling system considers only those contract commitments that are tied to specific production centers at firm prices. For this reason, the model in some instances projects production at lower levels than contract commitments.

Appendix C

Nuclear Units Operable as of December 31 1994

Appendix C

World Nuclear Units Operable as of December 31, 1994

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
Argentina	Atucha 1	Lima, Buenos Aires	335	CN	PHWR	SIEM	03/74
	Embalse	Rio Tercero, Cordoba	600	CN	PHWR	AECL	04/83
	Total: 2 Units		**935**				
Belgium	Doel 1	Doel, East Flanders	392	EL	PWR	ACW	08/74
	Doel 2	Doel, East Flanders	392	EL	PWR	ACW	08/75
	Doel 3	Doel, East Flanders	970	EL	PWR	FRAM/ACW	06/82
	Doel 4	Doel, East Flanders	1,001	EL	PWR	ACW	04/85
	Tihange 1	Huy, Leige	863	EL	PWR	ACLF	03/75
	Tihange 2	Huy, Leige	894	EL	PWR	FRAM/ACW	10/82
	Tihange 3	Huy, Leige	1,015	EL	PWR	ACW	06/85
	Total: 7 Units		**5,527**				
Brazil	Angra 1	Itaorna, Rio de Janeiro	626	FN	PWR	WEST	04/82
	Total: . 1 Unit		**626**				
Bulgaria	Kozloduy 1	Kozloduy, Vratsa	408	EA	PWR	AEE	07/74
	Kozloduy 2	Kozloduy, Vratsa	408	EA	PWR	AEE	10/75
	Kozloduy 3	Kozloduy, Vratsa	408	EA	PWR	AEE	12/80
	Kozloduy 4	Kozloduy, Vratsa	408	EA	PWR	AEE	05/82
	Kozloduy 5	Kozloduy, Vratsa	953	EA	PWR	AEE	11/87
	Kozloduy 6	Kozloduy, Vratsa	953	EA	PWR	AEE	08/91
	Total: 6 Units		**3,538**				
CIS/ Kazakhstan	BN 350	Aktau, Mangyshlak	70	KZ	FBR	N/A	07/73
	Total: 1 Unit		**70**				
CIS/Russia	Balakovo 1	Balakovo, Saratov	950	RC	PWR	MTM	12/85
	Balakovo 2	Balakovo, Saratov	950	RC	PWR	MTM	10/87
	Balakovo 3	Balakovo, Saratov	950	RC	PWR	MTM	12/88
	Balakovo 4	Balakova, Saratov	950	RC	PWR	MTM	04/93
	Beloyarsky 3(BN-600)	Zarechnyy, Sverdlovsk	560	RC	FBR	MTM	04/80
	Bilibino A	Bilibino, Chukotka, Russia	11	RC	LGR	MTM	01/74
	Bilibino B	Bilibino, Chukotka, Russia	11	RC	LGR	MTM	12/74
	Bilibino C	Bilibino, Chukotka, Russia	11	RC	LGR	MTM	12/75
	Bilibino D	Bilibino, Chukotka, Russia	11	RC	LGR	MTM	12/76

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
CIS/Russia	Kalinin 1	Udomlya, Tver	950	RC	PWR	MTM	05/84
(continued)	Kalinin 2	Udomlya, Tver	950	RC	PWR	MTM	12/86
	Kola 1	Polyarnyye Zori, Murmansk	411	RC	PWR	MTM	06/73
	Kola 2	Polyarnyye Zori, Murmansk	411	RC	PWR	MTM	12/74
	Kola 3	Polyarnyye Zori, Murmansk	411	RC	PWR	MTM	03/81
	Kola 4	Polyarnyye Zori, Murmansk	411	RC	PWR	MTM	10/84
	Kursk 1	Kurchatov, Kursk	925	RC	LGR	MTM	12/76
	Kursk 2	Kurchatov, Kursk	925	RC	LGR	MTM	01/79
	Kursk 3	Kurchatov, Kursk	925	RC	LGR	MTM	10/83
	Kursk 4	Kurchatov, Kursk	925	RC	LGR	MTM	12/85
	Leningrad 1	Sosnovyy Bor, St. Petersburg	925	LN	LGR	MTM	12/73
	Leningrad 2	Sosnovyy Bor, St. Petersburg	925	LN	LGR	MTM	07/75
	Leningrad 3	Sosnovyy Bor, St. Petersburg	925	LN	LGR	MTM	12/79
	Leningrad 4	Sosnovyy Bor, St. Petersburg	925	LN	LGR	MTM	02/81
	Novovoronezh 3	Novovoronezhskiy, Voronezh	385	RC	PWR	MTM	12/71
	Novovoronezh 4	Novovoronezhskiy, Voronezh	385	RC	PWR	MTM	12/72
	Novovoronezh 5	Novovoronezhskiy, Voronezh	950	RC	PWR	MTM	05/80
	Smolensk 1	Desnogorsk, Smolensk	925	RC	LGR	MTM	12/82
	Smolensk 2	Desnogorsk, Smolensk	925	RC	LGR	MTM	05/85
	Smolensk 3	Desnogorsk, Smolensk	925	RC	LGR	MTM	01/90
	Total: 29 Units		**19,843**				
CIS/Ukraine	Chernobyl 1	Pripyat, Kiev	721	UK	LGR	MTM	09/77
	Chernobyl 2	Pripyat, Kiev	721	UK	LGR	MTM	12/78
	Chernobyl 3	Pripyat, Kiev	925	MA	LGR	MTM	11/81
	Khmelnitski-1	Neteshin, Khmelnitski	950	MA	PWR	MTM	12/87
	Rovno 1	Kuznetsovsk, Rovno	406	UK	PWR	MTM	12/80
	Rovno 2	Kuznetsovsk, Rovno	406	UK	PWR	MTM	12/81
	Rovno 3	Kuznetsovsk, Rovno	950	MA	PWR	MTM	12/86
	South Ukraine 1	Konstantinovka, Nikolae	950	MA	PWR	MTM	12/82
	South Ukraine 2	Konstantinovka, Nikolae	950	MA	PWR	MTM	01/85
	South Ukraine 3	Konstantinovka, Nikolae	950	MA	PWR	MTM	09/89
	Zaporozhe 1	Energodar, Zaporozhe	950	MA	PWR	MTM	12/84
	Zaporozhe 2	Energodar, Zaporozhe	950	MA	PWR	MTM	07/85
	Zaporozhe 3	Energodar, Zaporozhe	950	MA	PWR	MTM	12/86
	Zaporozhe 4	Energodar, Zaporozhe	950	MA	PWR	MTM	12/87
	Zaporozhe 5	Energodar, Zaporozhe	950	MA	PWR	MTM	08/89
	Total: 15 Units		**12,679**				

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
Canada	Bruce 1	Tiverton, Ontario	848	OH	PHWR	OH/AECL	01/77
	Bruce 2	Tiverton, Ontario	848	OH	PHWR	OH/AECL	09/76
	Bruce 3	Tiverton, Ontario	848	OH	PHWR	OH/AECL	12/77
	Bruce 4	Tiverton, Ontario	848	OH	PHWR	OH/AECL	12/78
	Bruce 5	Tiverton, Ontario	860	OH	PHWR	OH/AECL	12/84
	Bruce 6	Tiverton, Ontario	860	OH	PHWR	OH/AECL	06/84
	Bruce 7	Tiverton, Ontario	860	OH	PHWR	OH/AECL	02/86
	Bruce 8	Tiverton, Ontario	860	OH	PHWR	OH/AECL	03/87
	Darlington 1	Newcastle Township, Ontario	881	OH	PHWR	OH/AECL	12/90
	Darlington 2	Newcastle Township, Ontario	881	OH	PHWR	OH/AECL	01/90
	Darlington 3	Newcastle Township, Ontario	881	OH	PHWR	OH/AECL	12/92
	Darlington 4	Newcastle Township, Ontario	881	OH	PHWR	OH/AECL	04/93
	Gentilly 2	Becancour, Quebec	640	HQ	PHWR	AECL	12/82
	Pickering 1	Pickering, Ontario	515	OH	PHWR	OH/AECL	04/71
	Pickering 2	Pickering, Ontario	515	OH	PHWR	OH/AECL	10/71
	Pickering 3	Pickering, Ontario	515	OH	PHWR	OH/AECL	05/72
	Pickering 4	Pickering, Ontario	515	OH	PHWR	OH/AECL	05/73
	Pickering 5	Pickering, Ontario	516	OH	PHWR	OH/AECL	12/82
	Pickering 6	Pickering, Ontario	516	OH	PHWR	OH/AECL	11/83
	Pickering 7	Pickering, Ontario	516	OH	PHWR	OH/AECL	11/84
	Pickering 8	Pickering, Ontario	516	OH	PHWR	OH/AECL	01/86
	Point Lepreau	Bay of Fundy, New Brunswick	635	NB	PHWR	AECL	09/82
	Total: 22 Units		**15,755**				
China	Guangdong 1	Shenzhen, Guangdong	906	GV	PWR	FRAM	09/93
	Guangdong 2	Shenzhen, Guangdong	906	GV	PWR	FRAM	02/94
	Qinshan 1	Haiyan, Zhejiang	288	QN	PWR	CNNC	12/91
	Total: 3 Units		**2,100**				
Czech Republic	Dukovany 1	Trebic, Jihomoravsky	412	ED	PWR	SKODA	02/85
	Dukovany 2	Trebic, Jihomoravsky	412	ED	PWR	SKODA	01/86
	Dukovany 3	Trebic, Jihomoravsky	412	ED	PWR	SKODA	11/86
	Dukovany 4	Trebic, Jihomoravsky	412	ED	PWR	SKODA	06/87
	Total: 4 Units		**1,648**				
Finland	Loviisa 1	Loviisa, Uusimaa	445	IV	PWR	AEE	02/77
	Loviisa 2	Loviisa, Uusimaa	445	IV	PWR	AEE	11/80
	TVO 1	Olkiluoto, Turku Pori	710	TV	BWR	A-A	09/78
	TVO 2	Olkiluoto, Turku Pori	710	TV	BWR	A-A	02/80
	Total: 4 Units		**2,310**				
France	Belleville 1	Loire, Cher	1,310	EF	PWR	FRAM	10/87
	Belleville 2	Loire, Cher	1,310	EF	PWR	FRAM	07/88
	Blayais 1	Blaye, Gironde	910	EF	PWR	FRAM	06/81

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
France (continued)	Blayais 2	Blaye, Gironde	910	EF	PWR	FRAM	07/82
	Blayais 3	Blaye, Gironde	910	EF	PWR	FRAM	08/83
	Blayais 4	Blaye, Gironde	910	EF	PWR	FRAM	05/83
	Bugey 2	Loyettes, Ain	920	EF	PWR	FRAM	05/78
	Bugey 3	Loyettes, Ain	920	EF	PWR	FRAM	09/78
	Bugey 4	Loyettes, Ain	900	EF	PWR	FRAM	03/79
	Bugey 5	Loyettes, Ain	900	EF	PWR	FRAM	07/79
	Cattenom 1	Cattenom, Moselle	1,300	EF	PWR	FRAM	11/86
	Cattenom 2	Cattenom, Moselle	1,300	EF	PWR	FRAM	09/87
	Cattenom 3	Cattenom, Moselle	1,300	EF	PWR	FRAM	07/90
	Cattenom 4	Cattenom, Moselle	1,300	EF	PWR	FRAM	05/91
	Chinon B1	Chinon, Indre-et-Loire	905	EF	PWR	FRAM	11/82
	Chinon B2	Chinon, Indre-et-Loire	870	EF	PWR	FRAM	11/83
	Chinon B3	Chinon, Indre-et-Loire	905	EF	PWR	FRAM	10/86
	Chinon B4	Chinon, Indre-et-Loire	905	EF	PWR	FRAM	11/87
	Creys-Malville	Bouvesse, Isere	1,200	CR	FBR	NOVA	01/86
	Cruas 1	Cruas, Ardeche	915	EF	PWR	FRAM	04/83
	Cruas 2	Cruas, Ardeche	915	EF	PWR	FRAM	09/84
	Cruas 3	Cruas, Ardeche	880	EF	PWR	FRAM	05/84
	Cruas 4	Cruas, Ardeche	880	EF	PWR	FRAM	10/84
	Dampierre 1	Ouzouer, Loiret	890	EF	PWR	FRAM	03/80
	Dampierre 2	Ouzouer, Loiret	890	EF	PWR	FRAM	12/80
	Dampierre 3	Ouzouer, Loiret	890	EF	PWR	FRAM	01/81
	Dampierre 4	Ouzouer, Loiret	890	EF	PWR	FRAM	08/81
	Fessenheim 1	Fessenheim, Haut-Rhin	880	EF	PWR	FRAM	04/77
	Fessenheim 2	Fessenheim, Haut-Rhin	880	EF	PWR	FRAM	10/77
	Flamanville 1	Flamanville, Manche	1,330	EF	PWR	FRAM	12/85
	Flamanville 2	Flamanville, Manche	1,330	EF	PWR	FRAM	07/86
	Golfech 1	Valence, Tarn et Garonne	1,310	EF	PWR	FRAM	06/90
	Golfech 2	Valence, Tarn et Garonne	1,310	EF	PWR	FRAM	06/93
	Gravelines 1	Gravelines, Nord	910	EF	PWR	FRAM	03/80
	Gravelines 2	Gravelines, Nord	910	EF	PWR	FRAM	08/80
	Gravelines 3	Gravelines, Nord	910	EF	PWR	FRAM	12/80
	Gravelines 4	Gravelines, Nord	910	EF	PWR	FRAM	06/81
	Gravelines 5	Gravelines, Nord	910	EF	PWR	FRAM	08/84
	Gravelines 6	Gravelines, Nord	910	EF	PWR	FRAM	08/85
	Nogent 1	Nogent sur Seine, Aube	1,310	EF	PWR	FRAM	10/87
	Nogent 2	Nogent sur Seine, Aube	1,310	EF	PWR	FRAM	12/88

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
France (continued)	Paluel 1	Veulettes, Seine-Maritime	1,330	EF	PWR	FRAM	06/84
	Paluel 2	Veulettes, Seine-Maritime	1,330	EF	PWR	FRAM	09/84
	Paluel 3	Veulettes, Seine-Maritime	1,330	EF	PWR	FRAM	09/85
	Paluel 4	Veulettes, Seine-Maritime	1,330	EF	PWR	FRAM	04/86
	Penley 1	St.-Martin-en, Seine-Maritime	1,330	EF	PWR	FRAM	05/90
	Penley 2	St.-Martin-en, Seine-Maritime	1,330	EF	PWR	FRAM	02/92
	Phenix	Marcoule, Gard	233	CE/EF	FBR	CNIM	12/73
	Saint-Alban 1	Auberives, Isere	1,335	EF	PWR	FRAM	08/85
	Saint-Alban 2	Auberives, Isere	1,335	EF	PWR	FRAM	07/86
	Saint-Laurent B1	St-Laurent-des-Eaux, Loir-et-Cher	915	EF	PWR	FRAM	01/81
	Saint-Laurent B2	St-Laurent-des-Eaux, Loir-et-Cher	880	EF	PWR	FRAM	06/81
	Tricastin 1	Pierrelatte, Drome	915	EF	PWR	FRAM	05/80
	Tricastin 2	Pierrelatte, Drome	915	EF	PWR	FRAM	08/80
	Tricastin 3	Pierrelatte, Drome	915	EF	PWR	FRAM	02/81
	Tricastin 4	Pierrelatte, Drome	915	EF	PWR	FRAM	06/81
	Total: 56 Units		**58,493**				
Germany	Biblis A	Biblis, Hessen	1,146	RW	PWR	KWU	08/74
	Biblis B	Biblis, Hessen	1,240	RW	PWR	KWU	04/76
	Brokdorf (KBR)	Brokdorf, Schleswig-Holstein	1,326	BK	PWR	KWU	10/86
	Brunsbuettel (KKB)	Brunsbuettel, Schleswig-Holstein	771	KG	BWR	KWU	07/76
	Emsland (KKE)	Lingen, Niedersachsen	1,290	KN	PWR	SIEM/KWU	04/88
	Grafenrheinfeld (KKG)	Grafenrheinfeld, Bayem	1,275	BY	PWR	KWU	12/81
	Grohnde (KWG)	Emmerthal, Niedersachsen	1,325	GG	PWR	KWU	09/84
	Gundremmingen B	Gundremmingen, Bayem	1,240	KE	BWR	KWU	03/84
	Gundremmingen C	Gundremmingen, Bayem	1,248	KE	BWR	KWU	11/84
	Isar 1 (KKI)	Essenbach, Bayem	870	KI	BWR	KWU	12/77
	Isar 2 (KKI)	Essenbach, Bayem	1,330	KJ	PWR	SIEM/KWU	01/88
	Kruemmel (KKK)	Geesthacht, Schleswig-Holsten	1,260	KK	BWR	KWU	09/83
	Muelheim-Kaerlich	Rheinland, Pfalz	1,219	RW	PWR	BBR	03/86
	Neckarwestheim 1 (GKN)	Neckarwestheim, Baden-Wuerttemberg	785	GK	PWR	KWU	07/76
	Neckarwestheim 2 (GKN)	Neckarwestheim, Baden-Wuerttemberg	1,269	GK	PWR	SIEM/KWU	01/89
	Obrigheim (KWO)	Obrigheim, Baden-Wuerttemberg	340	KO	PWR	SIEM/KWU	10/68
	Philippiburg 1 (KKP)	Philippsburg, Baden-Wuerttenberg	864	KP	PWR	KWU	05/79

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
Germany (continued)	Philippsburg 2 (KKP)	Philippsburg, Baden-Wuerttenberg	1,324	KP	PWR	KWU	12/84
	Stade (KKS)	Stade, Niedersachsen	640	KS	PWR	SIEM/KWU	01/72
	Unterweser (KKU)	Rodenkirchen, Niedersachsen	1,255	KU	PWR	KWU	09/78
	Wuergassen (KWW)	Lauenforde, Niedersachsen	640	PR	BWR	AEG/KWU	12/71
	Total: 21 Units		**22,657**				
Hungary	Paks 1	Paks, Tolna	430	PK	PWR	AEE	12/82
	Paks 2	Paks, Tolna	433	PK	PWR	AEE	09/84
	Paks 3	Paks, Tolna	433	PK	PWR	AEE	09/86
	Paks 4	Paks, Tolna	433	PK	PWR	AEE	08/87
	Total: 4 Units		**1,729**				
India	Kakrapar 1	Kakrapar, Gujarat	202	NP	PHWR	DAE/NPCIL	11/92
	Kalpakkam 1	Kalpakkam, Tamil Nadu	155	NP	PHWR	DAE	07/83
	Kalpakkam 2	Kalpakkam, Tamil Nadu	155	NP	PHWR	DAE	09/85
	Narora 1	Narora, Uttar Pradesh	202	NP	PHWR	DAE/NPCI	07/89
	Narora 2	Narora, Uttar Pradesh	202	NP	PHWR	DAE/NPCI	01/92
	Rajasthan 1	Kota, Rajasthan	90	NP	PHWR	AECL	11/72
	Rajasthan 2	Kota, Rajasthan	187	NP	PHWR	AECL/DAE	11/80
	Tarapur 1	Tarapur, Maharashtra	150	NP	BWR	GE	04/69
	Tarapur 2	Tarapur, Maharashtra	150	NP	BWR	GE	05/69
	Total: 9 Units		**1,493**				
Japan	Fugen ATR	Tsuruga, Fukui	148	PF	HWLWR	HIT	07/78
	Fukushima-Daiichi 1	Ohkuma, Fukushima	439	TP	BWR	GE	11/70
	Fukushima-Daiichi 2	Ohkuma, Fukushima	760	TP	BWR	GE	12/73
	Fukushima-Daiichi 3	Ohkuma, Fukushima	760	TP	BWR	TOS	10/74
	Fukushima-Daiichi 4	Ohkuma, Fukushima	760	TP	BWR	HIT	02/78
	Fukushima-Daiichi 5	Ohkuma, Fukushima	760	TP	BWR	TOS	09/77
	Fukushima-Daiichi 6	Ohkuma, Fukushima	1,067	TP	BWR	GE	05/79
	Fukushima-Daini 1	Naraha, Fukushima	1,067	TP	BWR	TOS	07/81
	Fukushima-Daini 2	Naraha, Fukushima	1,067	TP	BWR	HIT	06/83
	Fukushima-Daini 3	Naraha, Fukushima	1,067	TP	BWR	TOS	12/84
	Fukushima-Daini 4	Naraha, Fukushima	1,067	TP	BWR	HIT	12/86
	Genkai 1	Genkai, Saga	529	KY	PWR	MHI	02/75
	Genkai 2	Genkai, Saga	529	KY	PWR	MHI	06/80
	Genkai 3	Genkai, Saga	1,127	KY	PWR	MHI	06/93
	Hamaoka 1	Hamaoka-cho, Shizuoka	515	CB	BWR	TOS	08/74
	Hamaoka 2	Hamaoka-cho, Shizuoka	806	CB	BWR	TOS	05/78
	Hamaoka 3	Hamaoka-cho, Shizuoka	1,056	CB	BWR	TOS	01/87
	Hamaoka 4	Hamaoka-cho, Shizuoka	1,092	CB	BWR	TOS	01/93

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
Japan (continued)	Ikata 1	Ikata-cho, Ehime	538	SH	PWR	MHI	02/77
	Ikata 2	Ikata-cho, Ehime	538	SH	PWR	MHI	08/81
	Ikata 3	Ikata-cho, Ehime	846	SH	PWR	MHI	06/94
	Kashiwazaki Kariwa 1	Kashiwazaki, Niigata	1,067	TP	BWR	TOS	02/85
	Kashiwazaki Kariwa 2	Kashiwazaki, Niigata	1,067	TP	BWR	TOS	02/90
	Kashiwazaki Kariwa 3	Kashiwazaki, Niigata	1,067	TP	BWR	TOS	12/92
	Kashiwazaki Kariwa 4	Kashiwazaki, Niigata	1,067	TP	BWR	HIT	12/93
	Kashiwazaki Kariwa 5	Kashiwazaki, Niigata	1,067	TP	BWR	HIT	09/89
	Mihama 1	Mihama-cho, Fukui	320	KA	PWR	WEST	08/70
	Mihama 2	Mihama-cho, Fukui	470	KA	PWR	WEST/MHI	04/72
	Mihama 3	Mihama-cho, Fukui	780	KA	PWR	MHI	02/76
	Ohi 1	Ohi-cho, Fukui	1,120	KA	PWR	WEST	12/77
	Ohi 2	Ohi-cho, Fukui	1,120	KA	PWR	WEST	10/78
	Ohi 3	Ohi-cho, Fukui	1,127	KA	PWR	MHI	06/91
	Ohi 4	Ohi-cho, Fukui	1,127	KA	PWR	MHI	06/92
	Onagawa 1	Onagawa, Miyagi	497	TC	BWR	TOS	11/83
	Sendai 1	Sendai, Kagoshima	846	KY	PWR	MHI	09/83
	Sendai 2	Sendai, Kagoshima	846	KY	PWR	MHI	04/85
	Shika 1	Shika-machi, Ishikawa	505	HU	BWR	HIT	01/93
	Shimane 1	Kashima-cho, Shimane	439	CK	BWR	HIT	12/73
	Shimane 2	Kashima-cho, Shimane	790	CK	BWR	HIT	07/88
	Takahama 1	Takahama-cho, Fukui	780	KA	PWR	WEST	03/74
	Takahama 2	Takahama-cho, Fukui	780	KA	PWR	MHI	01/75
	Takahama 3	Takahama-cho, Fukui	830	KA	PWR	MHI	05/84
	Takahama 4	Takahama-cho, Fukui	830	KA	PWR	MHI	11/84
	Tokai 1	Tokai Mura, Ibaraki	159	JP	GCR	GEC	11/65
	Tokai 2	Tokai Mura, Ibaraki	1,080	JP	BWR	GE	03/78
	Tomari 1	Tomari-mura, Hokkaido	550	HD	PWR	MHI	12/88
	Tomari 2	Tomari-mura, Hokkaido	550	HD	PWR	MHI	08/90
	Tsuruga 1	Tsuruga, Fukui	341	JP	BWR	GE	11/69
	Tsuruga 2	Tsuruga, Fukui	1,115	JP	PWR	MHI	06/86
	Total: 49 Units		**38,875**				
Korea, South	Kori 1	Kori, Kyongnam	556	KR	PWR	WEST	06/77
	Kori 2	Kori, Kyongnam	605	KR	PWR	WEST	04/83
	Kori 3	Kori, Kyongnam	895	KR	PWR	WEST	01/85
	Kori 4	Kori, Kyongnam	895	KR	PWR	WEST	11/85
	Ulchin 1	Ulchin, Kyongbuk	920	KR	PWR	FRAM	04/88
	Ulchin 2	Ulchin, Kyongbuk	920	KR	PWR	FRAM	04/89
	Wolsong 1	Kyongju, Kyongbuk	629	KR	PHWR	AECL	12/82
	Yonggwang 1	Yonggwang, Chonnam	900	KR	PWR	WEST	03/86
	Yonggwang 2	Yonggwang, Chonnam	900	KR	PWR	WEST	11/86
	Yonggwang 3	Yonggwang, Chonnam	950	KR	PWR	KHIC/KAE	10/94
	Total: 10 Units		**8,170**				

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
Lithuania	Ignalina 1	Snieckus, Lithuania	1,185	MA	LGR	MTM	12/83
	Ignalina 2	Snieckus, Lithuania	1,185	MA	LGR	MTM	08/87
	Total: 2 Units		**2,370**				
Mexico	Laguna Verde 1	Laguna Verde, Veracruz	654	FC	BWR	GE	04/89
	Laguna Verde 2	Laguna Verde, Veracruz	654	FC	BWR	GE	11/94
	Total: 2 Units		**1,308**				
Netherlands	Borssele	Borssele, Zeeland	449	PZ	PWR	KWU	07/73
	Dodewaard	Dodewaard, Gelderland	55	GN	BWR	GE	10/68
	Total: 2 Units		**504**				
Pakistan	Kanupp	Karachi, Sind	125	PA	PHWR	CGE	10/71
	Total: 1 Unit		**125**				
Slovak Republic	Bohunice 1	Trnava, Zapadoslovensky	408	EB	PWR	AEE	12/78
	Bohunice 2	Trnava, Zapadoslovensky	408	EB	PWR	AEE	03/80
	Bohunice 3	Trnava, Zapadoslovensky	408	EB	PWR	SKODA	08/84
	Bohunice 4	Trnava, Zapadoslovensky	408	EB	PWR	SKODA	08/85
	Total: 4 Units		**1,632**				
Slovenia	Krsko	Krsko, Vrbina	632	NR	PWR	WEST	10/81
	Total: 1 Unit		**632**				
South Africa	Koeberg 1	Melkbosstrand, Capetown	921	EK	PWR	FRAM	04/84
	Koeberg 2	Melkbosstrand, Capetown	921	EK	PWR	FRAM	07/85
	Total: 2 Units		**1,842**				
Spain	Almaraz 1	Almaraz, Caceres	900	CS	PWR	WEST	05/81
	Almaraz 2	Almaraz, Caceres	900	CS	PWR	WEST	10/83
	Asco 1	Asco, Tarragona	898	AN	PWR	WEST	08/83
	Asco 2	Asco, Tarragona	898	AN	PWR	WEST	10/85
	Cofrentes	Confretes, Valencia	955	IB	BWR	GE	10/84
	Jose Cabrera 1 (Zorita)	Zorita, Guadalajara	153	UE	PWR	WEST	07/68
	Santa Maria de Garona	Santa Maria de Garona, Burgos	440	NU	BWR	GE	03/71
	Trillo 1	Trillo, Guadalajara	1,000	UE/IB/HC	PWR	KWU	05/88
	Vandellos 2	Vandellos, Tarragona	961	AV	PWR	WEST	12/87
	Total: 9 Units		**7,105**				
Sweden	Barsebeck 1	Barsebaeck, Malmohus	600	SY	BWR	A-A	05/75

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
Sweden (continued)	Barsebeck 2	Barsebaeck, Malmohus	600	SY	BWR	A-A	03/77
	Forsmark 1	Forsmark, Uppsala	968	FK	BWR	A-A	06/80
	Forsmark 2	Forsmark, Uppsala	969	FK	BWR	A-A	01/81
	Forsmark 3	Forsmark, Uppsala	1,158	FK	BWR	A-A	03/85
	Oskarshamn 1	Oskarshamn, Kalmar	442	OK	BWR	A-A	08/71
	Oskarshamn 2	Oskarshamn, Kalmar	605	OK	BWR	A-A	10/74
	Oskarshamn 3	Oskarshamn, Kalmar	1,160	OK	BWR	A-A	03/85
	Ringhals 1	Varberg, Halland	795	VA	BWR	A-A	10/74
	Ringhals 2	Varberg, Halland	875	VA	PWR	WEST	08/74
	Ringhals 3	Varberg, Halland	915	VA	PWR	WEST	09/80
	Ringhals 4	Varberg, Halland	915	VA	PWR	WEST	06/82
	Total: 12 Units		**10,002**				
Switzerland	Beznau 1	Doettingen, Aargau	350	NK	PWR	WEST	07/69
	Beznau 2	Doettingen, Aargau	350	NK	PWR	WEST	10/71
	Goesgen	Daeniken, Solothurn	940	GP	PWR	KWU	02/79
	Leibstadt	Leibstadt, Aargau	990	LK	BWR	GETSCO	05/84
	Muehleberg	Muehleberg, Bern	355	BR	BWR	GETSCO	07/71
	Total: 5 Units		**2,985**				
Taiwan	Chinshan 1	Chinshan, Taipei	604	TW	BWR	GE	11/77
	Chinshan 2	Chinshan, Taipei	604	TW	BWR	GE	12/78
	Kuosheng 1	Kuosheng, Wang-Li, Taipei	951	TW	BWR	GE	05/81
	Kuosheng 2	Kuosheng, Wang-Li, Taipei	951	TW	BWR	GE	06/82
	Maanshan 1	Herng Chuen	890	TW	PWR	WEST	05/84
	Maanshan 2	Herng Chuen	890	TW	PWR	WEST	02/85
	Total: 6 Units		**4,890**				
United Kingdom	Bradwell 1	Bradwell, Essex	123	NE	GCR	TNPG	07/62
	Bradwell 2	Bradwell, Essex	123	NE	GCR	TNPG	07/62
	Calder Hall 1	Seascale, Cumbria	50	BF	GCR	UKAE	08/56
	Calder Hall 2	Seascale, Cumbria	50	BF	GCR	UKAE	02/57
	Calder Hall 3	Seascale, Cumbria	50	BF	GCR	UKAE	03/58
	Calder Hall 4	Seascale, Cumbria	50	BF	GCR	UKAE	04/59
	Chapelcross 1	Annan, Dumfriesshire	50	BF	GCR	UKAE	02/59
	Chapelcross 2	Annan, Dumfriesshire	50	BF	GCR	UKAE	07/59
	Chapelcross 3	Annan, Dumfriesshire	50	BF	GCR	UKAE	11/59
	Chapelcross 4	Annan, Dumfriesshire	50	BF	GCR	UKAE	01/60
	Dungeness A1	Lydd, Kent	220	NE	GCR	TNPG	09/65
	Dungeness A2	Lydd, Kent	220	NE	GCR	TNPG	11/65
	Dungeness B1	Lydd, Kent	555	NE	AGR	APC	04/83
	Dungeness B2	Lydd, Kent	555	NE	AGR	APC	12/85
	Hartlepool A1	Hartlepool, Cleveland	605	NE	AGR	NPC	08/83
	Hartlepool A2	Hartlepool, Cleveland	605	NE	AGR	NPC	10/84

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
United Kingdom (continued)	Heysham A1	Heysham, Lancashire	575	NE	AGR	NPC	07/83
	Heysham A2	Heysham, Lancashire	575	NE	AGR	NPC	10/84
	Heysham B1	Heysham, Lancashire	625	NE	AGR	NPC	07/88
	Heysham B2	Heysham, Lancashire	625	NE	AGR	NPC	11/88
	Hinkley Point A1	Hinkley Point, Somerset	235	NE	GCR	EBT	02/65
	Hinkley Point A2	Hinkley Point, Somerset	235	NE	GCR	EBT	03/65
	Hinkley Point B1	Hinkley Point, Somerset	610	NE	AGR	TNPG	10/76
	Hinkley Point B2	Hinkley Point, Somerset	610	NE	AGR	TNPG	02/76
	Hunterston B1	Ayrshire, Strathclyde	585	SC	AGR	TNPG	02/76
	Hunterston B2	Ayrshire, Strathclyde	585	SC	AGR	TNPG	03/77
	Oldbury 1	Oldbury, Avon	217	NE	GCR	TNPG	11/67
	Oldbury 2	Oldbury, Avon	217	NE	GCR	TNPG	04/68
	Sizewell A1	Sizewell, Suffolk	210	NE	GCR	EBT	01/66
	Sizewell A2	Sizewell, Suffolk	210	NE	GCR	EBT	04/66
	Torness 1	Dunbar, East Lothian	625	SC	AGR	NNC	05/88
	Torness 2	Dunbar, East Lothian	625	SC	AGR	NNC	02/89
	Wylfa 1	Anglesey, Wales	475	NE	GCR	EBT	01/71
	Wylfa 2	Anglesey, Wales	475	NE	GCR	EBT	07/71
	Total: 34 Units		**11,720**				
United States	3 Mile Island 1	Middletown, Pennsylvania	786	GU	PWR	B&W	06/74
	Arkansas Nuclear 1	Russellville, Arkansas	836	AK	PWR	B&W	05/74
	Arkansas Nuclear 2	Russellville, Arkansas	858	AK	PWR	C-E	12/78
	Beaver Valley 1	Shippingport, Pennsylvania	810	DL	PWR	WEST	07/76
	Beaver Valley 2	Shippingport, Pennsylvania	820	DL	PWR	WEST	08/87
	Big Rock Point	Charlevoix, Michigan	67	CC	BWR	GE	08/62
	Braidwood 1	Braidwood, Illinois	1,090	CM	PWR	WEST	07/87
	Braidwood 2	Braidwood, Illinois	1,090	CM	PWR	WEST	05/88
	Browns Ferry 1	Decatur, Alabama	1,065	TN	BWR	GE	12/73
	Browns Ferry 2	Dacatur, Alabama	1,065	TN	BWR	GE	08/74
	Browns Ferry 3	Decatur, Alabama	1,065	TN	BWR	GE	08/76
	Brunswick 1	Southport, North Carolina	767	CA	BWR	GE	11/76
	Bruncwick 2	Southport, North Carolina	754	CA	BWR	GE	12/74
	Byron 1	Byron, Illinois	1,120	CM	PWR	WEST	02/85
	Byron 2	Byron, Illinois	1,120	CM	PWR	WEST	01/87
	Callaway 1	Fulton, Missouri	1,115	UU	PWR	WEST	10/84
	Calvert Cliffs 1	Lusby, Maryland	835	BG	PWR	C-E	07/74
	Calvert Cliffs 2	Lusby, Maryland	840	BG	PWR	C-E	11/76
	Catawba 1	Clover, South Carolina	1,129	DP	PWR	WEST	01/85
	Catawba 2	Clover, South Carolina	1,129	DP	PWR	WEST	05/86
	Clinton 1	Clinton, Illinois	930	IP	BWR	GE	04/87
	Comanche Peak 1	Glen Rose, Texas	1,150	TX	PWR	WEST	04/90

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
United States (continued)	Comanche Peak 2	Glen Rose, Texas	1,150	TX	PWR	WEST	04/93
	Cooper 1	Brownville, Nebraska	778	ND	BWR	GE	01/74
	Crystal River 3	Red Level, Florida	812	FF	PWR	B&W	01/77
	Davis Besse 1	Oak Harbor, Ohio	868	TO	PWR	B&W	04/77
	Diablo Canyon 1	Avila Beach, California	1,073	PG	PWR	WEST	11/84
	Diablo Canyon 2	Avila Beach, California	1,087	PG	PWR	WEST	08/85
	Donald C. Cook 1	Bridgman, Michigan	1,000	IM	PWR	WEST	10/74
	Donald C. Cook 2	Bridgman, Michigan	1,060	IM	PWR	WEST	12/77
	Dresden 2	Morris, Illinois	772	CM	BWR	GE	12/69
	Dresden 3	Morris, Illinois	773	CM	BWR	GE	03/71
	Duane Arnold	Palo, Iowa	515	IE	BWR	GE	02/74
	Fermi 2	Newport, Michigan	1,085	DE	BWR	GE	07/85
	Fort Calhoun 1	Fort Calhoun, Nebraska	476	OP	PWR	C-E	08/73
	Grand Gulf 1	Port Gibson, Mississippi	1,143	SR	BWR	GE	11/84
	H.B. Robinson 2	Hartsville, South Carolina	683	CA	PWR	WEST	09/70
	Haddam Neck	Haddam Neck, Connecticut	560	CY	PWR	WEST	06/67
	Hatch 1	Baxley, Georgia	744	GA	BWR	GE	10/74
	Hatch 2	Baxley, Georgia	768	GA	BWR	GE	06/78
	Hope Creek 1	Salem, New Jersey	1,031	PS	BWR	GE	07/86
	Indian Point 2	Buchanan, New York	931	CO	PWR	WEST	09/73
	Indian Point 3	Buchanan, New York	980	PW	PWR	WEST	04/76
	James Fitzpatrick 1	Scriba, New York	800	PW	BWR	GE	10/74
	Joseph M. Farley 1	Dothan, Alabama	815	AP	PWR	WEST	06/77
	Joseph M. Farley 2	Dothan, Alabama	825	AP	PWR	WEST	03/81
	Kewaunee	Carlton, Wisconsin	526	WS	PWR	WEST	12/73
	LaSalle 1	Seneca, Illinois	1,048	CM	BWR	GE	08/82
	LaSalle 2	Seneca, Illinois	1,048	CM	BWR	GE	03/84
	Limerick 1	Pottstown, Pennsylvania	1,055	PE	BWR	GE	08/85
	Limerick 2	Pottstown, Pennsylvania	1,055	PE	BWR	GE	08/89
	Maine Yankee	Wicasset, Maine	870	MY	PWR	C-E	06/73
	McGuire 1	Cowens Ford, North Carolina	1,129	DP	PWR	WEST	07/81
	McGuire 2	Cowens Ford, North Carolina	1,129	DP	PWR	WEST	05/83
	Millstone 1	Waterford, Connecticut	641	NN	BWR	GE	10/70
	Millstone 2	Waterford, Connecticut	873	NN	PWR	C-E	09/75
	Millstone 3	Waterford, Connecticut	1,120	NN	PWR	WEST	01/86
	Monticello	Monticello, Minnesota	539	NS	BWR	GE	01/71
	Nine Mile Point 1	Oswego, New York	605	NM	BWR	GE	08/69
	Nine Mile Point 2	Oswego, New York	1,045	NM	BWR	GE	07/87
	North Anna 1	Mineral, Virginia	900	VE	PWR	WEST	04/78
	North Anna 2	Mineral, Virginia	887	VE	PWR	WEST	08/80
	Oconee 1	Seneca, South Carolina	846	DP	PWR	B&W	02/73

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
United States (continued)	Oconee 2	Seneca, South Carolina	846	DP	PWR	B&W	10/73
	Oconee 3	Seneca, South Carolina	846	DP	PWR	B&W	07/74
	Oyster Creek 1	Forked River, New Jersey	619	GU	BWR	GE	08/69
	Palisades	South Haven, Michigan	755	CC	PWR	C-E	10/72
	Palo Verde 1	Wintersburg, Arizona	1,270	AZ	PWR	C-E	06/85
	Palo Verde 2	Wintersburg, Arizona	1,270	AZ	PWR	C-E	04/86
	Palo Verde 3	Wintersburg, Arizona	1,270	AZ	PWR	C-E	11/87
	Peach Bottom 2	Lancaster, Pennsylvania	1,093	PL	BWR	GE	12/73
	Peach Bottom 3	Lancaster, Pennsylvania	1,035	PL	BWR	GE	07/74
	Perry 1	North Perry, Ohio	1,169	CI	BWR	GE	11/86
	Pilgrim 1	Pylmouth, Massachusetts	665	BE	BWR	GE	09/72
	Point Beach 1	Two Creeks, Wisconsin	492	WE	PWR	WEST	10/70
	Point Beach 2	Two Creeks, Wisconsin	481	WE	PWR	WEST	03/73
	Prairie Island 1	Red Wing, Minnesota	513	NS	PWR	WEST	04/74
	Prairie Island 2	Red Wing, Minnesota	512	NS	PWR	WEST	10/74
	Quad Cities 1	Cordova, Illinois	769	CM	BWR	GE	12/72
	Quad Cities 2	Cordova, Illinois	769	CM	BWR	GE	12/72
	River Bend 1	St. Francisville, Louisiana	931	GS	BWR	GE	11/85
	Robert E. Ginna	Rochester, New York	470	RG	PWR	WEST	09/69
	Salem 1	Salem, New Jersey	1,106	PS	PWR	WEST	12/76
	Salem 2	Salem, New Jersey	1,106	PS	PWR	WEST	05/81
	San Onofre 2	San Clemente, California	1,070	SL	PWR	C-E	09/82
	San Onofre 3	San Clemente, California	1,080	SL	PWR	C-E	09/83
	Seabrook 1	Seabrook, New Hampshire	1,150	NH	PWR	WEST	03/90
	Sequoyah 1	Daisy, Tennessee	1,111	TN	PWR	WEST	09/80
	Sequoyah 2	Daisy, Tennessee	1,106	TN	PWR	WEST	09/81
	Shearon Harris 1	New Hill, North Carolina	860	CA	PWR	WEST	01/87
	South Texas 1	Bay City, Texas	1,241	HL	PWR	WEST	03/88
	South Texas 2	Bay City, Texas	1,241	HL	PWR	WEST	03/89
	St Lucie 1	Ft. Pierce, Florida	839	FP	PWR	C-E	03/76
	St Lucie 2	Ft. Pierce, Florida	839	FP	PWR	C-E	06/83
	Summer 1	Jenkinsville, South Carolina	885	SE	PWR	WEST	11/82
	Surry 1	Surry, Virginia	781	VE	PWR	WEST	05/72
	Surry 2	Surry, Virginia	781	VE	PWR	WEST	01/73
	Susquehanna 1	Berwick, Pennsylvania	1,040	PV	BWR	GE	11/82
	Susquehanna 2	Berwick, Pennsylvania	1,094	PV	BWR	GE	06/84
	Turkey Point 3	Florida City, Florida	666	FP	PWR	WEST	07/72
	Turkey Point 4	Florida City, Florida	666	FP	PWR	WEST	04/73

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
United	Vermont Yankee 1	Vernon, Vermont	496	VY	BWR	GE	02/73
States	Vogtle 1	Waynesboro, Georgia	1,164	GA	PWR	WEST	03/87
(continued)	Vogtle 2	Waynesboro, Georgia	1,164	GA	PWR	WEST	03/89
	Waterford 3	Taft, Louisiana	1,075	LP	PWR	C-E	03/85
	WNP 2	Richland, Washington	1,086	WP	BWR	GE	04/84
	Wolf Creek	Burlington, Kansas	1,160	WC	PWR	WEST	06/85
	Zion 1	Zion, Illinois	1,040	CM	PWR	WEST	10/73
	Zion 2	Zion, Illinois	1,040	CM	PWR	WEST	11/73
	Total: 109 Units		**99,148**				
Total World	**432 Units**		**340,711**				

[a]EIA's review of the latest data sources may have resulted in revisions of names, capacities, and operation dates. For the United States, revisions are based on the Energy Information Administration (EIA) Form-860, "Annual Electric Generator Report."
[b]MWe = Megawatts-electric.
[c]See Table C2 for key to abbreviations of utility names.
[d]Reactor Types: AGR, advanced gas-cooled, graphite-moderated reactor; BWR, boiling light-water-cooled and moderated reactor; FBR, fast breeder reactor; GCR, gas-cooled, graphite-moderated reactor; HWLWR, heavy-water-moderated, boiling light-water-cooled reactor; LGR, light-water-cooled, graphite-moderated reactor; PHWR, pressurized heavy-water-moderated and cooled reactor; PWR, pressurized light-water-moderated and cooled reactor.
[e]See Table C3 for key to abbreviations of reactor supplier names.
[f]"Date of Operation" is the date foreign units were connected to the electrical grid. For U.S. units, "month operable" is the date the unit received its full-power operating license. Retired units are not included.
Note: Totals may not equal sum of components due to independent rounding.
Sources: International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1995). Energy Information Administration Form EIA-860, "Annual Electric Generator Report." Nuclear Regulatory Commission, *Information Digest, 1995 Edition* (NUREG-0350, March 1995) for units which started operating after 1978; Program Summary Report (NUREG-0380, May 1980) for units which started operating between 1960 through 1978.

Table C2. Key to Utility Codes for Rosters of Nuclear Generating and Construction Pipeline Units

Code	Name of Utility	Country
CN	Comision Nacional de Energia Atomica (CNEA)	Argentina
EL	Electrabel	Belgium
FN	Furnas Centrais Electricas SA	Brazil
EA	National Electricity Company, Branch NPP-Kozloduy	Bulgaria
GR	Government of Armenia	CIS/Armenia
KZ	Kazakh State Atomic Power Engineering and Industry Corporation	CIS/Kazakhstan
LN	Leningrad NPP	CIS/Russia
MA	Minatomenergoprom, Ministry of Nuclear Power and Industry	CIS/Russia
RC	Rosenergoatom, Consortium	CIS/Russia
UK	Ukratomenergoprom	CIS/Ukraine
HQ	Hydro Quebec	Canada
NB	New Brunswick Electric Power Commission	Canada
OH	Ontario Hydro	Canada
GV	Guangdong Nuclear Power Joint Venture Company, Ltd. (GNPJVC)	China
MI	Ministry of Nuclear Industry	China
QN	Qinshan Nuclear Power Company	China
CU	Ministerio de la Industria Basica	Cuba
CP	Czech Power Board	Czech Republic
ED	Electrostation Dukovany	Czech Republic
ET	Electrostation Temelin	Czech Republic
IV	Imatran Voima Oy	Finland
TV	Teollisuuden Voima Oy	Finland
CE	Commissariat A L'Energie Atomique	France
CR	Centrale Nucleaire Europeene A Neutrons Rapides, SA (NERSA)	France
EF	Electricite de France	France
BK	Kernkraftwerk Brokdorf GmbH	Germany
BY	Bayernwerk AG	Germany
GG	Gemeinschaftskernkraftwerk Grohnde GmbH	Germany
GK	Gemeinschafts-Kernkraftwerk Neckar GmbH	Germany
KE	Kernkraftwerke Gundremmingen Betriebsgesellschaft MBH	Germany
KG	Kernkraftwerk Brunsbuettel GmbH	Germany
KI	Kernkraftwerk Isar GmbH	Germany
KJ	Gemeinschaftskernkraftwerk Isar 2 GmbH	Germany
KK	Kernkraftwerk Kruemmel GmbH	Germany
KN	Kernkraftwerk Lippe-Emsland GmbH	Germany
KO	Kernkraftwerk Obrigheim GmbH	Germany
KP	Kernkraftwerk Philippsburg GmbH	Germany
KS	Kernkraftwerk Stade GmbH	Germany
KU	Kernkraftwerk Unterweser GmbH	Germany
PR	PreussenElektra AG	Germany
RW	Rheinisch-Westfaelisches Elektrizitaetswerk AG	Germany
PK	Paks Nuclear Power Plant Ltd	Hungary
NP	Nuclear Power Corporation of India, LTD	India
CB	Chubu Electric Power Company	Japan
CK	Chugoku Electric Power Company, Inc	Japan
HD	Hokkaido Electric Power Company	Japan
HU	Hokuriku Electric Power Company	Japan
JP	Japan Atomic Power Company	Japan
KA	Kansai Electric Power Company, Inc.	Japan
KY	Kyushu Electric Power Company	Japan
PF	Power Reactor and Nuclear Fuel Development Corporation	Japan

Table C2. Key to Utility Codes for Rosters of Nuclear Generating and Construction Pipeline Units (Continued)

Code	Name of Utility	Country
SH	Shikoku Electric Power Company	Japan
TC	Tohoku Electric Power Company	Japan
TP	Tokyo Electric Power Company	Japan
KR	Korea Electric Power Corporation	Korea, South
FC	Comision Federal de Electricidad	Mexico
GN	Gemeenschappelijke Kernenergiecentrale Nederland (GKN)	Netherlands
PZ	NV Electriciteits-Producktiemaatschappij Zuid-Nederland	Netherlands
PA	Pakistan Atomic Energy Commission	Pakistan
PP	National Power Corporation	Philippines
RE	Romanian Electricity Authority (RENEL)	Romania
EB	Electrostation Bohunice	Slovak Republic
EM	Electrostation Mochovce	Slovak Republic
NR	Nukleama Elektrana Krsko	Slovenia
EK	Eskom	South Africa
AN	Asociacion Nuclear de Asco	Spain
AV	Empresa Nacional de Electricidad, SA/Iberdrola, SA	Spain
CS	Compania Sevillana de Electricidad, SA/Iberdrola, SA/Union Electrica-Fenosa, SA	Spain
HC	Hidroelectrica del Cantabrico, SA	Spain
IB	Iberdrola, SA	Spain
NU	Nuclenor, SA	Spain
UE	Union Electrica Fenosa, SA	Spain
FK	Forsmark Kraftgrupp AB	Sweden
OK	OKG-Aktiebolag	Sweden
SY	Sydkraft AB	Sweden
VA	Vattenfall AB	Sweden
BR	Bernische Kraftwerke AG	Switzerland
GP	Kernkaftwerk Goesgen-Daeniken AG	Switzerland
LK	Kernkraftwerk Leibstadt	Switzerland
NK	Nordostschweizerische Kraftwerk AG	Switzerland
TW	Taiwan Power Company	Taiwan
BF	British Nuclear Fuels plc	United Kingdom
NE	Nuclear Electric plc	United Kingdom
SC	Scottish Nuclear Ltd.	United Kingdom
AK	Arkansas Power & Light Company	United States
AP	Alabama Power Company	United States
AZ	Arizona Public Service Company	United States
BE	Boston Edison Company	United States
BG	Baltimore Gas & Electric Company	United States
CA	Carolina Power & Light Company	United States
CC	Consumers Power Company	United States
CI	Cleveland Electric Illuminating Company	United States
CM	Commonwealth Edison Company	United States
CO	Consolidated Edison Company	United States
CY	Connecticut Yankee Atomic Power Company	United States
DE	Detroit Edison Company	United States
DL	Duquesne Light Company	United States
DP	Duke Power Company	United States
FF	Florida Power Corporation	United States
FP	Florida Power & Light Company	United States
GA	Georgia Power Company	United States

Table C2. Key to Utility Codes for Rosters of Nuclear Generating and Construction Pipeline Units (Continued)

Code	Name of Utility	Country
GS	Gulf States Utilities Company	United States
GU	GPU Nuclear Corporation	United States
HL	Houston Lighting & Power Company	United States
IE	Iowa Electric Light & Power Company	United States
IM	Indiana/Michigan Power Company	United States
IP	Illinois Power Company	United States
LP	Louisiana Power & Light Company	United States
MY	Maine Yankee Atomic Power Company	United States
ND	Nebraska Public Power District	United States
NH	Public Service Company of New Hampshire	United States
NM	Niagra Mohawk Power Corporation	United States
NN	Northeast Nuclear Energy Company	United States
NS	Northern States Power Company	United States
OP	Omaha Public Power District	United States
PE	Philadelphia Electric Company	United States
PG	Pacific Gas & Electric Company	United States
PL	Philadelphia Electric Company/ Public Service Electric & Gas Company	United States
PS	Public Service Electric & Gas Company	United States
PV	Pennsylvania Power & Light Company	United States
PW	Power Authority of the State of New York	United States
RG	Rochester Gas & Electric Corporation	United States
SE	South Carolina Electric & Gas Company	United States
SL	Southern California Edison Company	United States
SR	System Energy Resources, Inc.	United States
TN	Tennessee Valley Authority	United States
TO	Toledo Edison Company	United States
TX	Texas Utilities Electric Company	United States
UU	Union Electric Company	United States
VE	Virginia Electric & Power Company	United States
VY	Vermont Yankee Nuclear Power Corporation	United States
WC	Wolf Creek Nuclear Operating Corporation	United States
WE	Wisconsin Electric Power Company	United States
WP	Washington Public Power Supply System	United States
WS	Wisconsin Public Service Corporation	United States

Table C3. Key to Reactor Supplier Codes for Rosters of Nuclear Generating and Construction Pipeline Units

Code	Name of Supplier	Country
ACC	ACEC/Cockerill	Belgium
ACEC	Ateliers de Constructions Electriques de Charleroi SA	Belgium
ACW	ACECOWEN/(ACEC Cockerill/Westinghouse)	Belgium
AECL	Atomic Energy of Canada, Ltd.	Canada
CGE	Canadian General Electric	Canada
DAEC	Department of Atomic Energy, Canada Ltd	Canada
OH	Ontario Hydro	Canada
CNNC	China National Nuclear Corporation	China
SKODA	SKODA Concern Nuclear Power Plant Works	Czech Republic
ACLF	ACECOWEN/Creusot-Loire/FRAMATOME	France
CNIM	Constructions Navales et Industrielles de Mediterranee	France
FRAM	Framatome	France
NOVA	Novatome NIRA/Nuclear Italina Reattori Avanzati	France
AEG	Allegemeine Elektricitaets-Gesellschaft	Germany
BBR	Brown Boveri Reaktor GmbH	Germany
KWU	Siemens Kraftwerk Union AG	Germany
SIEM	Siemens AG	Germany
DAE	Department of Atomic Energy, India	India
NPCIL	Nuclear Power Corporation of India, Ltd.	India
HIT	Hitachi, Ltd.	Japan
MHI	Mitsubishi Heavy Industries, Ltd.	Japan
TOS	Toshiba Corporation	Japan
KAE	Korea Atomic Energy Research Institite	Korea, South
KHIC	Korea Heavy Industries and Construction Company	Korea, South
RDM	Rotterdamse Drookdok Madtdschappij	Netherlands
FECNE	Fabrica Echipamente Centrale Nuclearoelectrice Bucuresti	Romania
AEE	Atomenergoexport	Russia
MTM	MINTYAZHMASH	Russia
A-A	ASEA-Atom	Sweden
APC	Atomic Power Construction, Ltd.	United Kingdom
EBT	English Electric Co. Ltd./Babcock and Wilcox Co./Taylor Woodrow Construction Co.	United Kingdom
GEC	General Electric Company	United Kingdom
NNC	National Nuclear Corporation	United Kingdom
NPC	Nuclear Power Company, Ltd.	United Kingdom
PPP	PWR Power Projects	United Kingdom
TNPG	The Nuclear Power Group, Ltd.	United Kingdom
UKAE	United Kingdom Atomic Energy Authority	United Kingdom
B&W	Babcock and Wilcox	United States
C-E	Combustion Engineering, Inc.	United States
GE	General Electric Company	United States
GETSCO	General Electric Technical Services Company	United States
WEST	Westinghouse Corp.	United States
VAR	Various suppliers	Various countries

Appendix D

WORLD

Nuclear Generating Units in the Construction Pipeline as of December 31 1994

Appendix D

World Nuclear Generating Units In the Construction Pipeline as of December 31, 1994

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1994

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Type[d]	Reactor Supplier[e]	Percent Complete[f]	Expected Date of Operation		
								Published[g]	EIA[h]	
									Low	High
Argentina	Atucha 2	Lima, Buenos Aires	692	CN	PHWR	KWU	88	12/97	2002	2000
	Total: 1 Unit		**692**							
Brazil	Angra 2	Itaoma, Rio de Janeiro	1,245	FN	PWR	KWU	71	11/1999	2001	1999
	Angra 3	Itaoma, Rio de Janeiro	1,229	FN	PWR	WEST	42	09/2004	--	2010
	Total: 2 Units		**2,474**							
CIS/ Armenia	Medzamor 1	Metsamor, Armenia	370	GA	PWR	AEE	--		--	2000
	Medzamor 2	Metsamor, Armenia	370	GA	PWR	AEE	--	1995	1996	1995
	Total: 2 Units		**740**							
CIS/ Russia	Balakovo 5	Balakovo, Saratov	950	RC	PWR	MTM	--	--	1999	1997
	Balakovo 6	Balakovo, Saratov	950	RC	PWR	--	--	--	2015	2010
	Kalinin 3	Udomyla, Tver	950	RC	PWR	MTM	70	1995	1996	1995
	Kursk 5	Kurchatov, Kursk	925	RC	LGR	MTM	--	--	1996	1995
	Rostov 1	Volgodonsk, Rostov	950	RC	PWR	MTM	95	--	2000	1998
	Rostov 2	Volgodonsk, Rostov	950	RC	PWR	MTM	30	--	2008	2006
	South Urals 1	Chelyabinsk	750	RC	FBR	--	--	--	2009	2005
	South Urals 2	Chelyabinsk	750	RC	FBR	--	--	--	2015	2010
	Voronezh 1	Voronezh	500	RC	PWR		--	--	2011	2007
	Voronezh 2	Voronezh	500	RC	PWR			--	2013	2010
	Total: 10 Units		**8,175**							
CIS/ Ukraine	Khmelnitski 2	Neteshin, Khmelnitski	950	MA	PWR	MTM	90	1997	1998	1996
	Khmelnitski 3	Neteshin, Khmelnitski	950	MA	PWR	MTM	30	12/98	2000	1998
	Khmelnitski 4	Neteshin, Khmelnitski	950	MA	PWR	MTM	15	12/99	2002	1999
	Khmelnitski 5	Neteshin, Khmelnitski	950	MA	PWR	MTM	--	ID	--	2010

See notes at end of table.

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Type[d]	Reactor Supplier[e]	Percent Complete[f]	Expected Date of Operation: Published[g]	EIA[h] Low	EIA[h] High
CIS/	Rovno 4	Kuznetsovsk, Rovno	950	MA	PWR	MTM	75	1998	2008	2005
Ukraine (continued)	South Ukraine 4	Konstantinovka, Nikolae	950	MA	PWR	MTM	—	ID	2010	2008
	Zaporozhe 6	Energodar, Zaporozhe	950	MA	PWR	MTM	100	ID	1996	1995
	Total: 7 Units		**6,650**							
China	Guangdong 3	Shenzhen, Guangdong	985	GV	PWR	FRAM	--	2002	2008	2003
	Guangdong 4	Shenzhen, Guangdong	985	GV	PWR	FRAM	--	2002	2010	2004
	Qinshan 2	Haiyan, Zhejiang	600	MI	PWR	CNNC	--	12/2000	2002	2001
	Qinshan 3	Haiyan, Zhejiang	600	MI	PWR	CNNC	--	12/2001	2004	2002
	Total: 4 Units		**3,170**							
Cuba	Juragua 1	Cienfuegos	408	CU	PWR	AEE	--	ID	2007	2005
	Juragua 2	Cienfuegos	408	CU	PWR	AEE	--	ID	--	2012
	Total: 2 Units		**816**							
Czech Republic	Temelin 1	Temelin, Jihocesky	912	ET	PWR	SKODA	75	05/1997	1998	1997
	Temelin 2	Temelin, Jihocesky	912	ET	PWR	SKODA	55	11/1998	2001	1999
	Total: 2 Units		**1,824**							
France	Chooz B1	Chooz, Ardennes	1,455	EF	PWR	FRAM	95	02/1996	1996	1995
	Chooz B2	Chooz, Ardennes	1,455	EF	PWR	FRAM	80	07/1996	1996	1996
	Civaux 1	Civaux, Vienne	1,455	EF	PWR	FRAM	40	04/1997	1998	1997
	Civaux 2	Civaux, Vienne	1,450	EF	PWR	FRAM	30	11/1998	1999	1998
	Le Carnet 1	Le Carnet	1,455	EF	PWR	FRAM	0	2002	2015	2014
	Le Carnet 2	Le Carnet	1,455	EF	PWR	FRAM	0	2004	--	2015
	Penley 3	St. Martin-en, Seine-Maritime	1,455	EF	PWR	FRAM	0	2002	2013	2010
	Penley 4	St. Marint-en, Seine-Maritime	1,390	EF	PWR	FRAM	0		2014	2012
	Total: 8 Units		**11,570**							
India	Kaiga 1	Kaiga, Karnataka	202	NP	PHWR	NPCIL	69	12/1996	1998	1997
	Kaiga 2	Kaiga, Karnataka	202	NP	PHWR	NPCIL	40	06/1997	2000	1998
	Kaiga 3	Kaiga, Karnataka	220	NP	PHWR	--	0	1998	2007	2005
	Kakrapar 2	Kakrapar, Gujarat	202	NP	PHWR	DAEC/NPCIL	100	1995	1996	1995
	Rajasthan 3	Kata, Rajasthan	202	NP	PHWR	NPCIL	60	05/1997	2000	1998
	Rajasthan 4	Kata, Rajasthan	202	NP	PHWR	NPCIL	31	11/1997	2001	1999
	Tarapur 3	Tarapur, Maharashtra	470	NP	PHWR	--	0	08/2000	2006	2005

See notes at end of table.

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Type[d]	Reactor Supplier[e]	Percent Complete[f]	Expected Date of Operation: Published[g]	EIA[h] Low	EIA[h] High
India (continued)	Tarapur 4	Tarapur, Maharashtra	470	NP	PHWR	--	0	05/2001	2007	2005
	Total: 8 Units		**2,170**							
Japan	Ashihama 1	Ashihama	1,315	CB	ABWR	--	0	2003	2005	2003
	Ashihama 2	Ashihama	1,315	CB	ABWR	--	0	2004	2008	2005
	Ashihama 3	Ashihama	1,315	CB	ABWR	--	0		2015	2009
	Genkai 4	Genkai, Saga	1,127	KY	PWR	MHI	61	07/1997	1999	1998
	Hamaoka 5	Hamaoka-cho, Shizuoka	1,092	CB	ABWR	--	0	2008	--	2010
	Higashidori 1	Higashidori	1,067	TC	BWR	--	0	2004	2009	2007
	Higashidori 2	Higashidori	1,067	TC	BWR	--	0	2005	2011	2009
	Hohoku 1	Houhoko	1,067	CK	BWR	--	0	2010	2008	2012
	Hohoku 2	Houhoko	1,067	CK	BWR	--	0	2012	2009	2015
	Kashiwazaki Kariwa 6	Kashiwazaki, Niigata	1,315	TP	BWR	TOS/GE	75	12/1996	1998	1997
	Kashiwazaki Kariwa 7	Kashiwazaki, Niigata	1,315	TP	BWR	HIT/GE	54	07/1997	1999	1998
	Maki 1	Maki, Niigata	780	TC	BWR	--	0	10/2002	2005	2009
	Maki 2	Maki, Niigata	1,067	TC	BWR	--	0		--	2012
	Monju	Tsuruga, Fukui	246	PF	FBR	MHI	100	1995	1995	1995
	Onagawa 2	Onagawa, Miyagi	796	TC	BWR	TOS	98	07/1995	1995	1995
	Oura 1	Oura	1,296	KA	APWR	--	0	2010	--	2014
	Oura 2	Oura	1,296	KA	APWR	--	0	2010	--	2014
	Shika 2	Shika-machi, Ishikawa	796	HU	ABWR	--	0	2006	2010	2010
	Total: 18 Units		**19,339**							
Korea, North	Pyongan 1	Taechon, Korea	200	--	HWR	--	--		1998	--
	Total: 1 Unit		**200**							
Korea, South	Ulchin 3	Ulchin, Kyongbuk	960	KR	PWR	KHIC/KAE	37	06/1998	1999	1998
	Ulchin 4	Ulchin, Kyongbuk	960	KR	PWR	KHIC/KAE	37	06/1999	1999	1999
	Ulchin 5	Ulchin, Kyongbuk	950	KR	PWR	--	0		2007	2006
	Ulchin 6	Ulchin, Kyongbuk	950	KR	PWR	--	0	--	2009	2007
	Wolsong 2	Kyongju, Kyongbuk	650	KR	PHWR	AECL/ KHIC	50	06/1997	1998	1997
	Wolsong 3	Kyongju, Kyongbuk	650	KR	PHWR	AECL/ KHIC	17	06/1998	2000	1998
	Wolsong 4	Kyongju, Kyongbuk	650	KR	PHWR	AECL/ KHIC	17	06/1999	2000	1999

See notes at end of table.

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Type[d]	Reactor Supplier[e]	Percent Complete[f]	Expected Date of Operation: Published[g]	EIA[h] Low	EIA[h] High
Korea, South	Wolsong 5	Kyongju, Kyongbuk	650	KR	PHWR	--	0	--	2010	2008
(continued)	Yonggwang 4	Yonggwang, Chonnam	950	KR	PWR	KHIC/KAE	95	03/1996	1996	1995
	Yonggwang 5	Yonggwang, Chonnam	950	KR	PWR	--	0	--	2005	2004
	Yonggwang 6	Yonggwang, Chonnam	950	KR	PWR	--	0	--	2006	2005
	Total: 11 Units		**9,270**							
Pakistan	Chasnupp 1 (Chasma)	Mianwali, Punjub	300	PA	PWR	CNNC	24	03/1999	2002	1999
	Total: 1 Unit		**300**							
Philippines	BNPP 1	Morong, Bataan	620	PP	PWR	WEST	98	ID	--	2009
	Total: 1 Unit		**620**							
Romania	Cernavoda 1	Cernavoda, Constanta	635	RE	PHWR	AECL	89	04/1995	1996	1995
	Cernavoda 2	Cernavoda, Constanta	630	RE	PHWR	AECL	32	1998	2003	2000
	Cernavoda 3	Cernavoda, Constanta	630	RE	PHWR	FECNE	23	ID	2007	2005
	Cernavoda 4	Cernavoda, Constanta	630	RE	PHWR	FECNE	12	ID	2012	2010
	Cernavoda 5	Cernavoda, Constanta	630	RE	PHWR	FECNE	8	ID	--	2015
	Total: 5 Units		**3,155**							
Slovak Republic	Mochovce 1	Mochovce, Zapadoslovensky	388	EM	PWR	SKODA	85	12/1997	2000	1998
	Mochovce 2	Mochovce, Zapadoslovensky	388	EM	PWR	SKODA	65	06/1998	2001	1999
	Mochovce 3	Mochovce, Zapadoslovensky	388	EM	PWR	SKODA	45	1999	--	--
	Mochovce 4	Mochovce, Zapadoslovensky	388	EM	PWR	SKODA	20	--	--	--
	Total: 4 Units		**1,552**							
Taiwan	Yenliao 1	Yenliao, Taiwan	900	TW	PWR	--	0	2000	2003	2001
	Yenliao 2	Yenliao, Taiwan	900	TW	PWR	--	0	2001	2005	2003
	Total: 2 Units		**1,800**							

See notes at end of table.

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1994 (continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Type[d]	Reactor Supplier[e]	Percent Complete[f]	Expected Date of Operation		
									EIA[h]	
								Published[g]	Low	High
United Kingdom	Sizewell B	Sizewell, Suffolk	1,188	NE	PWR	PPP	100	02/1995	1995	1995
	Sizewell C	Sizewell, Suffolk	1,188	NE	PWR	PPP	0	--	--	2010
	Total: 2 Units		2,376							
United States	Bellefonte 1	Scottsboro, Alabama	1,212	TN	PWR	B&W	80	ID	--	--
	Bellefonte 2	Scottsboro, Alabama	1,212	TN	PWR	B&W	45	ID	--	--
	Perry 2	North Perry, Ohio	1,169	CI	BWR	GE	57	ID	--	--
	Watts Bar 1	Spring City, Tennessee	1,170	TN	PWR	WEST	99	1996	1996	1996
	Watts Bar 2	Spring City, Tennessee	1,170	TN	PWR	WEST	70	ID	--	--
	WNP 1	Richland, Washington	1,250	WP	PWR	B&W	65	ID	--	--
	WNP 3	Richland, Washington	1,250	WP	PWR	C-E	75	ID	--	--
	Total: 7 Units		8,433							
Total:	98 Units		85,326							

[a]The Energy Information Administration's review of the latest data sources may have resulted in revisions of names, capacities, and operation dates. For the United States, revisions are based on the Form-860 "Annual Electric Generator Report."
[b]MWe = Megawatts-electric.
[c]See Table C2 for key to abbreviations of utility names.
[d]Reactor Types: APWR, advanced pressurized light-water-moderated and cooled reactor; ABWR advanced boiling light-water-cooled and moderated reactor; BWR, boiling light-water-cooled and moderated reactor; FBR, fast breeder reactor; LGR, light-water-cooled, graphite-moderated reactor; PHWR, pressurized heavy-water-moderated and cooled reactor; PWR, pressurized light-water-moderated and cooled reactor.
[e]See Table C3 for key to abbreviations of reactor supplier names.
[f]Percent complete is an estimate of how close the nuclear unit is to completion. A dash (--) indicates that an approximation of the units' completion is unknown.
[g]Published date is the estimated date of commercial operation.
[h]EIA projections in the Low and High Cases refer to when a nuclear unit is estimated to become operable. A dash (--) indicates that the estimated year of operability is beyond the year 2015.
ID = Indefinitely deferred.
Note: Totals may not equal sum of components due to independent rounding.
Sources: International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1995); *Nuclear News*, "World List of Nuclear Power Plants" (March 1995), pp. 27-42. NAC International, "Nuclear Generation," (February 1995), Section E, pp. 1-40; Form EIA-860 "Annual Electric Generator Report."

Appendix E

Long-Term Projections of Capacity, Generation, and Spent Fuel in the United States, 1994 through 2040

Appendix E

Long-Term Projections of Capacity, Generation, and Spent Fuel in the United States, 1995 Through 2040

This appendix contains long-term projections of nuclear capacity, nuclear electricity generation, and spent fuel discharges in the United States through 2040. There are two scenarios, a Low and High Case. Basically, these projections are an extension of those shown for the United States through 2015 in the main body of the report. The assumptions are the same.

For the Low Case, there are no new orders for reactors in the United States, and the reactors currently in operation continue for the term of their operating licenses. One unit under construction is projected to start operation in 1996 (see Appendix D).

For the High Case, it is assumed that half the current nuclear units will renew their operating license for an additional 20 years. However, this additional capacity over the Low Case could result from a combination of less than half the nuclear units renewing their license, while some new advanced light-water reactors come on line in the out-years of the projection. The High Case scenario represents a reasonable surrogate for this and other possible outcomes, and no other additional scenarios are modeled.

Nuclear capacity in the United States is projected to be between 2 gigawatts electric (GWe) and 52 GWe by 2030 (Table E1 and Figure E1). By 2036, capacity is projected to 37 or less GWe. Both of these scenarios show a decline in nuclear power capacity through 2040, only the rate of decline is less for the High Case. In the past, the Energy Information Administration has modeled a growth scenario for nuclear capacity. A growth scenario was not modeled this year because of the high degree of uncertainty in the future of nuclear power in the United States. In order for an upsurge to occur, nuclear power must show that it is economically competitive with alternative electric power sources, the nuclear waste problem must be resolved, and public perception of nuclear power must improve.

Projections of annual nuclear electricity generation through 2030 are between 18 net terawatthours (TWh) and 349 net TWh (Table E2). The industry-wide annual capacity factor used to calculate electricity generation is 75 percent in 1995, increasing to about 76 percent through 2030. Improvements in capacity factors are due primarily from older, poor performing plants retiring from service. The newer plants (i.e., those coming on-line in the 1980's) have better performance records than older plants, on the average, and this difference in performance is assumed to continue over the years.

Projections of spent fuel permanently discharged from nuclear power units range between 84 and 89 thousand metric tons of uranium (MTU) by 2030 (Table E3 and Figure E2). As of the end of 1994, there were 29.8 thousand MTU of spent fuel discharges.

Table E1. Projections of U.S. Nuclear Capacity, 1995-2040
(Gigawatts Electric)

Year	Low Case	High Case
1995	99.1	99.1
1996	100.3	100.3
1997	100.3	100.3
1998	100.3	100.3
1999	100.3	100.3
2000	100.3	100.3
2001	100.3	100.3
2002	100.3	100.3
2003	100.3	100.3
2004	100.3	100.3
2005	100.3	100.3
2006	99.5	100.3
2007	98.2	98.9
2008	96.2	98.1
2009	94.5	96.4
2010	91.1	95.0
2011	90.3	95.0
2012	86.2	93.7
2013	73.7	85.3
2014	63.2	77.9
2015	61.4	76.0
2016	55.1	71.7
2017	52.4	71.7
2018	49.8	71.7
2019	49.8	71.7
2020	46.7	69.5
2021	43.7	68.4
2022	39.6	68.4
2023	35.5	67.3
2024	27.6	62.8
2025	22.0	58.4
2026	12.5	55.4
2027	6.9	53.3
2028	5.7	53.3
2029	3.5	52.5
2030	2.3	52.0
2031	2.3	50.7
2032	2.3	48.4
2033	1.2	43.3
2034	1.2	39.6
2035	1.2	39.6
2036	0.0	36.6
2037	0.0	33.8
2038	0.0	31.3
2039	0.0	31.3
2040	0.0	30.4

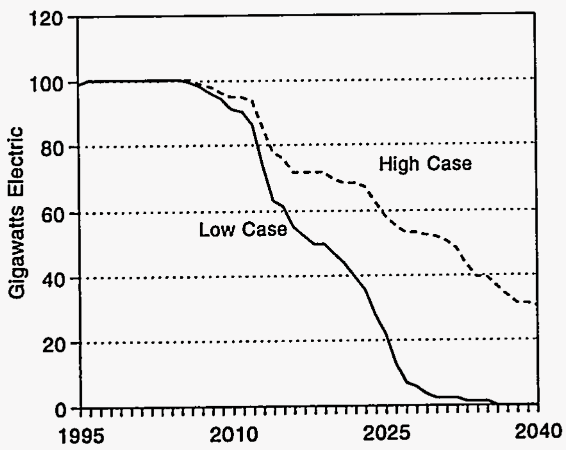
Note: Low Case = No new orders, High Case = 50 percent license renewal.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Table E2. Projections of U.S. Nuclear Electricity Generation, 1995-2040
(Net Terawatthours)

Year	Low Case	High Case
1995	651	651
1996	651	651
1997	651	651
1998	651	651
1999	651	651
2000	650	650
2001	650	650
2002	650	650
2003	650	650
2004	650	650
2005	650	650
2006	647	650
2007	644	647
2008	634	638
2009	618	630
2010	597	616
2011	586	616
2012	575	613
2013	527	592
2014	450	536
2015	406	504
2016	386	491
2017	357	474
2018	340	474
2019	329	474
2020	322	469
2021	302	460
2022	286	455
2023	246	451
2024	204	435
2025	161	401
2026	104	378
2027	63	365
2028	41	353
2029	29	349
2030	18	349
2031	15	339
2032	15	334
2033	8	299
2034	8	276
2035	8	263
2036	0	249
2037	0	237
2038	0	220
2039	0	209
2040	0	207

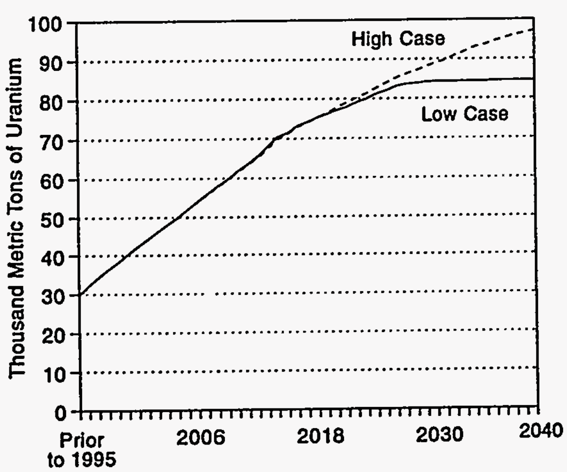
Note: Low Case = No new orders, High Case = 50 percent license renewal. Generation for 1995 and 1996 are slightly different from EIA's short-term energy outlook. The difference is due to different techniques for projecting capacity factors.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Figure E1. Projections of U.S. Nuclear Capacity, 1995-2040



Note: Low Case = No new orders, High Case = 50 percent license renewal.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Figure E2. Projections of Cumulative U.S. Spent Fuel Discharges, 1995-2040



Note: Low Case = No new orders, High Case = 50 percent license renewal.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Table E3. Projections of U.S. Cumulative Spent Fuel Discharges Through 2040
(Thousand Metric Tons of Uranium (U))

Year	Low Case	High Case
Prior 1995[a]	29.8	29.8
1995	32.2	32.2
1996	34.4	34.4
1997	36.4	36.4
1998	38.3	38.3
1999	40.4	40.4
2000	42.4	42.4
2001	44.3	44.3
2002	46.2	46.2
2003	48.1	48.1
2004	50.0	50.0
2005	52.1	52.1
2006	54.1	54.0
2007	56.1	56.0
2008	58.1	57.9
2009	59.9	59.8
2010	62.0	61.8
2011	63.7	63.5
2012	65.7	65.3
2013	68.1	67.5
2014	70.5	69.9
2015	71.4	71.1
2016	73.2	72.9
2017	74.2	74.0
2018	75.3	75.3
2019	76.2	76.5
2020	77.2	77.9
2021	78.0	79.0
2022	79.1	80.2
2023	80.0	81.3
2024	81.2	82.7
2025	82.0	84.0
2026	83.2	85.3
2027	83.7	86.3
2028	83.9	87.1
2029	84.2	88.1
2030	84.3	89.0
2031	84.3	89.8
2032	84.3	91.0
2033	84.4	92.0
2034	84.4	93.1
2035	84.4	93.7
2036	84.5	94.6
2037	84.5	95.3
2038	84.5	96.1
2039	84.5	96.6
2040	84.5	97.1

[a]Actual discharges.
Note: Low Case = No new orders, High Case = 50 percent license renewal.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Appendix F

Nuclear Fuel Cycle Facilities that Prepare Fuel for Nuclear Power Plants

Appendix F

World Nuclear Fuel Cycle Facilities That Prepare Fuel for Nuclear Power Plants

Table F1. 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	Converdyn	Metropolis, Illinois	14,000 MTU/year
Canada	CAMECO	[c]Port Hope, Ontario	10,500 MTU/year
	CAMECO	[d]Blind River, Ontario	18,000 MTU/year
People's Republic of China	CNNC	Lanzhou	[e]1,000 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	50 MTU/year
South Africa	AEC	Pelindaba	1,000 MTU/year
United Kingdom	British Nuclear Fuels, Ltd.	Springfields, Lancashire	6,000 MTU/year
Russia	Techsnabexport	Tomsk, Ekaterinburg, and Angarsk	14,000 MTU/year
India	DAE	Trombay	185 MTU/year
	DAE	Hazia	110 MTU/year
		Uranium Enrichment Facilities[i]	
Gaseous Diffusion Plants			
United States	U.S. Enrichment Corp.	Paducah, Kentucky	11,300 MTSWU/year
	U.S. Enrichment Corp.	Portsmouth, Ohio	7,900 MTSWU/year
France	EURODIF	Tricastin	10,800 MTSWU/year
People's Republic of China	CNNC	Lanzhou	500 MTSWU/year
Centrifuge Plants			
Germany, Netherlands, and United Kingdom	Urenco	Gronau, Almelo, and Capenhurst	3,375 MTSWU/year
Japan	PNC	Ningyo Toge	200 MTSWU/year
	Japan Nuclear Fuels, Ltd.	Rokkashomura	600 MTSWU/year
Russia	Minatom-TENEX	Ekaterinburg, Tomsk, Krasnoyarsk, and Angarsk	[j]14,000 MTSWU/year

See footnotes at end of table.

Table F1. World Nuclear Fuel Cycle Facilities That Prepare Fuel for Nuclear Power Plants (continued)

Country	Owner/Controller	Plant Name/Location	Capacity[a]
	Uranium Fuel Fabrication Facilities[k]		
United States	B&W Fuel Company	Lynchburg, Virginia	400 MTU/year
	ABB C-E	Hematite, Missouri	450 MTU/year
	Siemens Power Corp.	Richland, Washington	700 MTU/year
	Westinghouse	Columbia, South Carolina	1,150 MTU/year
	General Electric	Wilmington, North Carolina	1,200 MTU/year
Belgium	FBFC	Dessel	400 MTU/year
	Belgonucleaire SA	Dessel (MOX fuel)	35 MTIHM/year
Brazil	FEC	Resende	100 MTU/year
Russia	Elektrostal	Elektrostal	500 MTU/year
	Novosibirsk	Novosibirsk	1,000 MTU/year
France	FBFC	Romans-sur-Isere	750 MTU/year
	FBFC	Pierrelatte	500 MTU/year
	COGEMA	Cadarache (MOX Fuel)	15 MTIHM/year
Germany	Advanced Nuclear Fuels	Lingen	400 MTU/year
	Siemens-I	Hanau	600 MTU/year
	Siemens-II	Karlstein	170 MTU/year
India	Nuclear Fuel Complex	Hyderabad	25 MTU/year
Japan	Japan Nuclear Fuels, Ltd.	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
	PNC	Tokai-Mura (MOX fuel)	10 MTIHM/year
Korea	KNFC	Seoul, Taejeon	200 MTU/year
Spain	ENUSA	Juzbado	200 MTU/year
South Africa	AEC	Pelindaba	100 MTU/year
Sweden	ABB-Atom	Vasteras	400 MTU/year
United Kingdom	British Nuclear Fuels, Ltd.	Springfields, Lancashire	200 MTU/year
	British Nuclear Fuels, Ltd.	Sellafield (MOX fuel)	5 MTIHM/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.

[a]Status as of December 1994. MTU, metric tons of uranium; MTSWU, metric tons of separative work units; MTIHM, metric tons initial heavy metal.

[b]NAC International, *Nuclear Industry Status Report on UF_6, A Fuel-Trac Product* (Norcross, GA, February 1995), Table B-3.1.

[c]UO_3 to UF_6.

[d]U_3O_8 to UO_3.

[e]NAC's estimate based on domestic fuel-cycle industry.

[f]U_3O_8 to UF_4.

[g]UF_4 to UF_6.

[h]Conversion of reprocessed (irradiated) $UO_3(NO_3)_2$ to UF_6.

[i]NAC International, *Nuclear Industry Status Report on Enrichment, A Fuel-Trac Product* (Norcross, GA, February 1995), Table B-3.1. Enrichment capacity for South Africa not included due to plant closure scheduled for early 1995.

[j]Most likely available capacity, not confirmed by Minatom.

[k]NAC International, *Nuclear Industry Status Report on LWR Fabrication, A Fuel-Trac Product* (Norcross, GA, February 1995), Tables B-3.2 and B-3.3. Uranium oxide fuel fabrication unless otherwise noted.

Appendix G

Uncertainties in the U.S. Uranium Market

Appendix G

Uncertainties in the U.S. Uranium Market

Introduction

The uranium market has recently showed indications that oversupply, a dominant force for over a decade, could be significantly weakening, at least in the near term. These indications and the evolution of the uranium market are discussed in Chapter 3. Uncertainties over the availability of supply have been introduced into the U.S. market by recent developments regarding (1) restrictions on imports from the Former Soviet Union (FSU), (2) delays in implementing the HEU agreement between the United States and the Russian Federation, and (3) the default of a major uranium trading firm. The following section provides background on these developments and a discussion of their impact on the market.

Restrictions on Imports from the Former Soviet Union

The initial suspension agreements to the antidumping suit signed in October 1992 between the United States and the republics of the Former Soviet Union (FSU) prohibited imports of uranium from the republics until the U.S. Department of Commerce (DOC) determined that the price of U_3O_8 in the United States was at $13.00 per pound.[124] The initial agreements were reached in response to rulings by the DOC that uranium ores and concentrates, enriched uranium product, and uranium hexafluoride from the republics were being dumped in the United States at sale prices less than fair market.[125] Since the U.S. price did not rise to the DOC-determined level within a year after the suspension agreements were signed, the DOC and the republics engaged in consultations to amend the initial suspension agreements. Subsequent negotiations were carried out independently between the United States and the Republic of Kazakhstan ("Kazakh amendment"), the Russian Federation ("Russian amendment"), and Republic of Uzbekistan (unsigned as of July 1, 1995).[126] The goal of the amendments was to provide more realistic quotas that would allow the republics access to the U.S. market while minimizing adverse effects on the U.S. uranium industry. The amendment agreements signed by the governments of Kazakhstan and Russia, as described in the accompanying side bars, contain substantially different provisions. Legal challenges to the amendments,[127] different quota terms for each republic, and the DOC's interpretation of transactions involving the enrichment outside the United States of U_3O_8 from the republics have contributed to considerable uncertainty in the U.S. uranium market.

Initially, the market did not embrace the matched-sales concept of the Russian Amendment. The first contract was not completed until September 1994, nearly six months after the amendment was signed. Matched-sales have become more frequent, however, with the DOC granting approval to 14 contracts for a total of 4.8 million pounds U_3O_8 through December 31, 1994.[128] In addition, one matched enriched uranium sales contract was completed in 1994. Six U.S. producers were involved in these matched transactions.

[124]Some previously signed import contracts were exempted from the restrictions.

[125]A detailed historical perspective of the suspension agreements signed between the United States and the republics of the Former Soviet Union, as well as the preceding antidumping petition filed by the domestic uranium producers and the Oil, Chemical and Atomic Workers Union, is presented in Energy Information Administration, *World Nuclear Outlook 1994*, DOE/EIA-0436(94) (Washington, DC, December 1994), pp. 115-118.

[126]The initial suspension agreements to the antidumping suit were signed between the United States and six republics of the Former Soviet Union. Of these republics, only Kazakhstan, Russia, and Uzbekistan are currently in a position to actively export uranium to the United States.

[127]Legal challenges to the amendments are described in Energy Information Administration, *World Nuclear Outlook 1994*, DOE/EIA-0436(94) (Washington, DC, December 1994), pp. 115-118.

[128]R.L. MacDonald, "U.S. Policy Toward Uranium Trade with the C.I.S.," Paper presented at the *Fuel Cycle 95* (Coronado, CA, April 1995), pp. 2-3.

Amendment to the Suspension Agreement with the Russian Federation

- First of the amendment agreements; signed on March 11, 1994
- Agreement extended to March 31, 2004
- Matched-sales quota replaces price-determined quota
- Sales of Russian-origin natural (U_3O_8) or enriched uranium (SWU) are permitted as long as the quantities listed below are matched with newly produced U.S.-origin U_3O_8 or SWU - see schedule below
- Except for second year, sales involve equal qualities of Russian and U.S. products
- Contracts must be matched in duration (i.e., spot or long-term) and product type (i.e., U_3O_8 or enriched uranium)
- Enrichment bypass option (see text) not considered
- First matched sales contract completed in September 1994

Annual Russian-Origin Uranium Sales Authorized by the Amendment, 1994-2003

Year	Natural Uranium (Thousand pounds U_3O_8)	Enriched Uranium (Thousand SWU[a])
1994	6,614	2,000
1995	6,614	2,000
1996	1,930	N/A
1997	2,710	N/A
1998	3,600	N/A
1999	4,040	N/A
2000	4,230	N/A
2001	4,040	N/A
2002	4,890	N/A
2003	4,300	N/A

[a]SWU-separative work units.

Note: The quota volumes in 1994 and 1995 apply to sales. Deliveries pursuant to these contracts may be delivered in subsequent years.

Source: *Federal Register* "Amendment to the Agreement Suspending the Anti-dumping investigation on Uranium from the Russian Federation," Vol. 59, No. 63 (April 1, 1994), pp. 15373-15377.

Amendment to the Suspension Agreement with the Republic of Kazakhstan

- Signed on March 24, 1995; start date March 27, 1995
- Supersedes the agreement initialed in November 1994
- Slight modification of initial price-determined quota
- DOC price determination made twice annually
- DOC determination for April 1, 1995 was $12.06 per pound U_3O_8
- Imports of any uranium from Kazakhstan must be accompanied by an export license issues by the government of Kazakhstan
- Enrichment bypass not authorized; uranium from Kazakhstan that is enriched by a non-U.S. firm must be certified as Kazakh-origin, therefore, the amount of U_3O_8 feed is counted against the quota for Kazakhstan

Annual Kazakh-origin Uranium Sales Authorized by the Amendment, 1994-2003

Price Level (US$/lb U_3O_8	Natural Uranium (Thousand pounds U_3O_8)
12.00-13.99	1,000
14.00-14.99	1,200
15.00-15.99	1,400
16.00-16.99	1,800
17.00-17.99	2,500
18.00-18.99	3,500
19.00-19.99	4,000
20.00-20.99	5,000
21.00 and up	unlimited

Sources: *Federal Register*, "Agreement Suspending the Antidumping Investigation on Uranium from Kazakhstan," Vol. 60, No. 92 (May 12, 1995), pp. 25692-25693, and MacDonald, R.L., "U.S. Policy Toward Uranium Trade with the C.I.S.," paper presented at the *Fuel Cycle 95* conference, sponsored by the Nuclear Energy Institute (Coronado, California, April 2-5, 1995), pp. 3-5.

Meanwhile, certain transactions for enriched uranium product between U.S. utilities and foreign enrichers, whereby U_3O_8 from the republics of the FSU is used as feed, have come under scrutiny by the DOC. Under the initial suspension agreements, U_3O_8 originating from the republics was recognized as being substantially transformed by the enrichment process, thus the place of origin was the country where enrichment occurred. For example, Russian-origin U_3O_8 enriched in France would be considered a product of France. The DOC has more recently changed this interpretation, however, taking the position that these type of transactions, constitute circumvention of the quotas specified in the suspension agreements. Under this interpretation, uranium that is mined in the republics for sale to the United States will count against the quotas, whether being imported directly as natural uranium or indirectly as a feed component of product enriched in third countries. In the context of the DOC's circumvention interpretation, the latter type of transaction is referred to as "enrichment bypass option."

To address the bypass issue, the DOC invoked the consultation provision pursuant to article 10B of the agreements with the signatory governments in December 1994.[129] The Kazakh amendment is the only amendment agreement to date that specifically provides for all uranium mined in Kazakhstan to be considered of Kazakh origin, whether it is exported directly to the United States or enriched in a third country. Consultation between the United States and Russia and Uzbekistan have not yet produced an agreement on the bypass issue.

The grandfathering of bypass transactions is not granted in the Kazakh Amendment. Without an effective grandfathering clause, quantities of Kazakh-origin U_3O_8 already purchased by U.S. utilities for enrichment outside the United States would count against the quota. Utilities in this situation would have to pay a penalty on importing enriched material fed by Kazakh-origin uranium unless the government of Kazakhstan allocated a similar quantity from the quota. Furthermore, the outcome of the DOC's efforts to reach similar agreements on the bypass issue with the other republics is not certain. This could force utilities to enter into less favorable contracts for material that would meet DOC requirements.

Delays in Implementing the HEU Agreement

The HEU agreement signed between the United States and the Russian Federation in January 1994, provided for the purchase by the U.S. Enrichment Corporation (USEC) of 500 metric tons of highly enriched uranium (HEU) from the Russian Federation over 20 years.[130] The HEU, coming from the dismantling of Russian nuclear weapons, will be converted to low enriched uranium (LEU) containing 4.4 percent U_{235}, suitable for use as fuel in nuclear power plants.[131] Over the life of the agreement, the conversion of the Russian HEU is expected to yield about 15,259 metric tons of LEU, equivalent to about 398 million pounds U_3O_8 and 92 million SWU.[132] Based on the terms of the suspension agreement, the USEC is currently restricted through 2004 from selling the U_3O_8 feed component of this LEU in the United States.

The USEC was scheduled to purchase 10 metric tons of HEU annually in years one through five of the agreement. This amount is equivalent to 8 million pounds U_3O_8 and 1.9 million SWU per year.[133] The first LEU delivery under the agreement was expected in 1994, but that delivery was delayed, initially due to resolving the assurance that the HEU subject to the agreement is extracted from nuclear weapons (the so called "transparency issue").[134] A second HEU agreement was signed between the United States and Russia in March 1994 establishing a mutually acceptable framework for addressing transparency concerns.[135] Later, problems with meeting product specifications for the LEU, lack of sufficient capacity for blending in Russia, and payment issues contributed to further delays.

The Russians are reported to have met the required specifications by running the HEU through various processes at both the Tomsk and Ekaterinburg facilities.[136] This change in the conversion process, however, has resulted in increased costs and completion time. In June 1995, a protocol was signed by Vice President Gore and Russian Prime Minister Chernomyrdin that provided a pledge by the United States to pay the Russians simultaneously for the enriched and U_3O_8 components of the LEU obtained from the Russian HEU.[137] Combining these payments is a marked change from the original HEU agreement which stipulated that the USEC would pay the Russians only after the U_3O_8 feed was used either for overfeeding or sold in some other manner. With the resolution of these outstanding issues, the first shipment of LEU from Russian HEU that met specifications was delivered to the United States in June 1995.

The conversion of HEU is a vast potential supply considering that annual U.S. requirements for the next 20 years are projected not to exceed 50 million pounds of

[129]R.L. MacDonald, "U.S. Policy Toward Uranium Trade with the C.I.S.," paper presented at the *Fuel Cycle 95* conference (Coronado, CA, April 1995), pp. 3-4.

[130]A detailed historical perspective of the HEU agreement is presented in Energy Information Administration, *World Nuclear Outlook 1994*, (DOE/EIA-0436(94)) (Washington, DC, December 1994), pp. 118-120.

[131]The conversion process is expected to use a blendstock with a U_{235} content of 1.5 percent.

[132]Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), pp. 4-17, 4-18.

[133]Ibid.

[134]*NuclearFuel*, "Transparency Accord Removes a Bar to Transfer of Russian HEU to USEC" (March 28, 1994), pp. 6-8.

[135]*NuclearFuel*, "Transparency Accord Removes a Bar to Transfer of Russian HEU to USEC" (March 28, 1994), pp. 6-8.

[136]*Ux Weekly*, "HEU Illusion," (April 24, 1995), p. 1. Nuclear Fuel, "Transparency Accord Removes a Bar to Transfer of Russian HEU to USEC" (March 28, 1994), pp. 6-8.

[137]*Ux Weekly*, "Protocol signed on HEU," (July 3, 1995), p. 3.

U_3O_8 (projections of uranium requirements are presented in Chapter 3). The introduction of this supply could be expected to offset the effects of declining Western inventories and recent levels of World U_3O_8 production that have been well below demand. Delays in implementing the HEU agreement, however, have added uncertainty to assessing the potential impacts of supply from this source. This affects decisions by utilities regarding fuel procurement strategies, as well as U_3O_8 producers deciding whether to add additional capacity.

Default of Major Uranium Trading Firm

On February 23, 1995, Mr. Oren Benton and companies owned by him, Nuexco Trading Company (Nuexco), Concord Services Incorporated, Energy Fuels Limited, and Energy Fuels Exploration Company, filed a Chapter 11 petition under the U.S. Bankruptcy Code in U.S. Bankruptcy Court in Denver.[138] The petition listed debts of close to $500 million dollars owed to a list of creditors, including utilities around the world and suppliers in Russia and China. The bankruptcy was a culmination of unsuccessful attempts to reschedule payments and deliveries with creditors.

The concern that Nuexco might not be able to cover all of its loan commitments and other uranium transactions had been reported in industry business periodicals for over a year prior to the bankruptcy filing.[139] As a result, utilities became concerned about making transactions with intermediaries on the secondary market. This could explain the reduction of loans in 1994 to an amount that was about 20 percent of the average in each of the previous four years.[140] Since the bankruptcy filing, utilities have faced uncertainty over whether deliveries to uranium contracted with the defaulted companies would be completed. This uncertainty forced utilities to enter the spot market to procure alternative supplies for meeting their requirements. The Uranium Exchange Company estimated that 20 percent of purchases on the spot market during the second quarter of 1995 were made in response to the Nuexco default.[141]

[138]*NuclearFuel*, "Benton, Four of His Companies Ask Court for Chapter 11 Bankruptcy Code Protection," (February 27, 1995), pp. 1, 15.
[139]*Ux Report*, (December 20, 1993), p. 2.
[140]Energy Resources International, Inc., *1995 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1995), p. 4-39.
[141]*Ux Weekly*, "2nd Quarter Spot U_3O_8 Review," (July 3, 1995), p. 1.

Appendix H

U.S. Customary Units of Measurement, International System of Units (SI) and Selected Data Tables and the SI Metric Units

Appendix H

U.S. Customary Units of Measurement, International System of Units (SI), and Selected Data Tables in SI Metric Units

Standard factors for interconversion between U.S. customary units and the International System of Units (SI) are shown in the table below. These factors are provided as a coherent and consistent set of units for the convenience of the reader in making conversions between U.S. and metric units of measure for data published in this report. Conversion factors are provided only for the U.S. units of measurement quoted in this report. These forward cost category approximate equivalents are also needed for some conversions:

\$30 per pound U_3O_8 = \$80 per kilogram U.

\$50 per pound U_3O_8 = \$130 per kilogram U.

Conversion Factors for U.S. Customary Units and SI Metric Units of Measurement

To convert from:	To:	Multiply by:
feet	meters	0.304 801
short tons	metric tons	0.907 185
pounds U_3O_8	kilogram U	0.384 647
million pounds U_3O_8	thousand metric tons U	0.384 647

Table H1. Projected Cumulative Uranium Requirements for World Nuclear Power Plants, 1995-2015
(Thousand Metric Tons of Uranium (U))

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1995	18.1	18.1	1.5	1.5	8.0	9.3	21.4	21.8	9.1	8.9	1.2	1.1	59.3	60.7
1996	35.5	35.5	3.2	3.3	17.9	19.6	39.2	39.6	19.6	20.2	2.2	2.1	117.5	120.2
1997	52.4	52.4	4.8	4.9	27.2	29.5	60.6	60.4	30.7	31.6	3.0	3.7	178.1	182.5
1998	70.1	70.1	6.6	6.7	26.6	38.3	79.1	80.0	42.1	42.5	4.1	4.9	238.6	242.6
1999	86.0	86.0	8.2	8.4	45.5	46.8	97.0	98.1	53.3	54.4	5.8	6.4	295.8	300.1
2000	103.6	103.6	9.6	9.8	54.7	55.3	116.3	117.5	64.0	65.1	6.8	7.6	355.0	358.8
2001	122.0	122.0	11.3	11.4	64.6	64.6	134.9	136.5	74.8	79.1	8.3	8.9	416.0	422.5
2002	138.0	138.0	12.8	13.0	92.7	73.5	154.0	155.7	86.5	92.7	9.5	10.3	473.5	483.1
2003	155.7	155.7	14.6	14.7	81.2	85.5	173.1	174.8	99.0	105.5	10.6	12.5	534.2	548.7
2004	173.7	173.7	16.1	16.2	89.5	94.8	191.1	193.3	109.8	117.1	12.0	14.0	592.3	609.2
2005	191.5	191.5	17.6	17.7	98.0	104.0	208.2	210.5	121.3	130.1	13.7	15.7	650.2	669.5
2006	206.1	206.3	18.7	18.9	106.7	112.9	226.3	228.8	134.6	141.9	15.4	17.4	707.7	726.1
2007	222.4	222.6	20.3	20.4	115.1	121.8	244.6	247.4	149.3	158.7	17.0	19.1	768.7	790.1
2008	239.7	240.3	21.6	21.8	121.8	131.9	261.8	265.9	162.6	172.6	19.0	21.5	826.6	854.0
2009	254.0	255.8	22.9	23.1	129.3	142.7	279.2	283.5	174.2	184.5	20.6	23.5	880.1	913.0
2010	269.3	272.0	24.3	24.6	135.6	152.3	296.9	304.0	188.6	201.3	22.3	25.7	937.0	979.8
2011	281.4	285.8	25.3	25.8	142.5	162.9	314.0	322.7	202.2	245.8	23.8	27.8	989.2	1,040.7
2012	293.7	300.7	26.8	27.4	149.1	172.1	330.4	342.0	213.8	231.1	25.3	30.0	1,039.2	1,103.3
2013	303.2	312.1	28.3	29.1	155.4	183.1	346.8	362.7	228.4	246.9	27.3	33.1	1,089.4	1,166.9
2014	313.1	325.0	29.5	30.6	160.6	192.1	362.1	381.9	241.8	262.0	28.7	35.1	1,135.8	1,226.8
2015	322.6	337.0	30.8	32.2	165.3	201.2	377.5	397.8	255.1	277.1	30.2	37.7	1,181.5	1,283.1

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Table H2. Projected Annual Uranium Requirements for World Nuclear Power Plants, 1995-2015
(Thousand Metric Tons of Uranium (U))

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1995	18.1	18.1	1.5	1.5	8.0	9.3	21.4	21.8	9.1		1.2	1.1	59.3	60.7
1996	17.3	17.3	1.7	1.7	9.9	10.4	17.8	17.8	10.5	11.3	1.0	0.9	58.3	59.5
1997	17.0	17.0	1.6	1.6	9.4	9.8	20.8	20.8	11.1	11.4	0.8	1.6	60.6	62.3
1998	17.7	17.7	1.8	1.8	9.4	8.9	19.2	19.6	11.4	10.9	1.1	1.2	60.5	60.1
1999	15.9	15.9	1.6	1.6	8.8	8.4	17.9	18.1	11.2	12.0	1.7	1.4	57.1	57.5
2000	17.6	17.6	1.4	1.4	9.2	8.5	19.3	19.4	10.7	10.6	1.1	1.2	59.3	58.7
2001	18.5	18.5	1.7	1.7	9.9	9.3	18.6	18.9	10.8	14.0	1.5	1.3	60.9	63.7
2002	15.9	15.9	1.6	1.6	8.1	8.9	19.1	19.2	11.6	13.6	1.2	1.4	57.5	60.7
2003	17.7	17.7	1.7	1.7	8.5	12.0	19.0	19.2	12.5	12.8	1.1	2.2	60.7	65.6
2004	18.0	18.0	1.5	1.5	8.3	9.3	18.1	18.5	10.8	11.7	1.4	1.6	58.1	60.5
2005	17.8	17.8	1.5	1.5	8.5	9.2	17.1	17.2	11.4	13.0	1.7	1.7	58.0	60.3
2006	14.5	14.7	1.1	1.1	8.7	8.9	18.0	18.3	13.4	11.8	1.7	1.7	57.4	56.6
2007	16.3	16.3	1.6	1.6	8.4	9.0	18.3	18.6	14.7	16.8	1.6	1.7	61.0	64.0
2008	17.3	17.6	1.4	1.4	6.7	10.1	17.3	18.5	13.3	13.9	2.0	2.4	57.9	63.9
2009	14.3	15.5	1.3	1.3	7.5	10.8	17.3	17.6	11.6	11.9	1.5	2.0	53.5	59.0
2010	15.3	16.2	1.4	1.5	6.3	9.6	17.7	20.4	14.4	16.9	1.8	2.2	56.9	66.8
2011	12.1	13.8	1.0	1.2	6.9	10.6	17.1	18.7	13.6	14.5	1.5	2.1	52.2	60.8
2012	12.3	14.9	1.5	1.6	6.7	9.2	16.4	19.3	11.6	15.3	1.5	2.2	50.0	62.6
2013	9.5	11.4	1.5	1.8	6.3	11.0	16.4	20.7	14.6	15.8	2.0	3.1	50.2	63.7
2014	9.9	12.9	1.2	1.5	5.2	9.1	15.3	19.3	13.4	15.1	1.4	2.0	46.4	59.8
2015	9.5	12.0	1.3	1.6	4.7	9.1	15.3	15.9	13.4	15.1	1.5	2.6	45.7	56.3

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM95.WK3.

Table H3. Projected U.S. Spot-Market Prices for Uranium Under Current Market Conditions, 1995-2010
(Constant 1994 Dollars per Kilogram Uranium (U))

Year	Prices
1995	29.87
1996	31.51
1997	31.56
1998	31.27
1999	32.21
2000	32.99
2001	33.35
2002	33.82
2003	34.32
2004	35.28
2005	36.81
2006	38.68
2007	39.31
2008	41.39
2009	42.01
2010	43.05

Note: Adjusted by three-point smoothing.
Source: Energy Information Administration, Uranium Market Model run no. 1995_12.DAT, July 28, 1995.

Table H4. Projected U.S. Uranium Requirements, Net Imports, Commercial Inventories, and Production of Uranium, 1995-2010
(Thousand Metric Tons Uranium (U))

Year	Requirements[a]	Net Imports[a,b]	Commercial Inventories[a]	Production[a]
1995	17.5	12.9	29.6	1.7
1996	17.3	12.4	26.7	2.0
1997	16.8	12.3	24.4	2.2
1998	17.0	12.8	22.5	2.3
1999	17.3	13.4	21.1	2.3
2000	17.3	13.7	20.1	2.4
2001	17.4	13.8	19.3	2.6
2002	17.2	13.7	18.7	2.8
2003	17.8	14.4	18.2	3.0
2004	16.8	13.3	17.8	3.1
2005	16.2	12.4	17.4	3.4
2006	16.0	12.2	17.1	3.5
2007	16.0	12.4	16.8	3.3
2008	15.6	12.3	16.6	3.2
2009	13.9	11.0	16.4	2.7
2010	13.2	10.7	16.2	2.4

[a]Adjusted by three-point smoothing.
[b]Net imports (total imports less exports).
Source: **Requirements**—Energy Information Administration, International Nuclear Model, File INM95.WK3. **Net Imports, Inventories and Production**—Energy Information Administration, Uranium Market Model run no. 1995_12.DAT, July 28, 1995.

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): A reactor that 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.

Centrifuge Process: The enrichment process whereby the concentration of the uranium-235 (U-235) isotope contained in natural uranium is increased to a level suitable for use in nuclear power plants (generally 3 to 5 percent) by rapidly spinning cylinders containing the uranium in the form of gaseous uranium hexafluoride (UF_6). Due to differences in the masses of isotopes, the rapid spinning separates the U-235 isotope from U-238, the principal isotope contained in natural uranium.

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 is 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 use of a 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.

Forward Coverage: Amount of uranium required to assure uninterrupted operation of nuclear power plants.

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 (GCBR): A fast breeder reactor that is cooled by a gas (usually helium) under pressure.

Gaseous Diffusion Process: The enrichment process whereby the concentration of the uranium-235 (U-235) isotope contained in natural uranium is increased to a level suitable for use in nuclear power plants (generally 3 to 5 percent) by passing the uranium in the form of gaseous uranium hexafluoride (UF_6) through a series of porous membranes. In the process, the lighter U-235 isotope passes more easily through the membranes than does the heavier U-238, the principal isotope contained in natural uranium, resulting in progressively higher concentrations of U-235.

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, tieline 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.

Long-Term Contract Price: Delivery price determined when contract is signed; it can be either a fixed price or a base price escalated according to a given formula.

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.

Megawattday (MWd): Twenty-four MWh's or 24 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 approximately 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.

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.

Split Tails: Use of one tails assay for transaction of enrichment services and a different tails assay for operation of the enrichment plant. This mode of operations typically increases the use of uranium, which is relatively inexpensive, while decreasing the use of separative work, which is expensive.

Spot Market: The buying and selling of uranium for immediate or very near-term delivery, typically involving transactions for delivery of up to 500,000 pounds U_3O_8 within a year of contract execution.

Spot-Market Price: Price for material being bought and sold on the spot market.

Terawatthour (TWh): One trillion (10^{12}) watthours of electric energy.

Unfilled Requirements: Requirements not covered by usage of inventory or supply contracts in existence as of January 1 of the survey year.

Uranium (U): A heavy, naturally radioactive, metallic element of 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.

- **Concentrate:** A yellow or brown powder produced from naturally occurring uranium minerals as a result of milling uranium ores or processing of uranium-bearing solutions. Synonymous with "yellowcake," U_3O_8, or uranium oxide.

- **Natural Uranium:** Uranium with the U-235 isotope present at a concentration of 0.711 percent (by weight), that is, uranium with its isotopic content exactly as it is found in nature.

- **Uranium Hexafluoride (UF_6):** A white solid obtained by chemical treatment of U_3O_8, which forms a vapor at temperatures above 56 degrees centigrade. UF_6 is the form of uranium required for the enrichment process.

- **Uranium Oxide:** A compound (U_3O_8) of uranium. Also referred to as "yellowcake" or concentrate when in pure form.

- **Enriched Uranium:** Uranium enriched in the isotope U-235, from 0.711 percent (by weight) in natural uranium to an average of 3 to 5 percent U-235. Low-enriched uranium (LEU) contains up to 19 percent U-235, whereas highly enriched uranium (HEU) contains at least 20 percent U-235 and over 90 percent if used for nuclear weapons.

- **Fabricated Fuel:** Fuel assemblies composed of an array of fuel rods loaded with uranium dioxide pellets, manufactured after conversion of enriched uranium hexafluoride to uranium dioxide.

Uranium Resource Categories: Three classes of uranium resources reflecting different levels of confidence in the categories reported. These classes are reasonable assured resources (RAR), estimated additional resources (EAR), and speculative resources (SR). They are described below:

- **Uranium Reserves:** Estimated quantities of uranium in known mineral deposits of such size, grade, and configuration that the uranium could be recovered at or below a specified production cost with currently proven mining and processing technology and under current laws and regulations. Reserves are based on direct radiometric and chemical measurements of drill hole and other types of sampling of the deposits. Mineral grades and thickness, spatial relationships, depths below the surface, mining and reclamation methods, distances to milling facilities, and amenability of ores to processing are considered in the evaluation. The amount of uranium in ore that could be exploited within the forward cost levels are estimated according to conventional engineering practices, utilizing available engineering, geologic, and economic data.

- **Reasonably Assured Resources (RAR):** The 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. RAR correspond to DOE's Reserves category.

- **Estimated Additional Resources (EAR):** The uranium in addition to RAR that is expected to occur, mostly on the basis of direct geological evidence, in extensions of well-explored deposits, little explored deposits, and undiscovered deposits believed to exist along a well-defined geologic trend with known deposits, such that the uranium can subsequently be recovered within the given cost ranges. Estimates of tonnage and grade are based on available sampling data and on knowledge of the deposit characteristics as determined in the best known parts of the deposit or in similar deposits. EAR correspond to DOE's Probable Potential Resource Category.

- **Speculative Resources (SR):** Uranium in addition to EAR that is thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The locations of deposits in this category can generally be specified only as being somewhere within given regions or geological trends. As the term implies, the existence and size of such deposits are speculative. The estimates in this category are less reliable than estimates of EAR. SR corresponds to DOE's Possible Potential Resources plus Speculative Potential Resources categories.