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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 using nuclear power to generate electricity for commercial use. It also contains information and forecasts of developments in the worldwide nuclear fuel market. Long-term projections of U.S. nuclear capacity, generation, and spent fuel discharges for two different scenarios through 2040 are developed. A discussion on the decommissioning of U.S. nuclear power plants is presented. This report provides information to a wide audience, including the Congress, Federal and State agencies, the Organization for Economic Cooperation and Development, and the general public.

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. WINES 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.

This report was formerly published as “World Nuclear Outlook.”

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Executive Summary

Nuclear power continues to be an important source of electricity, accounting for 22 percent of total electricity generation worldwide. Although the nuclear power industry continues to grow, it faces a complex set of issues. This annual report presents the latest set of U.S. and international data and forecasts. In a special section, it also discusses issues regarding the decommissioning of U.S. nuclear power plants.

The following information presents a summary of the findings of this report.

Worldwide Status of Nuclear Capacity

- **In 1995, 5 commercial nuclear units became operable throughout the world, and 2 units were retired, bringing the total at the end of the year to 437 units.** In 1995, nuclear units had a combined total capacity of 344.4 net gigawatts-electric (GWe), generating 2,223.5 net terawatthours of electricity, a 4.3 percent increase from 1994.

- **Worldwide, there are 85 nuclear units under construction including 32 units in the Far East.** The 85 total is 13 units less than reported last year—6 units were added to and 19 units were removed from the construction pipeline.

- **In 1995, U.S. plants significantly improved their operating performance as they eclipsed the capacity factor record for the second straight year.** The new record of 77.5 percent exceeded the 1994 value of 73.8 percent. Over the past 8 years, U.S. capacity factor has increased 35 percent.

Worldwide Nuclear Capacity Projections

Over the long-term, the increase in nuclear power capacity remains uncertain as economic concerns stem from both the capital-intensive nature of nuclear power projects and the highly variable plant operating and maintenance cost. Other issues that will affect nuclear power's future are spent fuel management, global climate change, public perception, and waste disposal. The uncertain future of nuclear power is reflected in two scenarios. The **Reference Case** scenario reflects a continuation of the present trends in the nuclear power industry, and the **High Case** scenario reflects a revival in nuclear orders, especially vigorous growth in the Far East.

- **Up to the year 2000, worldwide nuclear capacity is projected to range between 359.4 GWe and 367.7 GWe (Figure ES1).** Since all the units that are projected to become operable by the turn of the century are already under construction, the range of uncertainty reflects potential delays in construction schedules and licensing.

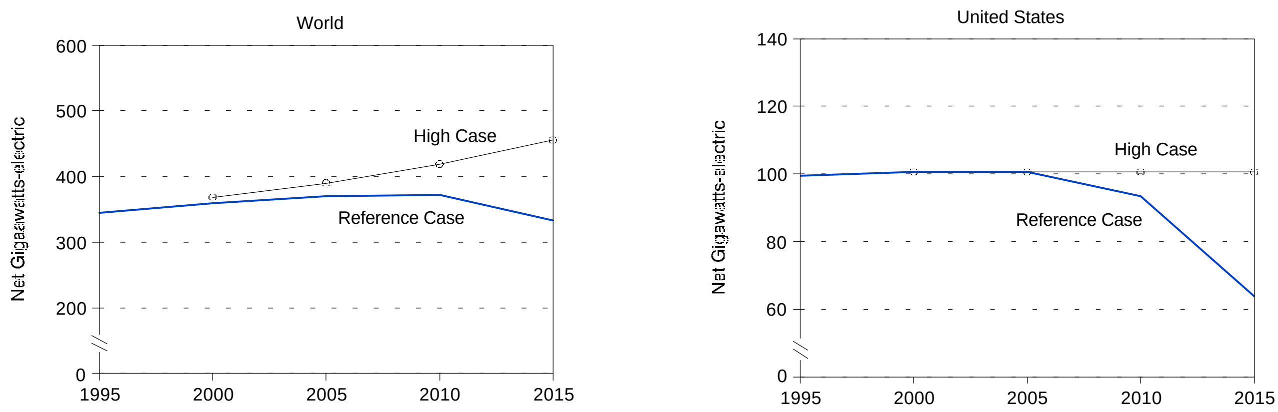
- **By 2015, U.S. nuclear capacity is projected to range from the constant 100.5 GWe projected for the High Case downward to the 63.7 GWe projected for the Reference Case (Figure ES1).** Increasing competition in the U.S. electricity industry and continuing stalemate over high-level radioactive waste disposal are among the key issues that must be resolved if new plants are ever to be built in the United States in the future.

- **By the year 2015, worldwide nuclear capacity is projected to range between 333.3 GWe and 455.2 GWe (Figure ES1).** Only in the Far East and in other countries with rapidly expanding economies is nuclear capacity projected to grow in both cases. The U.S. share of world nuclear capacity will drop from the current 28 percent to between 22 and 19 percent while that of the Far East will increase from 18 percent to between 26 and 29 percent.

Nuclear Fuel Cycle

The uranium market is undergoing fundamental changes as excess Western commercial inventories and imports from the Former Soviet Union (FSU) become less available. Meanwhile, world reactor fuel requirements continue to exceed the level of uranium production.

Figure ES1. 1995 Nuclear Capacity and Projected Capacity, 1996-2015



Note: 1995 data are as of December 31, 1995.

Source: **1995**—United States, Nuclear Regulatory Commission, "Information Digest, 1996 Edition" NUREG-0380 (July 1996); Foreign International Atomic Energy Agency (IAEA), "Nuclear Power Reactors in the World" (Vienna, Austria, April 1996); **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 1996 run) was used to supplement the 2015 capacity projection.

- **The average uranium spot-market price increased to $8.45 per pound U_3O_8 in 1995, compared to $7.05 per pound U_3O_8 in 1994, increasing to $13 by February 1996. In the restricted U.S. market, where FSU imports have been limited, the average spot-market price increased to $11.46 per pound U_3O_8 in 1995 from $9.31 per pound U_3O_8 in 1994, reaching $15 by February 1996.** These increases have moved spot prices to levels (in nominal dollars) not seen since the 1980's.

- **The rise in prices is attributed to the pressure of unexpected demand on tightening supplies**. In early 1995, the bankruptcy of the Nuexco Trading Company and related companies triggered sudden demand in the U.S. market.

- **The spot-market price (in constant 1995 dollars) is projected to rise to around $17.50 per pound U_3O_8 in 1997 due to the continued decline in Western commercial inventories and restrictions on imports from the FSU, and then fall around 2000 in response to an increase of supply. The price is projected to stabilize at the end of the projection period to currently prevailing levels.**

Future demand will be sufficient to stimulate both the opening of new uranium production centers and the sale of Russian and U.S. surplus Government inventories, including low-enriched uranium derived from highly enriched uranium.

- **Annual worldwide demand for U_3O_8 from 1996 through 2015 is projected to range from 119 million to 198 million pounds**. Reactors in Western Europe account for 31 percent of total demand during the projection period, the largest share of any region. The United States is projected to account for 28 percent.

Increased uranium prices have induced domestic producers to increase output. This trend is expected to continue as long as competitive low-cost reserves are available in the United States.

- **The United States produced 6.0 million pounds U_3O_8 in 1995, up significantly from the 3.4 million pounds in 1994**. Domestic production is projected to gradually rise to 8.8 million pounds U_3O_8 by 2004. As lower cost reserves are depleted, however, production is expected to gradually decline to 5.7 million pounds in 2010.

- **The average spot-market price for enrichment services in the restricted U.S. market increased to $92.42 per separative work unit (SWU) in 1995 from $85.63 per SWU in 1994. The enrichment services component of uranium enriched in Russia was sold at an average spot-market price of $81.83 per SWU in 1995, an increase from $67.58 per SWU in 1994**.

- **Annual worldwide demand for enrichment services from 1996 through 2015 is projected to range from 29 million SWU to 44 million SWU. Western Europe is expected to account for 34 percent of this total. This projected demand is less than the current worldwide capacity of 49 million SWU per year.**

- **Prices remained stable over the last several years in the markets for uranium conversion and light water reactor fuel fabrication, due to excesses in inventory and production capacity, respectively.**

The management and disposal of increasing amounts of commercial spent nuclear fuel is being exercised in different ways worldwide including interim storage and reprocessing.

- **Between 1996 and 2015, nuclear reactors worldwide are projected to discharge between 213 thousand and 227 thousand metric tons of uranium (MTU).**

- **By 2015, cumulative discharges of spent fuel from U.S. nuclear reactors are expected to increase to between 74 and 75 thousand MTU, compared to a total of 32.2 thousand MTU discharged through the end of 1995**.

Decommissioning of U.S. Nuclear Power Plants

Within the next 19 years, 49 of the 110 commercial nuclear power plants currently operating in the United States are scheduled to be retired after reaching the end of their operating license.[1] Several commercial reactors have been successfully decommissioned, demonstrating that decommissioning is well within the bounds of current technology. The greatest uncertainties, however, are in the areas of cost and the availability of LLW disposal sites.

- **Many factors enter into a nuclear utility's decision to choose one of the decommissioning options**, depending primarily on the expected escalation in low-level waste (LLW) costs. Factors favoring the option of immediate dismantlement and decontamination (DECON) include the availability of a highly skilled staff with experience at the plant, and the elimination of potential future cost uncertainties.

  Factors favoring an option where a facility is maintained until some decay of radioactivity, followed by dismantlement (SAFSTOR) include the desire to reduce the radioactivity and quantity of LLW and the possibility that new, more efficient disposal technologies may emerge.

- **Currently, only two sites accept LLW: Barnwell in South Carolina and Hanford in Washington.** Although these sites accept LLW, their disposal charges differ considerably, from $85 per cubic foot at Hanford to $385 per cubic foot at Barnwell. **NRC estimates of DECON cost of a reference reactor with LLW disposal at Hanford range from $133 to $158 million versus a range of $224 to $303 million for SAFSTOR option.**

- **With the continued delay in the Federal government's high-level waste repository, utilities must also consider the costs and benefits of continued pool storage versus those of placing all their spent fuel in an independent spent fuel storage installation (ISFSI).** Annual spent fuel storage costs are estimated at about $6 million for pool storage and $2 million for dry storage in an ISFSI.

[1] The license expiration date for U.S. nuclear plants is based on the operating license approval date as issued by the Nuclear Regulatory Commission.

1. Nuclear Capacity Status and Projections

The first commercial nuclear power plant came online in the late 1950s. In the 1970s and early 1980s, nuclear power capacity grew rapidly worldwide as early programs were expanded and more countries developed nuclear technology. Today, nuclear power accounts for over one-fifth of international electricity generation. The future of nuclear power development, however, is uncertain. Economic concerns stem from both the capital-intensive nature of nuclear power projects and the highly variable plant operating and maintenance costs. Recent trends toward deregulation and privatization of electricity supply systems led to increased pressure on nuclear plant operators to be economically competitive with other generating technologies. Accidents at Three Mile Island in the United States in 1978 and Chernobyl in the Ukraine in 1986 increased public concern about the safety of nuclear power plants. As a result, increases in both technological safety enhancements and public confidence in the safety of nuclear power must come about before widespread growth can be expected.

Additionally, spent fuel management and waste storage are creating problems that have yet to be solved in some countries. In the United States, for example, temporary on-site spent fuel storage pools at some locations are filling up because there is no provision for permanent storage. Theoretically, many options exist for either temporary storage or permanent disposal of the waste; however, these options require significant funds and significant time for research, construction, and regulatory approval.

This chapter concentrates on the status of nuclear power and its expected future for individual countries through the year 2015. In particular, it tracks the progress of nuclear reactors under construction and the potential development of new nuclear units. Following a summary of the current status statistics and projection methodology used to make the projection, the discussion of projections focuses on six regional groupings: (1) United States, (2) Canada, (3) Western Europe, (4) Eastern Europe, (5) Far East, and (6) Other. The report also discusses events that occurred during 1995 up to the first quarter of 1996.[1, 2] Readers are advised to review previous *World Nuclear Outlook's* for information on countries not included in this report.[3]

Status Statistics

At the end of 1995, 437 commercial nuclear units were operating in 31 countries throughout the world. They have a total capacity of 344.4 net gigawatts-electric (GWe) (Table 1).[4] During the year, four nuclear units were connected to their respective grids while one unit, (previously retired in 1989), was reconnected to the grid (Table 2).

Two nuclear units were officially retired in 1995: Bruce 2 and Wuersgassen. Canada's Bruce 2 is an 848-MWe pressurized heavy-water-cooled and moderated reactor (PHWR) located in Tiverton, Ontario. The unit was shutdown in September 1995 after 19 years in operation because it would have required large scale maintenance work, including replacing 480 fuel-carrying pressure tubes, had it remained in service. Germany retired the Wuergassen unit, a 640-MWe boiling light-water-cooled and moderated reactor (BWR) located in Lauenforde, Niedersachsen, after 24 years of operation.

The United States led all countries in nuclear capacity with 99.4 GWe, followed by France (58.5 GWe), Japan (39.9 GWe), Germany (22.0 GWe), Russia (19.8 GWe), Canada (14.9 GWe), Ukraine (13.6 GWe), and the United Kingdom (12.9 GWe) (Figure 1). Combined, these eight countries accounted for 82 percent of the world's capacity for generating electricity. World nuclear-generated

[1] Information about 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. It is primarily based on official utility projections. Some units, however, may be omitted from Appendix D because they were deemed unlikely to be built within the projected timeframe.

[2] 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); *Nuclear Europe Worldsan* (Berne, Switzerland, 1996); *Nuclear Fuel and Nucleonics Week* (New York: McGraw-Hill). Most of the sources reflect information reported through April 30, 1996, but a few sources include information reported through May 1996.

[3] This report was formerly published as “World Nuclear Outlook.”

[4] All capacity and generation values are “net” unless otherwise stated.

Table 1. Operable Nuclear Power Plant Statistics, 1994 and 1995

Country	Number of Operable Units[a] 1994	Number of Operable Units[a] 1995	Net Capacity (MWe) 1994	Net Capacity (MWe) 1995	Amount of Electricity from Nuclear Units Net TWh 1994	Amount of Electricity from Nuclear Units Net TWh 1995	Amount of Electricity from Nuclear Units Percent Change	1995 Share[b] (percent)
United States	109	109	99,148	99,394	640.4	673.4	5.2	[c]20.0
Canada	22	21	15,755	14,907	101.7	92.3	-9.2	17.3
Western Europe								
Belgium	7	7	5,527	5,631	38.2	39.2	2.6	55.5
Finland	4	4	2,310	2,310	18.3	18.1	-0.9	29.9
France	56	56	58,493	58,493	341.8	358.6	4.9	76.1
Germany	21	20	22,657	22,017	143.0	145.7	1.9	29.6
Netherlands	2	2	504	504	3.7	3.8	2.7	4.9
Slovenia	1	1	632	632	4.4	4.6	3.6	39.5
Spain	9	9	7,105	7,124	52.8	53.1	0.6	34.1
Sweden	12	12	10,002	10,002	70.2	66.7	-5.0	46.6
Switzerland	5	5	2,985	3,050	23.0	23.5	2.1	39.9
United Kingdom	34	35	11,720	12,908	79.4	81.6	2.8	24.9
Subtotal:	151	151	121,935	122,671	774.8	794.9	2.6	42.5
Eastern Europe								
Bulgaria	6	6	3,538	3,538	15.3	17.3	12.6	46.4
CIS/Armenia	0	1	0	376	0.0	0.0	0.0	0.0
CIS/Kazakhstan	1	1	70	70	0.4	0.1	-78.9	0.1
CIS/Russia	29	29	19,843	19,843	97.8	99.4	1.6	11.8
CIS/Ukraine	15	16	12,679	13,629	68.9	65.6	-4.7	37.8
Czech Republic	4	4	1,648	1,648	12.1	12.2	0.8	20.1
Hungary	4	4	1,729	1,729	13.2	13.2	-0.2	42.3
Lithuania	2	2	2,370	2,370	6.6	10.6	60.5	85.6
Slovak Republic	4	4	1,632	1,632	12.1	11.4	-5.7	44.1
Subtotal:	65	67	43,509	44,835	R226.5	229.9	1.5	18.5
Far East								
China	3	3	2,100	2,167	13.5	12.4	-8.3	1.2
Japan	R51	51	R39,917	39,893	258.3	286.9	11.1	33.4
Korea, South	10	11	8,170	9,120	55.9	63.7	13.9	36.1
Taiwan	6	6	4,890	4,884	33.5	33.9	1.2	35.4
Subtotal:	R70	71	R55,077	56,064	361.2	396.9	9.9	18.6
Other								
Argentina	2	2	935	935	7.7	7.1	-8.2	11.8
Brazil	1	1	626	626	0.0	2.5	0.0	1.0
India	9	10	1,493	1,695	4.3	6.5	50.2	1.9
Mexico	2	2	1,308	1,308	4.3	8.4	96.3	6.0
Pakistan	1	1	125	125	0.5	0.5	-8.0	0.9
South Africa	2	2	1,842	1,842	9.7	11.3	16.3	6.5
Subtotal:	17	18	6,329	6,531	26.5	36.2	36.6	3.5
Total World:	**R434**	**437**	**R341,753**	**344,402**	**R2,131.1**	**2,223.5**	**4.3**	**21.9**

[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]Each country's net electricity generated from nuclear power generating units as a percentage of net electricity generated from utilities and nonutilities. The source for nuclear generation data is the International Atomic Energy Agency (IAEA). The nuclear share of utility-generated electricity for the United States was 22.5 percent.

[c]1995 utility generation was obtained from the Energy Information Administration, *Monthly Energy Review, May 1996*, DOE/EIA-0035(96/05) (Washington, DC, May 1996). Forecasted 1995 gross nonutility generation data was obtained from the Energy Information Administration, Projection for the Short-Term Energy Outlook Memorandum, July 1996.

MWe = Megawatt-electric.

R = Revised.

TWh = Terawatthours.

Note: Two nuclear generating units in Japan were connected to the grid in 1994 but not included in the 1994 total: **Monju,** a Fast Breeder Reactor (Operable Capacity, 246 net megawatt-electric), connected to the grid in February 1994 and **Onagawa 2**, a Boiling Water Reactor (Operable Capacity, 796 net megawatt-electric), connected to the grid in December 1994.

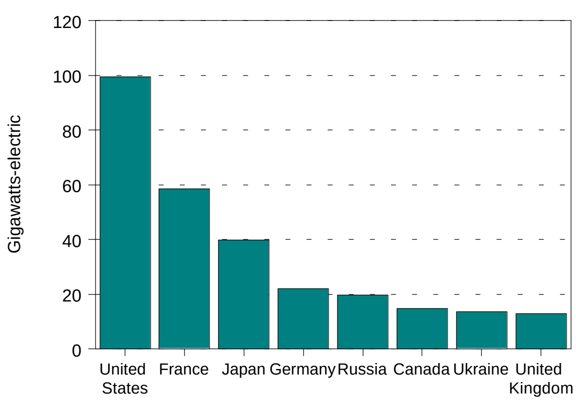
Sources: **1994**–International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1995). **1995**–International Atomic Energy Agency, *Nuclear Power Reactors in the World* (Vienna, Austria, April 1996).

Table 2. Nuclear Generating Units Connected to the Grid in 1995

Country	Unit Name	Reactor Type	Operable Capacity (Net MWe)	Grid Connection[a]
Armenia	Armenia 2[b]	PWR	376	November 1995
India	Kakrapar 2	PHWR	202	March 1995
South Korea	Yonggwang 4	PWR	950	July 1995
Ukraine	Zaporozhe 6	PWR	950	October 1995
United Kingdom	Sizewell B	PWR	1,188	February 1995

[a]Grid connection: The date when the plant is first connected to the electrical grid for the supply of nuclear power.
[b]Armenia 2 was reconnected to the grid in 1995 after shut down in 1989.
PHWR = Pressurized heavy-water-moderated and cooled reactor.
PWR = Pressurized light-water-cooled and moderated reactor.
Note: Two nuclear generating units in Japan were connected to the grid in 1994 but **not** included in the 1994 total: **Monju**, a Fast Breeder Reactor (Operable Capacity, 246 net megawatt-electric), connected to the grid in February 1994 and **Onagawa 2**, a Boiling Water Reactor (Operable Capacity, 796 net megawatt-electric), connected to the grid in December 1994.
Source: **1995**–International Atomic Energy Agency, "Nuclear Power Reactors in the World" (Vienna, Austria, April 1996).

Figure 1. Nations with the Largest Nuclear Generating Capacity, 1995



Source: 1995–International Atomic Energy Agency, "Nuclear Power Reactors in the World" (Vienna, Austria, April 1996), pp. 8-9.

electricity in 1995 equaled 2,223.5 net terawatthours (TWh), a 4.3-percent increase, compared with 2,131.1 net TWh generated in 1994.

As of December 31, 1995, the "construction pipeline" consisted of 85 units in various stages of construction (Table 3), with a total capacity of 77.0 GWe. Reactors in the construction pipeline vary in status from planned to active construction. Of the 85 units, 46 are less than 25 percent complete.[5] This total is a reduction of 13 units from the number in last year's report. Construction on five units was completed and the status of two units was changed to operable in 1995,[6] while 12 units were deleted from the pipeline: Balakovo 6 (Russia), Khmelnitski 5 (Ukraine), Kaiga 3 (India), Ashihama 3, Hohoku 1 and 2, Maki 1 (Japan), Pyongan 1 (North Korea), BNPP 1 (Philippines), Mochovce 3 and 4 (Slovak Republic), and Sizewell C (United Kingdom).

Six units were added to the construction pipeline: Qinshan 4 and 5 (China), Onagawa 3 and Namie Odaka 1 (Japan), and Bushehr 1 and 2 (Iran). The decision whether to include a reactor in the construction pipeline is based on an assessment of a country's expressed desire to build a nuclear reactor and the financial constraints involved in purchasing one. A total of 18 countries have been identified as having nuclear units currently in the construction pipeline. The Far East region continues to lead the world in nuclear construction programs with 32 units in the pipeline having a combined total capacity of 30.8 GWe.

Projection Methodology

EIA uses three methodologies when assessing the nuclear generating capacity of individual countries. The first approach projects nuclear capacity by estimating completion dates for units under construction in each country along with scheduled retirements of currently operating

[5] The 46 units that were listed as being less than 25 percent complete include those units whose percent completion is unknown.
[6] The seven units include the five units that were connected to the grid in 1995. In addition Japan's Monju and Onagawa 2 were moved to the operable status. Monju and Onagawa 2 were connected to the grid in 1994 but were inadvertently omitted last year.

Table 3. Status of Commercial Nuclear Generating Units in the Construction Pipeline as of December 31, 1995

Country	Percentage of Construction Completed									
	0 to 25		26 to 50		51 to 75		76 to 100		Total	
	No. of Units	Net MWe	No. of Units	Net MWe	No. of Units	Net MWe	No. of Units	Net MWe	No. of Units	Net MWe
United States	0	0	1	1,212	4	4,839	2	2,382	7	8,433
Western Europe										
France	4	5,800	1	1,450	1	1,450	2	2,910	8	11,610
Eastern Europe										
CIS/Armenia[a]	1	376	0	0	0	0	0	0	1	376
CIS/Russia	6	4,375	1	950	1	950	1	950	9	7,225
CIS/Ukraine	2	1,900	1	950	1	950	1	950	5	4,750
Czech Republic	0	0	0	0	1	912	1	912	2	1,824
Romania	3	1,950	1	650	0	0	1	650	5	3,250
Slovak Republic	0	0	0	0	1	388	1	388	2	776
Subtotal	12	8,601	3	2,550	4	3,200	5	3,850	24	18,201
Far East										
China	6	4,570	0	0	0	0	0	0	6	4,570
Japan	11	11,623	0	0	0	0	3	3,757	14	15,380
Korea, South	5	4,450	0	0	4	3,220	1	650	10	8,320
Taiwan	2	2,500	0	0	0	0	0	0	2	2,500
Subtotal	24	23,143	0	0	4	3,220	4	4,407	32	30,770
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	2	900	0	0	4	808	0	0	6	1,708
Iran	2	1,950	0	0	0	0	0	0	2	1,950
Pakistan	0	0	1	300	0	0	0	0	1	300
Subtotal	6	3,666	2	1,529	5	2,053	1	692	14	7,940
Total World	**46**	**41,210**	**7**	**6,741**	**18**	**14,762**	**14**	**14,241**	**85**	**76,954**

[a]The exact stage of construction for the Armenia 1 reactor is unknown.
MWe = Megawatt-electric.
Source: "World List of Nuclear Power Plants," *Nuclear News* (March 1996), pp. 29-44. *Nucleonics Week* (various issues).

units.[7] 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.[8] The WINES model projects nuclear generating capacity by using assumptions about economic growth, energy consumption, and the proportion of energy to be supplied by nuclear power. The third approach is used for countries that have no units in the construction pipeline. This approach develops projections based on an assessment of detailed country-specific nuclear power plant information that was an outcome of the 1996 Consultancy Meeting on International Nuclear Capacity Forecasting held by the International Atomic Energy Agency (IAEA) in March 1996 and supplemented by information from other available sources.

Given the uncertainties regarding nuclear power's future, two scenarios were developed for this report. The Reference Case scenario reflects a continuation of the present

[7] As noted earlier, the construction pipeline data developed by EIA may omit some units discussed in the text if the analysis shows that a unit is unlikely to be built within the projection timeframe.

[8] Detailed description of the World Integrated Nuclear Evaluation System (WINES) is presented in Appendix B.

trends in the nuclear power industry. The capacity projections are based solely on units in the construction pipeline, which are listed in Appendix D under the "Expected Date of Operation" column. 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. Each plant is expected to operate for an average of 30 years. Planned retirement dates for existing reactors are incorporated into the projections. Few new nuclear units are expected to be added to the construction pipeline, resulting in a decline in capacity.

The High Case scenario reflects a revival in nuclear orders spurred mostly by the Far East and Other groups. This scenario assumes each country's unfinished nuclear units in the construction pipeline are completed by 2015. The High Case also assumes that most countries will operate their units for 40 years in addition to adding new units to the pipeline. The two cases were developed to show the effects of different assumptions on projected nuclear generating capacity to satisfy the growing energy requirements.

World Projections

Up to the year 2000, worldwide nuclear capacity is projected to grow from 344.4 GWe in 1995 to between 359.4 GWe and 367.7 GWe (Table 4). Since all of the units that are projected to become operable by the turn of the century are already under construction, the range of uncertainty reflects potential delays in construction schedules and licensing. France, South Korea, Japan, and Russia account for 70 percent of the projected increase for the High Case through 2000. The projected regional percent share of nuclear capacity remains relatively unchanged through 2000 for both cases, with Western Europe accounting for 35 percent followed by the United States with 28 percent. After the turn of the century, the range of uncertainty regarding nuclear power evelopment widens. For most countries, new nuclear capacity has been slowed as countries look at the economics of nuclear power. Installed capacity in the Reference Case scenario is projected to be 3 percent less in 2015 than in 1995 despite expected growth in developing countries like China, Japan, India and South Korea. The projected regional percentage shares of nuclear capacity for the world is expected to change from 2000 through 2015 for both cases, with the Far East increasing its share to between 26 percent and 29 percent (Figure 2) and the U.S. share declining to between 22 percent and 19 percent. The Far East and Other regions are the only regions where nuclear capacity is expected to grow in both the Reference and High Cases. These regions have fewer indigenous resources and are experiencing large economic and population growth with a significant increase in energy consumption in industrial, commercial, and residential sectors.[9]

Regional Projections

United States

In 1995, U.S. plants improved their generating performance as they eclipsed the capacity factor record for the second straight year. The plants achieved an average capacity factor of 77.5 percent, topping the 1994 value of 73.8 percent.[10] Total nuclear generation also reached its highest level, 673.4 net TWh. This total was 5.2 percent higher than the previous high set in 1994.

Nuclear power generated 22.5 percent of total utility-generated electricity in 1995, compared with 22.0 percent in 1994. This is a 2.3 percent increase, largely attributable to improved performance. The nuclear share of total generation was largest in New England (46.9 percent) and New York / New Jersey (33.6 percent) (Table 5). Utilities in 6 of the 10 Federal regions generated more than 20 percent of their electricity from nuclear power plants.

Despite the recently improved economics of nuclear power, increasing competition in the electric generating sector may require even better future performance from existing plants.[11] The continuing stalemate over high-level radioactive waste disposal is among the key issues that must be resolved if nuclear utilities are to build new plants in the United States in the near future. By 2015, nuclear capacity is projected to range between 100.5 GWe in the High Case to 63.7 GWe in the Reference Case. As a result, the U.S. share of world capacity will decline to 22 and 19 percent for the High and Reference Cases, respectively.

The U.S. cases are also referred to as the **No New Orders** and the **License Renewal** cases which better define the assumptions used for each case. In the No New Orders case, it is assumed that no new advanced light-water reactors (ALWRs) will become operational before the year 2015 and all current nuclear units will operate to the end

[9] Energy Information Administration, *International Energy Outlook 1996*, May 1996, DOE / EIA-0084(96), pp. 5-18.
[10] Energy Information Administration, *Monthly Energy Review*, August 1996, DOE / EIA-0035(96 / 08) (Washington, DC, August 1996).
[11] Energy Information Administration, *An Analysis of Nuclear Plant Operating Costs: A 1995 Update*, SR / OIAF / 9501 (Washington, DC, April 1995).

Table 4. 1995 Operable Nuclear Capacities and Projected Capacities for 2000, 2005, 2010, and 2015
(Net Gigawatts-electric)

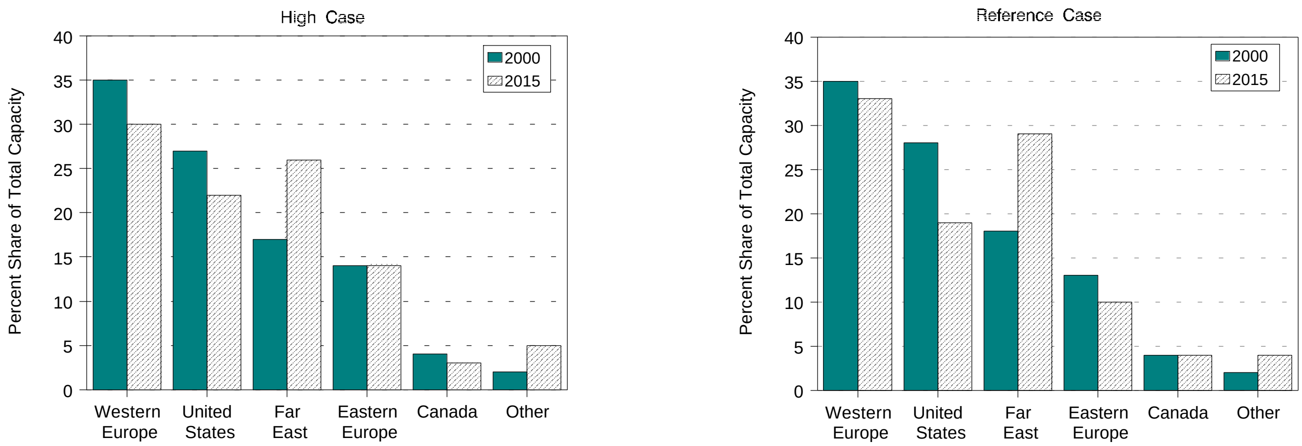
Country	1995[a]	2000		2005		2010		2015	
		Reference	High	Reference	High	Reference	High	Reference	High
United States	99.4	100.5	100.5	100.5	100.5	93.5	100.5	63.7	100.5
Canada	14.9	14.9	14.9	14.9	14.9	12.8	14.9	12.8	14.6
Western Europe									
Belgium	5.6	5.6	5.6	5.6	5.6	5.6	5.6	3.9	5.6
Finland	2.3	2.6	2.6	2.6	2.6	2.6	2.6	2.6	3.6
France	58.5	64.3	64.3	62.9	64.1	62.9	65.5	62.7	74.1
Germany	22.0	21.7	22.0	21.0	22.0	21.0	21.7	18.6	21.0
Italy	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	0.0	0.0	0.0	0.0	0.0	0.6
Slovenia	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Spain	7.1	7.1	7.1	7.0	7.1	6.5	7.0	6.5	6.5
Sweden	10.0	10.0	10.0	10.0	10.0	10.0	10.0	6.7	10.0
Switzerland	3.1	3.1	3.1	2.3	3.1	2.0	3.1	2.0	2.3
United Kingdom	12.9	11.8	11.8	10.5	10.5	9.5	10.5	7.2	9.5
Subtotal	122.7	127.3	127.6	122.6	125.6	120.9	126.6	110.9	134.6
Eastern Europe									
Bulgaria	3.5	2.7	3.5	2.3	3.7	1.9	3.8	1.9	3.8
CIS/Armenia	0.4	0.4	0.8	0.8	0.8	0.4	0.8	0.0	0.8
CIS/Kazakhstan	0.1	0.1	0.1	0.0	0.1	0.0	0.7	0.0	1.3
CIS/Russia	19.8	20.8	22.7	19.2	22.0	18.5	24.7	12.0	27.2
CIS/Ukraine	13.6	13.2	14.8	13.2	15.1	15.6	15.6	11.4	18.1
Croatia	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.6
Czech Republic	1.6	2.6	3.5	3.5	3.5	3.5	3.5	3.5	4.1
Hungary	1.7	1.7	1.7	1.7	1.7	1.7	2.3	1.7	2.9
Lithuania	2.4	2.4	2.4	2.4	2.4	1.2	2.4	1.2	1.2
Romania	0.0	0.7	0.7	0.7	1.3	1.3	2.6	1.3	3.3
Slovak Republic	1.6	1.6	2.0	1.6	2.4	1.6	1.6	0.8	2.2
Subtotal	44.8	46.1	52.1	45.3	52.8	45.7	58.5	33.7	65.4
Far East									
China	2.2	2.2	2.2	6.0	7.7	10.4	15.4	18.7	22.6
Indonesia	0.0	0.0	0.0	0.0	0.6	0.0	1.8	0.0	1.8
Japan	39.9	43.7	43.7	48.2	48.2	49.1	52.5	51.0	59.8
Korea, North	0.0	0.0	0.0	1.0	1.9	1.9	1.9	1.9	1.9
Korea, South	9.1	13.0	13.0	15.8	17.4	17.4	21.1	18.5	25.0
Taiwan	4.9	4.9	4.9	4.9	6.1	7.4	7.4	7.4	7.4
Subtotal	56.1	63.7	63.7	75.9	82.0	86.3	100.1	97.5	118.5
Other									
Argentina	0.9	0.9	0.9	1.6	1.6	1.3	1.3	1.3	1.3
Brazil	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	0.4	0.0	0.8	0.0	0.8
Egypt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
India	1.7	2.1	2.5	2.7	3.9	3.0	4.8	4.8	5.9
Iran	0.0	0.0	0.0	1.0	1.0	2.0	2.0	2.0	2.4
Israel	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
Pakistan	0.1	0.1	0.4	0.4	0.7	0.7	0.7	0.6	1.2
South Africa	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	1.0	1.0	2.0	1.0	2.0
Subtotal	6.5	6.9	8.9	10.7	13.6	13.0	17.8	14.7	21.6
Total World	**344.4**	**359.4**	**367.7**	**369.8**	**389.4**	**372.2**	**418.5**	**333.3**	**455.2**

[a]Status as of December 31, 1995.

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

Source: **1995**—United States, Nuclear Regulatory Commission, "Information Digest, 1996 Edition" NUREG-0380 (July 1996); Foreign International Atomic Energy Agency (IAEA), "Nuclear Power Reactors in the World" (Vienna, Austria, April 1996); **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 1996 run) was used to supplement the 2015 capacity projection.

Figure 2. World Nuclear Capacity Share by Region, Reference, and High Cases, 2000 and 2015



Source: Energy Information Administration, International Nuclear Model, File INM.WK4.

Table 5. U.S. Nuclear Capacity and Generation as of December 31, 1995, by Federal Region

Federal Region	Capacity (net MWe)	Actual 1995 Generation (net TWe)	Percent Share[a]
I New England	6,384	35,670,207	46.9
II New York/New Jersey	8,693	43,141,689	33.6
III Middle Atlantic	13,980	104,534,337	29.7
IV South Atlantic	26,890	188,958,997	26.3
V Midwest	21,644	143,910,370	25.1
VI Southwest	8,502	63,494,774	14.3
VII Central	4,074	29,519,428	18.2
VIII North Central	0	0	0
IX West	8,120	57,230,443	26.4
X Northwest	1,107	6,941,878	4.5
Total	**99,394**	**673,402,123**	**22.5**

[a]Nuclear-generated electricity as a percentage of utility-generated electricity. Nonutility generated electricity is not included.
MWe = Megawatt-electric.
TWh = Terawatthours.
Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report."

of their current license terms as recorded by the Nuclear Regulatory Commission. Both cases have incorporated the completion of Watts Bar 1, which received its full-power license on February 6, 1996. Although seven units are listed in the construction pipeline, six of these units are classified as indefinitely deferred and are not projected to come online in the forecast period.[12] All units officially remain in the construction pipeline until the Nuclear Regulatory Commission receives a formal letter from the utility stating that the unit will not be completed.

The License Renewal case assumes 10 additional years of operation for each unit (only one unit will retire by 2015). Conditions favoring such an outcome could include continued performance improvements, a solution to waste disposal, and stricter limits on emissions from fossil-fired

[12] The list is dated December 31, 1995. Watts Bar 1 received its full-power license in February 1996.

generating facilities. Both cases assume that Big Rock Point, located in Charlevoix, Michigan, will retire in 2000.

Canada

Canada's nuclear future is expected to be similar to that of the United States. The EIA projects that nuclear capacity will either remain constant at 14.6 GWe bzy 2015 in the High Case or decline to 12.8 GWe in the Reference Case. In an attempt to bring power demand and supply into balance, Ontario Hydro (OH), the country's largest utility, prematurely closed some of its baseload power plants including the Bruce 2 nuclear reactor.

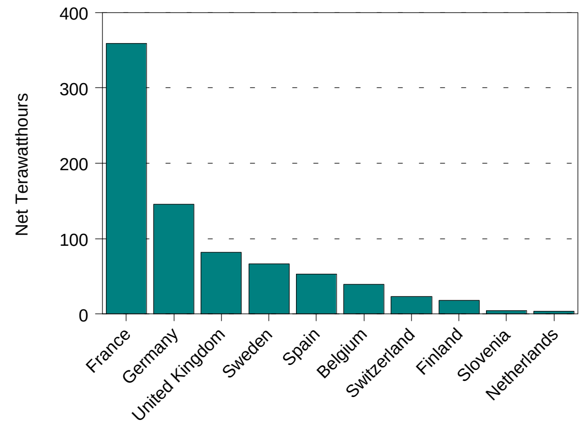
The Canadian nuclear industry is facing strong competition from other fuels and from electricity imports from the United States at a time when it is also restructuring its utility sector.[13] Currently, nuclear power accounts for about 60 percent of OH electricity. In an effort to remain competitive, OH management introduced a controversial proposal to privatize the company. Regardless of the outcome of the proposal, however, the outlook for nuclear growth in Canada is as unfavorable as that in the United States. As Canada's existing nuclear units are retired, there are no new units under construction or being planned to replace them.

Although OH has mothballed its Bruce 2 unit, the utility invited 10 potential nuclear equipment suppliers to solicit an interest in the possible restoration of the unit by the fall of 2000. The estimated cost to replace damaged fuel channels and all eight boilers at Bruce 2 is (Cdn) $500 million.[14]

Western Europe

Western Europe has a 36 percent share of total world nuclear capacity, the largest regional share in the world, and in 1995 it generated the most nuclear electricity of any region, 794.9 TWh (Table 1). France, Germany, Sweden, and the United Kingdom account for 82 percent of the region's total nuclear-generated electricity. France led all the countries in the region with 359 TWh of nuclear-generated electricity, followed by Germany with 146 TWh and the United Kingdom with 82 TWh (Figure 3). By 2015, nuclear capacity is projected to be between 110.9 GWe and 134.6 GWe for the region. The overall trend in Western Europe, however, is away from nuclear power construction. In the Reference Case, only France is projected to increase its nuclear capacity through 2015. Currently, France is the only country in the region to have units in the construction pipeline. The Chooz B1 and B2 units, located in Chooz, Ardennes, are expected to begin operation in 1996, and Civaux 1 and 2 are expected to be ready for operation by the spring of 1997 and the fall of 1998, respectively.[15] Seven other Western European countries are projected to decrease their total nuclear capacity due to retirements, while Slovenia's capacity is expected to remain unchanged. Overall, total capacity declines by 10 percent by 2015 in the Reference Case.

Figure 3. Nuclear Generation in Western Europe, 1995



Source: 1995–International Atomic Energy Agency, "Nuclear Power Reactors in the World" (Vienna, Austria, April 1996), pp. 8-9.

The Reference Case projection for Western Europe can be explained by several factors. As in the United States, economics, public perception, and uncertainties associated with disposal of spent nuclear fuel make nuclear power's future dim. Political opposition has stalled new nuclear construction in Finland, Germany, Spain, Sweden, and Switzerland. For these countries, the question of new nuclear capacity is overshadowed by age-related issues (i.e., steam generator degradation) and whether to extend the lives of existing plants in order to retain a competitive edge in an increasingly deregulated market. In the United Kingdom, the Government has determined that its nuclear power stations can be privatized. As a result, in July 1996, the Government privatized parts of its nuclear industry although concluding that the older Magnox stations

[13] Ray Silver, "Hydro Board Slashed as Government Gears for Privatization Push," *Nucleonics Week* (January 18, 1996), pp. 13-14.
[14] Ray Silver, "Even as Bruce-2 is Shut, Hydro Seeks Proposals to Revive it," *Nucleonics Week* (January 18, 1996), p. 6.
[15] *Nuclear News*, "Fuel Loading of First N4 Reactor" (December 1995), p. 14.

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.

In Germany, nuclear power will contribute a diminishing share of the energy demand, while natural gas usage for electricity generation will increase.[16] In September 1995, PreussenElecktra formally applied to the licensing authorities in Germany to decommission the Wuergassen 640-MWe BWR, shutdown since August 1994.[17] Evaluation of the plant showed that costly repairs and backfitting the plant to satisfy present safety standards would exceed the potential earnings from continued operation, even when the original cost of the plant had been completely written off. RWE Energie AG, operator of the Biblis reactor, is also contemplating decommissioning its plant for similar reasons.[18]

In the Reference Case, most plants are expected to operate for 30 years although some plants are projected to operate beyond the 30-year life. For example, the United Kingdom's Calder Hall and Chapelcross stations, which came online in the late 1950s, are not projected to be retired until 2001. Under German law, reactor life spans are not fixed. Reactors must be shut down only if they are deemed by regulators to not conform with technical safety criteria. The German political leadership and, in particular, the Social Democratic Party has tried to negotiate a firm schedule for remaining reactor lifetime, thus far without success.

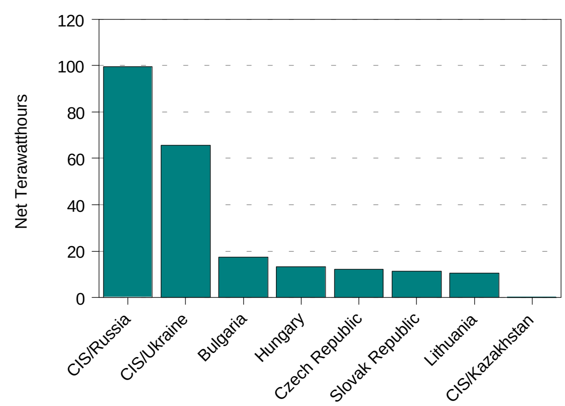
In the High Case, nuclear capacity increases slightly as many units operate for an additional 10 years and France brings on most of the region's additional capacity. Belgium, Finland, and Italy are projected to construct new reactors. But even with these additions, the region's share of total world installed nuclear capacity will still decrease to 30 percent. The High Case scenario also assumes that Sweden's attempt to close its existing units by 2010 will fail, as there may not be economically viable alternatives to nuclear power.

Eastern Europe

The EIA projects nuclear capacity to either decline from its current capacity of 44.8 GWe to 33.7 GWe by 2015 in the Reference Case or to increase to 65.4 GWe in the High Case. In the High Case scenario, all units in the construction pipeline become operational by 2015 in addition to existing units operating for 40 years. In addition, it is projected that 8.7 GWe of additional capacity will come online in the High Case. It is assumed that nuclear power is viewed as a viable economic advantage in the High Case and that most of the countries have the financing available to purchase a plant. Nuclear power is important for electricity generation, accounting for 19 percent of the region's total energy mix in 1995. Bulgaria, Ukraine, Hungary, Lithuania, and the Slovak Republic rely most heavily on the nuclear power, which generated over one-third of each country's electricity generation. Russia led all countries in nuclear electricity generation with 99 TWh, followed by Ukraine with 66 TWh (Figure 4). Several countries in the region have ambitious plans for additional capacity beyond those listed in Appendix D, but they will face many challenges that are likely to limit new nuclear units.

In November 1995, Armenia reconnected its Armenia 2 unit.[19] Restoration work is planned for the older unit, Armenia 1, over the next 2 to 3 years. The country must decide if it plans to operate the unit without one of its six steam generators since a hole was cut into one of them. Unless funding for replacement equipment is forthcoming, unit 1 might be forced to operate at lower power. Armenia 2 will help relieve the country's desperate shortage of electricity, which has limited most people to

Figure 4. Nuclear Generation in Eastern Europe, 1995



Source: 1995–International Atomic Energy Agency, "Nuclear Power Reactors in the World" (Vienna, Austria, April 1996), pp. 8-9.

[16] Mark Hibbs, "German Economy May Never Need New Reactors, Consultant Says," *Nucleonics Week* (January 18, 1996), pp. 1, 11.
[17] *Nuclear News*, "Decommissioning License Application for Wurgassen" (November 1995), p. 38.
[18] Mark Hibbs, "RWe Said to Mull Shutting Biblis in Lieu of Adding Safety System, *Nucleonics Week* (January 4, 1996), pp. 5-6.
[19] *Nuclear News*, "Armenia-2 Restarts After Six Years Shutdown (December 1995), p. 31.

around two hours of electricity per day over the past 3 years.[20]

The Czech Republic's Temelin 1 and 2 are around 90 and 55 percent complete, respectively. Work on units 1 and 2 was slowed for several years following the establishment of independent Czech and Slovak Republics.[21] Currently, the construction process involves upgrading the plant to international standards, most notably a new instrumentation and control system, a new fuel design, and a reactor core provided by Westinghouse. Completion of Temelin 1 is now projected sometime between June and September 1997.[22]

While the region is in transition to a market economy, investments in capital-intensive nuclear power projects will be difficult. Russia hopes to ease the economic difficulties facing the nuclear industry through more export contracts for its nuclear technology.[23] Besides completing Iran's Bushehr units, Russia is expected to build two VVER-1000 units at Liaoning, China, and may be contemplating other projects. In addition, Russia is trying to revive an old agreement with India for the construction of two 1,000-MWe reactors.

In 1996, Slovakia signed credit agreements worth nearly $900 million dollars to finance completion of its Mochovce nuclear power plant.[24] The financing agreements, among the largest the country has entered into, were signed with a consortium of local banks and four foreign banks, including Komercni Banka and Ceska Sporitelna of the Czech Republic, Kreditanstalt fur Wiederaufbau of Germany, and France's Societe Generale.

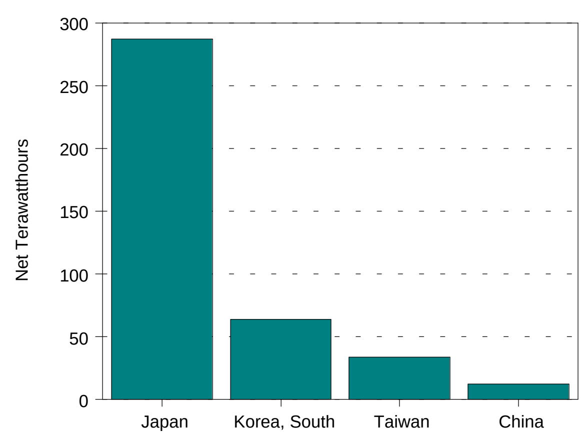
The Mochovce units are later-version VVER-440s, for which Siemens, the German high-technology group, and the French energy companies Framatome and Electricite de France will provide safety systems and quality assurance technology as recommended by the International Atomic Energy Agency. Construction of the Mochovce 1 unit is expected to be completed in 2 to 5 years.[25]

Currently, Ukraine's plan includes a broad range of improvements to the electricity system, such as upgrading hydroelectric and coal-fired power stations and completing more nuclear units, which have been classified as profitable projects that could be financed with some $1.8 billion in loans from the West. Many western nations are tying financing agreements to improved safeguards at current plants, or requiring that unsafe plants be shut down.[26] A Memorandum of Understanding on the completion of Romania's Cernavoda unit was signed recently by the Industry Ministry and Romanian Electricity Authority and Atomic Energy of Canada Limited and Ansaldo of Italy. Romania is currently seeking domestic or international participants who are willing to accept a share of the electricity production as payment for their investment.

Far East

Although China, Japan, South Korea, and Taiwan all operate nuclear plants, Japan currently has by far the largest nuclear program. In 1995, nuclear power accounted for 19 percent of the Far East's electricity, generating 396.9 TWh (Figure 5). Japan led the region's countries in nuclear-generated electricity with 287 TWh, followed by South Korea with 64 TWh. *Nuclear Power Generation and Fuel Cycle Report 1996* projects an increase in nuclear capacity from 56.1 GWe to 97.5 GWe in the Reference Case and to 118.5 GWe in the High Case. The

Figure 5. Nuclear Generation in the Far East, 1995



Source: 1995–International Atomic Energy Agency, "Nuclear Power Reactors in the World" (Vienna, Austria, April 1996), pp. 8-9.

[20] Ibid.
[21] *Nuclear News*, "Working Towards Completion at Temlin," (December 1995), pp. 32-33.
[22] Ibid.
[23] Nuclear Engineering International, *Russia Optimistic About Nuclear Sales* (January 1996), p. 13.
[24] *Nuclear News*, "Consortium to Implement all Required Upgrades (December 1995), p. 31.
[25] Ibid.
[26] Nuclear Engineering International, *Could Ukraine go it Alone* (November 1995), pp. 36-37.

region is expected to increase its share of world capacity from 16 percent in 1995 to between 26 percent (High Case) and 29 percent (Reference Case) by 2015.

The region has ambitious plans for further nuclear expansion, mainly to help achieve energy independence. China is a prime example of this trend. This year's projection for China is significantly different from last year's due to the country's aggressive campaign for further nuclear expansion. Foreign capital is essential if China is to reach its ambitious goal of 30 GWe to 50 GWe of nuclear capacity by 2020.[27] China's nuclear capacity is projected to grow at an annual average rate of between 11 percent and 13 percent. To achieve its goal, the country is involved in several negotiations for additional nuclear projects.

The purchase of the Lingao 1 and 2 units, each 985 net MWe PWRs, was agreed upon in January 1995 between China and the French vendor Framatome.[28] The station is to be built at Lingao in the Guangdong province, only a few kilometers from Guangdong 1 and 2.[29] Construction on Lingao 1 and 2, which are due to enter service in 2002 and 2003, respectively, could start before the end of 1995.[30]

China has six units totaling 4.6 GWe, in the construction pipeline: Qinshan 2, 3, 4, and 5 and Lingao 1 and 2 (referred to last year as Guangdong 3 and 4). Qinshan 2 and 3, located in Haiyan, Zhejiang, are both 600-MWe PWRs that China's National Nuclear Corporation hopes will become a standardized Chinese design for those provinces where systems and finances are not yet suitable for large imported nuclear power plants.[31] South Korea will be supplying the reactor pressure vessels, and other equipment orders have been placed with companies in Spain, Japan, the United Kingdom, and the United States. Concrete was poured in late 1995 for both units at the Qinshan site, and the Chinese Government estimates site completion by 2000 and 2001, respectively.

In addition to the six units that are under construction, agreements have recently concluded that could lead to the supply of nuclear power plants for the eastern provinces of China. In May 1995, Chinese authorities in Beijing approved the construction of two Russian-built 1,000-MWe PWRs at Wufangdian in the northeastern province of Liaoning.[32] Continuing economic growth will help increase China's nuclear capacity to between 18.7 GWe and 22.6 GWe.

The latest power development plan for South Korea calls for 35 percent of new generating capacity over the next 10 years to come from nuclear power.[33] Next to Japan, South Korea has the largest number of nuclear plants in the construction pipeline, totaling 8.3 GWe.

Other

Accounting for only 2 percent of the world's total nuclear capacity, the "other" countries have relatively small nuclear power programs, compared with the major regions. Of the six countries in this category, India has the most aggressive nuclear program. In March 1995, India's Kakrapar 2 was connected to the grid.[34] The unit was delayed for about one year to allow modification to fire protection arrangements following the 1993 turbo generator fire and station blackout at Narora 1. Work on Kaiga 1 and 2 is 75 percent complete, and both are expected to be completed by late 1998. Two more units of the 235 gross MWe design are under construction at Rajasthan 3 and 4 and are expected to enter service in 1997. Another four units are planned for the Rajasthan site, but they may not be realized until the middle of the next decade.

Nuclear power generation currently accounts for less than 4 percent of the total electricity generation among the countries in the Other group. The capacity of this region is projected to increase between 14.7 GWe in the Reference Case and 21.6 GWe in the High Case by the year 2015. By 2015, the region is projected to increase its share of world capacity from its current 2 percent to 4 percent in the Reference Case and to 5 percent in the High Case. Because of high capital costs, the countries of this group are not projected to have large programs such as those in the United States or Japan. Indeed, most of the countries in this group require financial and technological assistance from established nuclear countries. For example, the completion of Cuba's Juragua station will require the formation of an international association consisting of Cubans, Russians, and other international partners. The Iranian Atomic Energy Organization signed an agreement with

[27] John S. DeMott, "Ambitious Dragon," *Nuclear Energy*, First Quarter 1995, pp. 24-29.
[28] *Nuclear News*, "Final Contract for Lingao Signed in October" (December 1995), p. 26.
[29] Ibid.
[30] Ibid.
[31] Simon Rippon, "China: Ready for More Nuclear Power," *Nuclear News* (June 1995), pp. 32-33.
[32] *Nucleonics Week*, "Russian Vendor Experts Predict Liaoning-1 Wont Start Until 2004" (December 7, 1995), p. 12.
[33] Bo Hun Chung, "Nuclear Power Development in South Korea," *Nuclear News* (June 1995), pp. 34-37.
[34] Nuclear Engineering International, *Kakrapur-2 Goes Commercial* (October 1995), p. 12.

Russia in August 1995 for the completion within 4.5 years of the first of two planned Bushehr VVER-1000 units.[35] The agreement also covers nuclear fuel supplies from 2001 to 2011 and the return of spent fuel to Russia for storage and eventual reprocessing. Work continues at Pakistan's Chasnupp 1 unit, which is expected to start up in 1998.[36] This date may be optimistic, since China plans to fabricate the reactor pressure vessel and that work has been delayed.

[35] *Nuclear News*, "Russia Pledges Credits for Juragua Completion" (December 1995), p. 27.
[36] *Nuclear News*, "Vessel Supply Problem for Chashma PWR Project" (November 1995), p. 38.

2. Nuclear Fuel Cycle

The term "nuclear fuel cycle" applies to the steps necessary to prepare fuel for loading into nuclear reactors, and to manage spent fuel (see Appendix A for a general overview of these steps). Canada, France, Russia, and the United States possess domestic operations in all "front-end" stages of the nuclear fuel cycle while other countries have more limited industries. The "back-end" of the nuclear fuel cycle is presently restricted in the United States to interim storage at nuclear power plants. In contrast, spent nuclear fuel can be reprocessed to recover plutonium and uranium. New mixed-oxide fuel (MOX) using the separated plutonium is manufactured in Western Europe and Russia.

In the United States, uranium production facilities are concentrated in the West, near to uranium reserve areas (Figure 6). Downstream processes involving conversion, enrichment, and fuel fabrication are carried out primarily in the Midwest and the East. With a legal framework established in 1996 for privatizing enrichment services, the United States is positioned to become the first country to totally eliminate government ownership in its nuclear fuel industry.

Nuclear fuel markets have taken on an increasingly global aspect since the late 1980's. Nontraditional sources of supply have become available as imports of natural and enriched uranium from the republics of the Former Soviet Union, as well as through the disposition of excess government-held inventories from both Russia and the United States. While the diversity of sources portends an adequate world supply, political and trade issues continue to limit their availability. Furthermore, a protracted period of low uranium prices has restrained the development of new uranium production capacity needed to meet future demand. Meanwhile, the debate continues in many countries, including the United States, on a long-term solution for disposing spent fuel.

Projections derived from EIA's International Nuclear Model PC Version (PCINM) for uranium and enrichment service requirements and spent fuel discharges are presented for the world through 2015. The Uranium Market Model (UMM) is used by EIA to project uranium spot prices, domestic production, net imports, and inventories; the projections are presented for the period 1996-2010. Detailed descriptions of PCINM and UMM are presented in Appendix B.

Overview of World Uranium Market Developments

Fundamental Changes in the Market

The uranium market is undergoing fundamental changes as the importance of certain sources of supply diminish. For over a decade, the world uranium market has been driven by excess inventories in Western countries[37] and the availability of nontraditional supplies,[38] namely imports from the Former Soviet Union (FSU) and other countries with centrally planned economies. As orders for new nuclear power plants were canceled in the late 1970's, utilities under contract obligations to purchase uranium began accumulating large excess inventories. A secondary market was created to accommodate the trading of excess inventories. Thus, the drawdown of inventories became the driving force in the market. Beginning in the late 1980's, imports from the FSU, China, and Mongolia further contributed to oversupply. The market reacted to this oversupply by substantially discounting the price of uranium from a high of $43.23 per pound U_3O_8 (in nominal dollars) in 1978 to a low of around $7.00 per pound in 1994.[39] Persistent depressed prices forced the closure of higher cost production capacity and postponed the development of additional reserves. As a result, world U_3O_8 production has fallen to levels well below Western reactor fuel requirements (Figure 7).[40]

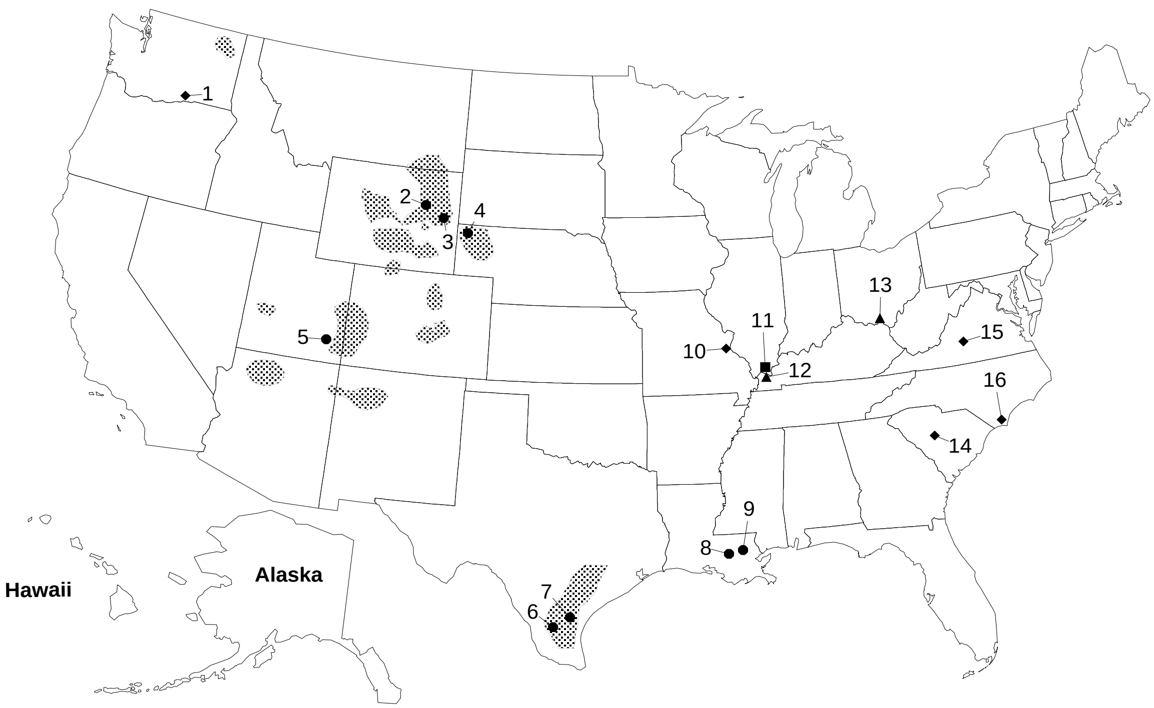
[37] Western refers to the countries of the world outside the current and former centrally planned economies.

[38] Nontraditional supplies consist of (1) imports of U_3O_8 and enriched uranium from countries with current and former centrally planned economies, including low enriched uranium (LEU) from the blending down of weapons-grade highly enriched uranium (HEU) in Russia, (2) U.S. Government inventories, including LEU from HEU, and (3) reprocessed spent fuel.

[39] TradeTech, *Nuexco Review* (Denver, CO, November 1995), p. 25.

[40] Non-Western countries sell uranium in the world market, but generally do not purchase uranium from Western countries.

Figure 6. Operating Nuclear Fuel Cycle Facilities and Major Uranium Reserve Areas in the United States, December 31, 1995



Uranium Concentrate [a]

2. Malapai Resources, Christensen Ranch (ISL)[b]
3. Converse County Mining Venture, Highland (ISL)
4. Crow Butte Resources, Crow Butte (ISL)
5. Energy Fuels Nuclear, White Mesa (CNV)[b]
6. Malapai Resources, Holiday - El Mesquite (ISL)
7. Uranium Resource, Rosita (ISL)
8. IMC - Agrico, Sunshine Bridge (BPR)[b]
9. IMC - Agrico, Uncle Sam (BPR)

Uranium Hexafluoride Conversion [a]

11. Converdyn, Metropolis, Illinois

Uranium Enrichment [a]

12. U.S. Enrichment Corporation, Paducah, Kentucky
13. U.S. Enrichment Corporation, Portsmouth, Ohio

Uranium Fuel Fabrication [a]

1. Siemens Power Corporation, Richland, Washington
10. ABB C-E, Hematite, Missouri
14. Westinghouse, Columbia, South Carolina
15. B&W Fuel Company,[c] Lynchburg, Virginia
16. General Electric, Wilmington, North Carolina

Nuclear Fuel Cycle Facilities

- ● Uranium Concentrate
- ■ Uranium Hexafluoride Conversion
- ▲ Uranium Enrichment
- ◆ Uranium Fuel Fabrication

Major Uranium Reserve Areas

[a]Uranium concentrate production facilities are listed by operator and facility name. Conversion, enrichment, and fuel fabrication plants are distinguished by operator and locality.

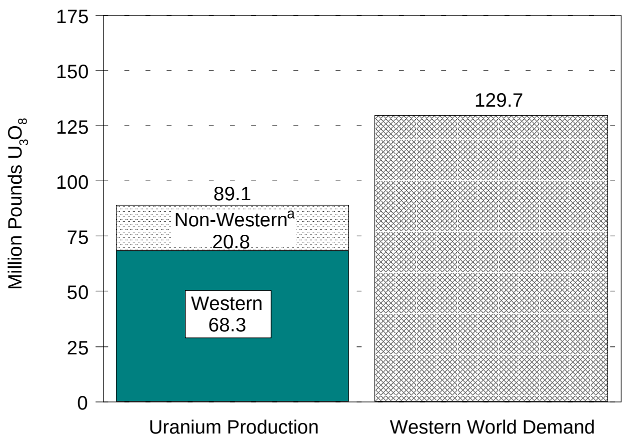
[b]The types of uranium concentrate production facilities are indicated as follows: BPR = byproduct recovered from the processing of phosphate ore; CNV = conventional milling; and ISL = in situ leaching.

[c]Company was renamed Framatome Cogema Fuels in 1996.

[d]Major areas containing reasonably assured resources at \$50 per pound U_3O_8 or less.

Sources: **Uranium concentrate production facilities**—Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), Figure 4; **All other facilities**—Energy Information Administration, *Nuclear Power Generation and Fuel Cycle Report 1996* (this report), Tables 12 (conversion), 13 (enrichment), and 16 (fuel fabrication).

Figure 7. Comparison of World Uranium Production and Western World Demand, 1995



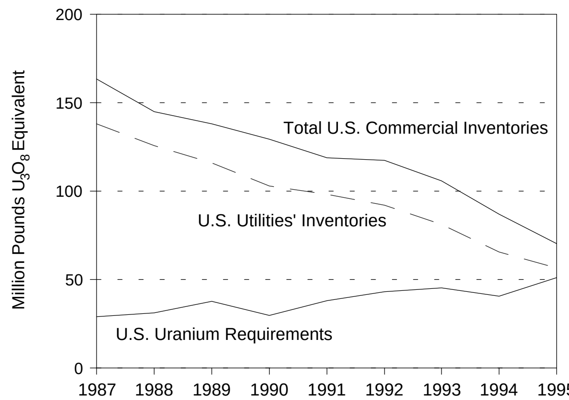
[a]Estimated for the Republics of the Former Soviet Union, China, and Mongolia.

Source: **Production:** Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report*, (Washington, DC, May 1996), pp. 4-27,65,68; and **Demand:** Energy Information Administration, International Nuclear Model, File INM95.WK3, low-case with mixed-oxide fuel recycling.

Declining Inventories

Excess inventories of natural and enriched uranium held by utilities in the Western world have steadily declined.[41] At the end of 1995, the quantity of these inventories was estimated to be sufficient to cover almost 2 years of reactor requirements, a nearly 1-year decrease in coverage from the previous year.[42] [43] Moreover, the inventory coverage by U.S. utilities is below the world average. At the end of 1995, U.S. utility-held inventories were sufficient to cover just over 1 year of annual reactor requirements, down from about 1.5 years at the end of 1994, and over 4 years during the mid-1980's (Figure 8). With U.S. utilities holding 6-9 months strategic inventory and 9-12 months of processing inventory,[44] it appears unlikely that the drawdown of Western utility-held inventories will continue to be a major source of supply in the future.

Figure 8. Comparison of U.S. Commercial Inventories, U.S. Uranium Requirements, 1987-1995



Note: U.S. Commercial Inventories are quantities of natural uranium (U_3O_8) and natural and enriched uranium hexafluoride (UF_6) 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**: 1987-1993: Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), Table ES1; 1994-1995: Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), p. 29. **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 1995,* DOE/EIA-0478(95) (Washington, DC, May 1996), uranium used in fuel assemblies, p. 26.

Restrictions on Imports from the Former Soviet Union

Beginning in 1991, the United States and the European Union took measures to limit the impact of imports from the FSU on their respective nuclear fuel industries. The initial suspension agreements to an antidumping suit filed by U.S. producers,[45] signed with Kazakhstan, Russia, and

[41] Utility inventories consist of strategic and processing pipeline components. Strategic inventory is held as a hedge against disruptions in supply. Processing pipeline inventory is utility-owned uranium that is being prepared for fuel to be loaded into nuclear reactors.

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

[43] Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), p. 4.9.

[44] Ibid.

[45] 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 proceeding 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.

Legal Framework for Marketing Nontraditional Sources of Uranium in the United States, 1995-2005

Amendment to the Suspension Agreement with the Russian Federation

Summary: Russian-origin U_3O_8 and enriched uranium (SWU) can be imported as long as the quantities specified in Table 6 are matched with newly produced U.S.-origin U_3O_8 or SWU. This type of transaction is called a "matched sales" transaction. Agreement ends in 2003. Sales of low-enriched uranium (LEU) derived from the blending down of Russian highly enriched uranium (HEU) are covered under the United States Enrichment Corporation Privatization Act of 1995.

Amendment to the Suspension Agreement with the Republic of Kazakhstan

Summary: The quota listed in Table 6 is based on price determinations made semi-annually by the U.S. Department of Commerce (DOC). 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. Agreement ends in 2003.

Amendment to the Suspension Agreement with the Republic of Uzbekistan

Summary: The quota listed in Table 6 is based on U.S. uranium production levels, except during the first two years when the quota is based on price determinations made semi-annually by the DOC. The maximum amount of uranium allowed for the first two years is 940,000 pounds U_3O_8 annually, as long as the DOC-determined price is equal to or exceeds $12.00 per pound. Uranium from Uzbekistan that is enriched by a non-U.S. firm must be certified as Uzbek-origin, therefore, the amount of U_3O_8 feed is counted against the quota for Uzbekistan. Agreement ends in 2004.

The United States Enrichment Corporation (USEC) Privatization Act of 1996[a]

Summary: Privatization Act was signed into law in April 1996; it provides the mechanism for privatizing USEC, a government corporation engaged in uranium enrichment services. The act also provides a schedule for selling uranium in the U.S. market from the blending down of weapons-grade Russian and U.S. HEU into LEU for use in commercial nuclear power plants (Table 6). Also stipulated, sales in the United States of the equivalent U_3O_8 contained in the feed component of the LEU blended down from Russian HEU would count against the quotas specified in the Amendment to the Suspension Agreement with the Russian Federation. The U.S. Department of Energy (DOE) was given the authority to transfer certain U.S. Government-owned stocks of natural uranium and HEU to USEC without charge, and to sell remaining surplus without causing adverse material impact on the domestic industry.

[a]USEC Privatization Act is contained within Sections 3101-3117 of Public Law 104-134: Omnibus Consolidated Recissions and Appropriation Act of 1996 (April 26, 1996).
Sources: See Table 6.

Uzbekistan in 1992, were amended during 1994 and 1995 to allow these countries a more realistic access to the U.S. market. The amended agreements established different quotas for each country (Table 6). While accomplishing their objective to implement more realistic quotas, the amended agreements actually provided the U.S. Department of Commerce with even more control on imports. This was done by addressing the "enrichment bypass option" in the agreements with Kazakhstan and Uzbekistan, and creating matched sales transactions for Russian imports. The enrichment bypass option is exercised when uranium in the form of U_3O_8 mined either in Kazakhstan or Uzbekistan is enriched in a third country before shipment to the United States as low-enriched uranium

Table 6. Specified Quotas and Schedules for Marketing Nontraditional Sources of Uranium in the United States, 1995-2010
(Million Pounds U_3O_8 Equivalent)

Year	Russian Matched Sales U_3O_8[a]	Russian Matched Sales SWU	Kazakh-Origin	Uzbek-Origin	Russian HEU[b]	U.S. Government-Owned HEU & Natural Uranium[c]
1995	6.6	2.0	1.0[d]	0.9[e]	0	0
1996	1.9	NA	d	0.9[e]	0	0
1997	2.7	NA	d	e	0	0
1998	3.6	NA	d	e	2.0	3.1
1999	4.0	NA	d	e	4.0	3.1
2000	4.2	NA	d	e	6.0	3.1
2001	4.0	NA	d	e	8.0	3.1
2002	4.9	NA	d	e	10.0	3.1
2003	4.3	NA	d	e	12.0	3.1
2004	NA	NA	NA	e	14.0	3.1
2005	NA	NA	NA	NA	16.0	3.1
2006	NA	NA	NA	NA	17.0	3.1
2007	NA	NA	NA	NA	18.0	3.0
2008	NA	NA	NA	NA	19.0	NA
2009	NA	NA	NA	NA	20.0	NA
2010	NA	NA	NA	NA	20.0[f]	NA

[a]Sales of the equivalent U_3O_8 contained in the feed component of the LEU blended down from Russian HEU would also count against the quotas specified in the Russian amendment agreement.

[b]U_3O_8 equivalent of the LEU blended down from Russian HEU. Sales of the U_3O_8 contained in the feed component of this material would count against the quotas specified by the Russian amendment agreement (see note a).

[c]The schedule as of April 30, 1996, for disposing U.S.-Government stocks of HEU and natural uranium is based on the transfer of the following from the DOE to USEC: 30.9 million pounds U_3O_8 equivalent contained in 50 metric tons of HEU and 7,000 metric tons of natural uranium and LEU.

[d]The DOC-determined price was $12.06 per pound U_3O_8 in April 1995, therefore, 1 million pounds of U_3O_8 equivalent could be imported to the United States in 1995. Potential imports of Kazakh-origin U_3O_8 in future years would be based on the following DOC-determinations of price ($US/pound U_3O_8): 12.00-13.99: 1.0 million pounds, 14.00-14.99: 1.2 million pounds, 15.00-15.99: 1.4 million pounds, 16.00-16.99: 1.8 million pounds, 17.00-17.99: 2.5 million pounds, 18.00-18.99: 3.5 million pounds, 19.00-19.99: 4.0 million pounds, 20.00-20.99: 5.0 million pounds, 21.00 and up: unlimited.

[e]The DOC-determined price exceeded $12.00 per pound U_3O_8 in April 1995 and is expected to remain above $12.00 in 1996, therefore, 940,000 pounds of uranium could be imported to the United States in 1995 and 1996. Potential imports of Uzbek-origin U_3O_8 in future years would be based on 500,000 pound-increments of U.S. production (U_3O_8) as follows: lower quota level of 0.6 million pounds of imports at production 1 pound over 3.0 million pounds and an upper quota level at 1.0 million pounds of imports at production 1 pound over 8.5 million pounds. If U.S. production exceeds 9.0 million pounds annually, unlimited quantities of Uzbek-origin uranium can be imported into the United States.

[f]Quantity remains at 20.0 million pounds beyond 2010.

NA = Not applicable.

Sources: Russian Amendment-*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; Kazakh Amendment-*Federal Register*, “Agreement Suspending the Antidumping Investigation on Uranium from Kazakhstan,” Vol. 60, no. 92 (May 12, 1995), pp. 25692-25693; Uzbek Amendment-*Ux Weekly* (October 16, 1995), p. 2; USEC Privatization Act-West Publishing Company, *United States Code Congressional and Administrative News, 104th Congress–Second Session* (St. Paul, MN, June 1996), pp. 780-818.

(LEU). The country in which the enrichment took place, not the country providing the U_3O_8 feed, was considered as the country of origin under the initial suspension agreements. Under the amendments to the suspension agreements, however, uranium that is mined in Kazakhstan or Uzbekistan for sale to the United States will count directly against the quota, whether being imported directly as U_3O_8 or indirectly as a feed component of product enriched in a third country. While not resolving the enrichment bypass issue, the amended agreement with Russia gives a boost to the U.S. industry by requiring that imports of Russian-origin uranium under the specified quota be matched with equal quantities of newly produced U.S.-origin uranium.

Meanwhile, the countries of the FSU experienced declines in U_3O_8 production. They produced an estimated 16.5 million pounds U_3O_8 in 1995,[46] down from an estimated 35 million pounds in 1991.[47] Uranium output from the FSU was based more on government-planned objectives than market considerations. Although considered a strategic material, government planners saw uranium exports as a means to secure foreign exchange. Since the dissolution of the FSU, however, higher cost production facilities were closed or replaced by less costly recovery methods. Thus, heap leaching[48] and in situ leaching have replaced conventional underground and open pit mining in many areas.[49] As the decline in production further constrained the export capability of the countries of the FSU, additional pressure was placed on the price of uranium.

Uranium Prices Rise

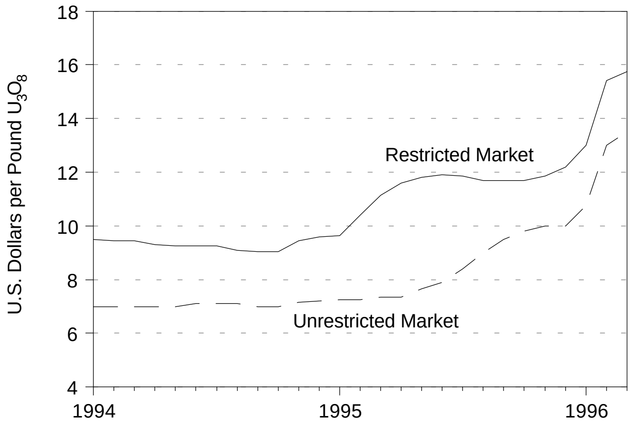
With a decline in the availability of excess Western inventories and imports from the FSU, it became inevitable that the price of uranium would eventually rise. The bankruptcy and subsequent inability of a group of major uranium suppliers to cover contract delivery commitments provided the event to trigger the dramatic price increases in 1995 (Figure 9). The average unrestricted Nuexco spot-market price increased 20 percent to $8.45 per pound U_3O_8 in 1995 from $7.05 per pound U_3O_8 in 1994.[50] For the restricted U.S. market,[51] the average Nuexco spot-market price was $11.46 per pound U_3O_8 in 1995, an increase of 23 percent from $9.31 per pound in 1994.[52] By February 1996, the price per pound for the unrestricted and restricted markets reached $13.00 and $15.00, respectively.[53]

The increase in prices, however, did not happen simultaneously across the restricted and unrestricted markets. In February 1995, Mr. Oren Benton and companies controlled by him (Nuexco Trading Company, Concord Services Incorporated, Energy Fuels Limited, and Energy Fuels Exploration Company) filed a Chapter 11 petition under the U.S. Bankruptcy Court in Denver.[54] With the bankruptcy filing, utilities faced uncertainty over whether deliveries of uranium from the defaulted companies would be completed. This uncertainty forced some U.S. utilities to procure alternative supplies through spot purchases in the restricted market. Consequently, prices in the restricted market were the first to respond to the sudden increase in demand. Throughout 1994, the differences in price between the restricted market and the unrestricted market remained in a narrow range between $2.00 and $2.50 per pound U_3O_8 (Figure 10). Responding to the Benton bankruptcy, however, the differential broke out of this range in February 1995, reaching a high of $4.25 per pound U_3O_8 in April 1995.

The declining availability of uranium in the unrestricted market became increasingly evident as U.S. utilities took deliveries of Russian-origin uranium through matched sales transactions (Figure 11). Most of the 2.1 million pounds U_3O_8 equivalent of Russian-origin was delivered in the second half of 1995.[55] The increased demand on already tight supplies of FSU uranium caused the spot price for the unrestricted market to rise at a relatively faster rate than the spot price for the restricted market. As a result, the differential between the unrestricted and unrestricted prices returned to its historical range in September 1995 (Figure 10).

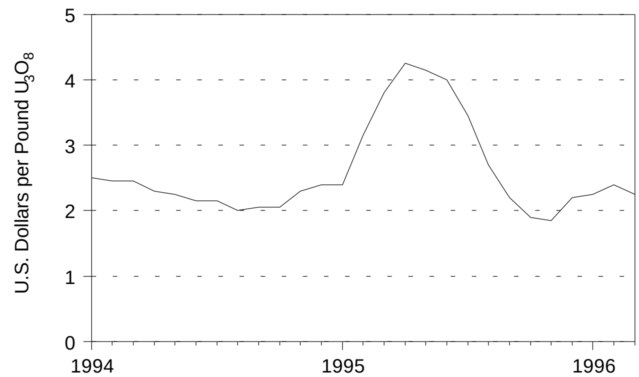
[46] Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), p. 4.64.
[47] Energy Information Administration, *Uranium Industry Annual 1991*, DOE/EIA-0478(91) (Washington, DC, October 1992), p. 10.
[48] Mined ore is mechanically crushed and placed in piles or "heaps" on the surface or in underground excavations, where it is leached. The ensuing uranium-bearing solution is piped to a processing plant.
[49] *Nukem Market Report*, "Uranium Industry in Kazakhstan-An Insiders View" (May 1994), pp. 9-13.
[50] TradeTech, *Nuexco Review* (Denver, CO, November 1995), p. 25, and *Ux Weekly*, December 1995 through May 1996.
[51] 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.
[52] TradeTech, Nuexco Review (Denver, CO, November 1995), p. 25, and *Ux Weekly*, December 1995 through May 1996.
[53] Ibid.
[54] *NuclearFuel*, "Benton, Four of His Companies Ask Court for Chapter 11 Bankruptcy Code Protection," (February 27, 1995), pp. 1, 15.
[55] Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey 1995."

Figure 9. Comparison of Spot Prices for the Restricted and Unrestricted U_3O_8 Markets, January 1994–March 1996



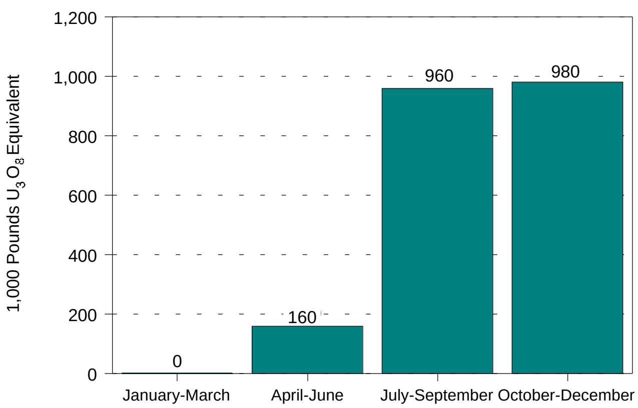
Note: Prices are in nominal dollars.
Source: TradeTech, *Nuexco Review* (Denver, CO, November 1995), and *Ux Weekly*, December 1995 through May 1996.

Figure 10. Differential Between Spot Prices for the Restricted and Unrestricted U_3O_8 Markets, January 1994–March 1996



Note: Prices are in nominal dollars.
Source: Derived from monthly Nuexco Exchange Values prices reported in TradeTech, *Nuexco Review* (Denver, CO, November 1995), and *Ux Weekly*, December 1995 through May 1996.

Figure 11. Quantities of Russian Uranium Delivered to U.S. Utilities in 1995 as Matched Sales Transactions



Note: Deliveries generally in the form of enriched uranium hexafluoride (UF_6).
Source: Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey 1995."

New Production Capacity Under Development

Higher prices over the last year have encouraged producers to announce schedules for opening new mines in Australia, Canada, and the United States. Substantial additions to existing capacity are also planned in Australia and Namibia. Increased U_3O_8 production capacity from these planned projects will be required to maintain the balance of supply as excess inventories no longer drive the market. The following is a summary of the more significant developments in new production capacity.

With large low-cost reserves, Canada is expected to add the most new production capacity by 2000. This will ensure Canada's position as the world's largest uranium producer for many years. The planned production centers, Cigar Lake, McArthur River, McLean Lake, and Midwest Lake are located in the Province of Saskatchewan. Construction of the McLean Lake mine-mill complex was begun in 1995, making it the first such facility built in the world since the late 1980's. Final government approval is pending for the remaining projects. The development plans summarized below were disclosed by the operating companies in a series of Environmental Impact Statements issued during the second half of 1995.[56] [57] [58] These projects are expected to contribute up to 42 million pounds U_3O_8 of new production capacity by 2000.

The Cigar Lake, McLean Lake, and Midwest Lake projects are to be operated as a joint venture, whereby Cameco

[56] Cigar Lake Mining Corporation, *Environmental Impact Study for the Cigar Lake Mining Project* (Executive Summary) (Saskatoon, Canada, July 1995).
[57] Cogema Resources Inc., *Environmental Impact Study for the Midwest Lake Project* (Executive Summary) (Saskatoon, Canada, August 1995).
[58] Cameco Corporation, *Environmental Impact Study for the McArthur River Project* (Executive Summary) (Saskatoon, Canada, November 1995).

Corporation will operate the Cigar Lake mine; Cogema Resources Inc. will operate the McLean and Midwest mines, and the McLean Lake mill which will process ore from all mines; and Indemitsu Uranium Exploration Canada, Ltd. will administer the joint venture. Uranium is currently being mined from open pits at McLean Lake and stockpiled for future milling. Once milling commences, tailings will be disposed in the mined out pits. The high U_3O_8 content and weak supporting conditions at Cigar Lake and Midwest Lake necessitated the development of advanced mining technologies. This includes freezing the ore zone to improve structural integrity and using remote mining equipment to limit employees' exposure to radiation. Cameco Corporation will be the operator of the McArthur River project. Ore from the McArthur River mine will be processed at the existing Key Lake mill.

A change in governing parties in Australia could have a profound effect on that country's uranium industry. Although containing abundant low-cost reserves, Australia was restricted for 16 years by government policy from developing new uranium production centers. In 1983, passage of a bill known as the "three-mine policy" limited 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 became a two-mine policy when the government did not approve of an additional site after the Nabarlek mine was closed in 1988. The defeat of the Australian Labor Party (ALP) in March 1996 was followed by expectations that the newly elected Liberal-National Party Coalition Government would allow new uranium production.[59] A change in policy would allow Energy Resources of Australia (ERA) to pursue its longstanding plans to develop the North Ranger 2 (formerly named Jabiluka) orebody to feed the nearby Ranger mill as reserves from the Ranger mine are depleted. With Ranger 2 under production, ERA could expand the capacity of the Ranger mill to nearly 9 million pounds U_3O_8.[60] In May 1996, RTZ Corporation-CRA Limited announced that it would seek governmental approval for the Kintyre deposit in Western Australia.[61]

In the United States, Rio Algom Mining Corporation began constructing an in situ leach facility on its Smith Ranch property in 1996 with the intent to start production in September 1997.[62] The company announced that 50 percent of its first two years' production is committed to meeting matched sales contracts.[63] Smith Ranch could produce up to 2 million pounds U_3O_8 per year. The increase in uranium prices has led other producers to announce plans to construct production facilities in the United States, principally those that will employ in situ leaching. In situ leaching is currently the lowest cost, environmentally acceptable method for producing uranium in select areas of the United States, including Nebraska, New Mexico, Texas, and Wyoming.[64]

Disposition of Surplus Government Inventories

Another key component of the future nuclear fuel supply balance will come from the disposition of inventories for military use declared surplus by the Russian and U.S. Governments. These inventories consist of highly enriched uranium (HEU), and natural uranium and LEU held as feedstock for HEU. To become available for commercial use, the HEU must be blended down to LEU. The HEU agreement signed between the United States and the Russian Federation in January 1994 became the first step in realizing this historic transfer of uranium from the military sector to the commercial nuclear fuel market. This agreement provided for the purchase by the U.S. Enrichment Corporation (USEC) of 500 metric tons of HEU from the Russian Federation over 20 years.[65] The HEU, coming specifically from the dismantling of Russian nuclear weapons, is converted in Russia to LEU containing 4.4 percent U-235, suitable for use as fuel in nuclear power plants.[66] 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

[59] NAC International, "Australia Set to Dump Three-Mines Policy," in *Focus-Nuclear Fuel Cycle Quarterly* (Norcross, GA, Spring 1996), pp. 15-17.
[60] Ibid.
[61] *Ux Weekly*, May 28, 1996, p. 2.
[62] Rio Algom Limited, *First Quarter Interim Report to Shareholders, March 31, 1996* (Toronto, Canada, May 1996), p. 4.
[63] Ibid.
[64] Energy Information Administration, *Uranium Industry Annual 1993*, DOE/EIA-0478(93) (Washington, DC, September 1994), pp. ix-xxv.
[65] 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.
[66] The conversion process is expected to use a blendstock with a U-235 content of 1.5 percent.

pounds U_3O_8 and 92 million separative work units (SWU).[67 68]

The HEU agreement called for the USEC to purchase 10 metric tons of HEU annually in years 1 through 5 of the agreement. This amount is equivalent to 8 million pounds U_3O_8 or 1.9 million SWU per year.[69] The initial shipment of LEU derived from Russian HEU was delayed due to a series of problems including (1) the LEU did not meet product specifications, (2) lack of a mutually acceptable framework for verifying that the LEU ultimately came from dismantled Russian weapons, and (3) payments made to Russia did not include the U_3O_8 feed component. With the resolution of these problems, the first shipment of LEU derived from Russian HEU was delivered to the United States in June 1995. A total of nine shipments were made in 1995, all meeting product specifications.[70] The quantities at which this LEU and its U_3O_8 feed component can be sold by the USEC is specified by the USEC Privatization Act (Table 6).

Consistent with statements made by the two countries, the United States joined Russia in declaring surplus fissile materials from its nuclear arsenal. On March 1, 1995, President Clinton announced that 200 metric tons of U.S.-origin fissile materials were surplus. Further evaluation has expanded the amount of surplus to 213 metric tons, 175 metric tons HEU and 38 metric tons plutonium.[71] Of the total HEU, 73 metric tons could be readily converted into LEU for use as fuel in nuclear power plants. However, 10 metric tons of HEU suitable for conversion will be held in Government inventory for non-weapons use to meet safeguard requirements stipulated by the International Atomic Energy Agency. The remaining 102 metric tons contain various isotopic impurities that would hinder its conversion into commercial-grade LEU. In October 1995, the Department of Energy's (DOE) Office of Fissile Materials Disposition issued a draft environmental impact statement on HEU for public comment.[72] This step is preparatory to a final decision on making the HEU available for use in preparing commercial nuclear fuel.

Thus, 63 metric tons of HEU are expected to become available for commercial use over the next several years. Of the total, 13 metric tons have already been transferred to the USEC without placing any restrictions on the sale of LEU derived from this HEU. The remaining 50 metric tons of HEU have been authorized for transfer to the USEC by the USEC Privatization Act (see the following section). The sale of LEU derived from the 50 metric tons of HEU, however, is restricted by the Act. The total U.S. Government surplus HEU is equivalent to 20.6 million pounds U_3O_8, assuming an average U-235 content of 50 percent for the HEU and 1.5 percent for the blendstock.[73] Thus, U.S. Government surplus HEU is not expected to have as great an impact on the market as Russian HEU.

In February 1996, the Department of Energy's (DOE) Office of Fissile Materials Disposition issued a draft programmatic environmental impact statement to seek public comments on alternatives for disposing and storing of surplus plutonium.[74] One disposal option under consideration is its consumption by commercial nuclear power plants as MOX fuel. This option is technically feasible since MOX fuel is used in the European Union, Japan, and Russia. The DOE would be expected to compensate utilities for costs that would exceed the use of ordinary uranium fuel, as well as the disposal of MOX spent fuel assemblies and shipment to storage facilities.[75] The use of all 38 metric tons of plutonium declared surplus for mixed-oxide (MOX) fuel is estimated to displace about 20 million pounds U_3O_8 equivalent.[76] To gather feedback from utilities on acceptance of the nuclear fuel option, the DOE issued a "Request for Interest" in December 1995. A number of U.S. utilities expressed interest in using MOX fuel from this surplus plutonium. Its penetration in the marketplace, however, is not expected for many years,

[67] Since characteristic uranium compounds are produced in the different stages of the nuclear fuel cycle (i.e., U_3O_8, mining and milling; UF_6, conversion and enrichment; and UO_2 fuel fabrication), industry convention provides for all materials to be expressed as equivalent U_3O_8. Separative Work Unit (SWU) is the standard measure of enrichment services (see glossary).

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

[69] Ibid.

[70] Timbers, W.H., Jr., "Report on the Status of U.S. Enrichment Corporation Privatization," speech presented at the Nuclear Energy Institute's *96 Fuel Cycle Conference* (New Orleans, LA, March 26, 1996).

[71] Tousley, D.R., "U.S. Department of Energy Plutonium and Highly-Enriched Uranium Disposition Programs," paper presented at the Nuclear Energy Institute's *96 Fuel Cycle Conference* (New Orleans, LA, March 26, 1996), p. 1.

[72] U.S. Department of Energy, Office of Fissile Materials Disposition, *Disposition of Surplus Highly Enriched Uranium Draft Environmental Impact Statement*, (DOE/EIS-0240-D) (Washington, DC, October 1995).

[73] Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 4.15-4.16.

[74] U.S. Department of Energy, Office of Fissile Materials Disposition, *Storage and Disposition of Weapons-Usable Fissile Materials Draft Programmatic Environmental Impact Statement*, (DOE/EIS-0229-I) (Washington, DC, February 1996).

[75] Naughton, W.F., "MOX Use in U.S. Commercial Reactors as a Disposition Tool," paper presented at the Nuclear Energy Institute's *96 Fuel Cycle Conference* (New Orleans, LA, March 26, 1996), pp. 8-9.

[76] *Ux Weekly*, April 22, 1996, p. 1.

as numerous political and licensing issues will have to be addressed.

Natural uranium and LEU have also been declared surplus by the DOE. The USEC Privatization Act authorizes the DOE to transfer to the USEC up to 7,000 metric tons of surplus natural uranium and LEU, equivalent to about 18 million pounds U_3O_8.[77] In addition to this transfer, the DOE was also authorized by the USEC Privatization Act to sell its remaining surplus natural uranium and LEU. The Secretary of Energy, however, must determine that the sales of surplus uranium will not have an adverse material impact on the domestic mining, conversion, and enrichment industries, and that the price paid for the uranium is not less than fair market value.

In August 1996, the DOE's Office of Nuclear Energy, Science and Technology issued a draft environmental assessment report which sought public comment on its proposal for selling 21.5 million pounds U_3O_8 equivalent (20.3 million pounds of natural uranium and 1.2 million pounds of LEU).[78] If the proposal is adopted, the surplus uranium would be made available for purchase by domestic or foreign utilities and suppliers beginning in 1996. In addition, the draft environmental assessment provides a proposal for selling 14.2 million pounds U_3O_8 equivalent of the natural feed component of LEU derived from Russian HEU.[79] The DOE was authorized by the USEC Privatization Act to be the sales agent for this feed. A description of the USEC Privatization Act is presented in the following section. The proposed sale of the natural feed component could be made to a combination of purchasers including (1) Russia during 1996, (2) end users outside the United States at any time, (3) U.S. enrichers for overfeeding plants at any time,[80] and (4) U.S. end users, not prior to January 1, 2002, in annual volumes not to exceed 3 million pounds U_3O_8 equivalent.

USEC Privatization Act

On April 26 1996, the USEC Privatization Act was signed into law as part of the Public Law 104-134, the Omnibus Consolidated Rescissions and Appropriation Act of 1996. The United States Enrichment Corporation (USEC) was created as a separate government corporation in 1993 to carry out the uranium enrichment services formerly provided by the DOE. While providing the framework for privatization, the Act also specifies USEC's role as an agent for selling LEU derived from Russian HEU, and natural and enriched uranium transferred from the DOE. The USEC Privatization Act's role in making these materials available to the market is discussed in this section. Its impact on the enrichment services market is discussed later in this chapter.

The USEC Privatization Act gives the USEC the authority to sell both LEU derived from Russian HEU and natural uranium and LEU transferred from the DOE, including LEU derived from U.S. HEU (Table 6). USEC is permitted to sell 2 million pounds U_3O_8 equivalent of LEU derived from Russian HEU in 1998. This limit expands by annual increments of 2 million pounds until reaching 16 million pounds in 2005. For the next 4 years, the limit increases by 1 million pounds until reaching the maximum allowable quantity of 20 million pounds in 2009 and thereafter. Should Russia purchase the U_3O_8 feed component of LEU derived from Russian HEU and deliver it to U.S. consumers, the imports would count against the matched sales quota specified in the amendment to the suspension agreement with the Russian Federation (Table 6). In the case of 30.9 million pounds U_3O_8 equivalent of natural and enriched uranium transferred from the DOE, the USEC is limited to selling 3.1 million pounds U_3O_8 per year, beginning in 1998. In addition to transfers to the USEC, the DOE is also authorized to sell its remaining surplus natural uranium and LEU. Although the quantities and scheduling of sales are not specified, the USEC Privatization Act specifies that sales of uranium from U.S. Government inventories should not have an "adverse material impact" on the domestic uranium industry.

The USEC Privatization Act plays an important role in the market by providing an orderly framework for disposing of surplus government inventories. With the technical aspects of blending down HEU into LEU well established, the schedule provided by the USEC Privatization Act has removed much of the uncertainty in assessing the impact of supply from these sources. However, the total impact on the market will be significant. By 2007, for example, the quantity of material from Russian and U.S. Government inventories that can be sold in the United States could reach 21 million pounds U_3O_8 equivalent. This compares with production of about 14 million pounds U_3O_8 in 1995 from the Key Lake mine in Canada, the world's largest.[81]

[77] Ibid.

[78] U.S. Department of Energy, *Environmental Assessment of DOE Sale of Surplus Natural and Low Enriched Uranium* (draft), DOE/EA-1172 (Washington, DC, August 1996), pp. 2.1-2.3.

[79] Ibid.

[80] Overfeeding involves using more relatively less expensive uranium to produce the same quality of enriched product with less relatively more expensive power.

[81] Natural Resources Canada, "Fact Sheet," in *Canada's Uranium Industry* (Ottawa, Canada, May 31, 1996).

U.S. Uranium Market Activities

Domestic Uranium Production

Improved market conditions for suppliers had a positive effect on uranium concentrate production in the United States during 1995. Output surged by about 80 percent to 6.0 million pounds U_3O_8, compared with an output of 3.4 million pounds in 1994.[82] The output for 1995 was the highest since 1991, but is well below the record 43.7 million pounds produced in 1980.[83] Eight production facilities were operating at the end of 1995 (Figure 7). Nonconventional production came principally from five in situ leaching plants in Nebraska, Texas, and Wyoming, and as a byproduct recovered from phosphate ore processed for phosphoric acid at two plants in Louisiana. Conventional milling resumed in the United States during 1995 for the first time since 1992, with one mill in Utah utilizing as feedstock ore stockpiled from previous years' mining activities. Conventional open pit and underground mines, however, remained closed due to their relatively high production costs. Production in 1996 will continue to come principally from less costly nonconventional plants. The rise in U_3O_8 prices could provide incentive for some in situ leaching plants on standby to resume operating in 1996.

Domestic Utility and Supplier Transactions

Domestic utilities loaded 51.1 million pounds U_3O_8 equivalent into U.S. reactors in 1995.[84 85] These requirements were far greater than domestic production. Thus, much of U.S. demand was met by the sales and purchases of uranium from imports and the drawdown of domestic inventories (Table 7).[86]

In 1995, U.S. utilities took delivery of 43.4 million pounds U_3O_8 equivalent, 5.2 million pounds from domestic sources and 38.2 million pounds as imports.[87] The delivered material came from the following sources: U.S. producers, 5.3 million pounds; U.S. brokers and traders, 16.2 million pounds; U.S. converters, enrichers, and fabricators, 0.6 million pounds; and foreign suppliers, 21.4 million pounds.[88] The quantity-weighted average price of deliveries to U.S. utilities in 1995 was $11.11 per pound U_3O_8 equivalent for domestic contracts and $11.39 per pound for foreign contracts.[89]

Chief origins for imports delivered to U.S. utilities in 1995 were Canada (39 percent), Russia (13 percent), and Australia (10 percent).[90] Deliveries of Russian-origin uranium in 1995 included 2.1 million pounds U_3O_8 equivalent purchased as matched sales transactions.[91] The matched sales transactions were made in accordance with the import quotas specified by the Amendment to the Suspension Agreement between the Russian Federation and the United States.[92] By agreement, some imports of uranium from Russia and other republics of the Former Soviet Union have been excluded from quotas.

Direct import purchases totaled 41.3 million pounds U_3O_8 equivalent in 1995, 21.1 million pounds by utilities and 20.2 million pounds by suppliers.[93] The quantity-weighted average price of deliveries to U.S. utilities and suppliers under foreign purchase contracts was $10.20 per pound U_3O_8 equivalent in 1995.[94] Import commitments of utilities and suppliers from 1996 through 2005 totaled 123.8 million pounds.[95] In 1994, direct purchases of imports by suppliers and U.S. utilities totaled 36.6 million pounds U_3O_8 equivalent.[96] Their contract commitments at the end of 1994 were 124.7 million pounds.[97]

82 Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), p. 7.
83 Energy Information Administration, *Uranium Industry Annual 1993*, DOE/EIA-0478(93) (Washington, DC, September 1994). p. 17.
84 See footnote 42.
85 Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), p. 26.
86 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.
87 Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), p. 19.
88 Ibid, p. 18.
89 Ibid, p. 20.
90 Ibid, derived from p. 19.
91 Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey" (1995).
92 Matched sales transactions and the Amendment to the Suspension Agreement with the Russian Federation are described earlier in this chapter.
93 Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), p. 27.
94 Ibid.
95 Ibid, p. 23.
96 Energy Information Administration, *Uranium Industry Annual 1994*, DOE/EIA-0478(94) (Washington, DC, July 1995), p. 29.
97 Ibid.

Table 7. U.S. Uranium Market Data, 1994-1995

	1994	1995
	(Million Pounds U_3O_8 equivalent)	
Demand and Uranium Production		
Uranium used by domestic utilities in fuel assemblies	40.4	51.1
Domestic concentrate production	3.4	6.0
Utility and Supplier Transactions		
Deliveries by domestic utilities to U.S. and foreign enrichment plants	37.6	44.3
Deliveries to U.S. utilities	38.3	43.4
Direct import purchases by utilities	15.5	21.1
Deliveries to U.S. utilities of Russian-origin U_3O_8 and UF_6 as matched sales transactions	NA	2.1
Direct import purchases by domestic suppliers	21.1	20.2
Commercial Inventories[a]		
Utility inventory, U_3O_8	21.3	22.7
Utility inventory, natural and enriched UF_6	44.1	33.5
Supplier inventory, U_3O_8	13.1	11.6
Supplier inventory, natural and enriched UF_6	8.4	2.3
Total Commercial Inventories	86.9	70.1
Contract and Spot-Market Prices	(Dollars per Pound U_3O_8 equivalent)	
Quantity-weighted average price of deliveries to U.S. utilities under domestic purchase contracts	10.30	11.11
Quantity-weighted average price of deliveries to U.S. utilities under foreign purchase contracts	10.53	11.39
Quantity-weighted average price of deliveries to U.S. utilities and suppliers under foreign purchase contracts	8.95	10.20
Average spot-market price (unrestricted market)	7.05	8.45
Average spot-market price (restricted U.S. market)	9.31	11.46

[a]Excludes inventories held by the U.S. Department of Energy and the U.S. Enrichment Corp.
NA = Not available.
R = Revised data.
Note: Totals may not equal sum of components due to independent rounding.
Sources: **Spot-market prices** (NUEXCO Exchange Values)—TradeTech, *NUEXCO Review* (Denver, CO, January 1996), p. 25; **Matched Sales transactions**–Energy Information Administration, Form EIA-858, “Uranium Industry Annual Survey” (1995); **All other data**–Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), pp. x, 20, 25, 27, 29.

U.S. utilities delivered 44.3 million pounds U_3O_8 equivalent of feed to the suppliers of enrichment services in 1995.[98] The delivered feed was purchased by U.S. utilities in 1995 and in prior years. U.S. enrichment plants received 33.9 million pounds, while foreign enrichment plants received 10.4 million pounds.[99] Chief recipients of uranium feed delivered by U.S. utilities for enrichment outside the United States were plants in France, 46 percent; Russia, 26 percent; and the United Kingdom, 10 percent.[100] A more detailed discussion of the enrichment

[98] Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), p. 24.
[99] Ibid.
[100] Ibid, derived from p. 24.

services market is presented later in the Chapter.[101] Imports continue to be the major source of uranium feed delivered by utilities to enrichers. In 1995, foreign-origin feed contributed 35.1 million pounds U_3O_8 equivalent, or 79 percent of the total feed deliveries.[102] In comparison, 29.1 million pounds of foreign-origin uranium made up 77 percent of total feed delivered in 1994.[103] Main sources of imported uranium feed delivered by U.S. utilities to domestic and foreign enrichers in 1995 were Canada (51 percent), Russia (20 percent), and Australia (9 percent).[104]

Through 2015, mixed-oxide fuel (MOX) will displace some of the demand for uranium in Western Europe and Japan. The displacement of demand for U_3O_8 will be around 6 million pounds by the end of the century, and will increase to almost 9 million pounds by 2015.[105] This projection assumes that all operators of reactors applying for MOX licenses will receive them, that all 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.

Domestic Inventories

Domestic commercial inventories of natural uranium and enriched uranium totaled 70.1 million pounds U_3O_8 equivalent at the end of 1995, 56.2 million pounds held by utilities and 13.9 million pounds held by suppliers.[106] The inventories included U_3O_8, 49 percent; natural uranium hexafluoride (UF_6), 28 percent; and enriched UF_6, 23 percent.[107] At the end of 1994, domestic inventories totaled 86.9 million pounds U_3O_8 equivalent, 65.4 million pounds held by utilities and 21.5 million pounds held by suppliers.[108] Declining inventories and their impact on uranium supply are discussed in a previous section of this chapter. This development indicates that U.S. utilities are not anticipating interruptions in supply of the magnitude that would require maintaining large strategic inventories.

It should be noted that the quantities of commercial inventories listed do not include inventories held by the U.S. Department of Energy (DOE) and by the U.S. Enrichment Corporation (USEC), a government-owned corporation. DOE and USEC inventories were 110.8 million pounds U_3O_8 equivalent, of which 82.0 million pounds were in the form of U_3O_8 and natural UF_6 and 28.8 million pounds were in the form of enriched UF_6.[109]

Projections of World Uranium Requirements

Uranium requirements are defined as the amount of U_3O_8 needed to manufacture fuel for nuclear reactors. These uranium requirements do not include the purchase of uranium to be held as inventory for later use. From 1996 through 2015, nuclear reactors worldwide are projected to need between 3.1 billion and 3.5 billion pounds U_3O_8 (Table 8). The projected annual world uranium requirements range from 119 million to 169 million pounds U_3O_8 in the Reference Case and from 156 million to 198 million pounds U_3O_8 in the High Case (Table 9). In the Reference Case, Western Europe with 35 percent of the world's operating reactors is projected to require 957.9 million pounds U_3O_8, which is 31 percent of the world uranium requirements for 1996 through 2015. The United States follows with projected uranium requirements of 843.3 million pounds U_3O_8, with the Far East next having requirements of 713.8 million pounds U_3O_8 for the same period. Canada, Eastern European countries, and the rest of the world are projected to need a combined total of 542.1 million pounds U_3O_8. In the High Case, a similar distribution exists: Western Europe is projected to require 1017.7 million pounds U_3O_8, the United States 925.5 million pounds, and the Far East 809.4 million pounds.

U.S. Uranium Industry Projections

Projections of spot-market prices, domestic production, net imports, and domestic inventories are developed for 1996 through 2010 using EIA's Uranium Market Model. The projections are based on certain assumptions, some of which relate to world demand for uranium, the existing sources of supply, and planned and prospective sources of supply as a function of future requirements (See text box below). The assumptions used in developing these

[101] Although the enrichment services market is described in a later section, the enriched component of the commercial uranium market is considered in this section since it takes into account the equivalent natural uranium that served as feedstock.
[102] Energy Information Administration, *Uranium Industry Annual 1995*, DOE/EIA-0478(95) (Washington, DC, May 1996), p. 25.
[103] Ibid.
[104] Ibid, derived from p. 25.
[105] Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995), Table 12.
[106] Ibid, p. 28.
[107] Ibid, derived from p. 29.
[108] Ibid, p. 29.
[109] Ibid, p. 29.

Table 8. Projected Cumulative Uranium Requirements for World Nuclear Power Plants, 1996-2015
(Million Pounds U_3O_8)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other[a]		Total World	
	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High
1996 . . .	45.3	45.3	4.9	4.9	22.4	22.7	54.4	54.5	28.5	29.2	3.1	3.3	158.5	160.1
1997 . . .	100.7	100.7	8.9	8.9	43.5	44.6	108.0	107.4	57.4	58.0	5.4	7.1	324.0	326.8
1998 . . .	140.8	140.8	13.4	13.4	66.4	70.2	158.5	158.7	88.3	89.4	7.8	9.8	475.1	482.3
1999 . . .	190.0	190.0	17.1	17.1	88.3	94.6	208.3	208.8	112.9	115.8	12.3	13.4	629.0	639.8
2000 . . .	237.0	237.0	21.7	21.7	106.4	116.3	258.3	259.4	144.6	147.4	15.2	18.7	783.1	800.6
2001 . . .	283.2	283.2	25.9	25.9	126.5	140.4	308.1	309.9	178.1	185.3	18.4	22.4	940.2	967.1
2002 . . .	329.9	329.9	30.5	30.5	147.5	166.8	357.4	359.6	205.6	220.6	21.5	27.4	1,092.5	1,134.7
2003 . . .	378.0	378.0	34.7	34.7	166.0	189.2	407.3	410.3	248.5	260.3	26.7	32.6	1,261.1	1,305.0
2004 . . .	421.8	421.8	38.8	38.8	187.4	214.9	453.5	458.8	279.5	297.0	30.2	38.8	1,411.2	1,470.1
2005 . . .	471.4	472.5	42.9	43.1	207.2	238.2	501.7	508.5	318.4	336.2	33.7	44.5	1,575.3	1,642.9
2006 . . .	517.7	519.4	47.3	48.0	230.4	262.1	550.2	558.9	351.4	372.2	39.9	49.5	1,736.9	1,810.1
2007 . . .	557.2	560.5	50.3	51.4	251.4	294.0	601.1	611.4	391.8	420.4	44.0	55.5	1,895.8	1,993.1
2008 . . .	605.6	610.2	54.0	55.8	270.3	318.6	648.9	662.5	428.7	466.0	48.4	63.5	2,056.0	2,176.6
2009 . . .	647.5	656.8	58.3	60.6	288.3	344.2	695.7	711.8	466.9	507.4	52.8	70.0	2,209.5	2,350.8
2010 . . .	694.3	707.2	61.7	64.5	305.1	376.9	741.7	764.4	512.5	558.4	57.9	77.8	2,373.2	2,549.1
2011 . . .	731.5	750.2	64.8	67.8	321.4	403.4	789.3	814.7	551.2	607.1	62.9	84.1	2,521.1	2,727.3
2012 . . .	762.7	792.9	69.2	72.7	337.6	433.0	835.0	867.9	593.4	658.9	66.6	91.5	2,664.5	2,916.9
2013 . . .	790.8	836.9	72.8	76.6	353.6	460.1	876.5	920.9	636.2	711.3	72.8	98.9	2,802.7	3,104.7
2014 . . .	821.3	884.5	76.2	80.4	366.9	488.7	918.4	972.5	677.3	760.6	77.7	106.4	2,937.8	3,293.1
2015 . . .	843.3	925.5	80.1	84.7	379.2	514.1	957.9	1,017.7	713.8	809.4	82.8	115.1	3,057.0	3,466.7

[a]Other includes Argentina, Brazil, Cuba, Egypt, India, Iran, Israel, Mexico, Pakistan, South Africa and Turkey.
Notes: See Table 4 for a list of the countries making up each region. 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 INM.WK4.

projections also reflect information on the quality of reserves and associated economic costs of mining, milling, and marketing, and the levels of current domestic and foreign inventories.

Spot-Market Price

Over the forecast period, uranium spot-market prices are expected to see both upward and downward movements as the market responds to adjustments in the balance of supply. The spot-market price in constant 1995 dollars is expected to rise to around $17.50 per pound U_3O_8 in 1997 (Table 10). This upward price movement will be caused by the continued decline in Western commercial inventories and restrictions on imports from the countries of the FSU. As such, additional supplies would be needed to meet projected demand. These supplies are expected to enter the market as additional production from new and expanded mines, principally in Canada and Australia, and the disposition of Russian and U.S. Government inventories, including LEU blended down from HEU. With an increase of supply from these sources, the spot price is projected to decline by about $2.50 per pound by 2000. While further decline is expected through 2004, the spot price in 1995 dollars will remain above 1995 levels throughout the forecast period. In the longer term, however, prices are expected to rise after 2005 as reserves become depleted for many of the currently operating low-cost production centers, and as incremental growth ends for sales from government inventories. The spot-market price in constant 1995 dollars is projected to be around $16.10 per pound by 2010.

Supply

The increase in spot-market prices over the next several years should induce domestic production to gradually rise to 8.8 million pounds U_3O_8 by 2004 (Table 11). Although a correction in prices is expected during the first half of the next decade, the overall level of prices is expected to support the cost of this new production. As lower cost reserves are depleted, production is expected to gradually

Table 9. Projected Annual Uranium Requirements for World Nuclear Power Plants, 1996-2015
(Million Pounds U_3O_8)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other[a]		Total World	
	Refer-ence	High	Refer-ence	High	Refer-ence	High	Refer-ence	High	Refer-ence	High	Refer-ence	High	Refer-ence	High
1996 . . .	45.3	45.3	4.9	4.9	22.4	22.7	54.4	54.5	28.5	29.2	3.1	3.3	158.5	160.1
1997 . . .	55.4	55.4	4.0	4.0	21.1	21.9	53.6	52.9	29.0	28.8	2.3	3.8	165.4	166.7
1998 . . .	40.0	40.0	4.5	4.5	22.8	25.6	50.5	51.3	30.9	31.4	2.4	2.7	151.2	155.6
1999 . . .	49.2	49.2	3.7	3.7	22.0	24.4	49.8	50.1	24.6	26.4	4.5	3.5	153.9	157.5
2000 . . .	47.0	47.0	4.5	4.5	18.1	21.7	50.0	50.6	31.6	31.6	2.9	5.3	154.1	160.8
2001 . . .	46.2	46.2	4.2	4.2	20.1	24.1	49.8	50.4	33.5	37.9	3.2	3.7	157.1	166.6
2002 . . .	46.7	46.7	4.6	4.6	21.0	26.3	49.4	49.7	27.4	35.3	3.1	5.0	152.2	167.6
2003 . . .	48.1	48.1	4.1	4.1	18.4	22.4	49.8	50.7	42.9	39.7	5.2	5.2	168.6	170.3
2004 . . .	43.8	43.8	4.2	4.2	21.4	25.7	46.3	48.5	31.0	36.8	3.5	6.2	150.1	165.1
2005 . . .	49.6	50.7	4.1	4.2	20.0	23.3	48.2	49.7	38.9	39.1	3.5	5.7	164.1	172.8
2006 . . .	46.4	47.0	4.4	4.9	23.2	23.9	48.5	50.4	33.0	36.0	6.2	4.9	161.6	167.2
2007 . . .	39.5	41.0	3.0	3.5	21.0	31.9	51.0	52.4	40.4	48.2	4.1	6.0	158.8	183.0
2008 . . .	48.5	49.7	3.8	4.4	18.9	24.6	47.8	51.2	36.9	45.5	4.4	8.0	160.2	183.5
2009 . . .	41.9	46.7	4.2	4.7	18.0	25.6	46.8	49.3	38.2	41.4	4.4	6.5	153.5	174.2
2010 . . .	46.8	50.3	3.4	3.9	16.8	32.7	46.0	52.6	45.6	51.0	5.1	7.7	163.7	198.3
2011 . . .	37.2	43.0	3.1	3.3	16.3	26.5	47.6	50.4	38.7	48.7	5.0	6.3	147.9	178.2
2012 . . .	31.2	42.7	4.4	4.9	16.1	29.6	45.7	53.2	42.2	51.8	3.7	7.4	143.4	189.6
2013 . . .	28.1	44.1	3.6	3.8	16.1	27.1	41.4	53.0	42.8	52.4	6.2	7.4	138.1	187.8
2014 . . .	30.5	47.6	3.4	3.8	13.2	28.7	42.0	51.6	41.1	49.3	5.0	7.5	135.1	188.5
2015 . . .	22.0	41.0	3.9	4.4	12.3	25.4	39.5	45.2	36.5	48.8	5.1	8.7	119.3	173.6

[a]Other includes Argentina, Brazil, Cuba, Egypt, India, Iran, Israel, Mexico, Pakistan, South Africa and Turkey.
Notes: See Table 4 for a list of the countries making up each region. 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 INM.WK4.

decline to 5.7 million pounds in 2010. Lower cost imports and the availability of nontraditional supplies are expected to limit the overall growth of U.S. production. Over the forecast period, domestic production is projected to cover no more than 20 percent of U.S. reactor requirements.

The level of domestic production, although projected to rise in the coming years, will continue to be well below the requirements of U.S. nuclear power plants. Thus, domestic demand will continue to be met by imports as supply from inventory drawdown will continue to decline (Table 11). Over the forecast period, net imports are projected to supply more than 60 percent of domestic requirements. Net imports are projected to rise toward the end of the requirements in 2010.

The level of inventories deemed optimal by U.S. utilities will depend in the future on many factors, including cost considerations of operating in the newly deregulated electric power market and perceptions of the magnitude and availability of uranium supplies. U.S. inventories are projected to fall below their current level, which on average, cover 1.4 years of reactor requirements (Table 11). Continued decline will push inventories to less than 1-year of coverage by 2000, as utilities employ innovative ways to minimize costs associated with their maintenance inventories. Suppliers will substantially reduce their excess inventories to take advantage of price increases.

World Conversion Market Developments

Overview

Most conversion services are purchased through long-term contracts.[110] The trend of spot-market prices nevertheless, is an important indicator of market fundamentals. The

[110] *UX Weekly*, January 9, 1996, p. 5.

Key Assumptions Used in U.S. Uranium Industry Projections

Demand

Projected Uranium Requirements for World Nuclear Power Plants, 1996-2010

- EIA Reference Case (see Table 9)
- Less savings projected by EIA for using mixed oxide (MOX) fuel (reprocessed fuel)[a]

Uranium Production Centers

United States	• Expansion of current centers' capacity completed in 1997 • Reserves of current centers depleted in 2009 • New centers begin producing in 1997
Canada	• Reserves of current centers depleted in 2002 • New centers begin producing in 1997
Australia	• Current centers continue to produce beyond 2010 • Expansion of current centers' capacity completed by 2005 • Political change in 1996 results in end to restrictions on developing new mines ("three-mine policy") • New centers begin producing in 1998
Namibia	• Expansion of current center's capacity completed by 2005
Gabon and Niger	• Production continued to be supported by the French nuclear power program
Kazakhstan and Uzbekistan	• Production stabilizes by 2005, ending trend of declining production

Quotas/Schedules for Marketing Nontraditional Sources of Uranium in the United States[b]

Uranium from Kazakhstan, Russia, and Uzbekistan	• Quotas determined by Amendments to the Suspension Agreements between the United States and each republic
Russian HEU	• Annual sales of LEU from blending down of Russian HEU not to exceed 12 million pounds U_3O_8 equivalent per year after 2003 • Sales of uranium feed component is counted against the quota specified by the Amendment to the Suspension Agreement with the Russian Federation
U.S. Surplus Government Inventory	• Annual sales of material transferred from DOE to USEC not to exceed 3 million pounds U_3O_8 equivalent per year between 1998-2008

[a]Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995), Table 12.
[b]See Table 6 and text under "Uranium Market Developments" in this chapter for more detailed information on the quotas/schedules and their legal framework.

Table 10. Projected U.S. Spot-Market Prices for Uranium Under Current Market Conditions, 1996-2010
(Constant 1995 Dollars per Pound U_3O_8)

Year	Price
1996	16.15
1997	17.48
1998	17.27
1999	15.04
2000	15.02
2001	14.57
2002	14.17
2003	14.12
2004	13.33
2005	13.49
2006	13.46
2007	14.23
2008	14.76
2009	15.83
2010	16.13

Note: Adjusted by three-point smoothing.
Source: Energy Information Administration, Uranium Market Model run no. 1996_11.DAT, July 8, 1996.

current conversion services market has been strongly influenced by the closure of the Sequoyah Fuels Company plant in the United States at the end of 1992.[111] That plant's nominal capacity of 9.1 thousand metric tons of uranium, or about 17 percent of the Western world's capacity available in 1992, was considered excess by the market.[112] Responding to this decline in excess capacity, spot-market prices, as indicated by the average Nuexco Conversion Value, increased 28 percent from $3.20 per kilogram U in January 1993 to $4.08 per kilogram U in February 1993.[113] This was the most significant price movement for conversion services in the 1990's. Between the end of 1993 and the end of March 1996, the spot price increased gradually to $5.85 per kilogram U from $5.35 per kilogram U.[114] [115] Unlike the U_3O_8 and enrichment markets, considerable inventories of natural UF_6 are held by utilities and suppliers. These excess inventories have kept prices from rising in absence of excess capacity.

Conversion Services Profile

The current worldwide nominal capacity for uranium hexafluoride (UF_6) conversion of 61.2 thousand metric tons uranium is available from 13 plants in 9 countries (Table 12). These plants produce UF_6, the basic feedstock for enriching uranium used as fuel in light water reactors. Other plants which produce intermediate conversion products that are ultimately converted to UF_6 are not included in Table 12. France, Russia, and the United States are major providers of conversion services.

Converdyn, a joint venture between Allied Signal and General Atomics, operates the only conversion facility in the United States at Metropolis, Illinois. The joint venture was created in 1993, as General Atomics wished to remain in the conversion business after it closed the Sequoyah Fuels Company's plant at the end of 1992.[116] The Metropolis plant is across the Ohio River from the U.S. Enrichment Corporation's enrichment plant at Paducah, Kentucky (Figure 7).

Several countries have conversion facilities that can serve special fuel requirements.[117] In Canada, conversion services are available to meet the requirements of Canadian-designed Candu reactors, as well as those of light water reactors. All conversion services in Canada begin at the Blind River, Ontario plant where U_3O_8 is converted into UO_3. UO_3 can be loaded directly into Candu reactors without enrichment. For conversion services required by light water reactors, UO_3 represents an intermediate product that is further converted to UF_6 at the Port Hope, Ontario plant. In France, uranium from reprocessed spent fuel can be converted to UF_6 at the Pierrelatte 2 facility.

EIA does not make projections of conversion service requirements. However, these requirements are expected to reflect similar trends reported in the following section on Enrichment Services requirements. Countries in the Far East will offer the greatest growth in demand for nuclear fuel services. On the supply side, the use of mixed-oxide fuels and the disposition of Russian and U.S. Government inventories of LEU and HEU will decrease the demand for conversion services. At least until 2003, sales of LEU from Russian HEU will follow quotas

[111] NuclearFuel, "General Atomics' Bank is Unwilling to Finance Closed Sequoyah Fuels Corporation's Decommissioning," (December 7, 1992), pp. 6-8.
[112] Energy Information Administration, *World Nuclear Capacity and Fuel Cycle Requirements,* DOE/EIA-0436(92) (Washington, DC, December 1992), p. 115.
[113] TradeTech, *Nuexco Review* (Denver, CO, November 1995), p. 27.
[114] TradeTech, *Nuexco Review* (Denver, CO, November 1995), p. 27.
[115] *Ux Weekly*, April 1, 1996, p. 5.
[116] NuclearFuel, "Sequoyah Fuels to Call It Quits in July, but Decommissioning Questions Remain" (February 15, 1993), pp. 3-4.
[117] NAC International, *Nuclear Industry Status Report on UF_6, A Fuel-Trac Product* (Norcross, GA, February 1995), Table B-3.1.

Table 11. Projected U.S. Uranium Requirements, Net Imports, Commercial Inventories, and Production of Uranium, 1996-2010
(Million Pounds U_3O_8 Equivalent)

Year	Requirements[a]	Net Imports[a,b]	Commercial Inventories[a]	Production[a]
1996	46.9	29.7	69.3	7.2
1997	46.9	30.4	62.0	8.0
1998	48.2	29.4	55.9	8.2
1999	45.4	30.0	50.1	8.2
2000	47.5	30.8	47.3	8.2
2001	46.6	32.5	44.6	8.4
2002	47.0	33.0	42.6	8.4
2003	46.2	33.4	40.1	8.7
2004	47.2	33.5	39.6	8.8
2005	46.6	33.7	38.6	8.5
2006	45.2	33.8	37.6	7.7
2007	44.8	33.8	36.8	7.7
2008	43.3	35.2	36.1	7.7
2009	45.7	35.8	35.6	7.2
2010	42.0	35.9	35.1	5.7

[a]Adjusted by three-point smoothing.
[b]Net imports = total imports less exports.
Source: **Requirements**—Energy Information Administration, International Nuclear Model, File INM.WK4. **Net Imports, Inventories and Production**—Energy Information Administration, Uranium Market Model run no. 1996_11.DAT, July 8, 1996.

Table 12. World Uranium Hexafluoride Conversion Facilities

Country	Owner/Controller	Plant Name/Location[a]	Capacity[b]
United States	Converdyn	Metropolis, Illinois	14,000 MTU/year
Canada	Cameco	[c]Port Hope, Ontario	10,500 MTU/year
China	CNNC	Lanzhou	[d]1,000 MTU/year
France	COMURHEX	[e]Pierrelatte 1	14,000 MTU/year
	COMURHEX	[f]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	Minatom	Tomsk, Ekaterinburg, and Angarsk	14,000 MTU/year
India	DAE	Trombay	185 MTU/year
	DAE	Hazia	110 MTU/year
Total			**61,195 MTU/year**

[a]Conversion of U_3O_8 to uranium hexafluoride (UF_6) unless otherwise noted.
[b]Nominal capacity as of December 31, 1994.
[c]UO_3 to UF_6. U_3O_8 is converted to UO_3 as an intermediate step at Blind River, Ontario.
[d]NAC International's estimate based on domestic fuel cycle industry.
[e]UF_4 to UF_6. U_3O_8 is converted to UF_4 as an intermediate step at the Malvesi plant.
[f]Conversion of reprocessed uranium to UF_6.
MTU = metric tons of uranium.
Source: NAC International, *Nuclear Industry Status Report on UF_6, A Fuel-Trac Product* (Norcross, GA, February 1995), Table B-3.1.

established by the USEC Privatization Act and the Amendment to the Suspension Agreement with the Russian Federation. Although the USEC Privatization Act allows for the conversion component of Russian HEU to be sold without restrictions, the overall quota on LEU should minimize the effect of this material on existing converters through 2003. The U.S. Government will also dispose of inventories of LEU and HEU in a predictable way, as specified by the USEC Privatization Act.

World Enrichment Market Developments

Overview

Most purchases of enrichment services are made through long-term contracts. In 1995, 10 U.S. and foreign utilities entered into long-term contracts with enrichers for about 7 million separative work units (SWU) to be delivered through 2005.[118] The average contract length was 6.5 years for U.S. utilities and 7.5 years for foreign utilities.[119] In contrast, spot purchases of enrichment services in the world market totaled 920 thousand SWU in 1995.[120] The average spot-market price for the restricted market in 1995, as indicated by the average Nuexco SWU Value, was $92.42 per SWU, an increase of 8 percent from $85.63 per SWU in 1994.[121] For the unrestricted market, the average Nuexco SWU Value was $81.83 per SWU, an increase of 21 percent from $67.58 per SWU in 1994.[122] Prices for both the restricted and unrestricted markets during the first quarter 1996 did not change from those at year-end 1995, $95.00 per SWU and $90.00 per SWU, respectively.[123]

The enrichment market also experienced declining excess inventories and restrictions on imports. Imports were further restricted as the amendment to the suspension agreement with the Russian Federation called for matched SWU transactions to end in March 1996. As a result, less supply was available for secondary market transactions. Unlike U_3O_8 producers, however, the enrichment industry has substantial excess capacity. In 1995, requirements were about 70 percent of the world's available enrichment capacity.[124] Moreover, demand is projected to increase only marginally over the next decade (projections are presented later in the chapter). Thus, less upward pressure was exerted on SWU prices than on U_3O_8 prices during 1995.

Responding to a "buyers" market, suppliers are offering utilities more flexible contracts. In addition to offering more flexible contracts, enrichers could enhance their competitive position by marketing enriched uranium product (EUP).[125] With the option of purchasing EUP, utilities are expected to benefit by incurring less administrative and inventory holding costs.

The quantity of EUP by which an enricher can supply depends on its access to competitively priced feed. In the late 1980's, the Soviets became the first to sell EUP, because uranium from the United States and other Western countries could not be shipped to Russia for enrichment. Low prices made these imports particularly attractive. In 1994, the U.S. Enrichment Corporation (USEC) began marketing EUP through long-term contracts.[126] The USEC was authorized by The Energy Policy Act (1992) to market EUP, an option that had not been made available to DOE. The feed for the USEC's EUP comes from natural and enriched UF_6 inventories that were transferred from the DOE. Other major enrichers apparently have not sold EUP to date.[127] In recent years, EUP transactions have been limited because most utilities had previously entered into long-term contracts for U_3O_8, conversion, and enrichment services. Furthermore, the availability of EUP from Russia has been subject to trade restrictions in the European Union and the United States. The demand for EUP from utilities in the United States, however, could increase to 40 percent of requirements in 10 years.[128]

[118] Uranium Exchange Company, *Enrichment Market Outlook* (New Fairfield, CT, May 1996), p. 7.
[119] Ibid.
[120] Ibid, p. 4.
[121] TradeTech, *Nuexco Review* (Denver, CO, November 1995), p. 26, and *Ux Weekly*, December 1995 through May 1996.
[122] Ibid.
[123] Ibid.
[124] NAC International, *Nuclear Industry Status Report on Enrichment, A Fuel-Trac Product* (Norcross, Georgia, February 1996), Table 3.1 (capacity); Section F, p. 1 (requirements).
[125] Enriched uranium product (EUP) transactions differ from traditional enrichment service arrangements, in that the customer purchases a product, rather than a service. The purchase price of the EUP includes the feed component as well as the enrichment component. The customer, however, does not procure the feed and deliver it to the enricher.
[126] The United States Enrichment Corporation (USEC) was created as a separate government corporation in 1993 to carry out the uranium enrichment services formerly provided by the U.S. Department of Energy (DOE).
[127] Uranium Exchange Company, *The Evolving EUP Market, Implications for Suppliers, Utilities, and Government Agencies* (Danbury, CT, November 1995), pp. 6-7.
[128] Ibid., p. iv.

The USEC Privatization Act was signed into law on April 26, 1996, as Public Law 104-134; it provided a legal framework for fully privatizing the uranium enrichment assets owned by the U.S. Government. To accomplish this objective, a dual-track schedule was authorized that consisted of a merger or acquisition involving a strategically related company or consortium, followed by an initial public stock offering. In addition, the USEC Privatization Act specifies the quantities of LEU from Russian HEU and U.S. Government excess inventories that can be sold by the USEC (Table 6). In addition to having access to these supplies, the competitive strength of the new company could be further enhanced by earlier agreements with the DOE in which technology was transferred and certain liabilities were taken over by the Government.

Government agencies continue to review the Louisiana Energy Services' (LES) application for a license to build a 1.5 million-SWU per year centrifuge plant in Claiborne Parish, Louisiana. In May 1996, LES received a favorable ruling from the NRC on its emergency, security, and safeguards plans, and a permit from the U.S. Environmental Protection Agency for discharging normal wastewater.[129] Ownership of LES is held between a supplier of enrichment services (Urenco), utilities (Duke Power and others), and a firm involved in the construction of the facility (Fluor Daniel Corp.). If completed, the Claiborne facility would be the first new enrichment plant to be built in the United States since the mid-1950's.

Enrichment Services Profile

The current worldwide installed enrichment capacity is 48.7 million SWU per year,[130] 30.5 million SWU from gaseous diffusion plants and 18.2 million from centrifuge plants (Table 13). The USEC with plants in Portsmouth, Ohio, and Paducah, Kentucky (Figure 7), holds 39 percent of this capacity. Russia and France also hold significant capacity with shares of 29 and 22 percent, respectively.

Table 13. World Uranium Enrichment Facilities
(Thousand Separative Work Units)

Type of Facility / Country	Owner/Controller	Plant Name/Location	Capacity[a]
Gaseous Diffusion Plants			
United States	U.S. Enrichment Corp.	Paducah, Kentucky	11,300
	U.S. Enrichment Corp.	Portsmouth, Ohio	7,900
France	EURODIF	Tricastin	10,800
China	CNNC	Lanzhou	500
Subtotal			30,500
Centrifuge Plants			
Germany, Netherlands, and United Kingdom	Urenco	Gronau, Almelo, and Capenhurst	3,375
Japan	PNC	Ningyo Toge	200
	Japan Nuclear Fuels, Ltd.	Rokkashomura	600
Russia	Minatom	Ekaterinburg, Tomsk, Krasnoyarsk, and Angarsk	[b]14,000
Subtotal			18,175
Total			**48,675**

[a]Nominal capacity as of December 31, 1995.
[b]Most likely available capacity, not confirmed by Minatom.
Source: NAC International, *Nuclear Industry Status Report on Enrichment, A Fuel-Trac Product* (Norcross, GA, February 1996), Table B-3.1.

[129] *Ux Weekly* (May 6, 1996), p. 3.
[130] Available capacity does not include plants in Argentina and Pakistan that are believed to have capacities of less than 100 metric tons SWU.

Four plants, in the United States, France, and China, use the gaseous diffusion technology. Nine centrifuge plants are operated in Germany, Japan, Netherlands, Russia, and the United Kingdom. Worldwide capacity currently exceeds projected requirements for enrichment services (projections of requirements are presented in the following section).

Gaseous diffusion plants require much more energy to operate than centrifuge plants. To reduce costs, Cogema and USEC operate to take advantage of off-peak electricity rates. As such, their economic capacity is actually less than their installed capacity. The gaseous diffusion plants are currently competitive largely because most of their capital costs have been depreciated.

Centrifuge plants have a greater capital component of total cost than do gaseous diffusion plants. In response, Urenco has added just enough centrifuge capacity to meet expected commitments. As capital costs become depreciated, centrifuge plants will incur far less total costs than gaseous diffusion plants. Centrifuge technology is also more amenable to enriching reprocessed fuel. To take advantage of these competitive benefits, an additional 3.5 million SWU centrifuge capacity could become available by 2000, primarily in Japan, Western Europe, and the United States.[131]

To increase its competitiveness in the future, the USEC could close one of its gaseous diffusion plants if the foregone capacity could be replaced by LEU from Russian HEU or by a facility less costly to operate. Although Russia has demonstrated its dependability in filling commitments in the past, the latter option is potentially a greater risk to USEC than operating its own facility. A new production facility, however, would not be ready for many years (see below). In the interim, the USEC could use Russian LEU to reduce production in its gaseous diffusion plants in order to optimize electricity consumption. The USEC could also provide EUP as a competitive strategy. Since the USEC is not an integrated producer like Cogema, however, its source of feed is limited to inventories transferred from the DOE. LEU from Russian HEU is not considered a source of EUP because the USEC does not control the feed component. To maintain its position as a supplier of EUP, the USEC could become vertically integrated in the upstream stages of the nuclear fuel cycle, either through acquisitions or strategic partnerships.

As a possible replacement for one or more of its gaseous diffusion plants, the USEC continues to develop the advanced vapor laser isotope separation (AVLIS) technology. The research for AVLIS, the first new fuel cycle technology since the 1950's, was started by the DOE. The technology uses lasers to separate U-235 atoms from vaporized solid uranium metal. A full-scale prototype was built by the USEC, but no license application for a pilot plant has been submitted to date.[132] AVLIS research and development spending in Fiscal Year 1996 more than doubled from the previous year. By March 1996, contracts were in place for architectural, engineering, environmental, licensing, and uranium management support. The USEC announced plans for AVLIS to start in 2002 and reach full production in 2003.[133]

Projections of World Uranium Enrichment Services Requirements

Total worldwide enrichment service requirements from 1996 through 2015 are projected at 664 million to 750 million SWU (Table 14). Projections on an annual basis range from 29 million to 44 million SWU (Table 15). The use of MOX fuel in Western Europe and Japan is expected to reduce annual world enrichment service requirements by about 2 million SWU after the turn of the century.[134] For the Reference Case, Western Europe accounts for 34 percent of the total projected enrichment service requirements through 2015. The United States and the Far East follow with shares of 29 percent and 24 percent, respectively. For the High Case, Eastern Europe and the Other regions are projected to increase their relative share of total projected enrichment requirements by 1 to 3 percent at the expense of Western Europe and the United States. It should be noted that while Canada requires natural uranium, the Candu-type reactors operating in that country do not require enrichment services.

World Light Water Reactor Fuel Fabrication Market Developments

Overview

Fuel fabrication is much less of a commodities business than the uranium, conversion, and enrichment industries.

[131] Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), p. 6.43.

[132] Timbers, W.H., Jr., “Report on the Status of U.S. Enrichment Corporation Privatization,” speech presented at the Nuclear Energy Institute's *96 Fuel Cycle Conference* (New Orleans, LA, March 26, 1996).

[133] Ibid.

[134] Energy Information Administration, *World Nuclear Outlook 1995,* DOE/EIA-0436(95) (Washington, DC, October 1995), Table 18.

Table 14. Projected Cumulative Enrichment Service Requirements for World Nuclear Power Plants, 1996-2015
(Million Separative Work Units)

Year	United States		Eastern Europe		Western Europe		Far East		Other[a]		Total World	
	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High
1996	11.2	11.2	4.3	4.6	12.0	12.3	6.2	6.1	0.4	0.4	34.1	34.6
1997	21.9	21.9	8.4	8.8	23.5	24.0	12.2	12.4	0.6	0.5	66.6	67.6
1998	31.3	31.3	12.8	13.7	35.1	35.5	18.5	18.6	1.0	1.2	98.7	100.2
1999	42.1	42.1	16.9	18.3	47.3	47.8	23.8	23.7	1.2	1.5	131.3	133.4
2000	51.7	51.7	21.0	23.0	58.8	59.3	30.2	30.5	1.7	1.9	163.4	166.3
2001	62.8	62.8	25.6	28.4	70.1	70.6	36.9	37.5	2.1	2.7	197.5	202.0
2002	74.2	74.2	29.9	33.7	81.6	82.4	43.3	43.8	2.6	3.0	231.6	237.2
2003	83.7	83.7	34.3	38.9	93.2	94.3	49.9	51.1	3.0	3.6	264.0	271.6
2004	94.4	94.4	38.7	44.2	104.3	105.7	58.0	59.9	3.4	4.2	298.8	308.5
2005	105.6	105.7	42.9	49.4	115.7	117.4	66.1	69.0	3.8	5.2	334.0	346.7
2006	114.6	115.0	47.7	54.7	127.4	129.6	73.6	77.2	4.3	5.7	367.7	382.1
2007	125.3	126.0	52.5	60.3	138.8	141.2	82.7	87.2	5.2	6.3	404.5	421.1
2008	136.1	137.0	56.4	67.2	150.1	152.7	91.0	97.6	5.5	7.1	438.9	461.6
2009	145.2	147.2	60.8	72.6	161.4	164.7	99.5	107.6	6.1	8.2	473.2	500.3
2010	155.6	158.0	64.4	78.4	172.3	176.2	108.8	118.0	6.8	8.8	508.0	539.5
2011	164.9	168.9	68.3	86.7	183.3	188.7	118.5	129.1	7.5	10.2	542.4	583.4
2012	172.4	179.2	71.8	92.5	194.2	200.8	127.6	140.7	7.7	11.0	573.8	624.2
2013	179.2	189.4	75.4	98.8	204.4	213.3	137.2	152.8	8.4	11.8	604.5	666.0
2014	186.8	200.3	78.4	104.7	214.3	225.2	146.5	164.1	9.0	12.9	635.0	707.2
2015	192.5	211.4	81.0	110.3	224.5	237.1	156.3	176.8	9.4	14.1	663.8	749.6

[a]Other includes Argentina, Brazil, Cuba, Egypt, India, Iran, Israel, Mexico, Pakistan, South Africa and Turkey.
Notes: See Table 4 for a list of the countries making up each region. 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 INM.WK4.

The major difference between the market for fuel fabrication and those of the upstream nuclear fuel cycle is that transactions are for combined design, manufacture, installation, and servicing of fuel assemblies and are tailored for a variety of nuclear power plants. This section will focus on the fabrication of fuel for light water reactors, because the majority of the Western world's nuclear power reactors are boiling water or pressurized water designs.[135] Uranium oxide is most commonly used in fuel assemblies installed in Western light water reactors. However, a demand has arisen for MOX fuel, specifically in Japan and Western Europe.

Worldwide, the current world capacity for light water reactor fuel fabrication is 150 percent of requirements.[136] Overcapacity is more pronounced in the United States, where domestic requirements are exceeded by approximately 200 percent.[137] Accordingly, contract prices for light water reactor fuel in nominal dollars are not expected to change appreciably in the coming years. They are around $185 per kilogram U for pressurized water reactors and around $260 per kilogram U for boiling water reactors.[138]

Nuclear fuel fabricators are driven to innovate to keep pace with changing fuel management practices.[139] To reduce outages, most U.S. utilities have increased refueling cycles for their light water reactors from 12 months to 18 or 24 months. Foreign utilities are beginning to adopt similar practices. Customers are also demanding higher enrichment assays and extended burnup levels. Because there is little actual experience in operating fuel

[135] A roster of nuclear power plants operating in the world, including reactor type, is presented in Appendix C.
[136] Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), p. 7.1.
[137] Ibid.
[138] Ibid, pp. 7.27-7.28.
[139] A detailed description of nuclear fuel management practices is provided in Appendix B.

Table 15. Projected Annual Uranium Enrichment Service Requirements for World Nuclear Power Plants, 1996-2015
(Million Separative Work Units)

Year	United States		Eastern Europe		Western Europe		Far East		Other[a]		Total World	
	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High
1996	11.2	11.2	4.3	4.6	12.0	12.3	6.2	6.1	0.4	0.4	34.1	34.6
1997	10.7	10.7	4.2	4.2	11.5	11.7	6.0	6.3	0.2	0.2	32.5	33.0
1998	9.4	9.4	4.4	4.9	11.6	11.5	6.3	6.2	0.4	0.6	32.1	32.6
1999	10.8	10.8	4.1	4.6	12.2	12.3	5.3	5.1	0.2	0.3	32.7	33.2
2000	9.6	9.6	4.1	4.7	11.4	11.5	6.4	6.8	0.6	0.4	32.1	32.9
2001	11.1	11.1	4.6	5.5	11.3	11.3	6.7	7.0	0.3	0.8	34.1	35.7
2002	11.4	11.4	4.2	5.2	11.6	11.8	6.4	6.3	0.5	0.4	34.1	35.1
2003	9.5	9.5	4.4	5.2	11.5	11.9	6.6	7.2	0.4	0.5	32.5	34.4
2004	10.7	10.7	4.4	5.3	11.1	11.4	8.1	8.8	0.4	0.7	34.7	36.9
2005	11.2	11.3	4.2	5.2	11.4	11.8	8.1	9.1	0.4	0.9	35.3	38.2
2006	9.0	9.2	4.8	5.3	11.8	12.2	7.6	8.3	0.5	0.5	33.6	35.4
2007	10.7	11.1	4.8	5.6	11.4	11.6	9.1	10.0	0.9	0.7	36.9	39.0
2008	10.8	10.9	3.9	6.9	11.2	11.5	8.3	10.3	0.2	0.8	34.4	40.5
2009	9.2	10.2	4.5	5.4	11.4	12.0	8.6	10.1	0.6	1.1	34.2	38.8
2010	10.4	10.9	3.6	5.8	10.9	11.5	9.3	10.3	0.6	0.6	34.8	39.1
2011	9.3	10.8	3.9	8.3	10.9	12.4	9.6	11.1	0.7	1.3	34.4	44.0
2012	7.5	10.3	3.5	5.8	10.9	12.2	9.2	11.6	0.2	0.8	31.3	40.8
2013	6.7	10.2	3.6	6.3	10.3	12.4	9.5	12.1	0.7	0.8	30.8	41.8
2014	7.6	10.9	3.0	5.9	9.9	11.9	9.3	11.4	0.6	1.1	30.5	41.2
2015	5.7	11.1	2.7	5.6	10.2	11.9	9.8	12.6	0.4	1.1	28.8	42.4

[a]Other includes Argentina, Brazil, Cuba, Egypt, India, Iran, Israel, Mexico, Pakistan, South Africa and Turkey.
Note: See Table 4 for a list of the countries making up each region. 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 INM.WK4.

assemblies at these specifications, utilities are asking for and receiving fuel reliability warranties from fabricators.

Fuel Fabrication Suppliers Profile

At the beginning of 1995, the total installed capacity for fabricating uranium oxide fuel for light water reactors was 11.1 thousand metric tons uranium at 24 facilities in 13 countries (Table 16). Most of this capacity was located in countries with large domestic nuclear power programs. The United States holds 35 percent of the world's uranium oxide fuel fabrication with plants in Missouri, North Carolina, South Carolina, Virginia, and Washington (Figure 7). Japan, Russia, France, and Germany account for 51 percent. For MOX fuel fabrication, a total installed capacity of 65 metric tons initial heavy metal (MTIHM) was available from four facilities in Belgium, France, Japan, and the United Kingdom in the beginning of 1995.

With the exception of the Far East, little growth in demand is expected for fabricating uranium oxide fuel for light water reactors. In response to overcapacity and declining profit margins, the industry has seen much consolidation over the last decade. This trend is particularly evident In the United States, where foreign firms have acquired three out of the five domestic fabricators.[140] Exxon and Babcock and Wilcox divested their interests in 1987 and 1993, respectively. Siemens Power and Framatome Cogema Fuels are the new operators. Framatome Cogema acquired Babcock and Wilcox's share of B&W Fuel Company in 1993, and the name was formally changed to Framatomme Cogema Fuels in January 1996. In 1990, Combustion Engineering was acquired by Asea Brown Boveri, Ltd.

MOX fuel is expected to show the greatest growth over the next several years, as the use of recycled uranium and

[140] Ibid, pp. 7.5-7.10.

Table 16. World Light Water Reactor Fuel Fabrication Facilities

Type of Facility / Country	Owner/Controller	Plant Name/Location	Capacity[a]
Uranium Oxide Fuel Fabrication			
United States	B&W Fuel Company[b]	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
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
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
South 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	190 MTU/year
Total			**11,090 MTU/year**
Mixed Oxide (MOX) Fuel Fabrication			
Belgium	Belgonucleaire SA	Dessel	35 MTIHM/year
France	COGEMA	Cadarache	15 MTIHM/year
Japan	PNC	Tokai-Mura	10 MTIHM/year
United Kingdom	British Nuclear Fuels, Ltd.	Sellafield	5 MTIHM/year
Total			**65 MTIHM/year**

[a]Nominal capacity as of December 31, 1994.
[b]Company was renamed Framatome Cogema Fuels in 1996.
MTU = metric tons of uranium.
MTIHM = metric tons of initial heavy metal.
Source: 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.

plutonium gain greater acceptance. For example, seven French reactors are currently using MOX fuel with plans to increase to 28.[141] In early 1995, MOX fuel production began at the Melox facility in France. Cogema, its owner, announced plans in September to apply for a license to increase the capacity at Melox from 100 MTIHM to 160 MTIHM.[142] Major expansion is also planned for Sellafield in the United Kingdom, where British Nuclear Fuel Limited (BNFL) expects to increase capacity to 120 MTIHM in 1998.[143] Expansion is also planned at facilities in Belgium and Japan. One of the largest MOX fuel fabricators, Cogema, also operates facilities for reprocessing

[141] Gloaugen, Alain, "Utility Experience with MOX Fuel: Economics and Public Acceptance Issues," paper presented at Nuclear Energy Institute's *1996 Fuel Cycle Conference* (New Orleans, LA, March 26, 1996).
[142] *NuclearFuel*, "Cogema Preparing Addition of MOX Capacity at Melox, La Hague," (September 25, 1995), pp. 10-12.
[143] NAC International, *Nuclear Industry Status Report on LWR Fabrication*, A Fuel-Trac Product (Norcross, GA, August 1995), Table B-3.2.

spent fuel, as well as for all parts of the front end processes.

Spent Fuel Disposal

Resolution of the spent nuclear fuel disposal problem is high on the list of priorities for the U. S. nuclear industry. Progress is still being made on site characterization at Yucca Mountain, Nevada with more than one-half of the planned five-mile exploratory tunnel having been completed ahead of schedule. This occurred in spite of a 40-percent reduction in funding for the 1996 fiscal year. Congress has directed the Office of Civilian Radioactive Waste Management (OCRWM) to continue existing scientific work to determine the feasibility and licensability of a permanent repository at Yucca Mountain while deferring the preparation and filing of a license application for the repository with the Nuclear Regulatory Commission. Accordingly, OCRWM has issued a draft program plan[144] that maintains a target for a license application to the Nuclear Regulatory Commission in 2002.

Also because of the reduced budget, the multi-purpose canister (MPC) development program[145] will end after the first phase which is the completion of the MPC safety analysis report design. OCRWM will not be funding the second (certification) nor the third (production) phases of the MPC development but will make the technology available to private industry for further development.[146] In fiscal year 1996, OCRWM has been developing a waste acceptance and transportation plan that will rely on the private sector for implementation. The goal is to allow fuel to be accepted from utilities and moved to an interim storage facility or repository as soon as either is available. This new plan should help U.S. utilities with their dilemma of possibly having their spent fuel pools or dry storage facilities reach capacity before the end of the operating life of their reactors.

An effort to develop a privately owned interim spent fuel storage failed as the Mescalero Apache tribe rejected the plan to build a temporary, above-ground storage facility on Mescalero land in New Mexico. The deal would have earned the Mescaleros about $240 million over the next 40 years. Opponents of the plan are concerned that the temporary repository could become a permanent one if the DOE fails to license the permanent underground repository in Nevada.

Some European countries have found unique ways to deal with the spent fuel disposal problem. For example, Finland's two nuclear utilities, Imatran Voima Oy (IVO) and Teollisuuden Voima Oy (TVO) have pooled their resources to deal with managing spent fuel. So far, they are disposing of low- and intermediate-level waste in repositories excavated at the Loviisa site of IVO and at Olkiluoto. They also have been cooperating in the search for a geological repository for high-level waste. In addition to searching for a repository site, this program will include the development of technical methods for suitable encapsulation of spent fuel and finally for the construction and operation of the final repository. If the site is selected by 2000, the construction will begin around 2010 and the expected date of operation for the repository will be 2020.

All projects are not running as smoothly. Voters in the Nidwalden region of Switzerland have rejected a plan to investigate a possible site for an intermediate- and low-level waste repository. The Swiss waste management agency, Nagra, has permission to build support buildings aboveground but was not able to get permission to tunnel into the side of the mountain which would provide a gallery for final investigations of the suitability for a waste repository.[147] A number of countries have experienced similar problems to those of the United States as there is political resistance to spent fuel disposal projects. In Japan new storage facilities estimated to hold about 13,000 tons will be necessary before 2010.[148] The problem is more pressing in South Korea since they will need to solve their storage problem just after 2000.

U.S. Utility At-Reactor Dry Storage

Spent nuclear fuel continues to be discharged from U.S. nuclear reactors at a moderately increasing rate. The problems associated with storing spent nuclear fuel are being resolved on a utility-by-utility basis. Some utilities are reracking their spent fuel storage pools and others

[144] Office of Civilian Radioactive Waste Management program Plan, Revision 1, DOE/RW-0458 (Washington, DC, May 1996).

[145] The multi-purpose canister development program involves the design of a canister which will be used to store, transport, and dispose of commercial spent nuclear fuel. This initiative requires the preparation of an environmental impact statement, and certification and licensing by the Nuclear Regulatory Commission.

[146] Microsoft Internet, http:\www.rw.doe.gov, June 12, 1996 letter by Linda J. Desell, Director Environmental and Operational Activities Division, Office of Civilian Radioactive Waste Management.

[147] Nuclear News, "Swiss Nidwalden region votes against repository," August 1995, p. 85

[148] C.K. Anderson, "Interim Spent Fuel Management: 1995 Update," *Nuclear Engineering International* (March 1995).

have built onsite dry storage facilities. Fifteen nuclear utilities have Independent Spent Fuel Storage Installations (ISFSI) in operation or under consideration.[149] Table 17 shows the status of the ISFSI's and the reactors whose current storage pool capacity is greater than half full.

Table 17. Percent of On-Site Pool Storage Capacity and Status of Independent Spent Fuel Storage Installation as of December 31, 1994

Reactor	Percent Capacity Remaining	Status of ISFSI
Prairie Island	4	Operational
Point Beach	13	Planned
Palisades	16	Operational
Maine Yankee	22	
Surry	23	Operational
Oyster Creek	23	Planned
Big Rock	24	
Calver Cliffs	24	Operational
Oconee	27	Operational
Davis Beese	28	Planned
Ginna	29	
North Anna	29	Planned
Arkansas Nuclear . .	30	Planned
Haddam Neck	31	
Kewaunee	31	
Vermont Yankee . . .	31	
Fitzpatrick	32	
Duane Arnold	33	
Hatch	34	
Millstone	34	
Dresden	36	Planned
Peach Bottom	39	
Pilgrim	43	
Quad Cities	43	
Zion	43	
Brunswick	44	Planned as backup to Robinson 2
Susquehanna	45	Planned
St. Lucie	46	
Fort Calhoun	47	
Catawba	48	
McGuire	48	

Note: List includes reactors with less than one-half of their storage pool capacity remaining.
ISFSI = Independent Spent Fuel Storage Installation.
Source: Spent Nuclear Fuel Discharges from U.S. Reactors, 1994, SR/CNEAF196-01, Energy Information Administration (Washington, DC, February 1996), Appendix C.

Spent Fuel Projections

As of December 31, 1995, 32.2 thousand metric tons of spent nuclear fuel was discharged from U.S. commercial nuclear reactors.[150] U. S. reactors are projected to discharge 2.3 thousand metric tons of uranium (MTU) in 1996 (Table 18). The spent fuel inventory is expected to grow to between 74 and 75 thousand MTU by 2015 while the average annual discharged spent fuel remains relatively stable (around 2 thousand MTU) over the projection period. Worldwide, cumulative spent nuclear fuel is projected to grow from 10 thousand MTU discharged in 1996 to between 213 thousand MTU (Reference Case) and 227 thousand MTU (High Case) in 2015 (Table 19). The greatest amount of spent nuclear fuel is projected to come from Western Europe. From 1996 to 2015, the cumulative discharged spent fuel is projected to be 59 thousand MTU in the Reference Case and 60 thousand MTU in the High Case (Table 19). The United States is projected to discharge between 40 and 42 thousand MTU, during this time period, while the Far East will be between 39 and 43 thousand MTU.

[149] Energy Information Administration, *Spent Nuclear Fuel Discharges from U.S. Reactors 1994*, SR/CNEAF/96-01 (Washington, DC, February 1996), pp. 50-51.
[150] Energy Information Administration, Form RW-859, "Nuclear Fuel Data" (1995).

Table 18. Projected Annual Discharges of Spent Fuel from World Nuclear Power Plants, 1996-2015
(Thousand Metric Tons of Uranium)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other[a]		Total World	
	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High
1996	2.3	2.3	1.6	1.6	1.3	1.3	3.3	3.3	1.4	1.4	0.5	0.5	10.3	10.3
1997	2.4	2.4	1.5	1.5	1.2	1.2	3.9	3.9	1.5	1.5	0.5	0.4	11.1	10.9
1998	2.2	2.2	1.6	1.6	1.2	1.2	3.4	3.4	1.6	1.7	0.4	0.5	10.5	10.6
1999	1.9	1.9	1.8	1.8	1.3	1.3	3.7	3.8	1.5	1.7	0.5	0.5	10.8	11.1
2000	2.2	2.2	1.5	1.5	1.6	1.2	3.8	3.8	1.5	1.6	0.5	0.6	11.0	11.0
2001	2.0	2.0	1.5	1.5	1.1	1.3	3.7	3.7	1.8	1.8	0.6	0.6	10.7	10.9
2002	2.3	2.3	1.5	1.5	1.3	1.5	2.9	2.9	1.7	1.8	0.5	0.7	10.2	10.6
2003	2.3	2.3	1.8	1.8	1.5	1.6	3.3	3.4	1.6	1.6	0.7	0.6	11.3	11.4
2004	1.8	1.8	1.6	1.6	1.2	1.5	3.5	3.6	1.7	1.9	0.7	1.0	10.5	11.3
2005	2.0	2.0	1.9	1.9	1.5	2.2	2.4	2.6	1.8	2.1	0.7	1.0	10.3	11.7
2006	2.2	2.1	1.4	1.5	1.3	1.3	3.2	2.6	2.3	2.5	0.8	1.2	11.2	11.2
2007	1.8	1.8	1.7	1.6	1.3	1.5	3.0	2.7	1.8	2.2	1.0	1.1	10.7	10.9
2008	2.0	2.0	1.5	1.7	1.4	1.8	2.3	2.6	2.6	2.5	0.9	1.2	10.6	11.8
2009	2.2	2.0	1.4	1.5	1.5	1.4	2.2	2.5	2.0	2.6	0.9	1.3	10.1	11.3
2010	1.9	1.8	1.3	1.5	1.5	1.8	2.3	2.5	2.5	2.5	0.9	1.2	10.4	11.4
2011	2.0	1.9	1.6	1.8	1.3	1.9	2.5	3.1	2.3	2.6	0.9	1.0	10.6	12.4
2012	2.1	1.9	1.3	1.5	1.3	1.8	2.5	3.2	2.3	2.6	1.0	1.4	10.6	12.4
2013	2.5	1.8	1.3	1.5	1.2	1.7	2.2	2.4	2.6	2.8	1.0	1.3	10.8	11.5
2014	2.4	1.8	1.4	1.5	1.1	2.5	2.4	2.4	2.2	2.9	1.1	1.3	10.7	12.4
2015	1.4	1.8	1.3	1.5	1.5	1.8	2.2	2.3	2.6	2.7	1.2	1.4	10.2	11.4

[a]Other includes Argentina, Brazil, Cuba, Egypt, India, Iran, Israel, Mexico, Pakistan, South Africa and Turkey.

Notes: See Table 4 for a list of the countries making up each region. Totals may not equal sum of components due to independent rounding. Spent fuel projections in the Reference Case are sometimes larger than spent fuel projections in the High Case due to more reactors retiring in the Reference Case and consequently discharging the entire reactor core.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM.WK4.

Table 19. Projected Cumulative Discharges of Spent Fuel from World Nuclear Power Plants, 1996-2015
(Thousand Metric Tons of Uranium)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other[a]		Total World	
	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High
1996	2.3	2.3	1.6	1.6	1.3	1.3	3.3	3.3	1.4	1.4	0.5	0.5	10.3	10.3
1997	4.7	4.7	3.1	3.1	2.6	2.5	7.2	7.2	2.9	2.9	1.0	0.9	21.4	21.2
1998	6.9	6.9	4.7	4.7	3.8	3.8	10.5	10.5	4.5	4.5	1.4	1.4	31.8	31.8
1999	8.8	8.8	6.6	6.6	5.0	5.1	14.2	14.3	6.0	6.3	1.9	1.9	42.7	43.0
2000	11.1	11.1	8.1	8.1	6.6	6.3	18.1	18.1	7.5	7.9	2.4	2.5	53.7	54.0
2001	13.1	13.1	9.6	9.6	7.7	7.6	21.8	21.8	9.3	9.7	3.0	3.2	64.4	64.8
2002	15.3	15.3	11.1	11.1	8.9	9.0	24.7	24.6	11.1	11.5	3.5	3.9	74.6	75.5
2003	17.6	17.6	12.9	12.9	10.4	10.7	28.0	28.0	12.7	13.1	4.2	4.5	85.8	86.9
2004	19.4	19.4	14.5	14.5	11.6	12.2	31.5	31.6	14.4	15.0	5.0	5.5	96.3	98.2
2005	21.4	21.4	16.4	16.4	13.1	14.3	34.0	34.1	16.1	17.1	5.7	6.5	106.6	109.9
2006	23.6	23.6	17.8	17.9	14.4	15.7	37.1	36.7	18.4	19.6	6.5	7.7	117.8	121.1
2007	25.5	25.3	19.6	19.5	15.7	17.2	40.2	39.4	20.2	21.8	7.4	8.8	128.6	132.0
2008	27.5	27.3	21.1	21.2	17.1	19.0	42.5	42.0	22.8	24.3	8.3	10.1	139.2	143.8
2009	29.6	29.3	22.4	22.7	18.6	20.4	44.7	44.5	24.8	26.9	9.2	11.4	149.3	155.2
2010	31.5	31.1	23.7	24.2	20.1	22.2	47.0	47.0	27.2	29.4	10.1	12.6	159.7	166.6
2011	33.5	33.1	25.3	26.1	21.4	24.1	49.5	50.1	29.6	32.0	11.0	13.6	170.3	179.0
2012	35.6	35.0	26.7	27.6	22.8	25.9	51.9	53.3	31.9	34.6	12.0	15.0	180.9	191.4
2013	38.1	36.8	28.0	29.0	24.0	27.6	54.2	55.8	34.5	37.4	13.0	16.3	191.7	202.9
2014	40.5	38.6	29.4	30.6	25.1	30.1	56.6	58.2	36.7	40.2	14.0	17.6	202.4	215.4
2015	41.9	40.4	30.7	32.0	26.6	31.9	58.8	60.5	39.3	42.9	15.3	19.0	212.6	226.7

[a]Other includes Argentina, Brazil, Cuba, Egypt, India, Iran, Israel, Mexico, Pakistan, South Africa and Turkey.

Notes: See Table 4 for a list of the countries making up each region. Totals may not equal sum of components due to independent rounding. Spent fuel projections in the Reference Case are sometimes higher than spent fuel projections in the High Case due to more reactors retiring in the Reference Case and consequently discharging the entire reactor core.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM.WK4.

3. Decommissioning U.S. Nuclear Plants

Introduction

Within the next 19 years, 49 of the 110 commercial nuclear power plants currently operating in the United States are scheduled to be retired after reaching the end of their operating license (Figure 12).[151] At least five years prior to license expiration, licensees of these plants are required to develop detailed plans describing how they intend to manage their plant sites after the plants are retired. These decommissioning plans, which will be made available for review by the general public, the Nuclear Regulatory Agency (NRC), and state regulatory agencies, will describe how the sites will be decontaminated and returned to unrestricted use, whether the licensee will elect to use a safe storage period prior to decommissioning the site, and how the licensee plans to finance the decommissioning activity.

While decommissioning a nuclear site has been successfully demonstrated and is well within the bounds of current technology, it is nonetheless a costly and complex procedure, and regulations governing the overall process are still evolving. In addition, recent premature retirements of several nuclear power plants and the threat of additional premature retirements have heightened public awareness about whether sufficient funds will be available to decommission a nuclear power plant once it has been retired.

The purpose of this chapter is to give an overview of the issues and options associated with post shutdown management of a nuclear power plant, including decommissioning the plant, the storage of the spent nuclear fuel produced during plant operation, and the status of low-level waste (LLW) disposal availability and costs. This chapter also describes some of the recent developments in the regulatory arena that will affect the decommissioning process, such as the deregulation of the electricity generation and proposed rulemakings for revising NRC decommissioning procedures and establishing radioactive release standards. In addition, this chapter presents the decommissioning status of the 11 commercial reactors that have been permanently shutdown as of December 31, 1995. These plants were removed from service because of a combination of technical and economic factors. Clearly, the nuclear industry is watching the decommissioning process at these plants in the hope that it will offer clues as to how much money utilities will need to spend to return a nuclear power plant site to unrestricted use and possibly a green field state.

Decommissioning

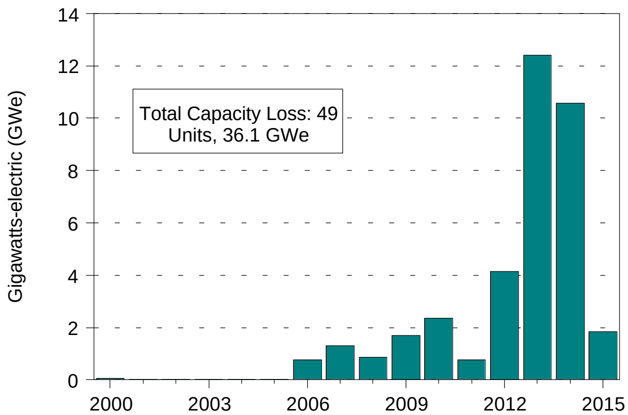
Title 10 of the *Code of Federal Regulation*s, Section 50.2, defines decommissioning as the safe removal of a facility (nuclear) from service and reduction of the residual radioactivity to a level that permits the release of the property for unrestricted use and termination of the facility's license. The NRC has defined three decommissioning alternatives: DECON, SAFSTOR, and ENTOMB.[152]

Under DECON, or immediate dismantlement and decontamination, the equipment, structure, and portions of the facility containing radioactive contaminants are removed to a level that permits the site to be released for unrestricted use and termination of the license. Under SAFSTOR, often considered "delayed DECON," a nuclear facility is maintained in a condition that allows the decay of radioactivity to reduce radiation levels at the facility: afterwards, the same procedure is followed as under DECON. Under ENTOMB, radioactive contaminants are encased in a structurally long-lived material such as concrete and the "entombed" structure is appropriately maintained and monitored until the radioactivity decays to a level that permits unrestricted release of the property. To be acceptable, however, the method selected must provide for completion of decommissioning within 60 years. A time beyond 60 years will be considered only when necessary to protect public health and safety in accordance with the NRC regulations.

[151] The license expiration date for U.S. nuclear plants is based on the operating license approval date as issued by the Nuclear Regulatory Commission.

[152] Described in the Generic Environmental Impact Statement on Decommissioning, NUREG-0586, August 1988.

Figure 12. Potential Loss of Nuclear Electric-Generating Capacity Due to License Expiration, 2000-2015



Source: Nuclear Regulatory Commission, "Information Digest 1996 Edition" (NUREG-0350, July 1996).

Under current NRC decommissioning criteria, a site eligible for unrestricted use may have some radioactivity above the natural background level: however, there must be no more than 5 additional microrems (10^{-6} rems) of surface contamination per hour. Currently, the NRC and EPA are in the process of establishing a rulemaking on new radioactive standards to qualify a site for unrestricted use. The current proposal would impose a limit in the total effective dose equivalent (TEDE)[153] of 15 mrem per year above background.[154] A participatory (public input) rulemaking for the residual radioactive standard was first proposed by the NRC in 1991. The rulemaking emerged because of failed attempts by the NRC to determine a threshold of radioactivity low enough not to warrant continued surveillance. Residual radioactivity standards determine the level of cleanup necessary at a site undergoing decommissioning. Depending on their nature and stringency, such standards may have a major impact on decommissioning timing and costs, waste generation, occupational and public health and safety, and the potential future uses of the sites.

Although the NRC's concern ends after the license has been terminated—that is, when the site has been decontaminated and is available for unrestricted use—returning the site to a green-field condition is under the discretion of the individual State and local authorities. A nuclear facility site is a valuable resource, particularly for the location of replacement power generating capacity. Among its assets are low seismic activity, proximity to a large supply of water, access to an electrical distribution system, and acceptance by local residents. If the site is to be used for another power generating facility, it need not be decommissioned to the same standards as for unrestricted release to the public domain. Nonetheless, local authorities will determine the extent of non-radioactive cleanup necessary.

Types of Waste

Three classes of commercial nuclear waste are recognized: high-level waste (HLW),[155] mixed low-level waste (MLLW), and low-level waste (LLW). The wastes are generated from both the operation and decommissioning of a nuclear power plant.

The bulk of HLW produced by a nuclear power plant is contained in the spent nuclear fuel, which represents less than 1 percent of the waste volume but more than 99.9 percent of the radioactivity emitted by commercial nuclear waste.[156] MLLW is a special subclass of LLW composed of both radioactive and hazardous chemical wastes.

The 1980 Low-Level Radioactive Waste Policy Act (LLRWPA) and its 1985 amendment define LLW as radioactive waste not classified as HLW and representing over 99 percent of the volume of all commercial nuclear waste. Although LLW is the bulk of the volume of nuclear waste, it accounts for less than 0.1 percent of total radioactivity.[157] LLW is produced during plant operations, repair and maintenance outages, and decommissioning. Typically, solid LLW includes contaminated worker clothing, gloves, equipment, and tools.

The NRC distinguishes four LLW types, ranked by increasing radioactivity: Class A, Class B, Class C, and greater-than Class C (GTCC).[158] Neutron activated materials generally may contain either of both quantities

[153] Dose Equivalent - The product of absorbed dose, quality factor, distribution factor, and other modifying factors necessary to obtain a point of interest in tissue evaluation of the effects of radiation received by exposed persons., so that the different characteristics of the radiation effects are taken into account.

[154] 59 Federal Register 43200 (August 1994).

[155] HLW is defined in the Nuclear Waste Policy Act of 1982.

[156] "Aging Nuclear Power Plants: Managing Plant Life and Decommissioning," Office of Technology Assessment, U.S. Congress, September 1993, p. 108.

[157] Ibid.

[158] Ibid.

of short and long-lived radionuclides, particularly cobalt-60, cesium-137, nickel-59, nickel-63, and niobium-94. Materials are activated when neutrons dispersed from the fission reaction collide with trace metal in their structures. A reactor pressure vessel, its internal components, and surrounding concrete biological shield are the major plant components that undergo activation. Classification depends on the type and concentration of the radionuclides present, which are determined by site-specific conditions, such as the duration of power operations and the amount of activated trace metals. Under NRC rules, the first three classes may be disposed by shallow land burial, although packaging, transportation, and disposal requirements are progressively more stringent with each waste class. The last class, GTCC, is not suitable for shallow land burial and must be disposed of by the Federal Government in a geological repository.

Even after 40 years of operation, most of the components of a nuclear plant will generally rank as Class A. In fact, Class A waste represents about 97 percent of the total commercial LLW volumes and remains harmful for about one century. Class A waste contain the short-lived radionuclides, such as cobalt-60 and cesium-137, which can be found in piping, concrete, and equipment located in a nuclear power plant. Other common Class A waste includes contaminated tools, worker clothing, and protective plastic sheeting.

Class B, C, and GTCC waste contain long-lived radionuclides such as nickel-59 and niobium-94. Class B and C waste remain harmful for several hundred years while GTCC remains harmful for several thousand years. As much as 25 percent of articles used by plant workers maybe classified as Class B or C. Some reactor internals such as control rod assemblies and control rod blades may undergo enough activation to rank as high as GTCC waste.

An extended storage period prior to any internal dismantlement could serve to reduce total LLW volumes, depending on the type, concentration, and distribution of radionuclides remaining after plant shutdown. Waiting 50 years to dismantle a reactor is expected to reduce final LLW volumes by 90 percent for both pressurized light-water reactors (PWRs) and boiling-water reactors (BWRs). Shorter waiting periods have less of an effect: LLW disposal volumes are virtually unchanged when a 30-year waiting period is assumed.

Low Level Waste Disposal Sites

Under the LLRWPA, individual States are responsible for establishing disposal sites for low-level radioactive waste produced from both nuclear power plants and other commercial and medical nuclear related activities within their boundaries. The Act establishes a framework for the States to enter into compacts that would designate one or more States to host a LLW disposal site. Congress has approved nine compacts (Table 20) incorporating 41 States and is considering the approval of a tenth compact containing an additional three States. Six States remain unaffiliated.

Only two LLW host sites, Hanford and Barnwell, are currently open and receiving waste, and both sites were operating prior to the passage of the LLRWPA. The Hanford facility in Washington State is the host site for the Northwest compact, but will also accept waste from the Rocky Mountain compact under a contract between the two compacts. The Barnwell facility in South Carolina, an unaffiliated state, is currently accepting LLW from all states except North Carolina. The Barnwell facility has been closed to out-of-state waste in the past, and future availability is not guaranteed. Out-of-state disposal costs at Barnwell are considerably more expensive than disposal costs at Hanford, but Hanford is only open to members of two compacts. Envirocare, a privately-owned LLW site in Utah, was developed independently of the LLRWPA and accepts only high-volume low activity waste.

The fact that no new sites have opened since the passage of the Act attest to the difficulty of siting and licensing a radioactive waste facility. A license has been issued for a facility in Ward Valley, California, but local opposition prompted the passage of county ordinances banning the facility. The jurisdictional dispute will ultimately be decided in the courts.

The availability of LLW disposal sites could become a serious impediment for reactor decommissioning. Some of the proposed host waste sites may not be able to accommodate all the LLW resulting from decommissioning reactors within their compact. The Ward Valley facility, for example, is expected to be able to accommodate only three of the 10 reactors in the Southwestern compact.

Another problem is that some LLW sites are expected to be licensed for 30 years or less, which means that the sites may be closed before some licensees in their compact can decommission their reactors.[159] The decision as to when to decommission a reactor may be heavily influenced by access to a LLW site.

[159] Gingerich, Ronald E., "Disposal Capacity for Low-Level Radioactive Waste from Decommissioning Activities: the Status of Compacts and Host States," Proceedings of the Topical Meeting On the Best of D&D, April 1996, American Nuclear Society.

Table 20. Low-Level Waste Compacts

Compact	Host State	Status
Appalachian	Pennsylvania	Implementing Volunteer Process
Central	Nebraska	License Application Submitted
Central Midwest	Illinois	Developing Screening Process
Midwest	Ohio	Developing Site Process
Northeast	Connecticut and New Jersey	Implementing Volunteer Process
Northwest	Washington	Facility in Operation
Rocky Mountain	None	Contract with Northwest
Southeast	North Carolina	License Application Submitted
Southwestern	California	License Issued
Texas	Texas	License Application Submitted
Unaffiliated	Massachusetts	Developing Volunteer Process
Unaffiliated	Michigan	Developing Volunteer Process
Unaffiliated	New Hampshire	Not Siting
Unaffiliated	New York	Considering Options
Unaffiliated	Rhode Island	Not Siting
Unaffiliated	South Carolina	Facility in Operation

Source: Gingerich, Ronald E., Disposal Capacity for Low-Level Radioactive Waste from Decommissioning Activities: the Status of Compacts and Host States, Proceedings of the Topical Meeting On the Best of D&D, April 1996, American Nuclear Society Table 1, p.9

Decommissioning Costs

To ensure that sufficient funds will be available to decommission a reactor after it has completed its useful life, regulatory authorities require licensees of nuclear power plants to maintain a trust fund to cover expected costs. The primary economic regulatory authority for electric utilities rests with the state public utility commissions (PUC) for retail sales and the Federal Energy Regulatory commission (FERC) for wholesale transactions. The NRC, under the aegis of regulating the public health and safety associated with nuclear power operations, has established minimum financial assurance requirements. However the NRC requirements are generally viewed as low, and many PUCs have set higher, more realistic target values.

Comparison of decommissioning cost estimates among plants is difficult because of differences in the approach used to estimate the costs. For example, some estimates include the cost of post-shutdown spent fuel storage[160] and site restorations and others do not. As decommissioning costs have tended to increase over time, comparison of cost estimates made in different year can be misleading. To emphasize this point, one need only look at the recent decommissioning costs reestimations made by several utilities, which resulted in substantial increases, partly in response to sizeable increases in the projected cost of LLW disposal and expectations of longer on site spent fuel storage. Some confusion may also exist between estimates made in constant and nominal dollars. For instance, one utility estimated plant decommission costs in 1993 dollars at $657 million and noted this is equivalent to $1,372 million in 2016, assuming a 3.25 percent escalation factor.[161]

Decommissioning Cost Estimates

The two methodologies commonly used to estimate decommissioning costs are the "detailed cost method" and the "unit cost method." In the detailed cost method, engineers develop a comprehensive decommissioning plan and determine plant-specific costs for each basic activity, such as the cutting and removal of a specific

[160] Post shutdown spent fuel storage costs can be divided into costs associated with wet pool storage and costs associated with extended storage in an Independent Spent Fuel Storage Installation (ISFSI). Some decommissioning costs estimates include only the costs of extended spent fuel storage. For accounting purposes, the cost of maintaining and operating the spent fuel pool are often considered operating costs, rather than decommissioning costs. Nonetheless, both spent fuel pool storage and ISFSI costs are post shutdown costs.

[161] Nuclear Decommissioning, Con Edison Annual Report for 1995, Consolidated Edison Company of New York, Inc., p. 35.

section of pipe. As the detailed cost method is both time consuming and expensive, the unit cost method was developed to minimize the expenditure of resources. In the unit cost method, analysts establish a set of generic costs and then apply factors to adjust for difficulty of performing comparable activities and differences in economic environments. Technical-difficulty factors account for variations in plant and component design and radiological exposure levels, and economic factors account for variations in labor rates and waste disposal costs.

NRC Reference Plants

The NRC has sponsored detailed cost studies for a single PWR, Trojan[162] in Prescott, Oregon, and a single BWR, Washington Nuclear Plant 2[163] in Richland, Washington. Cost estimates contained in these and predecessor reports[164] are used to establish NRC minimum financial assurance requirements. In the past, most licensees relied on a unit-cost type of approach or used the NRC minimum financial assurance requirements. The need for more realistic estimates of decommissioning costs, especially for older plants, has prompted many licensees to perform detailed cost studies. In addition, current NRC regulations also require licensees of plants which are permanently shutdown or are within five years of license termination to perform and submit for approval a plant-specific cost study.[165]

The NRC reports present costs for several decommissioning alternatives (DECON, SAFSTOR1, and SAFSTOR2) and two LLW site burial alternatives (Hanford and Barnwell) (Table 21). In the DECON and SAFSTOR2 cases all material that was originally radioactive is disposed of in a LLW facility. In SAFSTOR1 case, only the reactor pressure vessel and the concrete biosphere require disposal in a LLW facility. Presumably, the SAFSTOR1 and SAFSTOR2 cases provide bounding cases for letting the radioactivity decay during the SAFSTOR period, as the reports do not discuss the potential benefits of LLW volume reduction after a SAFSTOR period.

The NRC reports aggregate costs for four categories: labor and materials, energy and transportation, waste burial, and taxes and insurance, each with and without a 25 percent contingency factor.[166] The reports also provide cost tabulations by activity level (decontamination, removal, packaging, shipping, burial, and undistributed) and period (planning and preparation, defuel and lay up, spent fuel pool operations, extended safe storage, and deferred dismantlement).

The DECON costs for both the reference PWR and BWR are less than SAFSTOR2 costs. In both cases, the waste disposal costs are approximately the same for a given burial site, but there is a large increase in labor and material costs and taxes and insurance associated with the protracted safe-storage period. Curiously, the NRC reports state that the disposal costs for the SAFSTOR2 case are lower than those for the DECON cost because the wastes have an additional 51 years to decay. (Disposal costs are a function of both volume and radioactivity decay.) The cost differences, however, are minimal. In the PWR Hanford-disposal case, for example, waste disposal costs are $24.5 million for the DECON option versus $24.1 million for the SAFSTOR2 option.

The SAFSTOR1 costs are higher than the DECON costs for the both the BWR ($224.3 million vs $158.2 million) and PWR ($173.9 million[167] versus $133.3 million) Hanford cases. The increase in labor costs more than compensate for the decrease in waste costs. The result could be different if the LLWs are disposed in a facility with higher

[162] Smith, R.I., Bierschbach, M.C.., Konzek, G.J., McDuffie, P.N., *Revised Analyses of Decommissioning for the Reference Pressurized Water Reactor Power Station*, NUREG/CR-5884, November 1995.

[163] Smith, R.I., Bierschbach, M.C.., Konzek, G.J., McDuffie, P.N., *Revised Analyses of Decommissioning for the Reference Boiling Water Reactor Power Station*, NUREG / CR-6174, Draft September 1994.

[164] Smith, R.I., Konzek, G.J, *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station*,: Technical Support for Decommissioning Matters Relating to a Preparation of the Final Decommissioning Rule, NUREG / CR-0130, July 1988, U.S. Nuclear Regulatory Agency; and Smith, R.I., Konzek, G.J, *Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station*,: Technical Support for Decommissioning Matters Relating to Preparation of the Final Decommissioning Rule, NUREG / CR-0672, July 1988, U.S. Nuclear Regulatory Agency;

[165] 10 CFR 50.75(f) requires a licensee to submit a decommissioning plan that includes an up-to-date cost estimate. On July 20, 1995, the NRC published a proposed rulemaking for power reactor decommissioning (60 FR 37374) that would eliminate the current requirement for a licensee to submit a decommissioning plan, but the licensee would still be required to submit a preliminary cost proposal five years before permanent cessation of operations. The proposed rule requires the licensee to prepare a post shutdown decommissioning activities report (PSDAR) describing planned decommissioning activities and costs after the reactor has permanently ceased operations, but NRC approval is not required for the PSDAR. Under the current rule, the NRC must approve a licensee's decommissioning plan.

[166] All costs are in 1993 dollars.

[167] Smith, R.I., Bierschbach, M.C., Konzek, G.J., McDuffie, P.N., *Revised Analyses of Decommissioning for the Reference Pressurized Water Reactor Power Station*, NUREG / CR-5884, Draft September 1994, p. xvi.

Table 21. Decommissioning Costs for Reference PWR and BWR for DECON and SAFSTOR Options with Burial at Hanford and Barnwell
(Million 1993 dollars)

	Reference PWR			
	DECON		SAFSTOR2	
Decommissioning Cost	Hanford	Barnwell	Hanford	Barnwell
Labor and Material	89.9	90.4	149.8	150.3
Energy and Transportation	9.2	17.3	9.9	18.1
Waste Burial	24.5	110.1	24.1	108.1
Subtotal	**123.6**	**217.8**	**183.9**	**176.5**
Taxes and Insurance	9.7	9.7	54.0	54.0
Grand Total	**133.3**	**227.5**	**237.9**	**330.5**

	Reference BWR			
	DECON		SAFSTOR2	SAFSTOR1
DECON Alternative Burial Site	Hanford	Barnwell	Hanford	Hanford
Labor and Material	100.8	100.8	205.2	166.2
Energy and Transportation	5.1	11.8	5.7	3.9
Waste Burial	43.2	183.8	42.8	6.9
Subtotal	**149.1**	**296.4**	**253.8**	**177.4**
Taxes and Insurance	9.1	9.1	49.4	47.3
Grand Total	**158.2**	**305.7**	**303.1**	**224.3**

Notes: For both the DECON and SAFSTOR all material that was originally radioactive are disposed of in a low-level waste facility. In SAFSTOR1, only the reactor pressure vessel and the concrete biosphere require disposal in a low-level waste facility. Costs include a 25 percent continency factor. Totals may not add due to independent rounding.

Source: **Reference PWR:** Table C-1 through C-4, Smith, R.I., Bierschbach, M.C., Konzek, G.J., McDuffie, P.N., *Revised Analyses of Decommissioning for the Reference Pressurized Water Reactor Power Station*, NUREG/CR-5884, Draft September 1994, p. xvi. **Reference BWR:** Table C-1 through C-4, Smith, R.I., Bierschbach, M.C., Konzek, G.J., McDuffie, P.N., *Revised Analyses of Decommissioning for the Reference Boiling Water Reactor Power Station*, NUREG/CR-5884, Draft September 1994, p. xvi.

costs. When comparing costs, the reader should keep in mind that the NRC cost studies did not assume any escalation in LLW costs. It is interesting to note that in the predecessor reports the SAFSTOR1 option enjoyed a cost advantage over the DECON option, because of the decrease in residual radioactivity during the safe storage period. In those reports, the savings in LLW cost more than compensated for the additional costs for the safe storage years.

The NRC cost estimates are based upon non-discounted dollars. To illustrate the impact of a positive discount rate, the NRC reports presented the results of a sensitivity analysis using a three percent real discount rate. The present value cost estimates for the reference PWR Hanford-disposal cases are $108.4, $93.4, and $103.7 for the DECON, SAFSTOR1, and SAFSTOR2 alternatives. The present-value sensitivity analysis did not consider the impact of escalating LLW costs.

Decommissioning costs for the reference BWR are greater than those for the reference PWR, reflecting the fact that the reference BWR has a greater amount of LLW.[168] In a BWR, for example, the reactor coolant water drives the turbine, so the turbine is radioactive and must be disposed of in an LLW facility. In a PWR, the reactor coolant and turbine loops are isolated, and the turbine is not contaminated. In the DECON case, the amount of LLW is of 250,524 cubic feet for the reference PWR and 504,349 cubic feet for the reference BWR, which accounts for higher labor and waste disposal costs for the reference BWR. The reader should not infer that all BWRs have

[168] When the *Nuclear Power Generation and Fuel Cycle Report 1996* was finalized, NRC had not released the final BWR report. The decommissioning cost estimates in the final PWR report were slightly higher than those in the draft PWR report. For comparison, the PWR Hanford DECON cost estimates in the draft report were $124.6 and $206.1 million for Hanford and Barnwell disposal sites, respectively, versus $133.3 and $227.5 million in the final report.

higher decommissioning costs than PWRs since each plant's situation is unique, especially for LLW disposal costs, and such differences may more than compensate for differences in reactor type.

LLW burial costs at Barnwell are about 4.5 times as expensive as those at Hanford. For the NRC DECON cases, disposal costs at Barnwell were approximately $85 million and $140 million greater than at Hanford, for the reference PWR and BWR, respectively. To put the role of LLW costs in perspective, the total decommissioning costs for the reference PWR and BWR were 71 and 93 percent, respectively, more for Barnwell waste disposal than for Hanford waste disposal.

LLW costs are expected to increase in the future, and the impact on overall decommissioning costs can be significant. Hanford and Barnwell are the only two sites currently operating in the United States. Hanford serves only members of the Northwest and Rocky Mountain compacts. Barnwell will accept LLW from all states except North Carolina, but charges most users a hefty premium. Based on the NRC reports LLW costs are $85 per cubic foot for Hanford, and $374 to $384 per cubic foot for Barnwell. By comparison, Yankee Atomic Electric Company in a 1994 estimate of decommissioning costs at Yankee Rowe assumed a cost of $441 per cubic foot for disposal at Barnwell. The possibility of even higher LLW costs is a serious concern in the industry. In addition, the Low Level Radioactive Policy Act Amendment of 1985 (LLRWPAA-85) imposes costly surcharges: for States without compacts in compliance of the act, the surcharge is $120 per cubic foot; for States with compacts in compliance with the act but with no operational LLW facility, the surcharge is $40 per cubic foot.

Concerned that the cost estimates in the NRC reports were low, especially with recent escalations in LLW costs, the NRC informally reestimated the decommissioning costs for the reference BWR and PWR. In 1994 dollars, the PWR DECON estimates were $167 million and $384 million for disposal at Hanford and Barnwell, respectively, and BWR DECON estimates were $207 million and $430 million for disposal at Hanford and Barnwell, respectively.[169]

The NRC decommissioning cost estimates do not include costs for demolition of (1) non-radioactive structures and site restoration and (2) spent fuel storage and management. However, the NRC reports present analyses of both cost categories. Demolition and site restoration costs for Trojan are estimated at $30.5 million with no contingency factor and $38.1 million with a 25 percent contingency factor.[170] Annual spent fuel storage costs are estimated at $4.2 million for wet pool storage and $2.0 million for dry storage in an Independent Spent Fuel Storage Installation (ISFSI). One-time incremental capital costs for the IFSFI are estimated at $22.3 million, and ISFSI decommissioning costs[171] are estimated at $2.2 million.[172] Demolition and site restoration costs for WNP-2 are estimated $38.6 million with no contingency factor and $48.2 million with a 25 percent contingency factor.[173] Annual spent fuel storage costs are estimated at $5.5 million for wet pool storage and $2.1 million for dry storage in an ISFSI. One-time incremental capital costs for the IFSFI are estimated at $24 million, and IFSFI decommissioning costs are estimated at $2.9 million.[174] These incremental ISFSI capital costs are in addition to any capital costs already expended for IFSFI construction while the reactor was still operating and are specific to Trojan and WNP-2. Costs for site restoration and ISFSI construction and storage for other units will depend on the factors unique to each unit.

Utility Estimates

Many utilities have performed site-specific studies to estimate decommissioning costs. To provide a comparison to the reference NRC cost estimates, this section presents cost estimates for six utilities.

Portland General Electric (PGE), the operators of the Trojan power plant, are currently in the process of decommissioning the plant and have developed a comprehensive plan that calls for a completion of DECON activities by 2001 and site restoration beginning in 2018, after DOE picks up Trojans spent fuel. PGE plans to ship Trojan's LLW to Hanford for disposal. PGE, which owns 67.5 percent of the Trojan power plant, estimates its share of the decommissioning costs to be $234 million (1994 dollars) or $351 million in nominal dollars, which brings the total decommissioning costs to $347 million (1994 dollars) or $520 million in nominal dollars. The decommissioning cost estimate includes the costs of extended spent fuel storage and building demolition and

[169] Private discussions with NRC staff.
[170] NUREG / CR-5884, Vol 2., p L.2
[171] While the cost of decontaminating and decommissioning the spent fuel pool is included in the NRC decommissioning financial assurance requirements, the cost of decontaminating and decommissioning of an IFSFI is not.
[172] NUREG / CR-5884, Vol 2., p D.13
[173] NUREG / CR-6174 Vol 2 (Draft), pp H-2
[174] NUREG / CR-6174 Vol 2 (Draft), pp D-19 - D-20

non-radiological site remediation. PGE also estimates that an additional $51 million will be needed for spent fuel operating and maintenance costs though 1998. These transition costs are paid from current operating costs and are not charged to the decommissioning cost fund.[175] The Trojan DECON decommissioning estimate, net of site restoration costs ($42 million) and extended (ISFSI) spent fuel management costs ($102 million), is $203 million (1994 dollars) is substantially higher than the NRC's DECON estimate for Trojan of $137 million (1994 dollars).

In 1994, Consolidated Edison prepared a site-specific decommissioning plan for Indian Point 2 and the retired Indian Point 1 plants, which estimated total decommissioning costs in 1993 dollars for the two plants at $657 million, which includes $252 million for extended on-site spent fuel storage. The previous decommissioning cost estimate was for a total approximately $300 million in 1993 dollars.[176]

Baltimore Gas and Electric Company (BG&E) completed a facility-specific study of the Calvert Cliffs Nuclear plant in 1995 and arrived at an estimate of $521 million in 1993 dollars to decommission the radioactive portion of the plant. The previous amount approved by the public service commission in April 1993, was of $336 million in 1992 dollars.[177]

In a 1994 decommissioning cost study, Yankee Atomic Electrical Company estimated total decommissioning costs for the shutdown Yankee Rowe plant at $370 million in 1994 dollars. The costs included $49 million for an ISFSI and $24 million for site restoration. The ISFSI costs were based upon the assumption that DOE would pickup all Yankee Rowe's spent fuel by 2018.[178]

Consumers Power company estimated decommissioning costs for Big Rock Point and Palisades to be $303 million and $524 million (in 1995 dollars), respectively. NRC licenses for Big Rock Point and Palisade expire in 2000 and 2007, respectively. Because of the unavailability of low- and high-level radioactive waste disposal facilities, Consumers plans to maintain the facilities in a SAFSTOR condition until 2030 for Big Rock Point and 2046 for Palisades. By December 31, 1995, Consumers had an investment in nuclear decommissioning trust funds of $304 million.[179]

Pacific Gas and Electric Company (PG&E) estimated decommissioning cost of the Diablo Canyon plant at $1.2 billion (1995 dollars). At the end of 1995 PG&E had accumulated $770 million in its decommissioning trust fund.[180]

Decommissioning Fund

To assure that adequate funds will be available to decommission a shutdown plant, licensees must establish and maintain a decommissioning fund. NRC regulations require each licensee to provide financial assurance using minimum funding criteria specified in 10 CFR 50.75(c) or site-specific cost estimates. However, States and / or public utility commissions (PUC) may, and often do, impose further financial assurance requirements.

NRC financial assurance requirements cover only the costs of site decontamination and activities that lead to license termination. They explicitly exclude costs for demolition and restoring the site to a so-called "green fields" condition, i.e., the removal and restoration of non-radioactive structures; spent fuel storage and associated management; and post-closure activities such as security, plant maintenance, and license-related activities. The NRC decommissioning costs estimates are generally viewed by both the industry and the NRC to be on the low side, as their intent is to provide reasonable financial assurance for the minimum cost of decontaminating the site and do not include the cost elements noted above.

Moreover, the NRC minimum financial assurance requirements are based upon the reference plant DECON costs estimates for Hanford waste disposal. Low-level disposal costs for most licensees will be significantly higher.

Although spent fuel management and storage costs are not included in NRC financial assurances for decommissioning, licensees are required under 10 CFR Part 50.54(bb) to submit written notification to the NRC describing how the licensee plans to manage and provide funding for the management of its spent fuel, from time of cessation of permanent operation until license termination. The plan must be submitted within five years of license expiration or within two years following

[175] Portland General Electric Company, 1994 SEC 10K, pp 14-16
[176] Nuclear Decommissioning, Con Edison Annual Report for 1995, Consolidated Edison Company of New York, Inc., p. 35.
[177] Baltimore Gas and Electric Company, SEC Form 10-K for 1994, p. 40.
[178] William J. Szymczak, Estimating Decommissioning Costs: The 1994 YNPS Decommissioning Cost Study, American Nuclear Society Topical Meeting, Decommissioning, Decontamination, and Environmental Restoration, November 16, 1994.
[179] Consumers Power Co., 1995 SEC 10K.
[180] Pacific Gas and Electric Company, 1995 SEC 10K, pp. 27-28.

permanent cessation of operations, whichever comes first. The NRC does review and provide approval of a licensee's plan, but does not require the licensee to maintain a sinking fund to demonstrate financial assurance for post-shutdown spent fuel management. Many PUCs, however, do impose such a requirement.

State Regulatory Authority

The Federal and State governments both have a regulatory role in determining decommissioning funding requirements. The role of the NRC is to protect the public safety and health, and it is through this mandate that the NRC can require financial assurance for decommissioning funds. The economic regulatory authority, including rate making, currently rests with the States and PUC's for retail electric sales, which account for about 80 percent of all electricity sales, and FERC for wholesale sales, which account for about 20 percent of total electricity sales. These agencies are responsible for determining the amounts and schedules for sinking fund contributions, as long as NRC financial assurance requirements are met. PUC's must balance the financial interests of both the owners and the rate payers and resolve issues associated with deferred plant decommissioning, such as inter-generational fairness. Considerable variation exists in the way individual PUC's balance opposing interests and how they establish requirements for sinking fund contributions (Table 22).

Some PUC's require estimates to be based on plant-specific decommissioning studies, and many PUC's require the inclusion of one or more of the decommissioning cost elements not included in the NRC financial assurances requirements. For example, cost estimates for removing non-radiological structures and returning the Trojan nuclear power plant site to a green-field condition are about $40 million.[181] Estimates of spent fuel storage costs are $3 million to $5 million per year for in pool storage and $1 million to $4 million per year for dry storage in an IFSFI, exclusive of approximately $24 million in capital costs to establish an IFSFI.

Funding Options

Three options for establishing financial assurance are given in 10 CFR50.75(c); an external sinking fund, prepayment, or a surety method. All licensees are currently using the sinking fund method with annual contributions. Prepayment involves a lump sum advance contribution and is viewed by licensees as being less favorable than annual contributions to a sinking fund. In both these options, assumptions must be made about expected rates of return on licensee contributions. Currently, there is no active surety or insurance market for nuclear reactor decommissioning activities.

Prior to 1988, the NRC permitted the use of internal sinking funds. The bankruptcy of Public Service Company of New Hampshire prompted the NRC to adopt a requirement for an external sinking fund using a trust arrangement under the assumption that this would provide protection from creditors in the event of a bankruptcy proceeding. Some PUC's interpret this rule as applying only to the portion of the decommissioning fund under the jurisdiction of the NRC—i.e., to that portion required for site decontamination—and allow other fund contributions—e.g., for demolition and removal of non-radioactive structures—to be invested in internal funds.

Deregulating and Restructuring the Electricity Industry

The emerging deregulation of electricity generation and the restructuring of electrical utilities introduces a new set of issues for demonstrating financial assurance for decommissioning funds. The current NRC rule is based on the premise that the utility/operator of a nuclear power plant will be an ongoing, capital-intensive concern with significant financial resources, including rate base access, to cover any decommissioning-fund shortfall.[182] Under deregulation, many utilities may transfer their generation facilities to independent, unregulated[183] companies. One possibility is that a utility may establish a separate generating entity, whose assets consist solely of nuclear power plants. After the nuclear plants in such an independent entity are retired, there would not be a continuing revenue stream to cover any potential decommissioning fund shortfalls. Unlike a regulated utility, an independent generating company cannot collect monies from future rate payers to pay for liabilities associated with shutting down facilities.

Deregulation and restructuring are areas of current concern to the NRC. On April 8, 1996, the NRC posted an

[181] Nuclear Assurance Corporation International, *Influence of Decommissioning Costs on U.S. Nuclear Plant Operation* (November 1995), p. 2-2.
[182] The NRC may require accelerated funding of reactor's decommission fund if the utility/operator's bond rating is down rated below "A" by a national rating agency for a specific period of time. The NRC may consider other financial criteria in arriving at its decision. 57 Federal Register 30385 (July 9, 1992)
[183] Unregulated in an economic sense. Nuclear plant safety will still be regulated by the NRC.

Table 22. An Overview of Differences in Decommission Sinking Fund Requirements

Issue	Comment
Site-specific estimate versus NRC minimum	Site-specific estimates are typically higher than NRC minimum estimates. More and more licensees are using site-specific estimates.
Inclusion of decommission activities not included by NRC financial assurance requirements	These activities include demolition and removal of non- radiological structures and spent fuel storage costs. Some PUCs require inclusion of some or all of these elements, while others do not or explicitly require them to be excluded.
Contingency factors	NRC decommission-cost-estimate reports present costs with and without a 25 percent contingency factor. However, contingency factors used by licensees or specified by state PUCs range from 0 percent to 50 percent, based upon arguments that the cost estimates are too high and will come down as the industry gains experience to arguments that the cost estimates are too low (especially low-level waste costs) and that future ratepayers must be protected from cost uncertainty.
Funding schedule	In some cases, annualized sinking fund contributions are based on nominal dollars in other cases they are based on constant dollars. Those based on nominal dollars have a greater contributions in earlier years and provide a larger buffer in case of a premature shutdown.
Investment alternatives	How funds can be invested differs among PUCs, with some PUCs preferring safer investments over those that may produce larger gains, albeit with greater risk. There are also variations in the use or non-use of expected returns on investments in determining requirements for future sinking fund contributions.

announcement in the *Federal Register* soliciting public comment for a proposed rule making. The announcement stated that the NRC is considering rule making that would:

- Require that electric utility reactor licensees assure NRC that they can finance the full estimated cost of decommissioning if they are no longer subject to rate regulation by State agencies or by the Federal Energy Regulatory Commission and do not have a guaranteed source of income.

- Require utility licensees to report periodically on the status of their decommissioning funds. The present rule has no such requirement because State and Federal rate-regulating bodies actively monitor these funds. A deregulated nuclear utility would have no such monitoring.[184]

A number of options to demonstrate financial assurance are being studied. One alternative is to require prepayment of the decommissioning fund. While this option would eliminate the problem of a sinking-fund shortfall for a premature plant closure, it would not provide adequate protection from underestimating actual decommissioning costs. This suggests the possibility of requiring some type of surety guarantee. For a Federal Government licensee, the NRC is considering allowing the continued use of a statement of intent for financial assurance.

Restructuring would most likely result in the formation of two entities: an unregulated generation company and a regulated transmission and distribution company. An option being pursued by the industry is to transfer the responsibility for potential shortfalls to the regulated transmission and distribution company, which would be a continuing concern with future rate payers. While this approach is appealing from a financial assurance perspective, some issues would have to be resolved. For example, the power generated by an independent producer may be sold to parties other than the rate payers of the original transmission and distribution company, and it would be unfair to burden a group of rate payers with a financial obligation for which they may have received no benefit.

The proposed rulemaking would assign financial oversight to the NRC by requiring licensees to report periodically the status of their decommissioning fund to

[184] NRC Press Release, April 8, 1996, NRC Electronic Bulletin Board on FEDWORLD. Internet address is http://www.fedworld.gov.

the NRC. Whether the final rule does grant this authority to the NRC remains to be seen. In the past, however, the nuclear industry has resisted any proposals that would give NRC financial oversight responsibility.

Return on Decommission Sinking Funds

In the early 1980s, concern about the investment risk of decommission sinking funds led to regulations that placed limitations on the type of investments that were allowed. From 1986 through 1992, the federal tax code allowed licensees to exempt their decommissioning sinking fund contributions from federal taxation only if the contributors were invested in so-called qualified financial instruments, such as government bonds or bank deposits. If licensees invested their sinking fund contributions in stocks or other non-qualified securities, such contributions were taxed at the full corporate rate. The "safe investments" restrictions unfairly limited the earning potential of the sinking fund, and some analysts even argued that the funds could incur a minimal or even negative real rate of return. With the realization that there was misplaced emphasis on minimizing risk at the expense of maximizing return within an acceptable risk band, Congress repealed the investment restrictions for qualified decommissioning fund contributions when it passed the Energy Policy Act of 1992.[185]

While Federal tax regulations provided incentives for licensees to use certain types of investments, they did not require licensees to restrict their decommissioning funds to qualified funds. Some regulatory agencies, however, did. For example, in 1986 FERC required that decommissioning trust funds be invested in ultra-safe or so-called "Black-Lung" investments that were subject to the guidelines the Internal Revenue Service placed on Black Lung Disability trusts. After nearly a decade of these mandatory Black Lung investments, FERC, in a June 15, 1995, *Federal Register* notice, granted utilities permission to invest decommissioning trust funds in the same manner as a reasonable and prudent investor, e.g., stocks and mutual funds. The FERC rulings apply only to funds for which FERC has jurisdiction, namely money contributed for wholesale electricity sales.[186]

In the April 8, 1996, NRC *Federal Register* notice on revising the decommissioning funding rule, the NRC proposed allowing licensees to take credit for a positive, real rate of return on decommissioning trust funds during a period of safe storage. The current rule was based on the premise that there would be no real rate of return after inflation and taxes and does not allow a credit.

Cost Shortfall For Prematurely Retired Reactors

Because decommissioning sinking-fund schedules are based on annual contributions over the full term of a reactor's operating license, a premature retirement will result in a shortfall. So far, regulatory authorities have permitted utilities to collect all or most of the shortfall from the rate payers for the 11 commercial reactors that were shut down prior to their operating-license expiration date. Regulatory authorities generally recognize the issue of decommissioning cost shortfalls is related in principle to the issue of unrecovered capital costs, i.e., liabilities of a plant no longer generating revenue, and seem to treat them similarly. Currently, there appears to be a precedent to allow the recovery of both costs. FERC recently ruled that such costs could be recovered. Although individual PUCs have jurisdiction over retail sales and may arrive at their own determination for cost allowability, most of them follow federal guidelines.

Shutdown Reactors

As of the beginning of 1996, utilities have permanently shutdown 11 commercial nuclear reactors (Table 23). Five reactors were shut down because of technical problems, four because of economic considerations, one because of lack of consensus on the adequacy of its evacuation plan, and one after an accident that caused a core melt down.

Decommissioning activities are complete at Shoreham and are nearing completion at Fort St. Vrain. Both of these reactors had relatively low levels of radiation, so their decommissioning costs are not representative of other units.

Shoreham only operated for a brief time in low-power testing. Excluding the spent fuel, the total activated inventory at Shoreham was estimated to be 602 Curies.[187] The Long Island Power Authority (LIPA), which assumed responsibility for Shoreham after the Long Island Lighting Co. (LILCO) transferred the plant to the State of New York, completed the decommissioning of Shoreham and terminated its license on April 11, 1995. Total

[185] Energy Policy Act of 1992, Public law 102-486, 106 Stat 3024-3025, Sect 1917
[186] "DECOM Funds can Seek Higher Returns," *Nuclear News*, July 1995, pp. 15-16.
[187] Aging Nuclear Power Plants: Managing Plant Life and Decommissioning, Office of Technology Assessment, U.S. Congress, September 1993, p. 126.

Table 23. Status of Shutdown Reactors

Indian Point 1	
Date shutdown	October 31, 1974
Status	License amended to Possession Only Status (POL). Submitted decommissioning plan October 17, 1980. NRC review prompted supplemental submissions. Review process is ongoing.
Spent Fuel	Currently in spent fuel pool. Licensee is considering constructing an ISFSI.
Humboldt Bay	
Date shutdown	July 2, 1976
Status	SAFSTOR Decommissioning Plan approved, July 19, 1988.
Spent Fuel	Currently in spent fuel pool.
Dresden 1	
Date shutdown	October 31, 1978
Status	License amended to Possession Only Status (POL), July 23, 1986. SAFSTOR Decommissioning Plan approved, September 3, 1993.
Spent Fuel	Currently in spent fuel pool. Plan to move fuel to ISFSI.
Fort St. Vrain	
Date shutdown	August 18, 1989
Status	License amended to Possession Only Status (POL), May 21, 1991. DECON Decommissioning Plan approved, May 23, 1992 Decommissioning completion and license termination expected August 1996.
Spent Fuel	All fuel on a site in an ISFSI, June 11, 1992. DOE has assumed title to spent fuel.
Shoreham	
Date shutdown	June 28, 1989
Status	Decommissioning Plan approved, June 11, 1992 Decommissioning completion and license termination, April 11, 1995.
Spent Fuel	All fuel shipped to Philadelphia Electric Company for use in Limerick. Fuel had very low burnup since Shoreham only operated briefly in low-power testing.
Rancho Seco	
Date shutdown	June 7, 1989
Status	License amended to Possession Only Status (POL), March 17, 1992. SAFSTOR Decommissioning Plan approved, March 20, 1995.
Spent Fuel	Currently in spent fuel pool, but licensee plans to construct an ISFSI.
Comment	Licensee is considering expediting decommissioning because of concerns about low-level-waste site availability and costs.

Table 23. Status of Shutdown Reactors (Continued)

Yankee Rowe	
Date shutdown	October 1, 1991
Status	License amended to Possession Only Status (POL), August 5, 1992. SAFSTOR/DECON Decommissioning Plan approved, February 14, 1995.
Spent Fuel	Currently in spent fuel pool. Licensee plans to construct an ISFSI.
Three Mile Island 2	
Date shutdown	March 28, 1979
Status	License amended to Possession Only Status (POL), March 14, 1993.
Spent Fuel	None. Destroyed in core meltdown.
San Onofre 1	
Date shutdown	November 30, 1992
Status	License amended to Possession Only Status (POL), March 9, 1993. Decommissioning plan submitted November 3, 1994.
Spent Fuel	Currently in spent fuel pool. Licensee considering construction of an ISFSI.
Comment	Licensee is considering expediting the decommissioning of San Onofre 1, although San Onofre 2 and 3 are still operating.
Trojan	
Date shutdown	January 9, 1992
Status	License amended to Possession Only Status (POL), May 5, 1993. Decommissioning plan submitted November 3, 1994. Decommissioning Plan approved, April 16, 1996.
Spent Fuel	Currently in spent fuel pool. Licensee plan to move fuel to ISFSI in 1998.
La Crosse	
Date shutdown	April 30, 1987
Status	SAFSTOR approved.
Spent Fuel	Currently in spent fuel pool.

Source: Proceeding from the NRC Regulatory Information Conference, April 9, 1996, “Decommissioning Today,” Symore Weiss, p. 153-162.

decommissioning costs came to $178.6 million, slightly under the estimate of $186 million.[188] Because the exposure level of Shoreham’s spent fuel was very low, LIPA was able to sell it to Philadelphia Electric Company.

Most of the decommissioning of Fort St. Vrain has been completed, and the Public Service Company of Colorado (PSC) expects to finalize the process and terminate its license in August 1996. To contain decommissioning costs, PSC chose to sign a fixed price contract with a Westinghouse Team for a total cost of $188.1 million.[189] As Fort St.Vrain was originally built as a DOE demonstration gas-cooled, high-temperature reactor, DOE had agreed to take the title to the plant’s spent fuel. Under a 1965

[188] Adey, Charles W., Mann, Bruce, Petschauer, Frederick; *Shoreham Decommissioning: A Case Study*; Proceedings of the Topical Meeting On the Best of D&D, April 1996, American Nuclear Society.

[189] Fisher, Mary J., Chestnut, Sam W, *Fort St. Vrain Decommissioning: A Successful Conclusion*; Proceedings of the Topical Meeting On the Best of D&D, April 1996, American Nuclear Society.

agreement with DOE, PSC had shipped Fort St. Vrain's spent fuel to a DOE's Idaho National Engineering Laboratory. The shipments were curtailed due to public opposition and litigation activities, and PSC constructed an on-site ISFSI to hold Fort St. Vrain's spent fuel . Under a new agreement between DOE and PSC, DOE agreed to pay PSC for the costs of operating the ISFSI.[190]

Both PG&E, the operator of Trojan, and YAEC, the operator Yankee Rowe, are in the process of decommissioning their reactors. Both utilities chose the DECON option and have already removed some components and shipped them to LLW facilities. They both plan to construct ISFSIs to hold their spent fuel until DOE picks it up.

Sacramento Municipal Utility District (SMUD), the operator of Rancho Seco, had originally chosen the SAFSTOR alternative as the cheapest option. With the rapid escalation in LLW costs, SMUD is in the process of reevaluating its options. SMUD currently has access to the Barnwell facility, and although expensive, the cost and availability of LLW sites in the future are uncertain. SMUD plans to construct an ISFSI for its spent fuel.

Indian Point 1, Dresden 1, and San Onofre 1 are all part of multi-unit plants, whose other units are still operating. It is generally thought that decommissioning a multi-unit plant will proceed simultaneously after all units in the plant have ceased operation. However, Southern California Edison (SCE), which operates the San Onofre plant, is considering decommissioning San Onofre 1 prior to the retirement of the other two San Onofre units. In a proposed deregulation plan, the California PUC will allow utilities to recover past decommissioning costs directly from the rate payers through 2003. After 2003, utilities will be responsible for any additional costs.[191] Decommissioning San Onofre 1 early would remove a lingering and uncertain cost liability, which SCE might prefer to resolve prior to making the transition from a regulated environment to a competitive one.

Spent Fuel Management

All the high level waste (HLW) generated in commercial nuclear reactors is contained in the spent fuel and associated hardware. While the quantities of spent fuel are small compared to the amounts of LLW generated during reactor operations and decommissioning, the spent fuel contains the bulk of the radioactivity and remains hazardous for thousands of years. Compared to reactor decommissioning, spent fuel management and disposal poses a far greater challenge.

The Nuclear Waste Policy Act of 1982 (NWPA; P.L. 97-425) assigned responsibility for the ultimate disposal of spent nuclear fuel to the Federal government. When the NWPA was enacted, it was envisioned that the Federal Government would site and license a geologic disposal site by 1998. Accordingly, the Act designated 1998 as the year in which the Federal Government would begin receiving spent fuel from civilian reactors. However, the difficulties involved in qualifying, licensing, and developing a site were grossly under estimated. The Federal Government is currently conducting site characterization activities at Yucca Mountain, Nevada, to determine if the site is suitable for geologic disposal. The eventual outcome of the site characterization process is uncertain, and the current target date of 2010 for an operational repository is viewed as optimistic. With programmatic delays, the unavailability of a mined geologic repository, and ardent political opposition, it is uncertain when the government will actually begin receiving spent fuel.

Recognizing the enormous difficulty in siting and licensing a mined geological repository site, the Federal Government proposed establishing a monitored retrievable storage (MRS) facility to act as a buffer until an operational repository is opened. A multi-year attempt to find a voluntary host site for an MRS ended unsuccessfully due to ardent political opposition at the state level. Whether Congress will establish a temporary surface storage site by fiat is speculative.

Currently, licensees are utilizing and/or pursuing a mixture of three options for storing their spent fuel: (1) in-pool storage, (2) dry storage in an ISFSI, and (3) off-site storage. When a reactor is operating, spent fuel is discharged directly into the spent fuel pool, where it typically remains until the pool capacity becomes exhausted. After efforts to expand in-pool storage, such as reracking, have been exhausted, most licensees have turned to dry cask storage in an ISFSI to expand their on-site spent-fuel storage capacity. A few licensees have shipped fuel off-site, but the availability of off-site storage locations is severely limited.

With the growing realization that the Federal Government's program may be further delayed, licensees are

[190] "Fort St. Vrain DECOM Project Involves New Tools, Communication," *Nuclear News*, May 1996, pp.16-17.
[191] Fessler, Daniel W., "California's Move from Integrated Monopolies to Competitive Generation: Smooth Transition, Not Shock Therapy," *Nuclear News*, May 1996, p.39.

making plans to provide for potential long-term storage of their spent fuel. After all units in a plant are retired, a licensee must decide whether to transfer the spent fuel stored in the reactor's pool to an ISFSI. The decision is primarily economic: the longer the fuel remains on site the more cost beneficial an ISFSI. The desire to expedite decommissioning also enters into the equation, since decommissioning cannot be completed until all the spent fuel is removed from the reactor pool.

While the NRC does not consider the post-shutdown management and storage of spent fuel to be a decommissioning activity, it does strictly monitor spent fuel storage to ensure that public health and safety are protected. Under NRC regulations, an operating license cannot be terminated until the spent fuel is shipped to an independent site, even if the independent site is an ISFSI located on the licensee's property. The spent fuel pool is considered an integral part of the reactor and is subject to regulation under 10 CFR Part 50, which governs operating licenses for nuclear power plants. An ISFSI, however, is licensed under 10 CFR Part 72 as an independent storage facility and is subject to less regulation. As an independent site, an ISFSI must have the capability of shipping the fuel without returning it to the pool. To accommodate this requirement, vendors are licensing casks for both storage and transportation. However, construction of dry transfer facilities may be necessary in some cases.

In 1995, former NRC commissioner Ivan Sellin announced that the NRC "views dry storage as by far the preferred method for supplementary storage of spent fuel at operating reactors . . . and at those plants in premature or extended shutdown, the NRC finds several strong reasons why we would prefer to see dry storage systems replace existing fuel pools for on-site storage."[192] In-pool storage involves complex systems for cooling water decontamination, waste heat removal, and radiation and corrosion monitoring. In contrast, dry storage is passive and requires very little monitoring. The NRC emphasizes that dry storage offers fewer opportunities for failures.

Since most of the residual radioactivity is contained in the spent fuel, the separation of post-closure activities into decommissioning and spent fuel management may seem artificial to the general public. Funds have to be available both to decommission the reactor and to store the spent fuel. As previously noted, some licensees have estimated post-closure spent fuel storage costs to be as high as one-third of the total costs for decommissioning and spent fuel storage, and these estimates increase with further delays in the Federal Government's waste management program. In the final analysis, however, spent-fuel storage costs may be of secondary importance compared with a growing concern that individual reactor sites may become *de facto* hosts for long-term spent fuel storage.

Conclusions

Several commercial reactors have been successfully decommissioned, demonstrating that decommissioning is well within the bounds of current technology. The greatest uncertainties are in the areas of cost and the availability of LLW disposal sites. Labor and LLW disposal are the primary cost drivers. Inflation-adjusted labor costs are currently stable, but LLW disposal costs for some sites have been escalating rapidly and will have a significant impact on total decommissioning costs. Licensees within states whose LLW compacts do not have approved disposal sites must consider both the availability of and projected increases in cost for LLW disposal when making decommissioning decisions. Yankee Atomic, for instance, decided to expedite Yankee Rowe's decommissioning while it still had certain access to the Barnwell site.

Many factors enter into a licensee's decision to choose the DECON or SAFSTOR option. Presently, the economics appear to depend primarily on the expected escalation in LLW costs. Factors favoring the DECON option include the availability of a highly skilled staff with experience at the plant, the elimination of potential future cost uncertainties, and the desire to avoid inter-generational equity issues. Factors favoring the SAFSTOR option include the desire to reduce the radioactivity and quantity of LLW and the possibility that new, more efficient technologies may emerge. For reactors that are part of a multi-unit plant, most licensees are expected to decommission all units in the plant simultaneously.

The NRC's regulatory authority for decommissioning ends after the site is decontaminated and made suitable for unrestricted use. Individual states determine the extent of non-radiological decommissioning that will be required. The demolition and removal of non-radiological structures can be costly, and questions remain about the necessity of returning the site to a green-field condition versus a condition suitable for an industrial application such as another power plant.

The NRC and the EPA are currently in the process of establishing the maximum dose criteria for a site to

[192] Remarks by Ivan Sellin, Chairman, before the International High-Level Waste Management Conference, May 1, 1995, U.S. Nuclear Regulatory Commission, Office of Public Affairs, Washington D.C. 20555.

qualify for unrestricted use. At this time, the proposed dose rate is 15 mrem per year above ambient. The NRC has also proposed new regulations that would eliminate NRC approval of a licensee's decommissioning plan and define a structure for public comment.

The NRC has established minimum financial assurance requirements for decommissioning based on cost estimates for a reference BWR and a reference PWR. The NRC cost estimates cover activities related to decontamination and license termination and do not include costs for post-shutdown spent fuel management and site restoration; therefore, the NRC cost estimates are generally considered low by the industry. In addition, decommissioning costs vary widely, based on factors that are unique to each plant, such as labor and LLW costs and design features. Many licensees are now performing site-specific decommissioning studies that include spent fuel storage and site restoration costs to obtain a more realistic estimate of total costs.

Deregulating and restructuring in the electricity industry raise questions about the responsibility for shortfalls of decommissioning funds. The NRC is currently in the process of formulating financial assurance regulations that would be appropriate in a deregulated environment. Individual states and PUCs also have to address this issue, especially in the case where a licensee may no longer have direct access to the rate base.

With delays in the Federal Government's HLW management program, long-term storage of spent fuel at utility sites is becoming more of a possibility, and estimates of post-shutdown costs for spent fuel storage are likely to increase. Each utility must weigh the costs and benefits of continued pool storage versus that of placing all its spent fuel in an ISFSI. Annual costs for pool storage are more expensive than for an ISFSI, but there is a one-time capital cost associated with placing the spent fuel in an ISFSI. An important consideration is when the licensee decides to complete the decommissioning process, since the licensee must remove all the spent fuel from the reactor site to terminate an NRC reactor license. The NRC has stated that an ISFSI qualifies as a separate site. Because dry storage is more passive than wet storage, the NRC is also encouraging licensees to transfer their spent fuel from their pools into ISFSIs, if prolonged on-site storage is needed.

4. Comparison with Other Projections

Several organizations associated with the nuclear industry publish annual reports that contain projections of nuclear capacity and fuel cycle requirements. In this chapter, we present a comparison of EIA's Reference and High Case with Low and High Case projections made by NAC International (NAC), and Energy Resources International, Inc. (ERI). These organizations utilize unique methods to project nuclear capacity, spent fuel discharges, uranium enrichment services, and uranium requirements. Nuclear capacity projections are compared for the years 1996, 2000, 2005, 2010 and 2015. The fuel cycle requirements are compared in five-year increments, 1996-2000, 2001-2005, 2006-2010 and 2011-2015. Annual projections of nuclear capacity, electricity generation, and cumulative spent fuel discharges for 1996 through 2040 for the United States can be found in Appendix E.

In light of the current stagnant nature of the U.S. nuclear industry, this report considers two scenarios that represent probable bounds for U.S. nuclear fuel cycle projections: the No New Orders Case (Reference Case) and the License Renewal Case (High Case). The Reference Case anticipates no new orders for nuclear units, i.e., no new advanced light-water reactors will become operational before the year 2040. 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 (Reference Case), with the exception that all U.S. reactors have their licenses extended for 10 years beyond the current expiration date. While there are six reactors with construction permits in the United States, there is no construction activity and the reactor owners are not expected to receive operating licenses. Foreign projections are also presented with two cases, a Reference Case and a High Case.

The Reference Case scenario reflects a continuation of present trends in the nuclear power industry. The capacity projections are based on units in the construction pipeline. The reactors are projected to operate for about 30 years. The High Case reflects a revival in nuclear orders. The assumptions are that unfinished nuclear units are completed by 2015 and that most countries will operate their units for about 40 years.

Comparison of Actual Data with EIA Projections

Table 24 displays a comparison of EIA projections with actual data. The comparisons are of worldwide nuclear capacity, U.S. nuclear electric generation, and U.S. cumulative spent fuel discharges from EIA's 1992 through 1995 reports. For worldwide nuclear capacity, the differences range from -4.0 to 0.3. The best projections for this were made in 1994. The difference is between -0.5 and 0.4. In forecasting U.S. nuclear electricity generation, the 1995 projection is markedly better than the earlier years. EIA's earlier projections had not reflected the remarkable improvement in reactor operating efficiency as shown by increased capacity factors. For U.S. cumulative spent fuel discharges, the projections made in 1992 and 1995 equaled the actual values of 25.9 and 32.2 thousand metric tons of uranium (MTU).

Comparison with Last Year's Report

Domestic Projections

The U.S. Reference Case nuclear capacity projection made in 1995 and in this report are very similar. The slight differences are due to updated nuclear capacities and to Diablo Canyon 1 and 2 having their retirement dates adjusted based on the receipt of their fuel power license instead of the receipt of their construction permit. Consequently their retirement dates were adjusted in this report. The Reference Case capacity projection for the United States falls from 100.6 net GWe in 1996 to 63.7 net GWe in 2015 (Table 25). Whereas in the 1995 report, the Reference Case projection dropped from 100.3 net GWe in 1996 to 61.4 net GWe in 2015.

In the High Case for the United States, the license expiration dates of all the reactors were extended by 10 years. In the 1995 report, about 50 percent of the reactors had their license expiration dates extended for 20 years. This contributes to the greater differences in capacity in the High Case. EIA is projecting nuclear capacity to remain around 100.5 net GWe from 1996 to 2015. In the

Table 24. Comparison of Actual Data and EIA Forecasts

Year	Worldwide Nuclear Capacity (Net Gigawatts-Electric)				
	Year Forecast was Made				
	1992	1993	1994	1995	Actual
1992	324	NA	NA	NA	R329
1993	326	326	NA	NA	338
1994	327	327	342	NA	340
1995	333	331	343	342	344

Year	U.S. Nuclear Electric Generation (Net Terawatthours)				
	Year Forecast was Made				
	1992	1993	1994	1995	Actual
1992	610	NA	NA	NA	619
1993	612	605	NA	NA	610
1994	618	610	611	NA	640
1995	624	611	618	651	673

Year	U.S. Cumulative Spent Fuel (Thousand Metric Tons Uranium)				
	Year Forecast was Made				
	1992	1993	1994	1995	Actual
1992	25.9	NA	NA	NA	25.9
1993	28.1	28.3	NA	NA	R28.1
1994	30.0	29.9	29.9	NA	R30.0
1995	32.1	32.3	32.3	32.2	32.2

NA = Not applicable.
R= Revised.
Sources: Energy Information Administration, *World Nuclear Capacity and Fuel Cycle Requirements 1992*, DOE/EIA-0436(92) (Washington, DC, December 1992), pp. 108, 110; *World Nuclear Capacity and 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. 8, 106, 107; *Spent Nuclear Fuel Discharges from U.S. Reactors 1992*, SR/CNEAF/94-01 (Washington, DC, May 1994), p. 20; *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995), pp. 8, 116, 117.

1995 report, the High Case capacity was 100.3 GWe in 1996 and it dropped steadily, as reactors began to retire, to 76.0 net GWe in 2015.

The projection of domestic uranium requirements are higher this year for both the Reference and High Cases (Table 26). The same is true for domestic enrichment service requirements (Table 27). The domestic spent fuel projection for 1996 through 2015 for the Reference Case is 41.9 thousand metric tons of initial heavy metal (MTIHM) (Table 28). The projection last year was 39.2 thousand MTU. In the High Case, the domestic spent fuel projection for 1996 through 2015 is 40.4 thousand MTU. The cumulative Reference Case projection is a little higher than the High Case projection because there are more reactors retiring in the Reference Case and as reactors retire, they discharge an amount of spent fuel equal to the size of their core. During normal operation, reactors discharge about one-third of their core each cycle. The projections of domestic spent fuel discharges for the High Case in the 1995 report for 1996 through 2015 was 38.9 thousand MTIHM, about 10 percent less than the projection last year.

For U.S. reactors, EIA is projecting higher capacity factors than last year. The projection is 78 percent for 1996 and it grows to 79 percent by 2015. The capacity factor projections in last year's report were around 74 percent. This

Table 25. Comparison of Projections of U.S. Nuclear Capacity at Year End, 1996, 2000, 2005, 2010, and 2015

Source	Capacity (Net GWe)[a]				
	1996	2000	2005	2010	2015
Energy Information Administration					
Nuclear Power Generation and Fuel Cycle Report 1996					
Reference Case	100.6	100.5	100.5	93.5	63.7
High Case	100.6	100.5	100.5	100.5	100.5
World Nuclear Outlook 1995					
Low Case	100.3	100.3	100.3	91.1	61.4
High Case	100.3	100.3	100.3	95.0	76.0
Energy Resources International					
Low Case	98.9	92.1	92.1	85.9	61.2
High Case	100.0	100.0	100.6	104.5	115.8
NAC International					
Low Case	99.4	99.4	98.6	92.4	62.7
High Case	99.4	99.4	98.6	92.4	62.7

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

Sources: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 3-28 and 3-29; and NAC International, *Nuclear Megawatt Generation Status Report* (Norcross, GA, February 1996), p. C-42.

Table 26. Comparison of Projections of Total Uranium Requirements for the United States, 1996 Through 2015
(Million Pounds U_3O_8)

Source	Projection Period				Total 1996-2015
	1996-2000	2001-2005	2006-2010	2011-2015	
Energy Information Administration					
Nuclear Power Generation and Fuel Cycle Report 1996					
Reference Case	237.0	234.3	222.9	149.0	843.3
High Case	237.0	235.4	234.7	218.4	925.5
World Nuclear Outlook 1995					
Low Case	222.1	228.7	202.1	138.6	791.5
High Case	222.1	228.7	209.2	169.0	829.0
Energy Resources International, Inc.					
Low Case	206.0	202.1	191.8	143.5	743.4
High Case	233.3	233.9	254.4	280.2	1,001.8
NAC International					
Low Case	256.7	249.6	240.7	175.3	922.3
High Case	256.7	249.6	240.7	175.3	922.3

Sources: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 3-27 to 29, 4-43 to 45, and 6-39 to 41; NAC International, *U_3O_8 Status Report* (Norcross, GA, February 1996), pp. F1-6.

Table 27. Comparison of Projections of Total Enrichment Service Requirements for the United States, 1996 Through 2015
(Million Separative Work Units)

Source	Projection Period				Total 1996-2015
	1996-2000	2001-2005	2006-2010	2011-2015	
Energy Information Administration					
Nuclear Power Generation and Fuel Cycle Report 1996					
Reference Case	51.7	54.0	50.0	36.8	192.5
High Case	51.7	54.1	52.3	53.3	211.4
World Nuclear Outlook 1995					
Low Case	49.2	49.7	47.8	32.2	178.9
High Case	49.2	49.7	49.1	39.1	187.1
Energy Resources International, Inc.					
Low Case	46.3	44.5	42.7	33.9	167.4
High Case	51.9	51.1	54.4	61.2	218.6
NAC International					
Low Case	56.2	55.4	53.9	40.4	205.9
High Case	56.2	55.4	53.9	40.4	205.9

Sources: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 6-40 and 6-41; and NAC International, *Enrichment Status Report* (Norcross, GA, February 1996), pp. F1-6.

Table 28 Comparison of Projections of Total Spent Fuel Discharges for the United States, 1996 Through 2015
(Thousand Metric Tons of Uranium)

Source	Projection Period				Total 1996-2015
	1996-2000	2001-2005	2006-2010	2011-2015	
Energy Information Administration					
Nuclear Power Generation and Fuel Cycle Report 1996					
Reference Case	11.1	10.4	10.1	10.4	41.9
High Case	11.1	10.4	9.7	9.3	40.4
World Nuclear Outlook 1995					
Low Case	10.2	9.7	9.9	9.4	39.2
High Case	10.2	9.7	9.7	9.3	38.9
Energy Resources International, Inc.					
Low Case	9.7	9.4	9.2	10.2	38.5
High Case	9.7	9.4	9.2	10.2	38.5
NAC International					
Low Case	10.4	10.3	10.6	10.8	42.1
High Case	10.4	10.3	10.6	10.8	42.1

Sources: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 8-21; and NAC International, *Discharge Fuel/Reprocessing Status Report* (Norcross, GA, February 1996), pp. D-1, D-41.

increase in capacity factor projections contributes to the increase in projections of fuel cycle requirements.

Foreign Projections

In the Reference Case, the foreign nuclear capacity projection grows from 249.2 net GWe in 1996 to 278.7 net GWe in 2010. It then falls to 269.7 net GWe in 2015 (Table 29). In the 1995 report, the Low Case projected similar growth: from 248.7 net GWe in 1996 to 268.5 net GWe in 2010, followed by a decline to 250.2 net GWe in 2015. Unlike the Reference Case, the High Case foresees continued growth. In 1996, the foreign nuclear capacity is 249.2 net GWe. It grows to 318 net GWe in 2010 and continues to grow to 354.7 net GWe by 2015. The High Case in the 1995 report displayed the same trend, a steady growth from 250.7 net GWe in 1996 to 318.5 net GWe in 2015.

For 1996 through 2015, the projections of uranium requirements, enrichment service requirements and spent fuel discharges for foreign countries are higher in this report than in last year's report (Tables 30, 31, and 32).

The projected fuel cycle requirements differ mainly because the nuclear capacity projection has changed and also because of updated reactor capacity factors, updated fuel diets and nuclear capacity upgrades for some reactors.

Comparison with Other Reports

EIA's projections are compared with the projections made by

- Energy Resources International, Inc. and
- NAC International.

These organizations and EIA make assumptions about the reactors' operation dates, retirement dates, expected capacity factors, fuel management plans and other factors. EIA's projections are comparable to those made by the other organizations. The differences are due to dissimilar assumptions.

The nuclear capacity projections of all three organizations are determined after the analysts review their data and impart their knowledge of historical and current trends. EIA uses techniques similar to those used by the other organizations to project uranium requirements and enrichment service requirements. Uranium and enrichment service requirements are a function of five major, interrelated variables which deal with the fuel management and operating characteristics of the reactor.

Table 29. Comparison of Projections of Foreign Nuclear Capacity, 1996 Through 2015
(Net GWe)

Source	Projection Period				
	1996	2000	2005	2010	2015
Energy Information Administration					
Nuclear Power Generation and Fuel Cycle Report 1996					
Reference Case	249.2	258.9	269.3	278.7	269.7
High Case	249.2	267.2	288.9	318.0	354.7
World Nuclear Outlook 1995					
Low Case	248.7	262.6	260.8	268.5	250.2
High Case	250.7	266.1	273.8	290.8	318.5
Energy Resources International, Inc.					
Low Case	240.5	247.6	255.8	258.9	243.4
High Case	252.4	272.5	307.0	359.4	406.2
NAC International					
Low Case	251.7	273.8	285.3	273.5	244.9
High Case	251.8	273.8	310.1	312.5	284.0

Sources: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 3-28 and 3-29; and NAC International, *Nuclear Megawatt Generation Status Report* (Norcross, GA, February 1996), p. C-1.

Table 30. Comparison of Projections of Total Uranium Requirements for Foreign Countries, 1996 Through 2015
(Million Pounds U_3O_8)

Source	Projection Period				Total
	1996-2000	2001-2005	2006-2010	2011-2015	1996-2015
Energy Information Administration					
Nuclear Power Generation and Fuel Cycle Report 1996					
Reference Case	546.1	557.8	575.0	534.9	2,213.8
High Case	563.5	606.9	671.5	699.2	2,541.1
World Nuclear Outlook 1995					
Low Case	546.9	538.7	543.4	497.2	2,126.2
High Case	553.0	579.3	597.6	619.5	2,349.4
Energy Resources International, Inc.					
Low Case	490.2	493.1	490.1	473.6	1,947.0
High Case	529.4	580.8	679.6	784.2	2,574.0
NAC International					
Low Case	626.1	669.9	638.1	563.9	2,498.0
High Case	629.5	738.9	720.0	649.7	2,738.0

Sources: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 3-27 to 29, 4-43 to 45, and 6-39 to 41; NAC International, *U_3O_8 Status Report* (Norcross, GA, February 1996), pp. F1-6.

Table 31. Comparison of Projections of Total Enrichment Service Requirements for Foreign Countries, 1996 Through 2015
(Million Separative Work Units)

Source	Projection Period				Total
	1996-2000	2001-2005	2006-2010	2011-2015	1996-2015
Energy Information Administration					
Nuclear Power Generation and Fuel Cycle Report 1996					
Reference Case	111.7	116.7	123.9	119.0	471.3
High Case	114.7	126.3	140.5	156.8	538.2
World Nuclear Outlook 1995					
Low Case	112.3	114.2	118.6	108.9	454.0
High Case	114.6	120.7	129.6	135.0	499.9
Energy Resources International, Inc.					
Low Case	102.6	101.2	103.7	100.4	407.9
High Case	108.1	117.9	139.0	161.0	526.0
NAC International					
Low Case	121.6	132.7	125.0	114.3	493.6
High Case	122.0	144.2	143.0	133.3	542.5

Sources: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 6-40 and 6-41; and NAC International, *Enrichment Status Report* (Norcross, GA, February 1996), pp. F1-6.

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 – a measure of the amount of U-235 remaining in the waste stream
- Fuel burnup – the amount of energy generated from the fuel
- Fuel cycle length – the length of time the reactor operates before refueling.

EIA obtains these values by performing statistical analyses on historical reactor operating data from Form RW-859 and from data colleted by the U.S. Nuclear Regulatory Commission.

Comparison to Energy Resources International

ERI developed three nuclear power scenarios on a plant-by-plant basis, taking into consideration the political, social and economic conditions of the various countries. ERI assumes plutonium and uranium recycling in some Western European countries. Currently, EIA's recycling is handled outside of the model (i.e., is not included in the projected uranium requirements). We will compare ERI's Low and High cases to EIA's. ERI's Low Case represents a no-growth scenario, whereas the High Case is consistent with announced utility schedules for identified nuclear power plants in addition to some capacity expansion. EIA's Reference Case is also a no-growth case; reactors operate until they retire on their official license expiration date. In EIA's High Case, all reactors have their lives extended for 10 years past the license expiration date.

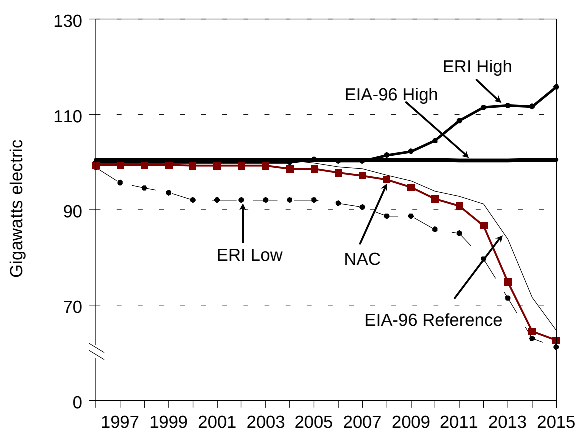
ERI projects U.S. nuclear capacity for the Low Case to fall from 98.9 net GWe in 1996 to 61.2 net GWe in 2015 (Figure 13. The resulting 2.4 percent annual rate of decline is close to that projected by EIA (2.3 percent). In the High Case, ERI projects nuclear capacity to grow from 100 net GWe in 1996 to 115.8 net GWe in 2015. EIA's projection holds steady around 100.5 net GWe for the same time period. For foreign reactors, ERI's Low Case starts at 240.5 net GWe in 1996 and grows to 258.9 net GWe by 2010, then declines to 243.4 net GWe by 2015 (Figure 14). EIA has foreign capacity growing from 249.2 net GWe in 1996 to 278.7 net GWe in 2010, then falling to 269.7 net GWe by 2015. In the High Case, ERI projects nuclear capacity in foreign countries to grow steadily from 252.4 net GWe

Table 32. Comparison of Projections of Total Spent Fuel Discharges for Foreign Countries, 1996 Through 2015
(Thousand Metric Tons of Uranium)

Source	Projection Period 1996-2000	2001-2005	2006-2010	2011-2015	Total 1996-2015
Energy Information Administration					
Nuclear Power Generation and Fuel Cycle Report 1996					
Reference Case	42.6	42.6	43.0	42.5	170.6
High Case	42.9	45.5	47.0	50.9	186.3
World Nuclear Outlook 1995					
Low Case	41.6	43.6	41.0	39.3	165.5
High Case	43.3	44.2	43.0	44.9	175.4
NAC International					
Low Case	42.2	47.2	40.5	38.6	168.5
High Case	42.1	48.2	45.6	44.2	180.0

Sources: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 8-21; and NAC International, *Discharge Fuel/Reprocessing Status Report* (Norcross, GA, February 1996), pp. D-1, D-41.

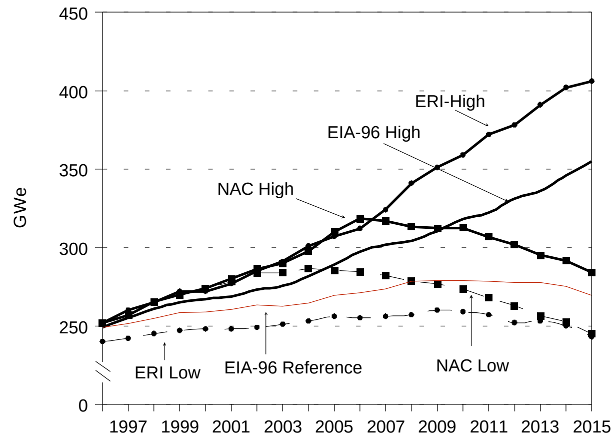
Figure 13. U.S. Nuclear Capacity, 1996-2015



EIA = Energy Information Administration.
ERI = Energy Resources International, Inc.
NAC = NAC International.

Source: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 3-28 and 3-29; and NAC International, *Nuclear Megawatt Generation Status Report* (Norcross, GA, February 1996), p. C-42.

Figure 14. Foreign Nuclear Capacity, 1996-2015



EIA = Energy Information Administration.
ERI = Energy Resources International, Inc.
NAC = NAC International.

Source: Energy Information Administration, International Nuclear Model, File INM.WK4; Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95) (Washington, DC, October 1995); Energy Resources International, Inc., *1996 Nuclear Fuel Cycle Supply and Price Report* (Washington, DC, May 1996), pp. 3-28 and 3-29; and NAC International, *Nuclear Megawatt Generation Status Report* (Norcross, GA, February 1996), p. C-1.

in 1996 to 406.2 net GWe by 2015. This is significantly higher than EIA's projection which is 249.2 net GWe in 1996, growing to 354.7 net GWe by 2015.

Generally speaking, for 1996 through 2015, EIA's projections of domestic and foreign uranium requirements and enrichment service requirements for the Reference and High Cases fall between ERI's projections, i.e., ERI's High Case is higher than EIA's High Case and ERI's Low Case is lower than EIA's Reference Case.

ERI projects domestic spent fuel discharges for one case. Their projection is 38.5 thousand MTU for 1996 through 2015. The projection is 8 percent less than EIA's Reference Case and 5 percent less than EIA's High Case. ERI does not project foreign spent fuel discharges.

Comparison to NAC International

NAC's database on operating reactors contains detailed information on utility operating plans and fuel management plans. This enables NAC to closely reproduce individual utility requirements. EIA's nuclear reactor data base contains some specific data but it consists primarily of generic fuel management plans that are derived from information at the country level. NAC modifies the utilities' commercial operating data to incorporate additional information from sources other than utilities. EIA uses the official commercial operating dates from the Nuclear Regulatory Commission and the International Atomic Energy Agency.

NAC's nuclear capacity projection for the United States is identical for the Low and High Cases, thereby making the fuel cycle requirement projections identical for the Low and High Cases. NAC projects U.S. nuclear capacity to fall from 99.4 net GWe in 1996 to 62.7 net GWe in 2015. This reflects an annual rate of decline of 2.3 percent. EIA's projection of U.S. nuclear capacity for the Reference Case also has an annual rate of decline of 2.3 percent. As discussed earlier, EIA's projection of U.S. nuclear capacity for the High Case holds steady around 100.5 net GWe for the same time period. For foreign reactors, NAC projects the nuclear capacity in the Low Case to be 251.7 net GWe in 1996 with a growth to 285.3 net Gwe in 2005 before falling to 244.9 net GWe in 2015. EIA has foreign capacity growing from 249.2 net GWe in 1996 to 278.7 net GWe in 2010 and falling to 269.7 net GWe in 2015 in the Reference Case. In the High Case, NAC projects nuclear capacity in foreign countries to grow from 251.8 net GWe in 1996 to 312.5 net GWe in 2010 and then begin a decline to 284 net GWe in 2015. EIA projects a growth from 249.2 net GWe in 1996 to 354.7 net GWe in 2015.

For domestic reactors, the projections of uranium requirements and enrichment service requirements made by NAC fall between EIA's Reference and High cases. NAC's projection of spent fuel discharges for 1996 through 2015 are higher than both of EIA's cases. On the foreign side, NAC's projections of fuel cycle requirements for 1996 through 2015 are higher than EIA's except for spent fuel discharges where NAC's projections are about 3 percent lower.

Summary

Nuclear capacity projections have a great impact on projections of fuel cycle requirements as do the capacity factor projections. EIA's Reference and High Case nuclear capacity projections for the United States generally fall between those of ERI's and NAC's Low and High cases. Therefore, it is not surprising that the same trend is observed in the projections of U.S. uranium requirements, U.S. enrichment service requirements and U.S. spent fuel discharges. EIA's foreign nuclear capacity projection is lower than the others in the High Case until 2010 when NAC's projection drops lower. In the Reference Case, EIA's foreign nuclear capacity projection is between ERI's and NAC's until 2009 when NAC drops lower. For foreign fuel cycle projections, NAC's projections are generally higher than EIA's, and ERI's projections are about 13 percent less.

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, use 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.[193] Generally, this "reaction" involves the uranium nucleus splitting (or "fissioning") 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.

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 for

[193]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.

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 during 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, megawattdays 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 highly radioactive spent nuclear fuel. 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.

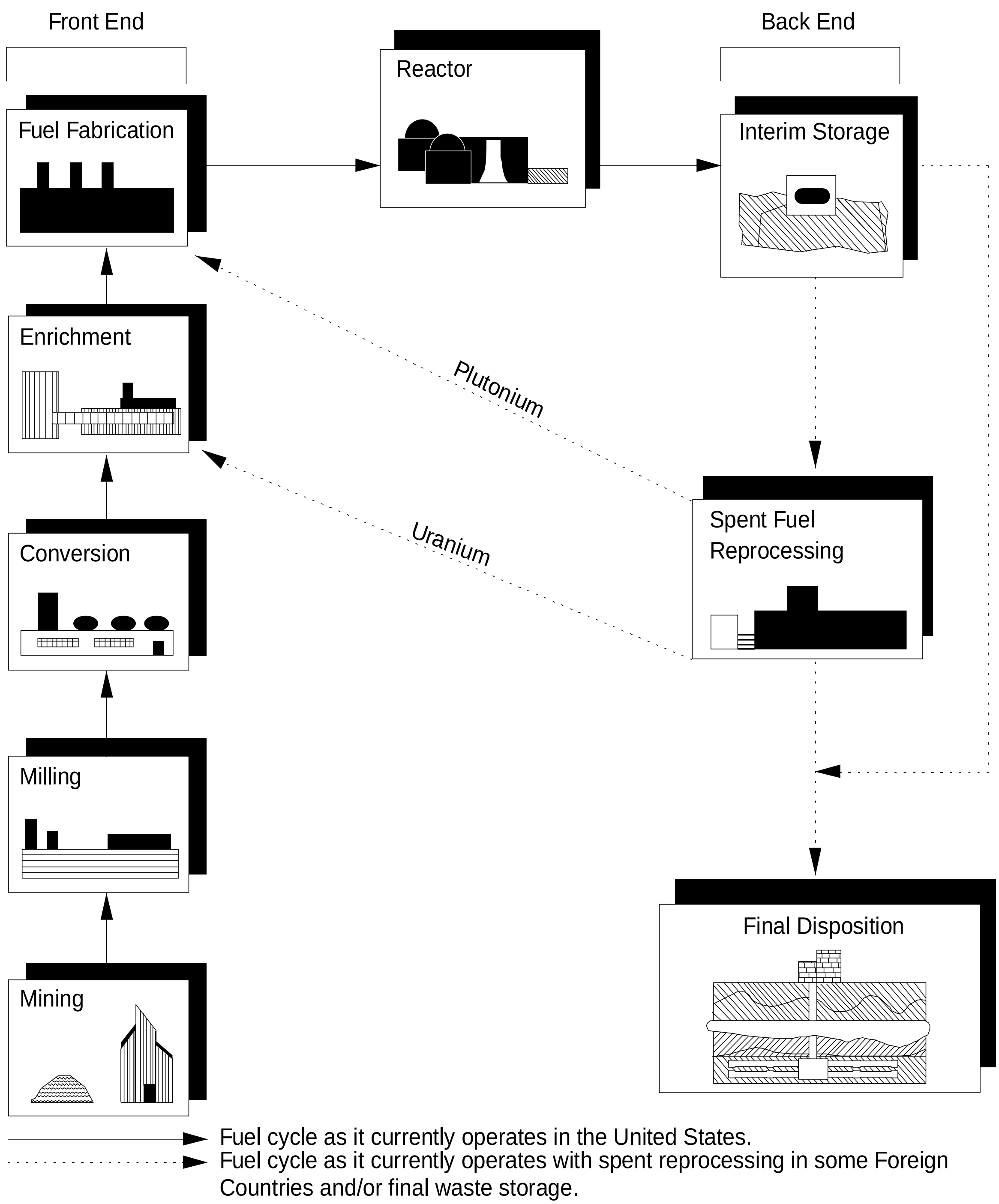
- **Mining**. Uranium-bearing ore is mined by methods similar to those used for other metal ores. The uranium content of ores in the United States typically ranges from 0.05 to 0.3 percent uranium oxide (U_3O_8). In foreign countries the uranium content of ores varies widely, from 0.035 percent in South 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's judgment. The WINES model was used to forecast non-U.S. nuclear capacity.

For the countries listed in Table B1, labor-age population growth rates are derived from population projections by the World Bank. The labor force participation fraction rate range from 0.1 percent to as high as 2.5 percent. Labor productivity is assumed to grow at an annual rate from 1.5 percent to as high as 4 percent (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 for most countries (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
China	2.5	4.0
France[a]	0.1	2.5
India	0.25	2.0
Japan[a]	0.1	3.5
Russia	1.0	1.5
South Korea[a] . . .	0.6	3.0
Ukraine	1.0	2.5

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

WINES = World Integrated Nuclear Evaluation System.

Note: Values are indicated for those countries where WINES was used to develop the forecasts.

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 than do 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

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
China	1.5	-0.3	0.6
France[a]	1.0	-0.3	0.6
India	1.5	-0.3	0.6
Japan[a]	1.0	-0.3	0.6
Russia	1.5	-0.3	0.6
South Korea[a]	1.5	-0.3	0.6
Ukraine	1.5	-0.3	0.6

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

Note: WINES = World Integrated Nuclear Evaluation System. Values are indicated for those countries where WINES was used to develop the forecasts.

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.

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 ranges from 10 to 30 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 ranges 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 12 to 85 percent (Table B3). France was estimated by analyzing its historical shares and fitting logistic market penetration functions to its historical data. The 1995 average domestic nuclear share of utility-electrical generation was 22.5 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 below 15 years; except for China because financing nuclear projects in China 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 through 1994. 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).[194] 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.

[194] Energy Information Administration, Form RW-859, "Nuclear Fuel Data (1994)."

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
China	20	20	20	30
France[a]	30	85	10	15
India	20	12	15	25
Japan[a]	30	35	10	15
Russia	10	13	20	11
South Korea[a]	20	70	15	8
Ukraine	13	40	18	10

[a]Member country of the Organization for Economic Cooperation and Development (OECD).
WINES = World Integrated Nuclear Evaluation System.
Note: Values are indicated for those countries where WINES was used to develop the forecasts.
Source: Decision Analysis Corporation of Virginia, *Final Report: WINES Model Analysis (OECD) Countries)*, DOE Contract No. DE-AC01-87El-19801 (Vienna, VA, November 15, 1991), Volumes 1-3; *WINES Model Analysis (Non-OECD Countries)*, DOE Contract No. DE-AC01-92El-22941 (Vienna, VA, March 27, 1992); Energy Information Administration, Office of Integrated Analysis and Forecasting.

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:

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

and

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

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.

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 0.80 and 0.79 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:

$$E = 1.110 + 0.0000443\, B\,(1 + F) \quad . \qquad (3)$$

For pressurized-water reactors:

$$E = 0.978 + 0.0000487\, B\,(1 + F) \quad . \qquad (4)$$

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.[195] Equation (2) can be written in the following difference format:

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	1.110	0.0000443	0.79
Pressurized-Water	Assay	0.978	0.0000487	0.80

Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, Analysis and Systems Division, working papers, April 1996.

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

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

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

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

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

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

As Equation (1) indicates, for a given discharge burnup and a given number of effective full-power days per cycle, the core fraction depends on the specific power of the reactor. The reactor fuel management plans used in the 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,

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

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).

Table B5. Results of the Regression Coefficient Tests

Parameter	Reactor Type: Boiling Water Reactor	Reactor Type: Pressurized-Water Reactor
Intercept		
Value from t Test	11.490	10.644
Significance Level	0.0001	0.0001
Burnup x (1 + Core Fraction)		
Value from t Test	22.111	32.215
Significance Level	0.0001	0.0001

Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, Analysis and Systems Division, working papers, April 1996.

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	3.17	36,000
1998	500	0.288	3.34	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	3.84	42,000
1998	470	0.378	4.07	46,000
2004	500	0.370	4.39	50,000
2008	511	0.344	4.73	55,000
2018	511	0.315	5.04	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, April 1996.

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 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 o f 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).[196] 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.

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

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	3.03	36,000
1998	300	0.191	3.12	39,000
2004	300	0.173	3.32	43,000
2009	300	0.161	3.46	46,000
Pressurized-Water Reactor				
1994	300	0.275	3.59	42,000
1998	300	0.251	3.78	46,000
2002	300	0.231	4.03	50,000
2007	300	0.210	4.33	55,000
Far East				
Boiling-Water Reactors				
1995	365	0.241	3.29	36,000
2001	395	0.241	3.40	39,000
2006	420	0.232	3.64	43,000
2012	445	0.230	3.82	46,000
Pressurized-Water Reactor				
1995	355	0.367	3.51	35,000
1997	365	0.338	3.72	39,000
2001	395	0.332	3.97	43,000
2009	420	0.310	3.40	49,000
2015	445	0.293	4.84	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, April 1996.

- **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 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.

Uranium Market Model

Overview

Most of the uranium projections in this report were generated by the Uranium Market Module (UMM). UMM 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 in the world. 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.

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 country, 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 annually. 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 geological, 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 are sold in the secondary market.[197] 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. Projected demand levels 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.[198] 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.

[197] 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.

[198] 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

World Nuclear Units Operable as of December 31, 1995

Appendix C

World Nuclear Units Operable as of December 31, 1995

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995

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	931	EL	PWR	ACLF	03/75
	Tihange 2	Huy, Leige	930	EL	PWR	FRAM/ACW	10/82
	Tihange 3	Huy, Leige	1,015	EL	PWR	ACW	06/85
	Total: 7 Units		**5,631**				
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/Armenia	Medzamor 2	Metsamor, Armenia	376	GA	PWR	AEE	11/95
	Total: 1 Unit		**376**				
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 (BN600)	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
	Kalinin 1	Udomlya, Tver	950	RC	PWR	MTM	05/84
	Kalinin 2	Udomlya, Tver	950	RC	PWR	MTM	12/86

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
CIS/Russia	Kola 1	Polyarnyye Zori, Murmansk	411	RC	PWR	MTM	06/73
(continued)	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
	Zaporozhe 6	Energodar, Zaporozhe	950	MA	PWR	MTM	10/95
	Total: 16 Units		**13,629**				
Canada	Bruce 1	Tiverton, Ontario	848	OH	PHWR	OH/AECL	01/77
	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

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
Canada	Bruce 6	Tiverton, Ontario	860	OH	PHWR	OH/AECL	06/84
(continued)	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: 21 Units		**14,907**				
China	Guangdong 1	Shenzhen, Guangdong	944	GV	PWR	FRAM	09/93
	Guangdong 2	Shenzhen, Guangdong	944	GV	PWR	FRAM	02/94
	Qinshan 1	Haiyan, Zhejiang	279	QN	PWR	CNNC	12/91
	Total: 3 Units		**2,167**				
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
	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

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
France	Bugey 3	Loyettes, Ain	920	EF	PWR	FRAM	09/78
(continued)	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
	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

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
France (continued)	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 (GKN) 1	Neckarwestheim, Baden-Wuerttemberg	785	GK	PWR	KWU	07/76
	Neckarwestheim (GKN) 2	Neckarwestheim, Baden-Wuerttemberg	1,269	GK	PWR	SIEM/KWU	01/89
	Obrigheim (KWO)	Obrigheim, Baden-Wuerttemberg	340	KO	PWR	SIEM/KWU	10/68
	Philippsburg 1 (KKP)		864		BWR		
	Philippsburg 2 (KKP)	Philippsburg, Baden-Wuerttemberg	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
	Total: 20 Units		**22,017**				
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**				

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
India	Kakrapar 1	Kakrapar, Gujarat	202	NP	PHWR	DAE/NPCIL	11/92
	Kakrapar 2	Kakrapar, Gujarat	202	NP	PHWR	DAEC/NPCIL	03/95
	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: 10 Units		**1,695**				
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
	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
	Monju	Tsuruga, Fukui	246	PF	FBR	MHI	02/94
	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
	Onagawa 2	Onagawa, Miyagi	796	TC	BWR	TOS	12/94
	Sendai 1	Sendai, Kagoshima	846	KY	PWR	MHI	09/83

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
Japan	Sendai 2	Sendai, Kagoshima	846	KY	PWR	MHI	04/85
(continued)	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	1,056	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: 51 Units		**39,893**				
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
	Yonggwang 4	Yonggwang, Chonnam	950	KR	PWR	KHIC/KAE	07/95
	Total: 11 Units		**9,120**				
Lithuania	Ignalina 1	Snieckus, Lithuania	1,185	IN	LGR	MTM	12/83
	Ignalina 2	Snieckus, Lithuania	1,185	IN	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	Bohunice 1	Trnava, Zapadoslovensky	408	EB	PWR	AEE	12/78
Republic	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**				

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
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	917	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 Garon	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		**7,124**				
Sweden	Barsebeck 1	Barsebaeck, Malmohus	600	SY	BWR	A-A	05/75
	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	965	GP	PWR	KWU	02/79
	Leibstadt	Leibstadt, Aargau	1,030	LK	BWR	GETSCO	05/84
	Muehleberg	Muehleberg, Bern	355	BR	BWR	GETSCO	07/71
	Total: 5 Units		**3,050**				
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	948	TW	BWR	GE	05/81
	Kuosheng 2	Kuosheng, Wang-Li, Taipei	948	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		**4,884**				

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
United	Bradwell 1	Bradwell, Essex	123	NE	GCR	TNPG	07/62
Kingdom	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
	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
	Sizewell B	Sizewell, Suffolk	1,188	NE	PWR	PPP	02/95
	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: 35 Units		**12,908**				
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	5/24
	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

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
United States	Brunswick 2	Southport, North Carolina	754	CA	BWR	GE	12/74
(continued)	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	1,125	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
	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	528	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	1,173	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	1,115	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	544	NS	BWR	GE	01/71

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
United States	Nine Mile Point 1	Oswego, New York	605	NM	BWR	GE	08/69
(continued)	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
	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	1,093	PL	BWR	GE	07/74
	Perry 1	North Perry, Ohio	1,169	CI	BWR	GE	11/86
	Pilgrim 1	Pylmouth, Massachusetts	669	BE	BWR	GE	09/72
	Point Beach 1	Two Creeks, Wisconsin	493	WE	PWR	WEST	10/70
	Point Beach 2	Two Creeks, Wisconsin	441	WE	PWR	WEST	03/73
	Prairie Island 1	Red Wing, Minnesota	514	NS	PWR	WEST	04/74
	Prairie Island 2	Red Wing, Minnesota	513	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	1,155	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	1,251	HL	PWR	WEST	03/88
	South Texas 2	Bay City, Texas	1,251	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	1,090	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
	Vermont Yankee 1	Vernon, Vermont	496	VY	BWR	GE	02/73
	Vogtle 1	Waynesboro, Georgia	1,164	GA	PWR	WEST	03/87
	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	1,107	WP	BWR	GE	04/84
	Wolf Creek	Burlington, Kansas	1,167	WC	PWR	WEST	06/85

See notes at end of table.

Table C1. Roster of Nuclear Generating Units Operable as of December 31, 1995 (Continued)

Country	Unit Name[a]	Location	Capacity (net MWe)[b]	Utility[c]	Reactor Type[d]	Reactor Supplier[e]	Date of Operation[f]
United States	Zion 1	Zion, Illinois	1,040	CM	PWR	WEST	10/73
(continued)	Zion 2	Zion, Illinois	1,040	CM	PWR	WEST	11/73
	Total: 109 Units		**99,394**				
Total World:	**437 Units**		**344,402**				

[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, "Date of Operation" 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 1996). Energy Information Administration Form EIA-860, "Annual Electric Generator Report." Nuclear Regulatory Commission, *Information Digest, 1996 Edition* (NUREG-0350, July 1996) 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 M.V. Nucleaire Produktie	Belgium
FN	Furnas Centrais Electricas SA	Brazil
EA	National Electricity Company, Branch NPP-Kozloduy	Bulgaria
KZ	National Corporation For Atomic Energy Industry	CIS/Kazakhstan
MY	Industrial Association Mayak	CIS/Russia
LN	Leningrad NPP	CIS/Russia
MA	Minatomenergoprom, Ministry of Nuclear Power and Industry	CIS/Russia
RC	Rosenergoatom, Consortium	CIS/Russia
GT	Goskomatom - State Committee of Ukraine on Nuclear Power Utilization	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
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
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	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
IN	Ignalina Nuclear Power Plant	Lithuania
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
RE	Romanian Electricity Authority (RENEL)	Romania
EB	Electrostation Bohunice	Slovak Republic
EM	Electrostation Mochovce	Slovak Republic
NR	Nuklearna Elektrana Krsko	Slovenia
EK	Eskom	South Africa
AN	Asociacion Nuclear de Asco	Spain
AV	Asociacion Nuclear de Vandellos	Spain
CS	Central Nuclear de Almaraz	Spain
HC	Hidroelectrica del Cantabrico, SA	Spain
IB	Iberdrola, SA	Spain
NU	Nuclenor, SA	Spain
UE	Union Fenosa, SA	Spain
FK	Forsmark Kraftgrupp AB	Sweden
OK	OKG-Aktiebolag	Sweden
SY	Barsebeck Kraft 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	Niagara 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 Instititе	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
MNE	Ministry of Nuclear Energy of Russian Corporation	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

Appendix D

World Nuclear Generating Units in the Construction Pipeline as of December 31, 1995

Appendix D

World Nuclear Generating Units In the Construction Pipeline as of December 31, 1995

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1995

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]	Expected Date of Operation: EIA[h] Reference	Expected Date of Operation: EIA[h] High
Argentina	Atucha 2	Lima, Buenos Aires	692	CN	PHWR	KWU	88	12/97	2005	2003
	Total: 1 Unit		**692**							
Brazil	Angra 2	Itaorna, Rio de Janeiro	1,245	FN	PWR	KWU	72	06/1999	2001	1999
	Angra 3	Itaorna, Rio de Janeiro	1,229	FN	PWR	WEST	43	09/2004	--	2010
	Total: 2 Units		**2,474**							
CIS/Armenia	Armenia 1	Metsamor, Armenia	376	MA	PWR	AEE	--		2001	1999
	Total: 1 Unit		**376**							
CIS/Russia	Balakovo 5	Balakovo, Saratov	950	RC	PWR	MTM	--	--	2004	2001
	Kalinin 3	Udomyla, Tver	950	RC	PWR	MTM	70	2000	2002	1999
	Kursk 5	Kurchatov, Kursk	925	RC	LGR	MTM	--	2001	2006	2000
	Rostov 1	Volgodonsk, Rostov	950	RC	PWR	MTM	95	2001	2000	1998
	Rostov 2	Volgodonsk, Rostov	950	RC	PWR	MTM	30	2002	2008	2006
	South Urals 1	Chelyabinsk	750	MY	FBR	--	--	--	2009	2005
	South Urals 2	Chelyabinsk	750	RC	FBR	--	--	--	2015	2007
	Voronezh 1	Voronezh	500	RC	PWR	--	--	2003	2008	2004
	Voronezh 2	Voronezh	500	RC	PWR	--	--	2005	2010	2006
	Total: 9 Units		**7,225**							
CIS/Ukraine	Khmelnitski-2	Neteshin, Khmelnitski	950	GT	PWR	MTM	90	1997	1998	1997
	Khmelnitski-3	Neteshin, Khmelnitski	950	GT	PWR	MTM	30	12/98	2007	2003
	Khmelnitski-4	Neteshin, Khmelnitski	950	GT	PWR	MTM	15	12/99	2010	2006
	Rovno 4	Kuznetsovsk, Rovno	950	GT	PWR	MTM	75	1998	1999	1998
	South Ukraine 4	Konstantinovka, Nikolae	950	GT	PWR	MTM	--	ID	2010	2004
	Total: 5 Units		**4,750**							

See notes at end of table.

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1995 (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]: Reference	EIA[h]: High
China	Lingao 1	Lingao, Guangdong	985	GV	PWR	FRAM	--	2002	2004	2003
	Lingao 2	Lingao, Guangdong	985	GV	PWR	FRAM	--	2003	2005	2004
	Qinshan 2	Haiyan, Zhejiang	600	MI	PWR	CNNC	--	12/2000	2002	2001
	Qinshan 3	Haiyan, Zhejiang	600	MI	PWR	CNNC	--	12/2001	2003	2002
	Qinshan 4	Haiyan, Zhejiang	700	--	PHWR	AECL	--	2003	2005	2004
	Qinshan 5	Haiyan, Zhejiang	700	--	PHWR	AECL	--	2004	2006	2005
	Total: 6 Units		**4,570**							
Cuba	Juragua 1	Cienfuegos	408	CU	PWR	AEE	--	ID	--	2002
	Juragua 2	Cienfuegos	408	CU	PWR	AEE	--	ID	--	2009
	Total: 2 Units		**816**							
Czech Republic	Temelin 1	Temelin, Jihocesky	912	ET	PWR	SKODA	90	1997	1998	1997
	Temelin 2	Temelin, Jihocesky	912	ET	PWR	SKODA	55	1999	2001	2000
	Total: 2 Units		**1,824**							
France	Chooz B1	Chooz, Ardennes	1,455	EF	PWR	FRAM	98	02/1996	1996	1996
	Chooz B2	Chooz, Ardennes	1,455	EF	PWR	FRAM	90	07/1996	1996	1996
	Civaux 1	Civaux, Vienne	1,450	EF	PWR	FRAM	60	04/1997	1998	1997
	Civaux 2	Civaux, Vienne	1,450	EF	PWR	FRAM	40	11/1998	1999	1998
	Le Carnet 1	Le Carnet	1,450	EF	PWR	FRAM	0	2002	2015	2014
	Le Carnet 2	Le Carnet	1,450	EF	PWR	FRAM	0	2004	--	2015
	Penley 3	St. Martin-en, Seine-Maritime	1,450	EF	PWR	FRAM	0	2002	2013	2010
	Penley 4	St. Marint-en, Seine-Maritime	1,450	EF	PWR	FRAM	0	--	2014	2012
	Total: 8 Units		**11,610**							
India	Kaiga 1	Kaiga, Karnataka	202	NP	PHWR	NPCIL	75	11/1998	1999	1998
	Kaiga 2	Kaiga, Karnataka	202	NP	PHWR	NPCIL	75	11/1998	2001	1999
	Rajasthan 3	Kato, Rajasthan	202	NP	PHWR	NPCIL	70	11/1998	2000	1998
	Rajasthan 4	Kato, Rajasthan	202	NP	PHWR	NPCIL	70	05/1999	2001	1999
	Tarapur 3	Tarapur, Maharashtra	450	NP	PHWR	--	10	08/2003	2004	2002
	Tarapur 4	Tarapur, Maharashtra	450	NP	PHWR	--	2	05/2004	2007	2003
	Total: 6 Units		**1,708**							
Iran	Bushehr 1	Bushehr	950	--	PWR	MTM	--	--	2005	2002
	Bushehr 2	Bushehr	1,000	--	PWR	MTM	--	--	2008	2006
	Total: 2 Units		**1,950**							

See notes at end of table.

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1995 (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] Reference	EIA[h] High
Japan	Ashihama 1	Ashihama, MIC	1,300	CB	ABWR	--	0	--	2011	2009
	Ashihama 2	Ashihama, MIC	1,300	CB	ABWR	--	0	--	2012	2009
	Genkai 4	Genkai, Saga	1,127	KY	PWR	MHI	85	07/1997	1997	1997
	Hamaoka 5	Hamaoka-cho, Shizuoka	1,092	CB	ABWR	--	0	--	2005	2005
	Higashidori 1	Higashidori, Aomri	1,067	TC	BWR	--	0	--	2005	2005
	Higashidori 2	Higashidori, Aomri	1,067	TC	BWR	--	0	--	2008	2006
	Kashiwazaki Kariwa 6	Kashiwazaki, Niigata	1,315	TP	BWR	TOS/GE	94	07/1996	1996	1996
	Kashiwazaki Kariwa 7	Kashiwazaki, Niigata	1,315	TP	BWR	HIT/GE	79	07/1998	1997	1997
	Maki 1	Maki, Niigata	780	TC	BWR	--	0	03/2003	2004	2004
	Namie Odaka	Fukushima	825	TC	BWR	TOS		--	--	2007
	Onagawa 3	Tsuruga, Fukui	796	TC	BWR	TOS	0	2002	2002	2002
	Oura 1	Oura, Wakayama	1,300	KA	APWR	--	0	--	--	2014
	Oura 2	Oura, Wakayama	1,300	KA	APWR	--	0	--	--	2014
	Shika 2	Shika-machi, Ishikawa	796	HU	ABWR	--	0	--	2005	2005
	Total: 14 Units		**15,380**							
Korea, South	Ulchin 3	Ulchin, Kyongbuk	960	KR	PWR	KHIC/KAE	64	06/1998	1999	1998
	Ulchin 4	Ulchin, Kyongbuk	960	KR	PWR	KHIC/KAE	64	06/1999	1999	1999
	Ulchin 5	Ulchin, Kyongbuk	950	KR	PWR	--	0	2003	2005	2004
	Ulchin 6	Ulchin, Kyongbuk	950	KR	PWR	--	0	2004	2006	2005
	Wolsong 2	Kyongju, Kyongbuk	650	KR	PHWR	AECL/KHIC	84	06/1997	1998	1997
	Wolsong 3	Kyongju, Kyongbuk	650	KR	PHWR	AECL/KHIC	54	06/1998	2000	1998
	Wolsong 4	Kyongju, Kyongbuk	650	KR	PHWR	AECL/KHIC	54	06/1999	2000	1999
	Wolsong 5	Kyongju, Kyongbuk	650	KR	PHWR	--	0	--	2007	2005
	Yonggwang 5	Yonggwang, Chonnam	950	KR	PWR	--	0	06/2001	2002	2001
	Yonggwang 6	Yonggwang, Chonnam	950	KR	PWR	--	0	06/2002	2003	2002
	Total: 10 Units		**8,320**							
Pakistan	Chasnupp 1 (Chasma)	Mianwali, Punjub	300	PA	PWR	CNNC	40	03/1999	2002	2000
	Total: 1 Unit		**300**							
Romania	Cernavoda 1	Cernavoda, Constanta	650	RE	PHWR	AECL	100	07/1996	1996	1996
	Cernavoda 2	Cernavoda, Constanta	650	RE	PHWR	AECL	32	12/2001	2006	2003

See notes at end of table.

Table D1. Roster of Nuclear Generating Units in the Construction Pipeline as of December 31, 1995 (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]: Reference	EIA[h]: High
Romania (continued)	Cernavoda 3	Cernavoda, Constanta	650	RE	PHWR	FECNE	23	ID	--	2006
	Cernavoda 4	Cernavoda, Constanta	650	RE	PHWR	FECNE	12	ID	--	2009
	Cernavoda 5	Cernavoda, Constanta	650	RE	PHWR	FECNE	8	ID	--	2012
	Total: 5 Units		**3,250**							
Slovak Republic	Mochovce 1	Mochovce, Zapadoslovensky	388	EM	PWR	SKODA	85	06/1998	2002	2000
	Mochovce 2	Mochovce, Zapadoslovensky	388	EM	PWR	SKODA	65	07/1999	2004	2002
	Total: 2 Units		**776**							
Taiwan	Lungmen 1	Yenliao, Taiwan	1,250	TW	PWR	--	0	2000	2006	2004
	Lungmen 2	Yenliao, Taiwan	1,250	TW	PWR	--	0	2001	2009	2006
	Total: 2 Units		**2,500**							
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	100	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:	**85 units**		**76,954**							

[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 Reference 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 1996); *Nuclear News,* “World List of Nuclear Power Plants” (March 1996), pp. 29-44. NAC International, “Nuclear Generation,” (February 1996), Section E, pp. 1-45; Form EIA-860 “Annual Electric Generator Report.”

Appendix E

Long-Term Projections of Capacity, Generation, and Spent Fuel in the United States, 1996 Through 2040

Appendix E

Long-Term Projections of Capacity, Generation, and Spent Fuel in the United States, 1996 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 Reference 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 Reference 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.

For the High Case, it is assumed that all the current nuclear units will renew their operating license for an additional 10 years. However, this additional capacity over the Reference 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 49 GWe by 2030 (Table E1). By 2036, capacity is projected to 13 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 2035 are between 8 net terawatthours (TWh) and 176 net TWh (Table E2). The industry-wide annual capacity factor used to calculate electricity generation is 78 percent in 1996 through 2013 and increases to 80 percent through 2035. 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 86 and 105 thousand metric tons of uranium (MTU) by 2040 (Table E3). By the end of 1995, 32.2 thousand MTU of spent fuel was discharged from U.S. reactors.

Table E1. Projections of U.S. Nuclear Capacity, 1996-2040
(Net Gigawatts Electric)

Year	Reference Case	High Case
1996	100.6	100.6
1997	100.6	100.6
1998	100.6	100.6
1999	100.6	100.6
2000	100.5	100.5
2001	100.5	100.5
2002	100.5	100.5
2003	100.5	100.5
2004	100.5	100.5
2005	100.5	100.5
2006	99.7	100.5
2007	98.4	100.5
2008	97.5	100.5
2009	95.8	100.5
2010	93.5	100.5
2011	92.7	100.5
2012	88.6	100.5
2013	76.1	100.5
2014	65.6	100.5
2015	63.7	100.5
2016	57.5	99.7
2017	54.7	98.4
2018	52.2	97.5
2019	52.2	95.8
2020	49.1	93.5
2021	46.0	92.7
2022	41.8	88.6
2023	37.7	76.1
2024	28.8	65.6
2025	22.1	63.7
2026	12.6	57.5
2027	7.0	54.7
2028	5.7	52.2
2029	3.5	52.2
2030	2.3	49.1
2031	2.3	46.0
2032	2.3	41.8
2033	1.2	37.7
2034	1.2	28.8
2035	1.2	22.1
2036	0.0	12.6
2037	0.0	7.0
2038	0.0	5.7
2039	0.0	3.5
2040	0.0	2.3

Note: Reference Case = No new orders, High Case = License renewal.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, International Nuclear Model, File INM.WK4.

Table E2. Projections of U.S. Nuclear Electricity Generation, 1996-2040
(Net Terawatthours)

Year	Reference Case	High Case
1996	683	683
1997	683	683
1998	683	683
1999	683	683
2000	683	683
2001	683	683
2002	683	683
2003	683	683
2004	683	683
2005	683	683
2006	679	683
2007	676	683
2008	667	683
2009	658	683
2010	640	683
2011	634	683
2012	623	683
2013	573	683
2014	495	683
2015	447	683
2016	425	679
2017	392	676
2018	372	667
2019	361	658
2020	354	640
2021	333	634
2022	317	623
2023	275	573
2024	231	495
2025	176	447
2026	111	425
2027	67	392
2028	43	372
2029	30	361
2030	18	354
2031	16	333
2032	16	317
2033	8	275
2034	8	231
2035	8	176
2036	0	111
2037	0	67
2038	0	43
2039	0	30
2040	0	18

Note: Reference Case = No new orders, High Case = License renewal.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels, International Nuclear Model, File INM.WK4.

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

Year	Scenario	
	Reference	High
Prior 1996[a]	32.2	32.2
1996	34.5	34.5
1997	36.9	36.9
1998	39.1	39.1
1999	41.0	41.0
2000	43.3	43.3
2001	45.3	45.3
2002	47.5	47.5
2003	49.8	49.8
2004	51.6	51.6
2005	53.6	53.6
2006	55.8	55.8
2007	57.7	57.5
2008	59.7	59.5
2009	61.8	61.5
2010	63.7	63.3
2011	65.7	65.3
2012	67.8	67.2
2013	70.3	69.0
2014	72.7	70.8
2015	74.1	72.6
2016	75.7	74.6
2017	77.0	76.4
2018	78.0	78.0
2019	79.0	79.8
2020	80.1	81.9
2021	81.1	83.5
2022	82.4	85.6
2023	83.4	88.0
2024	84.8	90.3
2025	85.6	91.5
2026	86.9	93.1
2027	87.4	94.1
2028	87.7	95.2
2029	87.9	96.1
2030	88.1	97.2
2031	88.1	98.3
2032	88.1	99.5
2033	88.3	100.6
2034	88.3	101.9
2035	88.3	102.9
2036	88.4	104.2
2037	88.4	104.7
2038	88.4	104.9
2039	88.4	105.2
2040	88.4	105.3

[a]Actual discharges.

Note: Totals may not equal sum of components due to independent rounding. Spent fuel projections in the Reference Case are sometimes larger than spent fuel projections in the High Case due to more reactors retiring in the Reference Case and consequently discharging the entire reactor core.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM.WK4.

Appendix F

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

Appendix F

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. The following 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 F1. Projected Cumulative Uranium Requirements for World Nuclear Power Plants, 1996-2015
(Thousand Metric Tons of Uranium)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High
1996	17.4	17.4	1.9	1.9	8.6	8.7	20.9	21.0	10.9	11.2	1.2	1.3	61.0	61.6
1997	38.7	38.7	3.4	3.4	16.7	17.2	41.6	41.3	22.1	22.3	2.1	2.7	124.6	125.7
1998	54.1	54.1	5.1	5.1	25.5	27.0	61.0	61.0	34.0	34.4	3.0	3.8	182.8	185.5
1999	73.1	73.1	6.6	6.6	34.0	36.4	80.1	80.3	43.4	44.6	4.7	5.1	241.9	246.1
2000	91.2	91.2	8.3	8.3	40.9	44.7	99.3	99.8	55.6	56.7	5.8	7.2	301.2	307.9
2001	108.9	108.9	10.0	10.0	48.7	54.0	118.5	119.2	68.5	71.3	7.1	8.6	361.7	372.0
2002	126.9	126.9	11.7	11.7	56.8	64.1	137.5	138.3	79.1	84.8	8.3	10.5	420.2	436.5
2003	145.4	145.4	13.3	13.3	63.8	72.8	156.6	157.8	95.6	100.1	10.3	12.5	485.1	502.0
2004	162.2	162.2	14.9	14.9	72.1	82.7	174.4	176.5	107.5	114.3	11.6	14.9	542.8	565.5
2005	181.3	181.7	16.5	16.6	79.7	91.6	193.0	195.6	122.5	129.3	13.0	17.1	605.9	632.0
2006	199.1	199.8	18.2	18.4	88.6	100.8	211.6	215.0	135.2	143.2	15.3	19.0	668.1	969.2
2007	214.3	215.6	19.3	19.8	96.7	113.1	231.2	235.2	150.7	161.7	16.9	21.3	729.2	766.6
2008	233.0	234.7	20.8	21.5	104.0	122.5	249.6	254.8	164.9	179.2	18.6	24.4	790.8	837.2
2009	249.1	252.6	22.4	23.3	110.9	132.4	267.6	273.8	179.6	195.2	20.3	26.9	849.9	904.2
2010	267.1	272.0	23.7	24.8	117.4	145.0	285.3	294.0	197.1	214.8	22.3	29.9	912.8	980.5
2011	281.4	288.5	24.9	26.1	123.6	155.2	303.6	313.4	212.0	233.5	24.2	32.3	969.7	1,049.0
2012	293.4	305.0	26.6	28.0	129.8	166.6	321.2	333.8	228.3	253.4	25.6	35.2	1,024.9	1,122.0
2113	304.2	321.9	28.0	29.4	136.0	177.0	337.1	354.2	244.7	273.6	28.0	38.0	1,078.0	1,194.2
2014	315.9	340.2	29.3	30.9	141.1	188.0	353.3	374.1	260.5	292.6	29.9	40.9	1,130.0	1,266.7
2015	324.4	356.0	30.8	32.6	145.8	197.8	368.4	391.5	274.6	311.3	31.9	44.3	1,175.9	1,333.4

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM.WK4.

Table F2. Projected Annual Uranium Requirements for World Nuclear Power Plants, 1996-2015
(Thousand Metric Tons of Uranium)

Year	United States		Canada		Eastern Europe		Western Europe		Far East		Other		Total	
	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High	Reference	High
1996	17.4	17.4	1.9	1.9	8.6	8.7	20.9	21.0	10.9	11.2	1.2	1.3	61.0	61.6
1997	21.3	21.3	1.5	1.5	8.1	8.4	20.6	20.3	11.1	11.1	0.9	1.5	63.6	64.1
1998	15.4	15.4	1.7	1.7	8.8	9.9	19.4	19.7	11.9	12.1	0.9	1.1	58.1	59.8
1999	18.9	18.9	1.4	1.4	8.5	9.4	19.2	19.3	9.5	10.2	1.7	1.4	59.2	60.6
2000	18.1	18.1	1.7	1.7	7.0	8.3	19.2	19.5	12.2	12.1	1.1	2.1	59.3	61.8
2001	17.8	17.8	1.6	1.6	7.7	9.3	19.2	19.4	12.9	14.6	1.2	1.4	60.4	64.1
2002	18.0	18.0	1.8	1.8	8.1	10.1	19.0	19.1	10.6	13.6	1.2	1.9	58.6	64.5
2003	18.5	18.5	1.6	1.6	7.1	8.6	19.2	19.5	16.5	15.3	2.0	2.0	64.8	65.5
2004	16.8	16.8	1.6	1.6	8.2	9.9	17.8	18.7	11.9	14.1	1.3	2.4	57.8	63.5
2005	19.1	19.5	1.6	1.6	7.6	9.0	18.5	19.1	15.0	15.1	1.3	2.2	63.1	66.5
2006	17.8	18.1	1.7	1.9	8.9	9.2	18.7	19.4	12.7	13.9	2.4	1.9	62.2	64.3
2007	15.2	15.8	1.1	1.3	8.1	12.3	19.6	20.2	15.5	18.5	1.6	2.3	61.1	70.4
2008	18.6	19.1	1.4	1.7	7.3	9.5	18.4	19.7	14.2	17.5	1.7	3.1	61.6	70.6
2009	16.1	18.0	1.6	1.8	6.9	9.9	18.0	18.9	14.7	15.9	1.7	2.5	59.1	67.0
2010	18.0	19.4	1.3	1.5	6.5	12.6	17.7	20.2	17.5	19.6	2.0	3.0	63.0	76.3
2011	14.3	16.5	1.2	1.3	6.3	10.2	18.3	19.4	14.9	18.7	1.9	2.4	56.9	68.5
2012	12.0	16.4	1.7	1.9	6.2	11.4	17.6	20.5	16.2	19.9	1.4	2.9	55.2	72.9
2113	10.8	17.0	1.4	1.5	6.2	10.4	15.9	20.4	16.5	20.2	2.4	2.8	53.1	72.2
2014	11.7	18.3	1.3	1.5	5.1	11.0	16.1	19.8	15.8	19.0	1.9	2.9	52.0	72.5
2015	8.5	15.8	1.5	1.7	4.7	9.8	15.2	17.4	14.0	18.8	2.0	3.3	45.9	66.8

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, International Nuclear Model, File INM.WK4.

Table F3. Projected U.S. Spot-Market Prices for Uranium Under Current Market Conditions, 1996-2010
(Dollars per Kilogram Uranium)

Year	Price
1996	41.99
1997	45.44
1998	44.90
1999	39.10
2000	39.05
2001	37.88
2002	36.84
2003	36.71
2004	34.66
2005	35.07
2006	34.99
2007	36.99
2008	38.37
2009	41.15
2010	41.93

Note: Adjusted by three-point smoothing.

Source: Energy Information Administration, Uranium Market Model run no. 1996_11.DAT, July 8, 1996.

Table F4. Projected U.S. Uranium Requirements, Net Imports, Commercial Inventories, and Production of Uranium, 1996-2010
(Thousand Metric Tons Uranium Equivalent)

Year	Requirements[a]	Net Imports[a,b]	Commercial Inventories[a]	Production[a]
1996	18.0	11.4	26.8	2.8
1997	18.0	11.7	24.0	3.1
1998	18.5	11.3	21.6	3.2
1999	17.5	11.5	19.4	3.2
2000	18.3	11.8	18.3	3.2
2001	17.9	12.5	17.2	3.2
2002	18.1	12.7	16.5	3.2
2003	17.8	12.8	15.5	3.3
2004	18.2	12.9	15.3	3.4
2005	17.9	13.0	14.9	3.3
2006	17.4	13.0	14.5	3.0
2007	17.2	13.0	14.2	3.0
2008	16.7	13.5	14.0	3.0
2009	17.6	13.8	13.8	2.8
2010	16.2	13.8	13.6	2.2

[a]Adjusted by three-point smoothing.

[b]Net imports = total imports less exports.

Source: **Requirements**—Energy Information Administration, International Nuclear Model, File INM.WK4. **Net Imports, Inventories and Production**—Energy Information Administration, Uranium Market Model run no. 1996_11.DAT, July 8, 1996.

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).

Byproduct Recovery (uranium): Uranium is recovered as a byproduct in plants where ore is treated primarily to recover other commodities such as copper or phosphoric acid. The uranium content in these ores is too low to be economically mined solely for the uranium.

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).

Conventional mill (uranium): A facility engineered and built principally for processing of uraniferous ore materials mined from the earth and the recovery, by chemical treatment in the mill's circuits, of uranium and/or other valued coproduct components from the processed ore.

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.

In situ leach mining (ISL): The recovery, by chemical leaching, of the valuable components of an orebody without physical extraction of the ore from the ground. Also referred to as "solution mining."

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 Re-source 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.