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The Changing Structure of the International Commercial Nuclear Power Reactor Industry

C. W. Forsberg
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W. J. Rowan

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-12284

Chemical Technology Division

THE CHANGING STRUCTURE OF THE INTERNATIONAL COMMERCIAL NUCLEAR POWER REACTOR INDUSTRY

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Date Published: December 1992

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. Department of Energy
under contract DE-AC05-84OR21400

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ACRONYMS AND ABBREVIATIONS

ABB	Asea Brown Boveri
ADS	automatic depressurization system
AEE	Atomenergoexport (Russia)
AGR	advanced gas-cooled reactor
ANA	Asociacion Nuclear Asco
ANPP	Arizona Nuclear Power Project
ANV	Asociacion Nuclear Vandellos
BEC	Boston Edison Company (USA)
BGE	Baltimore Gas and Electric (USA)
BKW	Bernische Kraftwerke AG (Germany)
BNFL	British Nuclear Fuels
bpd	barrels per day
BWR	boiling-water reactor
CANDU	Canadian deuterium uranium reactor (a type of heavy-water reactor)
CEA	Commissariat a L'Energie Atomique (France)
CEC	Commonwealth Edison Company (USA)
CEIC	Cleveland Electric Illuminating Company (USA)
CFE	Comsion Federal de Electricidad
CLP	Connecticut Light and Power (USA)
CNNC	China National Nuclear Corporation (China)
ConEd	Consolidated Edison Company (USA)
CPB	Czech Power Board
CPC	Consumers Power Company (USA)
CPL	Carolina Power and Light (USA)
CYAPC	Connecticut Yankee Atomic Power Company (USA)
DAE	Department of Atomic Energy (India)
DE	Detroit Edison (USA)
DKB	Dai-ichi Kangyo Bautz (Keiretsu Group)
DLC	Duquesne Light Company

DOE	U.S. Department of Energy
ECCS	emergency core cooling system
EPR	European pressurized-water reactor
EPZ	NV Elektriciteits-Producktiemaatschappij Zuid-Nederland (Netherlands)
FPC	Florida Power Company (USA)
FPL	Florida Power and Light (USA)
FSU	Former Soviet Union
GKN	Gemeinschaftskernkraftwerk Neckar (Germany)
GNPJVC	Guangdong Nuclear Power Joint Venture Company (China)
GP	Georgia Power (USA)
GPU	General Public Utilities Nuclear (USA)
GSU	Gulf State Utilities (USA)
HGET	Hitachi, General Electric, Toshiba Joint Venture
HLP	Houston Light and Power (USA)
HPC	Hungarian Power Companies, Ltd.
HWR	heavy-water reactor
IELP	Iowa Electric Light and Power (USA)
IMPC	Indiana/Michigan Power Company (USA)
IPC	Illinois Power Company (USA)
IVO	Imatran Voima Oy
JAPCO	Japan Atomic Power Company, Ltd.
JCPL	Jersey Central Power and Light (USA)
KBR	Kernkraftwerk Brokdorf GmbH (Germany)
KEPCO	Korea Electric Power Corporation
KKB	Kernkraftwerk Brunsbuettel GmbH (Germany)
KKE	Kernkraftwerk Lippe-EMS GmbH (Germany)
KKG-D	Kernkraftwerk Goesgen-Daeniken AG (Germany)
KKI	Kernkraftwerk Isar (Germany)
KKK	Kernkraftwerk Kruemmel GmbH (Germany)
KKL	Kernkraftwerk Leibstadt AG (Germany)
KKP	Kernkraftwerk Philippsburg (Germany)

KKS	Kernkraftwerk Stade GmbH (Germany)
KKU	Kernkraftwerk Unterweser GmbH (Germany)
KRB	Kernkraftwerk RWE-Bayernwerk GmbH (Germany)
KTF	Kaluga Turbine Factory (FSU)
KWG	Gemeinschaftskernkraftwerk Grohnde GmbH (Germany)
kWh	kilowatt-hour
KWO	Kernkraftwerk Obrigheim GmbH (Germany)
MAEP	Ministry of Atomic Energy and Industry Minatomenergoprom (FSU)
MBI	Ministry of Basic Industries (Cuba)
MELCO	Mitsubishi Electric Company
MHI	Mitsubishi Heavy Industry (Japan)
MHTGR	modular high-temperature gas-cooled reactor
MNI	Ministry of the Nuclear Industry (China)
MPS	Ministry of Power Stations (FSU)
MSHI	Mitsubishi (Keirestu Group)
MSUI	Mitsui (Keiretsu Group)
MTM	Mintyazhmash (Russia)
MTU	metric tons uranium
MW(e)	megawatts (electrical)
MT	metric ton
MW(t)	megawatts (thermal)
MYAPC	Maine Yankee Atomic Power Company (USA)
NCMPA	North Carolina Municipal Power Authority (USA)
NE	Nuclear Electric (Great Britain)
NEC	National Electric Company (Bulgaria)
NMPC	Niagara Mohawk Power Company (USA)
NNC	National Nuclear Corporation (Great Britain)
NOK	Nordostschweizerische Kraftwerk AG (Germany)
NPCIL	Nuclear Power Corporation of India, Ltd.
NPPD	Nebraska Public Power District (USA)
NSP	Northern States Power (USA)

NSSS	nuclear steam supply system
NVGKN	NV Gemeenschappelijke Kernenergiecentrale Nederland
NYPA	New York Power Authority
OKG	OKG Aktiebolag
OPPD	Omaha Public Power District (USA)
PAEC	Pakistan Atomic Energy Commission
PCCS	passive containment cooling system
PCS	passive containment spray
PEC	Philadelphia Electric Company (USA)
PG&E	Pacific Gas and Electric (USA)
PHWR	pressurized heavy-water reactor
PNC	Power Reactor and Nuclear Fuel Development Corporation
PNPC	Philippines Nuclear Power Corporation
PortGE	Portland General Electric (USA)
PPL	Pennsylvania Power and Light (USA)
PRHR	passive residual heat removal
PRIME	passive safety, resilient safety, inherent safety, malevolence resistance, extended time
PSEG	Public Service Electricity and Gas (USA)
PSNH	Public Service of New Hampshire (USA)
PWR	pressurized-water reactor
RBMK	water-cooled, graphite-moderated reactor (Chernobyl-type)
RCS	reactor coolant system
REA	Romania Electricity Authority
RGE	Rochester Gas and Electric (USA)
RHR	residual heat removal
RPV	reactor pressure vessel
RRC	Reactor Research Center
SCEC	Southern California Edison Company (USA)
SCUAE	State Committee for the Use of Atomic Energy (FSU)
SCEGC	South Carolina Electric and Gas Company (USA)

SEL	Savske Elektrarne Ljubijana
SEMS	Siemens (Germany)
SNL	Scottish Nuclear Limited
SNOC	Southern Nuclear Operating Company
SPB	Slovak Power Board
SPC	Soyland Power Cooperative (USA)
TEPCO	Tokyo Electric Power Company (Japan)
TOE	tons of oil equivalent
TPC	Taiwan Power Company
TPE	Technopromexport (Russia)
TVA	Tennessee Valley Authority (USA)
TVO	Teollisuuden Voima Oy
TWh	terawatt-hour
Ukratom	Ukratomenergoprom
VPC	Virginia Power Company (USA)
VYNPC	Vermont Yankee Nuclear Power Corporation (USA)
WCNOC	Wolf Creek Nuclear Operating Corporation (USA)
WE	Westinghouse (USA)
WEP	Wisconsin Electric Power (USA)
WPPSS	Washington Public Power Supply System (USA)
WPSC	Wisconsin Public Service Corporation (USA)

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ABSTRACT

The objective of this report is to provide an understanding of the international commercial nuclear power industry today and how the industry is evolving. This industry includes reactor vendors, product lines, and utility customers. The evolving structure of the international nuclear power reactor industry implies different organizations making decisions within the nuclear power industry, different outside constraints on those decisions, and different priorities than with the previous structure. At the same time, cultural factors, technical constraints, and historical business relationships allow for an understanding of the organization of the industry, what is likely, and what is unlikely. With such a frame of reference, current trends and future directions can be more readily understood.

Before 1980, the dominant reactor vendors were from the United States (Westinghouse, General Electric, Babcock and Wilcox, and Combustion Engineering). These corporations—directly or with participation from others—supplied 80% of the world's power reactors. Since 1980, the major reactor vendors in Europe [Framatome of France, Siemens of Germany, and Asea Brown Boveri (ABB) of Sweden and Switzerland] and in Japan (Mitsubishi, Hitachi, and Toshiba) have dominated new reactor sales. These European and Japanese vendors have supplied 45% of the world's power reactors since 1980. This change reflects the larger number of power reactors built in Japan and Europe in recent years, the lack of nuclear power plant orders in the United States, the development of foreign nuclear power capabilities, and the financial strengths of these organizations. Russia has a large nuclear power industry (34% of the world's power reactors since 1980), but the Chernobyl nuclear power accident and the collapse of the former Soviet Union have stopped development and created an uncertain future.

Nuclear power suppliers were originally organized along single-country, national lines—national laboratory, national vendor(s), and local utilities, with occasional foreign sales. Since 1980, vendors have been organizing into three types of international groups to reduce business risks and increase sales. First, international corporations such as ABB—the largest industrial equipment manufacturer in the world—own multiple reactor vendors in multiple countries. Second, international joint ventures between multiple reactor vendors have been created to sell, design, and build nuclear power plants. The largest such joint venture and the dominant European group is Nuclear Power Incorporated, which is controlled by Siemens (Germany) and Framatome (France). Last, international consortia for joint sales and product development have been created. A typical example is the Hitachi/General Electric/Toshiba group. More recently, Westinghouse and National Nuclear Corporation (United Kingdom) have formed such a partnership. The parent organizations are much larger than historic national vendors. For example, the historically dominant U.S. vendor, Westinghouse, has annual corporate sales totaling $12 billion, while many of the international groups have total annual corporate sales of hundreds of billions of dollars.

Historically, many types of power reactors have been developed, but today the market is dominated by three types: (1) pressurized-water reactors, (2) boiling-water reactors, and (3) Canadian heavy-water reactors. Several different types of reactors are now in various stages of development. The technology from these development efforts will likely be transferred rapidly throughout the industrial world as a result of the multiple licensing agreements between reactor vendors.

The potential customers for nuclear power plants include utilities in 28 countries that currently operate or are building nuclear power plants, in addition to another 25 countries with economies sufficiently large to support a nuclear power plant. Most future nuclear power reactor sales are expected to be in countries along the Pacific Rim (Japan, China, Indonesia, South Korea, etc.), where the combination of limited domestic energy resources, rapid electrical growth, and reasonable acceptance of nuclear power creates a demand for nuclear power plants. In some of these countries, the markets are open to international sales, while in other countries the markets are closed.

In the 1990s, several additional changes may occur. With the planned Siemens partial buyout of the Czechoslovakia vendor (Skoda Works), Siemens and NPI partners are well positioned to become the leading nuclear power plant vendor in eastern Europe and the former Soviet Union. Mitsubishi—historically the largest supplier for domestic Japanese power reactors—has aggressively entered the international market. The technical and financial strengths of Mitsubishi Heavy Industries (part of the Mitsubishi family of companies with annual sales of more than $300 billion) are likely to have a major impact on the reactor market. Korea has a rapidly growing nuclear power program and is also developing its own vendor capabilities. Currently, it produces ~90% of the technology in its nuclear power plants. Finally, the People's Republic of China is also developing a vendor capability. Its capability is currently very limited and dependent on foreign equipment, but the potential market that may be captive to the vendor is large.

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EXECUTIVE SUMMARY

The nuclear power reactor industry is in transition. The evolving structure of the international nuclear power reactor industry implies different organizations making decisions within the nuclear power industry, different outside constraints on those decisions, and different priorities than with the previous structure. At the same time, cultural factors, technical constraints, and historical business relationships allow for an understanding of the organization of the industry, what is likely, and what is unlikely. With such a frame of reference, current trends and future directions can be more readily understood.

This report consists of several components. The body of the report provides an overview of the international nuclear power reactor industry—the vendors, the utilities, the constraints, and the current commercial relationships. This overview provides a basis for understanding current developments and predicting likely future activities. The appendixes present additional information with details that may help in understanding the nuclear power industry. This detailed information should also help the reader recognize vendor and utility characteristics that are typical of organizations in various parts of the world.

Historically evolving from U.S. practices, the model for nuclear power reactor development has been as follows: (1) national government supports development of technology, (2) domestic vendor or vendors develop nuclear power plant design, and (3) utilities within the country buy from domestic reactor vendors. Traditional international nuclear power activities consisted primarily of technology-licensing agreements from U.S. vendors to foreign organizations (one-way) and limited sales based on combinations of economic and national policy considerations.

The worldwide nuclear power industry is becoming an industry based more on commercial considerations; however, there are still numerous constraints imposed by national governments. There are multiple reasons for this transition.

- Government involvement in the development of nuclear power has decreased in the United States and Europe—partly due to the maturity of the industry, the controversy over nuclear power, and the increasing complexity of regulatory requirements. In many countries, government involvement has changed from directing nuclear power development to defining boundaries within which the vendor and utility have freedom of choice.

- There are many large companies (extending across many countries) with capabilities to design and construct nuclear power plants. When the technology was held by a few countries and companies, the number and types of agreements were limited.

- The cost of developing a new product (reactor) is very high, and the market is uncertain. This creates major incentives for joint ventures to reduce financial and technical risks.

- The internationalization of the controversy over nuclear power has resulted in comparisons of reactor safety requirements worldwide. This is creating strong incentives for vendors and utilities to work together worldwide in developing uniform safety requirements. In some respects, this internationalization follows and historically parallels that of the aircraft industry.

- The utilities in developed countries—the ultimate customer for reactors and the accompanying architectural and engineering services—now better understand nuclear power issues, actively make decisions, and advocate positions to vendors and governments. Historically, utilities have had a commercial (vs government) orientation.

In the last decade, the historical business structures of the nuclear industry have been supplemented with three other types of commercial business organizations. In each case, the vendor objectives are to increase sales and reduce risks by customizing business structures that meet the requirements of the technology and the needs of customers.

- The international corporation sells power reactors in multiple countries through large local subsidiaries, which are, in some instances, reactor vendors themselves. The local subsidiaries meet local market needs. The best example of this structure is the Swedish-Swiss company Asea Brown Boveri (ABB), which owns the nuclear reactor vendors ABB-Atom in Sweden and ABB-Combustion in the United States. Another example of this structure is Siemens, which owns the reactor vendor Kraftwerk Union (Germany) and is buying Skoda (Czechoslovakia). This structure is similar to the relationships in many auto companies (e.g., Ford and Toyota).

- The international joint venture involves multiple vendors creating a joint company to design, sell, and build reactors. Each vendor brings its technical capabilities and customers to the joint venture. The best example is Nuclear Power Incorporated, which is controlled by Siemens (Germany) and Framatome (France), but indirectly may include Skoda of Czechoslovakia (planned Siemens purchase) and Babcock and Wilcox of the United States (a Framatome-controlled company). This structure is similar to the European Airbus consortium in the commercial aircraft industry.

- The international technical/marketing consortium involves multiple vendors developing a joint product with each vendor selling that product to its customers. By custom or by contract, each vendor has a home market (one or more countries), where it has, in many instances, exclusive marketing rights. An example is the Hitachi/General Electric/Toshiba consortium. More recently, Westinghouse and National Nuclear Corporation (United Kingdom) have formed a consortium. Outside of the nuclear power industry, the recently announced Siemens-IBM (International Business Machines)-Toshiba consortium for development of the next generation computer chip provides a good example of such arrangements.

Two technical characteristics of nuclear power have provided strong incentives for internationalization of the industry.

- The size of nuclear power plants has increased to improve the economics of nuclear power. A single power plant now costs several billion dollars. Only very large corporations or consortiums can handle the financing and business risks associated with such large facilities.

- A significant fraction of the total cost of a nuclear power plant is associated with design and development. These costs are the same if one or ten plants are sold. This creates a powerful economic incentive for multiple vendors in different nations to develop a common design and spread the development costs over the maximum number of plant sales in multiple countries. This phenomenon is similar to what is happening in the aircraft industry, where Boeing is in partnership with Japanese companies and where the European Airbus consortium includes French, German, and Spanish partners.

The above considerations have several implications. First, technology developed in any country rapidly diffuses around the world through these business relationships. Second, it is economically costly for a country to go it alone in developing this type of technological product.

Table S1 identifies major reactor vendors in the world and indicates their sizes and significant corporate interconnections. Several conclusions can be drawn. The largest vendors in terms of recent construction starts are from France, Germany, and Japan. These vendors are backed by national governments, large corporations, or large groups of companies. A special case is the Russian vendor, where a large nuclear power program existed until the Chernobyl nuclear power reactor accident and the breakup of the former Soviet Union. Its future is uncertain. In the 1990s, current developments will lead to reactor vendor capabilities in South Korea and China. Last, because it is very expensive to operate independently, international agreements or partnerships have become the norm.

The vendor product is the nuclear power reactor. Three technologies are now marketed: two types of light-water reactors and one type of heavy-water reactor. The current technologies have one characteristic that impacts the industry—the chosen technologies have significant economics of plant size. Vendors have stressed the development of large plants. The large size of current power reactors and the required support infrastructure confines sales to countries with large electric demands, large electrical grids, and large utilities within countries.

The utilities are the vendor's customers. The decision to buy a nuclear power plant depends on local conditions. Table S2 summarizes characteristics of candidate nuclear countries (i.e., countries not operating or constructing nuclear power plants, but with economies of sufficient size to support one) and nuclear countries (currently operating or constructing nuclear power plants). The vendor for the power plant may be chosen by political, cultural, economic, or technical criteria. As listed below, several conclusions can be drawn from Table S2 and an examination of worldwide utility practices.

Table S1. Nuclear power plant vendors

Country Company *Vendor*	Power reactor construction starts since 1980[a]	Approximate total corporate sales ($ billion)	Comments
Canada			
Atomic Energy of Canada	10	Gov[c]	Sole international supplier of heavy-water reactors, technical agreements with South Korea
China			
China National Nuclear Corporation	1	Gov[c]	Planned rapid expansion in 1990s, currently somewhat limited capabilities
France			
Commissariat a L'Energie Atomic (CEA) *Framatome (France)* *Babcock & Wilcox (U.S.)*	20	Gov[c]	Part owner with Siemens of joint venture: Nuclear Power Incorporated
Germany			
Siemens *Kraftwerk Union (Germany)* *Skoda (Czechoslovakia)*[d]	9	41/Mixed	Part owner with Framatome of joint venture: Nuclear Power Incorporated
Great Britain			
National Nuclear Corporation (NNC)	4	Mixed	Multiple agreements with Westinghouse: joint venture to build the first British pressurized-water reactor, agreement for joint bids on foreign plants
India			
Department of Atomic Energy	8	Gov[c]	Local vendor: no significant international activities, relatively small power reactors

Table S1. Nuclear power plant vendors (continued)

Country Company *Vendor*	Power reactor construction starts since 1980[a]	Approximate total corporate sales ($ billion)	Comments
Japan			
Hitachi	6	55	Part of larger Dia-ichi Kangyo Bank Group with 688 member companies, member of HGET[b] joint product development consortium
Mitsubishi Heavy Industry (MHI) and Mitsubishi Electric Co. (MELCO)	11	20 (MHI) 25 (MELCO)	Part of larger Mitsubishi Group with sales of $300 x 10^9/year, agreements with Westinghouse
Toshiba	7	36	Part of the larger Mitsui Group with 489 member companies, member of HGET[b] joint product development consortium
Russia			
Minatom	43	Gov[c]	Uncertain future; only major vendor not part of larger international consortium, many reactor construction projects shut down or cancelled
South Korea Korea Heavy Industries and Construction Co.		Mixed	Building Korean reactors with Asea Brown Boveri, Korean content ~90%, approaching independent vendor status
Sweden/Switzerland			
Asea Brown Boveri (ABB) *ABB Atom (Sweden)* *ABB Combustion (U.S.)*	5	27	Largest industrial and utility equipment manufacturing company in world, technical agreements with South Korea

Table S1. Nuclear power plant vendors (continued)

Country Company *Vendor*	Power reactor construction starts since 1980[a]	Approximate total corporate sales ($ billion)	Comments
United States			
General Electric	1	50	Member of HGET[b] joint product development consortium
Westinghouse	3	12	New agreement on future reactors with Mitsubishi, technical agreement with NNC and others

[a]Power reactors sold with start of construction after 1980. There have been major changes in market share among vendors over the last several decades. A power reactor requires 4 to 12 years to build. Listing reactors with start of construction since 1980 provides an estimate of recent vendor sales and capabilities. Construction starts rather than reactor sales provides the best measure of vendor business since some sales fail and some sales are, in fact, options for purchase.

[b]HGET = Hitachi/General Electric/Toshiba.

[c]Gov = government agency.

[d]Siemens has an agreement with Skoda to buy a controlling share of the Skoda division responsible for commercial nuclear power equipment.

Table S2. Summary of candidate and nuclear countries[a]

Income level[c] Country	Electric generating capacity (GW)[b] Total	Nuclear operating	Nuclear construction in progress	Type and number of utility organization[d]	Single vendor[e]
Low-income					
Nigeria	4.0	0.0	0.0	N1	NA
India	69.9	1.4	1.5	NM, RM	YG
China	98.0	0.0	2.1	N1, RM	YG
Pakistan	8.5	0.1	0.0	N1, R1	N
Indonesia	11.0	0.0	0.0	N1	NA
Egypt	11.0	0.0	0.0	N1, RM	NA
Cuba	3.2	0.0	0.8	N1	YN
Lower middle-income					
Philippines	6.6	0.0	0.6	N1, RM	N
Peru	2.7	0.0	0.0	N1, R8	NA
Colombia	8.9	0.0	0.0	N3, RM	NA
Thailand	7.9	0.0	0.0	N1, R2	NA
Turkey	14.6	0.0	0.0	N1, P1	NA
Romania	22.9	0.0	3.1	N1	N
Poland	32.0	0.0	0.0	N1	NA
Algeria	3.8	0.0	0.0	N1, R1	NA
Bulgaria	11.1	2.6	1.9	N1	YN
Malaysia	4.4	0.0	0.0	R3	NA
Argentina	16.6	0.9	0.7	NM, RM	N
Iran	13.8	0.0	2.4	N1	N
Upper middle-income					
Mexico	28.0	0.7	0.7	N1, P1	N
South Africa	26.5	1.8	0.0	N1, RM	N
Venezuela	17.7	0.0	0.0	N6, P7	NA
Brazil	52.1	0.6	1.2	NM, PM	N
Hungary	6.4	1.6	0.0	N1	YN
Yugoslavia	15.8	0.6	0.0	War	N
Czechoslovakia	17.7	3.3	3.3	N1	YN
Former USSR	341.0	34.7	21.3	R12	YG
Portugal	6.8	0.0	0.0	N1	NA
South Korea	23.5	7.2	1.9	N1, P1	Y

Table S2. Summary of candidate and nuclear countries[a] (continued)

	Electric generating capacity (GW)[c]				
Income level[b] Country	Total	Nuclear operating	Nuclear construction in progress	Utility organization[d] Type - #	Single vendor[e]
High-income					
Greece	8.2	0.0	0.0	N1, N1	NA
Saudi Arabia	16.5	0.0	0.0	N1, PM	NA
Ireland	3.7	0.0	0.0	N1	NA
Israel	4.1	0.0	0.0	N1	NA
Spain	42.7	7.1	0.0	NM, RM	N
Singapore	3.4	0.0	0.0	N1	NA
Hong Kong	7.5	0.0	0.0	P2	NA
New Zealand	7.0	0.0	0.0	N1, RM	NA
Belgium	13.4	5.5	0.0	N1, R2, P3	N
United Kingdom	71.4	11.5	1.2	PM	YG
Italy	50.0	0.0	0.0		N
Australia	35.0	0.0	0.0	R8	NA
Netherlands	17.3	0.5	0.0	NM, RM	N
Austria	15.2	0.0	0.0	N1, RM	NA
France	91.8	55.8	8.3	N1	YG
Canada	102.2	14.0	1.8		YG
United States	684.7	100.6	1.2	NM,RM,PM	N
Denmark	8.7	0.0	0.0	MM	NA
Germany	99.0	24.4	3.3	PM	Y
Norway	26.7	0.0	0.0	NM, RM, PM	NA
Sweden	31.5	9.8	0.0	N2, RM	N
Japan	181.9	30.9	9.0	N1, RM, P10	Y
Finland	11.0	2.3	0.0	N1, RM, P12	N
Switzerland	15.3	3.0	0.0	N1, RM, PM	N

[a]Source: Adapted from Tables C.1 through C.9 in Appendix C.

[b]Total and nuclear refer to total electric generating capacity and nuclear capacity, respectively, in 1990. Construct means the amount of nuclear capacity under construction.

[b]Based on the World Bank's classification of countries using per-capita income. Countries with $610 or less of per-capita income are low-income; those with $7,620 or more are classified as high-income.

[d]The entries in this column designate the organizational structure of the electric power sector in each of the countries. The first character in any two-character sequence refers to the ownership of the electric utilities: N = owned by the national government; R = owned by a regional (city, county, district) government; P = owned by the private sector; M = mixed, public-private ownership. The second character refers to the number of utilities in the country with that type of ownership, with M meaning many or multiple. A designation N1, R3, for example, means that the country has one utility owned by the national government and three owned by regional governments. In this example, the country has no privately owned utilities.

[e]Y indicates that utilities historically buy from the same vendor. YG indicates government-owned vendors and utilities; YN indicates utilities historically have bought from a particular nongovernment vendor. (These relationships may have changed with the breakup of the former Soviet Union.) NA = not applicable; N indicates no fixed vendor/customer relationship.

- The size and cost of nuclear power plants limit their construction to countries with large incomes. The candidate countries in Table S2 are all countries presently without nuclear power and with a total annual income in excess of $30 billion in 1990 (see Appendix C), the lowest national income level (with the exception of Bulgaria) of countries currently operating or constructing nuclear power plants.

- Different countries use different approaches in organizing their utility industries which, in turn, implies different types of decision makers choosing to build or not to build nuclear power plants.

  - Many countries have one large government-owned/controlled utility (e.g., France, South Korea) where the decision to build a nuclear power plant lies with the government. In such cases, the government may, through the utility, select the reactor vendor or force the creation of a local vendor. France historically used this mechanism to create a local nuclear power vendor. South Korea and China are currently using the mechanism to create new national reactor vendors in the 1990s.

  - Other countries have a large number of utilities with mixed government-private ownership. For example, the decision to construct a nuclear power plant in the United States does not rest with the government, but with the managers of the 2000 utilities.

  - The structure (number and type) of the utility industry in a country influences the use of nuclear power. In countries such as Japan (where there are only nine very large utilities), there are few financial, managerial, or technical constraints on choice of power plant. In countries such as the United States, (with thousands of utilities), only the large utilities have the resources to build nuclear power plants.

- In many countries, a utility, for political or cultural reasons, must buy nuclear power plants from a specified vendor. This includes (1) countries with national (i.e., government-owned) utilities and national vendors (France, Russia, India, China, Canada); (2) countries with business cultures where long-term vendor-utility relations have evolved (Japan, Germany); and (3) countries where national policy dictates choice. In many cases (France, Japan, Canada), the utilities have very powerful influences on the vendors and many times influence vendor decisions. The vendor, in turn, may develop the technology, license the technology from another vendor, or form a partnership with another vendor to obtain the product the utility wants.

- In other countries (the United States, Sweden, Switzerland, Belgium, Spain, etc.), the utilities have more freedom in choosing vendors. They may make their decision based on economics (including financing) and technology; however, other factors usually limit the choices to a few select vendors. These factors include the following:

  - Previous experience with the vendor in nuclear and nonnuclear transactions. Power plants are expected to last 30 to 40 years. The equipment lifetime is longer than in most industries. The utility prefers a vendor to support his product for the life of the plant. Long equipment lifetimes imply long customer-vendor relationships. Commercial relationships are slow to form or break.

- Reputation of the vendor. In the 1980s, the sales of reactors to countries without national vendors indicated that vendors with the most reliable reactors made the most sales.

- Cultural factors, standardization of requirements, and codification of criteria. Language, cultural factors, and national engineering codes strongly influence decisions. Building a power plant is complicated; thus, factors which aid communication have a significant impact on the selection of vendors.

- Most new orders for nuclear power plants in the 1990s are expected in Pacific rim countries (Japan, South Korea, China, Indonesia, and Taiwan). This reflects rapid economic growth with rapid growth in electrical demand, limited local energy resources, reasonable acceptance of nuclear power, and total electrical demands sufficiently large that large nuclear power plants are compatible with the local electric grid. Nuclear power growth in Europe is expected to be slower due to smaller growth in electric demand, saturation of nuclear power capacity in selected countries (France), and controversy over nuclear power.

The transitions in the nuclear power industry imply different organizations and individuals making key decisions. Utility and commercial considerations are becoming more important with less influence by governments. The industry is becoming international. Understanding historic commercial relationships and the evolving technology has become the basis for identifying likely future trends.

1. INTRODUCTION AND OBJECTIVES

The objective of this report is to provide an understanding of the international commercial nuclear power reactor market, including the suppliers, the products, and the customers. This objective includes two major components:

1. Identifying (1) major commercial reactor suppliers, (2) existing and future product lines, (3) influences on customers/practices, (4) views on market strategies, (5) major partnerships and agreements, and (6) customer [utility] constraints.

2. Understanding the slowly evolving connections between suppliers, technologies, customers, and national governments. The choice of nuclear reactor by a utility is determined not only by economics, but cultural factors, historical business relationships, and national policies.

Understanding the structure of the nuclear power industry provides an insight on why particular events occurred, provides a framework to understand what may occur, and a mechanism to understand what occurrences are unlikely.

The body of this report presents an overview of the structure of the industry, while the appendixes (70% of the report) provide more detailed reference information. Section 2 provides an overview of the structure of the international nuclear industry and its evolution with time. Section 3 describes vendors, their environments, and the apparent strategies of reactor suppliers. Section 4 describes the product lines, while Section 5 provides an understanding of the customers (utilities with various constraints on decisions). The possible philosophies and strategies of particular vendors combined with the constraints of utilities imply that when a utility orders a power plant, in practice, only one or a few vendors are possible suppliers. These relationships are described in Section 6.

2. EVOLUTION OF THE COMMERCIAL NUCLEAR POWER INDUSTRY

The structure of the international nuclear power industry is rapidly changing. This study provides a snapshot of that structure today, but to understand the structure and its possible future direction, some understanding of the key historical driving forces for change is required. Four primary factors have influenced the historical evolution of commercial nuclear power: government, internationalization of business, growth in electric demand, and technology.

2.1 GOVERNMENT INFLUENCE

Historically, national governments have been the dominant influence on the structure of the commercial nuclear power industry. As a commercial industry, nuclear power is unusual in this aspect. The original technology was developed by national governments for defense purposes. Thus, transition from national defense activity to commercial activity was required. That transition is currently not complete, and it may never be fully complete in all countries.

Commercial nuclear power worldwide is also influenced by government concerns about strategic energy availability, international balance of trade, and national employment. These influences have been major factors in European and Japanese government nuclear power policies to support national vendors and utilities. To understand these issues, some technical characteristics of nuclear power compared to other energy sources must be understood. The costs of electricity depend upon capital facilities costs, operating costs, and fuel costs. Fuel costs include cost of uranium, fuel preparation, transport, and waste disposal. The cost of the uranium is extremely low—$0.0014/kWh of electricity generation ($20/lb uranium). When the other fuel cost components (conversion, enrichment, fabrication, and waste disposal) are added, the total nuclear fuel cost is $0.006/kWh. For comparison, the cost of oil is $0.0300/kWh of electricity generated ($20/barrel with 40% conversion efficiency), and the cost of coal is $0.0150/kWh of electricity generated ($40/ton with 37% conversion efficiency).

Fuel availability is a major issue for governments in industrialized countries. For energy security by stockpiling of fuel, nuclear power offers two advantages: (1) the cost is low (10% of that of coal for equivalent energy), and (2) storage is easy (more than four orders of magnitude less mass than the mass of coal for equivalent energy). Furthermore, uranium, unlike coal or oil, will not degrade in storage.

Some countries have problems with the balance of trade. If they do not have internal energy resources, uranium is the preferred fuel because it costs the least. Less than 5% of the electricity cost from nuclear power is associated with uranium cost vs >50% of the cost of electricity from oil. This low associated fuel cost for uranium minimizes expenditure of scarce hard currency.

Nuclear power can use domestic employment; the employment is associated primarily with construction and operation of power plants rather than obtaining fuel. Much of the employment with fossil production of electricity is associated with the mining and transport of fuel.

Last, in addition to economic and energy concerns, there has been continued concern about nuclear weapons proliferation and the potential use of civilian nuclear power technology as a stepping stone to weapons production. This concern has resulted in various treaties and agreements to restrict certain nuclear power technologies.

2.2 INTERNATIONALIZATION OF BUSINESS

The nuclear power supply industry (vendors) has become an international industry. In part, this reflects the general trend of rapid economic growth in international trade and formation of multinational enterprises. This broad economic development is a result of political developments such as lowering of trade barriers and formation of free trade zones (e.g., the European Common Market). The internationalization of the nuclear power supply industry is also the result of certain economic characteristics of high technology industries. These characteristics provide strong incentives for internationalization of suppliers. A comparison of the steel and commercial aircraft industry can highlight these differences.

The costs of producing steel depend upon the costs of facilities, raw materials, and labor. Steel technology is not changing rapidly, thus, few resources are required for development of steel making technology. The product is also well defined. There are economies of scale up to a certain size. An international steel company with many steel plants may have only a small economic advantage over a steel company with a few facilities.

The commercial aircraft industry (Boeing, Airbus, etc.) has a fundamentally different cost structure. The development and licensing costs for a new commercial aircraft are measured in billions of dollars. Product development costs are extremely high. If the aircraft manufacturer doubles production of a new aircraft, additional facilities may cost a few hundred million dollars plus operating costs; however, the cost per aircraft drops dramatically because development and licensing costs are a significant fraction of total costs and independent of the number of aircraft produced. If partnerships or joint ventures with other companies can increase sales, this drastically reduces unit costs, reduces risks, and increases profits for all partners. The Boeing/Japan partnership and the Airbus consortium (French, German, Spanish companies) are designed to ensure wider markets for expensive-to-develop aircraft. The electronic integrated circuit industry is also similar except that the costs involve developing the production technology. The recent joint venture of IBM (United States), Toshiba (Japan), and Siemens (Germany) to develop the next generation of computer memory chip is a mechanism to spread the process development costs over products sold in North America, Japan, and Europe (Wallace 1992). In industries where product or process development costs are a major fraction of total costs, there are powerful incentives for international cooperation that spread development cost/risk over expanded markets.

The economics of constructing nuclear power plants are closer to the aircraft industry than the steel industry; thus, there are potentially large vendor economics of scale. National governments may prefer domestic suppliers, but unlike the steel industry, the economies push for either international companies or domestic companies as part of larger international consortia to spread development costs, minimize risks, and maximize markets.

2.3 DEMAND FOR ELECTRIC POWER--S CURVE OF NEW PRODUCT PENETRATION INTO A MARKET

New technologies and new products penetrate markets over a period of time. For most products, the rate of penetration as a function of time is described as a flattened S curve. When a product is first introduced, it slowly enters the market. As people learn about the new product, its acceptance increases rapidly and costs drop. Eventually, the market saturates and the demand for the product is limited by the replacement market and population growth. This applies to growth in demand for electricity and demand for nuclear power stations, and this phenomenon impacts which utilities will buy nuclear power plants.

The growth of electric demand in the United States provides an example of this phenomenon. The electric power industry started in the late 1800s. By the early part of the 1900s, electricity demand grew rapidly, slowed only by the great depression of the 1930s. Initially, electricity replaced other energy sources—electric lights for oil lamps and electric motors for factory steam engines. Later, new applications appeared—air conditioning and electronics. After decades of rapid growth, the electric growth rate slowed in the 1970s. At the time, it was assumed that the decreased growth rate was primarily due to the oil shocks, but today it is recognized that the slowdown would have occurred within a decade due to saturated demand. By the 1970s, the massive retrofit of factories and homes for air conditioning, electrification of home appliances, and other new uses were approaching saturation.

The change in growth rate for electric power drives the market for nuclear plants. The slowdown in growth of electric demand in the United States in the 1970s resulted in the cancellation of hundreds of planned coal, nuclear, and gas-fired power stations. This, in turn, shrank the size of the U.S. nuclear supply industry. Alternately, the rapid growth in electric power demand as part of the industrial development cycle in South Korea and Taiwan provides a major market for nuclear power stations and the home market for the emerging South Korean reactor vendor.

The S-curve phenomenon also applies to the growth of nuclear power to replace other sources of energy for electric power production. In a country, such as the United States, with 20% of the electricity from nuclear power, a significant growth of nuclear power is possible. In contrast, in a country such as France with 70% of the electricity from nuclear power, future nuclear power growth is limited by electric demand.

2.4 TECHNICAL CHARACTERISTICS OF NUCLEAR POWER

As currently designed, the economics of nuclear power favor very large power plants. Plant operations are complex and require a significant infrastructure for efficient operations. These technical characteristics limit the nuclear power market to large utility systems—primarily in large developed countries. Such technical limitations are unusual when compared to most other industrial products. Countries with large internal markets usually have large, local industrial suppliers. This is in contrast to the aircraft and integrated circuit electronics industries where significant markets exist outside the countries manufacturing the products.

Within the nuclear industry, there is considerable debate as to whether or not economies of scale are intrinsic characteristics of nuclear power or results of the historical development of the technology. If the technology were to change to allow smaller power plants, the industrial structure would be significantly altered.

3. VENDORS OF THE NUCLEAR INDUSTRY

Each nuclear vendor organization has a unique set of conditions that dominate its existence and growth. This section discusses many of these conditions—how they influence vendor growth, the competitive climate in the industry, and the strength of various reactor vendors. The major factors influencing vendor development have been placed in the following groups for discussion in this chapter:

- vendor history and ownership,
- local codes and technical constraints,
- influences on vendor development, and
- various vendor business structures.

A short summary on the competitive status of vendors is provided at the end of this chapter.

3.1 VENDOR HISTORY AND OWNERSHIP

3.1.1 Early History—Technological Experimentation

The first type of reactor to be commercialized was the light-water reactor (LWR). The LWR is a direct outgrowth of development of pressurized-water reactors (PWRs) for propulsion of U.S. nuclear power submarines. Before the development of nuclear power, submarines were powered by diesel engines when on the surface and battery-powered electric motors when under water. When the United States decided to develop nuclear power reactors for submarines, two contractors with experience in submarine propulsion (electrical equipment) were chosen—General Electric and Westinghouse Electric. The two companies were, at that time, the major U.S. suppliers of utility electrical equipment. Based on their experience with navy reactors, these two companies became the major commercial nuclear reactor vendors worldwide in the 1960s and 1970s. Two other U.S. companies also successfully entered the nuclear power business—Babcock and Wilcox and Combustion Engineering. These companies had also been involved in the submarine program and were, historically, the dominant suppliers of steam boilers for production of electricity from fossil fuels in the United States. These companies worked on LWR nuclear plants for the public utilities while the U.S. Government continued to conduct research and development (R&D) on heavy-water reactors (HWRs), gas-cooled reactors (GCRs), and liquid metal reactors (LMRs). In the United Kingdom, GCR work was being performed by British companies for their utilities, while LMR work was conducted in their government laboratories. The Canadian Government was developing HWR plants for its utilities. The Russians were developing PWRs, graphite moderated LWRs, and liquid-metal fast breeder reactors. The numerous military and government R&D programs continued to make major contributions to the technology.

During this period, the U.S., U.K., German, Swedish, Swiss, and Japanese major manufacturers of fossil power plant equipment were setting up nuclear power plant divisions. In other parts of the world, governments were initiating nuclear programs to explore the technology and potential contributions to the energy supply. The Americans, British, and

Canadians had a cadre of trained engineers from defense programs. With their knowledge of the new technology, these engineers rapidly moved into the newly created nuclear divisions of established suppliers of commercial power generation equipment vendors. In Canada, France, and Russia, the governments were aggressively developing their technological base. There was an exciting national pride about these efforts and the development of capabilities.

By 1970, the U.S.-designed LWRs dominated the world market. This was a result of the initial development of nuclear power in the United States and the classified characteristics of the technology in its early years, which allowed only U.S. companies access to the technology. The LWR became the dominant technology because (1) more resources were spent to develop this technology than any other technology and (2) technical requirements for Navy propulsion reactors (supply steam to turbine to power propeller) were similar to utility requirements (supply steam to turbine to power electric generator). As one historian noted (Arthur 1990), "the role of the U.S. Navy in early reactor construction contracts, efforts by the National Security Council to get a reactor—any reactor—working on land in the wake of the 1957 Sputnik launch . . . all acted to favor the early development of light-water reactors . . . ." Many foreign equipment suppliers obtained technology licenses from U.S. vendors to build nuclear power plants in their own countries. The advanced development of the LWR ultimately resulted in it becoming the preferred reactor in most countries, but the condition for sale in many countries was design and construction of the reactors by local vendors under license from U.S. vendors.

General Electric and Westinghouse, along with Babcock & Wilcox and Combustion Engineering, were competing for the U.S. domestic business. Two types of LWRs were developed: (1) the PWR and (2) the boiling-water reactor (BWR). In the U.S. the nuclear plant selection issue was influenced by the decision to use a BWR vs a PWR as much as the desire to go with a particular vendor. General Electric promoted and dominated the BWR field while Westinghouse promoted and dominated the PWR field. In many other countries, the preferred type of reactor was determined by which U.S. company licensed technology to the local vendor.

There were three important exceptions to U.S.-designed LWRs dominating the world market. The first is a company called Asea Brown Boveri (ABB). In the 1960s, ABB was a large Swedish company that decided to independently develop its own LWR technology (Kaijser 1992). It was very successful and built the most reliable LWRs in the world (Knox 1992). For decades ABB has been one of the most rapidly growing industrial companies in the world and is now the world's largest industrial equipment supplier, a major force in the international nuclear power industry, and a major exporter of nuclear power plants beyond home markets. In the late 1980s, ABB purchased one of the U.S. reactor vendors—Combustion Engineering.

The second exception is the Soviet Union with its parallel efforts to develop nuclear power. Like the United States, it developed the LWR (called the VVER) which became the dominant type of Soviet nuclear power plant. The second type of reactor, a graphite moderated light water-cooled reactor called the RBMK, was built in significant numbers until the Chernobyl accident raised fundamental safety questions about this reactor type. In addition to LWR nuclear power plants, one other type of nuclear power plant received international acceptance—the Canadian CANDU heavy-water reactor. It was designed to meet specific Canadian conditions:

- It is fueled with natural uranium. It does not require enriched uranium or a complex nuclear fuel cycle. This was designed to take advantage of abundant uranium resources in Canada without the need to build a large nuclear fuel cycle support infrastructure.

- It is designed to be built without requiring a very large industrial base—specifically without requiring a sophisticated steel industry to supply large pressure vessels and other very specialized components.

The CANDU reactor has its own unique history and fills what must be considered a niche market for nuclear power.

3.1.2 Changing Markets and Changing Vendors

In 1973, the oil embargo fundamentally altered energy markets and set into motion market forces that restructured the nuclear power industry. In the United States, the rate of increase in electric demand dropped rapidly. From today's perspective, much of the reduction in rate of growth in electric demand would have occurred in any case due to saturation of markets for electricity-using durables. In addition, the oil embargo created a concern about energy shortages that encouraged energy efficiency. Ongoing utility power plant construction resulted in constructing excess electric generating capacity with the market for all types of new electric power plants disappearing. Since most electric power plants burn coal, there was not a strong incentive to replace existing electrical generating capacity. The U.S. nuclear power reactor vendors lost their home markets.

In Europe and Japan, electricity-using durable markets were not saturated. Most of the power plants burned oil and became very expensive to operate. There were massive economic incentives to build nuclear power stations. The European and Japanese vendors had begun to develop their own capabilities to design and construct nuclear power plants. These vendors rapidly expanded their development and engineering staffs to meet demand. The U.S. vendors received licensing payments but did not build the plants. The rate of construction of new nuclear power plants continued at a high level through the mid-1980s until the growth was slowed by a combination of saturation of electric demand, saturation of nuclear power in selected countries (France), and opposition to nuclear power.

Simultaneously, the former Soviet Union (FSU) began a major program for use of nuclear power. Two economic forces encouraged this development. First, most of the electric energy demand was in Eastern Europe and the western portions of the FSU while most of the fossil fuel resources were in Siberia. The high costs of transportation made nuclear power preferable in the western FSU. Second, high world oil prices created strong incentives to export oil for needed hard currency rather than burn the oil to produce electricity.

In the 1980s, the original technology licensing agreements between the United States and foreign vendors began to expire. The foreign licensees were now independent reactor vendors in competition with U.S. vendors. The foreign vendors had large facilities and experienced staffs due to the large number of nuclear power plants that were built in Europe and Japan. Most of the nuclear power plants built in the 1980s were built by these vendors. The growth of the European common market encouraged further consolidation of industrial groups in Europe, which strengthened these vendors.

3.1.3 Historical Impacts of Nuclear Power on Traditional Vendor and Utility Structure

Vendors and customers (utilities) in the worldwide electric power industry traditionally had a mix of private, public, and government ownership. The introduction of nuclear power has not significantly changed the nature of the ownership of the customers' organizations (i.e., those who generate and distribute electricity); however, it has had a significant impact on the ownerships of vendors in the industry. Those countries that historically had utility ownerships dominated by governments continued in this vein, while countries that had private and/or public utility structures (United States and Japan) have also continued with their structure.

Historically, the component, equipment, and construction companies in the industrialized countries have been privately owned companies, sometimes separate divisions of the utilities, but rarely, if ever, government owned. In Canada and France, the introduction of nuclear technology changed this fact. Atomic Energy of Canada, Ltd., (AECL) designs and builds systems as well as hardware; Framatome, the reactor designer and manufacturer in France, is primarily owned by the French government agencies Compagnie General d'Electricia (CGE) and Commissariat a l'Energie Atomique (CEA) along with the French utility Electricitè de France (EdF), that is also owned by the French government. These developments have produced very large government-owned vendors who currently compete with private and/or publicly owned vendors in the world market. Consequently, publicly owned companies are changing their modes of operation to remain competitive. Some large privately owned companies, such as ABB and Siemens, have bought smaller nuclear vendors, while others, such as General Electric (GE) and Westinghouse (W), are developing numerous joint venture relationships. As discussed earlier (Sect. 2.2), there are very large economic advantages of scale if reactor development costs can be spread over many reactor sales. As a result of these evolutionary changes, the vendors and vendor groups competing in the international nuclear market can be separated into the following groups that have developed their own capabilities and/or licensed the use of technology and have bought companies with nuclear industry knowledge:

(1) **Government-owned companies**,

(2) **Large corporations**, and

(3) **Keiretsu organizations (Japan)** consisting of groups of related companies that own stock in each other.

The corporations in all of these groups participate in numerous joint ventures with each other and dominate many smaller suppliers, thus increasing their industrial base. This results in joint ventures that include vendors owned by governments, private investors, and keiretsu groups.

A dominant common characteristic of these groups and the joint ventures is the large financial strength that permits them to take large financial risks (Table S1). These groups and joint ventures have financial strength in one of the following forms—government backing, large corporate resources, or pooled resources through arrangements on R&D and/or marketing programs. These organizational relationships are shown in Table 3.1 by listing the parent organization/group/corporation in Column 1, the reactor vendors and complementary corporations as subsidiaries, and placing other details in the balance of the table. It is interesting to note that the organizations in Column 1 include governments, utilities, keiretsu, and corporations. These are the organizations that emerge when the owners and/or industrial group relationships of the reactor vendor companies are identified. Appendix A provides detailed backup information.

3.2 LOCAL RULES—TECHNICAL CONSTRAINTS

It is obvious that those who write the rules have an advantage in any game or competition. All industrialized countries have their rules (codes, standards, regulations, laws, etc.). In all countries, the local rules used to protect the public from the failure of equipment are voluminous, complicated, and a product of the local legal systems. These local rules constitute a barrier to the international acceptance of industrial equipment that is not always visible or obvious. Often these rules create powerful incentives for the development of local partnerships and international enterprises.

The American Society of Mechanical Engineers' (ASME) Boiler and Pressure Vessel Code (B&PV) emerged as a universally respected code for the design of pressurized components, equipment, and hardware for the power plant industry during the 20th century. At the turn of the century, fatalities due to steam boiler explosion reached a deplorable level and resulted in the ASME developing the B&PV code. The decline in boiler failures in the United States, due to improved designs that were developed in compliance with the B&PV code, was dramatic and established the ASME B&PV code as credible and potentially helpful code for many other countries. The code grew in stature and gained large international strength during the decades following World War II. International recognition was also attained by the codes of the American Institute of Electrical and Electronic Engineers (IEEE) and the American Society for Testing and Materials (ASTM). The requirements, rules, and guidance, developed by the U.S. Atomic Energy Commission (AEC) and subsequently the U.S. Nuclear Regulatory Commission (NRC), have been used as the base requirements or guidance by many foreign nations and world organizations. For decades, U.S. industry has written the rules that dominated the design and acceptance of pressure vessels, piping, nuclear hardware, and electrical equipment while many countries either used U.S. codes or slightly modified versions. This recognition and/or strength of U.S. codes and standards was probably due to:

- the strength of the U.S. economy during those decades;

Table 3.1. Major reactor vendors in the world market

Parent organization, company, or group (type)		Home country	Major subsidiaries and/or joint partners in building plants	Pre-1980	1980 and later	Currently operating
				Construction starts	Construction starts	
ABB	Asea Brown Boveri (Private)	Sweden and Switzerland	ABB-Atom ABB Combustion Engineering	10 15	1 4	11 15
AECL	Atomic Energy of Canada Ltd. (Gov't)	Canada	AECL	22	10	24
CEA	Commissariat a l'Energie Atomique (Gov't)	France	Framatome B&W Nuclear Power International (Joint with Siemens)	45 9	20 0	57 7
CNNC	China National Nuclear Corp. (Gov't)	China	CNNC	0	1	0
DAE	Department of Atomic Energy (Gov't)	India	DAE DAE/NPC with United Kingdom RRC/CEA of France	5	8	4
DKB	Dia-ichi Kangyo Bank (Keiretsu)	Japan	Hitachi	4	6	7
GE	General Electric (Private)	United States	Power Supply Division	57	1	56
KEPCO[a]	Korea Electric Power Company (Mixed)	South Korea		0	0	0
MSHI	Mitsubishi (Keiretsu)	Japan	Mitsubishi Heavy Ind. (MHI) Mitsubishi Electric Company (MELO)	9	11	15

Table 3.1 Major reactor vendors in the world market (continued)

	Parent organization, company, or group (type)	Home country	Major subsidiaries and/or joint partners in building plants	Pre-1980 Construction starts	1980 and later Construction starts	Currently operating
MSUI	Mitsui (Keiretsu)	Japan	Toshiba	7	7	10
NNC	National Nuclear Corporation[b] (Mixed)	United Kingdom		33	4	37
MTM	Minatom (Gov't)	Russia		49	43	69
SEMS	Siemens (Private)	Germany	KWU Kraftwerk Union	21	5	24
			SKODA of Czechoslovakia[c]	6	4	6
			Nuclear Power International (Joint with CEA)			
W	Westinghouse (Private)	United States	NES Nuclear Engineering System Div.	82	3	80
				374	128	422

[a]The Korean units were built primarily as joint efforts with ABB-CE and AECL. This included six units constructed before 1980 and now in operation, plus eight units with construction starts after 1980. Three of these latter units are now in operation. Korea is building a reactor vendor capability with increased Korean content with each subsequent power plant. Current plants are about 90% Korean.

[b]NCC is the sole surviving reactor vendor in Great Britain, the resources of the following organizations have eventually been consolidated with NNC: APC, Atomic Power Con; NNC; TNPG. The Nuclear Power Group, UKAEC, UK Atomic Energy Company; EE/BW/TW.

[c]Siemens has an agreement with Skoda to buy controlling shares of the division which manufactures power equipment.

- the quality of the engineering content, the amount of industrial support for the code/standards committee work, and the recognition of the relatively open consensus approach to code development;* and
- customers' (throughout the world) desire for U.S. products and engineering during a period when they were developing and/or rebuilding their economies and industries.

All countries cannot expect to have unique codes; however, the European Community and the Japanese seem to see merit in separating their codes from the U.S. codes. Europe and Japan are funding programs that encourage developing countries to develop standards that fit the standards of Europe or Japan (i.e., the countries that are providing the funds for their laboratories). Simultaneously, there is a major effort in Europe to create unified European nuclear standards. An example of this type of activity can be seen by the work of Nuclear Power International (NPI), the joint venture of Framatome and Siemens to design, develop, license, and construct the next generation LWRs for Europe. As a part of this effort, they are agreeing on when and how to integrate French, German, and other codes/standards. The European Fast Reactor (EFR) group is another example of a similar effort.

3.3 INFLUENCE ON VENDOR DEVELOPMENT

3.3.1 Complications and Conditions in the Market

Vendors, constraints, and customers in the pre-1960 market vs today's market are shown in Fig. 3.1. The number of vendors has increased, the number of customers has increased, and the complications due to new rules, regulations, and international organizations have increased. The comparisons shown in Fig. 3.1 give an indication of the growth of the industry and the associated complications that have developed during the last few decades. Fig. 3.1 only includes a part of the industry's total picture, only major reactor vendors (RVs) and some architect engineering (AEs) companies are included. The long list of component, equipment, and fuel suppliers is not included. Additionally, only the most visible constraining codes, standards, regulations, and international organizations have been identified and only the types of customers have been noted. The size and complications of the market can be appreciated when it is recognized that smaller suppliers and some countries' additional detailed regulations are not even included on this list, while the general categories of customers listed exist in over 30 countries.

The implications of this evolution is the decentralization of decisionmaking with no company or country having dominance over the industry. It also implies that typical vendors have less influence over customers because there are more alternative suppliers with the prerequisite technical and financial capabilities. This evolution further indicates that governments or very large corporations not currently in the nuclear power business can enter the business since the technology is generally available. The emerging South Korean vendor is an example of this.

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* (The committee members were respected technical people who contributed their time as well as their employer's time and acted as technical professionals working to satisfy "society's needs" without commitment to particular company desires.)

ORNL DWG 92A-667R

VENDORS

Major Players

Today

VENDORS
General Electric
Westinghouse
ABB–CE
Framatome – B&W
Siemens – KWU
Atomic Energy of Canada
Hitachi
Toshiba
Mitsubishi
Ansaldo
Nuclear Power International
China National Nuclear Corporation

AEs
Bechtel
UE&C
B&R
Stone & Webster
Sargent & Lundy
Fluor
Numerous Foreign Companies
Numerous Foreign Governments

Pre–1960

VENDORS
Babcock & Wilcox (B&W)
Combustion Engineering (CE)
General Electric
Westinghouse

AEs
Bechtel
UE&C
B&R
Stone & Webster
Sargent & Lundy
Fluor

CODES & STANDARDS

Today

ASME B&PV SECTION III & IX (for nuclear equipment)
ASME B&PV (for pressure equipment)
ASTM Standards
IEEE Standards
ISA Standards
RCC–M – French Code
CODAP – French Code
TRD – German Code
TRB – German Code
JIS – Japanese Standard Institute
BSI – British Standard Institute
Similar codes in other countries

Pre–1960

ASME B&PV (for pressure equipment)
ASTM Standards
IEEE Standards
ISA Standards
Building Codes
BSI–U.K.

REGULATIONS

Today

NRC – U.S. Regulations Guides
CFR – U.S.
MITI – Japan
– French
– German

Pre–1960

AEC Development of Rules
CFR Development Code for Nuclear

INTERNATIONAL ORGANIZATION

Today

OECD – NEA
IAEA –
WANO –

CUSTOMERS

Major Players

Today

- Utilities
- Distribution Companies
- Power Companies
- Industrial Groups
  - EPRI
  - USCEA
- Governments
  - Ministries of Energy, Trade, and Finance
- All of the above now exist in about 35 countries

Pre–1960

Utilities and governments in a few industrialized and politically credible countries

Fig. 3.1. Vendors, constraining rules, regulations, organizations, and customers

3.3.2 Vendor-Utility Relationships

The evolution of the market has resulted in the development of three types of vendor customer relationships.

1. The permanent relationship that develops between government agencies and/or departments. France, Canada, Russia, and China work with this type of relationship between their government-owned vendors and government-owned utilities. In France and Canada, the vendor structure also includes private groups.

   The relationship of a government-owned vendor and utility often extends beyond the domestic market to international sales. An example is France (Taylor 1992a). In France, the vendor Framatome supplies the nuclear reactor system, while the French government-owned utility EdF acts as the project manager and is the AE for the rest of the plant. In foreign sales, the utility is often a partner with the reactor vendor. For example, France sold the two-unit Guangdong nuclear power plant that will begin operations in 1993 to the Peoples Republic of China. While Framatome provided the nuclear power reactor system, EdF is the technical project manager. EdF is also providing training in operations and maintenance to the Chinese staff.

2. Long-term relationships develop between the people in large companies and the people in their large and old established customers. Siemens, ABB, and Japanese companies seem to focus on this approach, which effectively uses their established business relationships that have been developed with the customers through their nonnuclear businesses. This is common in Japan and Europe.

   This relationship is seen particularly in Japan, where long established relationships have a major impact on the strategic decisions that are made in the government organizations, utilities, and vendor companies. Traditionally, each Japanese utility buys from one or two specific vendors. These decisions are based on technical evaluations, political factors, and business linkages. Nontechnical factors are important to the consensus that is usually essential for actions or decisions in the Japanese organizations. Political and business thinking is complex and significantly influenced by the Japanese implementation of two concepts. Information flows through a "gakubatsu" (i.e., a club whose members are graduates of the same university) and business is usually conducted with members of a "zaibatsu" (i.e., a family of organizations usually headed by a major financial organization or bank that maintains a protective overview of its members). Keiretsu groups are a current form of the zaibatsu families that started before the 20th century.

   The influence exerted by members of a gakubatsu has a major impact on government, corporate, and utility decisions relative to the ordering of power plants in Japan. Information flows at all levels in these organizations and is significant in the development of national policy, corporate strategies, utility planning, and the selection of vendors. This type of integrated thinking can be very frustrating to the vendor, who is not privy to the gakubatsu communications.

3. The business relationships that develop between customers and their vendors when there are numerous vendors who provide competitive bids for design, fabrication, and/or construction on large projects. This individualistic, competitive approach is common in the U.S. vendor and utility selection process.

   The typical U.S. vendor-utility relationship may have contributed to the development of Electric Power Research Institute (EPRI) and several other organizations in the United States that do not have analogous organizations in most other countries of the world. EPRI is the electric utility's research organization that addresses problems that are common to U.S. utilities. (EPRI performs the coordinating R&D functions needed by many of the utility companies in the United States). To some extent, EPRI addresses issues that pertain to foreign vendor utility interactions. For example, EPRI has recently completed its work on developing the requirements for large LWRs [1200 MW(e)] that satisfy the future large plant needs, otherwise known as "the evolutionary LWR." EPRI has also completed work on smaller passive-design LWR requirements known as "the advanced LWR," that will cover the market for smaller plants [600 Mw(e)]. These documents are used when utilities discuss future power reactor purchases with vendors. In contrast, in Europe, the French utility, EdF, and the German association of nuclear utilities (EVU) have formed a joint committee (NNb 1992) with their long-term vendors on requirements for the European pressurized-water reactor (EPR).

Most of the vendors, who typically work or sell in one of these vendor-utility relationships, also want to sell to customers who are most familiar with another vendor-utility relationship. Therefore, they (the vendors) must recognize the differences and modify their business approaches if they expect to have successful long-term relationships in the new markets. The changes may be required to satisfy differences in cultures, customs, laws, specifications, codes, standards, and/or pricing structures. The flexibility of the vendors will probably have a major influence on their success. This flexibility will reflect their companies' restraints, their countries' laws, and the ability of their people to work effectively in, and with, these different vendor utility relationships. In some instances, it is convenient or necessary to have joint ventures in order to penetrate the markets.

The present and future international nuclear power reactor market appears to expect, and may flourish on, a comprehensive and long-term reactor vendor and plant operator relationship (i.e., more than reactor vendors have provided to the U.S. utilities over the past few decades). This change appears to be a consequence of the increased safety requirements and complexity of modern plants, which require many more types of specialists to maintain the plant. Such experts are not required full time for a single plant. This is similar to the aircraft and mainframe computer business, where vendors supply their expertise. The time and other resources required to familiarize a new supplier with current plant design/conditions creates strong incentives for long-term utility-supplier partnerships. The historical U.S. vendor-utility arrangement protects the independence and free competition for architect-engineers, builders, reactor manufacturers, and nuclear service companies; however, it may not provide the integrated design, build, and support responsibility that will be expected by the international market of the 21st century.

3.3.3 Scope of Vendor Responsibility

The customer ultimately determines the vendor's scope of responsibility. Construction of a nuclear power plant involves many activities: (1) design/fabrication of the nuclear reactor system that produces steam, (2) design/fabrication of the turbine/generator to produce electricity from the steam, (3) AE activities to integrate various systems together and design buildings, (4) construction of the plant, (5) startup/maintenance operations, and (6) other activities. Different utilities around the world have preferred different approaches for managing power plant projects. Some purchase the nuclear systems and perform the architect, engineering, and construction work with their own people (Duke Power in the United States and EdF in France), while others contract for various combinations of design, construction, support services, or (in some instances) the whole package. Reactor vendors also have approaches that they prefer and promote:

- **Siemens** advocates "turn-key" contracts where they design, build, and operate the entire plant for the first year before turning over the total facility to the ultimate owner. They have their own AE, construction, component, and system organizations including design, fabrication, operation, and maintenance people.

- **Framatome** usually delivers nuclear reactor systems, components, and services as part of a team effort, primarily with other organizations that are also owned by the French Government. The Japanese vendors have adopted a somewhat similar approach where the same private companies work together on multiple power plants.

- **General Electric and Westinghouse** deliver reactors with a variety of contractual arrangements with responsibilities shared between AE, constructors, and Nuclear Island suppliers. The AEs, constructors, and nuclear equipment/system suppliers are often independent companies that compete for the various segments of the plant work.

These approaches have developed as a response to the regional customers and as a result of the periods when the various companies entered the market.

How the customers' needs are satisfied reflect government policies, local customs, and regional business characteristics. Framatome supplies all the reactor plants for EdF, its parent government organization which supplies 90% of France's electricity. Mitsubishi has supplied all PWR power plants for particular Japanese utilities. These close reactor vendor and customer relationships are more involved and supportive of the customers' total need than the relationships that often exist between the utilities and reactor vendors in the United States.

In many countries AEs and construction companies are part of the vendor or utility parent organizations. KWU is the construction arm of Siemens. EdF, the French utility, does its own AE and construction work and partly owns Framatome. Mitsubishi Heavy Industries does the AE and construction work for Mitsubishi Electric Corporation.

The U.S. reactor vendors have been more restricted in the scopes of work they perform prior to the plant operation (i.e., they don't do the AE and construction work), and they do not automatically provide the degree of involvement with the plant operators that is commonly provided by their international competitors. The foreign organizations with their broad scopes often project a very protective/responsible feeling about the overall operation of the plants they build. This often includes large corporate staffs permanently in residence at the utilities' plants, as is common in France, Japan, and Germany. This also provides the vendor with a better understanding of utility needs which provides a competitive advantage in future work to the vendor.

3.4 VARIOUS VENDOR BUSINESS STRUCTURES

The dominant characteristic of nuclear power in terms of business structure is that a single nuclear power plant may cost several billion dollars. The large cost of a single unit implies that reactor vendors must have large financial resources and large organizations to build such facilities. The organization of the industry worldwide reflects this reality.

3.4.1 Parent Corporate Structures

As discussed previously, the evolution of reactor vendors resulted in government-owned companies, large privately owned corporations, and keiretsu companies. These organizations evolved as a result of the local customs/conditions as well as the market demand.

3.4.1.1 Government-Owned Vendors

In France, China, Russia, India, and Canada, the governments made clear decisions regarding the countries' need to (1) use nuclear power and (2) establish government controlled reactor vendors. National policies were adopted with plans and schedules that were implemented and followed.

Framatome is currently a major reactor vendor in the world market place and a classic example of a government-owned reactor vendor. The French Government owns most of the French nuclear industry, including the utility (EdF), the reactor manufacturer Framatome (which also owns the previous U.S. manufacturer B&W), the nuclear fuel supplier (Cogema), and numerous small, but very competent, suppliers. This combination of companies has vertical and horizontal integration. It combines the government, utility, hardware suppliers, and waste management organizations for vertical integration. This combination also has multiple reactor hardware suppliers, multiple fuel suppliers, and all French nuclear power stations for horizontal integration. AECL of Canada is another example of a government-owned vendor with similar relationships, but inclusion of more private companies as partners or suppliers.

3.4.1.2 Large Corporation Vendors

ABB is a classic example of a large corporation (210,000 employees) competing as a nuclear power reactor supplier in the world market who owns reactor vendors in multiple countries. In 1988, Asea of Sweden and Brown Boveri of Switzerland (two intensely competitive world-class industrial corporations) joined forces to form ABB; 50% owned by Asea traded on the Swedish stock exchange and 50% owned by Brown Boveri traded on the Swiss stock exchange. Asea was known for its management talent, reactor designs, and numerous industrial products sold throughout the world. Brown Boveri was known for its manufacturing expertise and numerous industrial products sold throughout the world. In 1990, ABB acquired control of Combustion Engineering, a U.S. supplier of nuclear reactors that sold plants in the United States and throughout the world. This combination of engineering talents, manufacturing capabilities, large financial resources, and international marketing organizations constitute a very formidable competitor.

Siemens and General Electric are even larger reactor vendor corporations, both with over 300,000 corporate employees. Siemens owns Kraftwerk Union (the German reactor manufacturer) and is buying Skoda, the Czechoslovakian reactor manufacturer. Westinghouse, while the smallest of the large corporation vendors (120,000 corporate employees), has built the largest number of reactor plants, however, it has not sold a significant number of plants in the last decade.

3.4.1.3 Keiretsu Vendors

The Japanese reactor suppliers (Hitachi, Mitsubishi, and Toshiba) are each large companies, but more importantly, they are members of industrial groups with very large resources. These groups — Dai-ichi Kangyo Bank (Hitachi's group), Mitsubishi, and Mitsui Taiyo Kobe (Toshiba's group)—are each linked to about a dozen major companies and hundreds of small companies. Each of these vendors also has close relationships with particular Japanese utilities.

The keiretsu organizations in Japan and similar organizational structures in other Pacific Rim countries are somewhat different than traditionally managed (top-down) U.S. or European corporations. In a keiretsu, each member corporation is a major stockholder in other companies that are part of the same group. If a member of the group has financial or management difficulties, the group as a whole can provide financial support or force change in management of a specific corporation. Keiretsu has been developed as a mechanism to allow creation of very large groups while avoiding the difficulties of organizational rigidity and slowness in adapting to technological change.

The advantage that a vendor has as a member of a keiretsu cannot be underestimated by a competitive vendor who expects to sell in the same market. Effectively, the member of the keiretsu has the depth of resources owned by all members. Financially, each member can obtain funds at attractive interest rates with little or no concern about having sufficient collateral. Technically, each member also has access to engineering information from other members of the family. These Japanese groups are huge networks (annual sales of hundreds of billions of dollars) that can disperse the financial risks associated with business ventures to many companies that may not even have the same product lines or sell in the same markets.

3.4.2 Joint Ventures

All of the major vendors (except those in Russia) are currently participating in various forms of joint ventures with other reactor vendors, AE companies, and construction firms. These joint ventures serve many purposes, including the sharing of financial risks, R&D cost, and introduction into new markets.

The European company "Nuclear Power International" is a joint venture of Framatome, EdF, and Siemens aimed at designing, developing, and building the next generation of European LWRs.

General Electric, Hitachi, and Toshiba have joined forces and are currently building a large advanced BWR in Japan. Westinghouse and Mitsubishi are currently working on the design of the advanced pressurized water reactor, which is expected to be the next PWR to be built in Japan. Westinghouse and National Nuclear Corporation are currently building the first large PWR in the United Kingdom. ABB-CE is building reactors with and/or for the Korean Electric Power Company (KEPCO). Atomic Energy of Canada Limited has a similar arrangement with South Korea.

The major nuclear reactor design and development programs all over the world are joint ventures between various combinations of government-owned companies, large corporations, and corporations that are part of keiretsu groups. The bulk of the current market is being served by combinations of companies as compared with the initial nuclear market (1950s and 1960s) that was served by individual reactor vendors. These ongoing projects typically have broad vendor scopes with characteristics of the "turnkey contracts."

3.4.3 Vendor Business Structures

Table 3.1 shows parent organizations and reactor vendor corporations. The strength of the ties to the financial depth of parent organizations is the key to the financial risk that can be taken by a reactor vendor. The ability of the joint venture associations to use or count on the resources of their partners is, at times, nebulous. However, the resources of the large corporations and the government-owned corporations are real and very visible. Whether significant funds for commitment are available for the reactor vendors is another question that is usually resolved in the final contractual details. Often, the initial perception of large government or corporate financial strength and depth is sufficient to provide the needed competitive advantage.

The remaining independent U.S. reactor vendors—General Electric and Westinghouse—are similar to the European large corporations and Japanese keiretsu corporation groups, while the other U.S. reactor vendors—Combustion Engineering and Babcock and Wilcox—have been acquired by ABB and Framatome, respectively. Parent organizations in the nuclear power reactor industry are becoming the major players as much as the individual reactor vendor corporations.

The competitive positions of different reactor vendors or different countries depend upon multiple factors:

(1) number of nuclear power reactors being built in the home markets,
(2) number of nuclear power reactors operating in home markets that require maintenance, fuel, and other services,

(3) the size of reactor vendor,
(4) the size of parent corporation,
(5) the national support of related R&D activities/facilities,
(6) the industrial standards for equipment and operations, and
(7) the university structure to provide trained personnel.

Before the mid-1970s, the United States dominated each of the above categories, thus, U.S. vendors (primarily Westinghouse and General Electric) were the major vendors in the world. Today, the United States has the largest number of operating power plants and the largest university systems. Since the 1970s, however, most new reactors have been built in Europe or Japan. France and Japan have built very large nationally supported R&D programs. Furthermore, Japanese business groups organizations are typically larger than their U.S. counterparts, while the French reactor vendor is owned by the government. Last, the development of the European Common Market is creating an industrial market sufficiently large (i.e., larger than the U.S.) for development of standards and regulations. These standards are competing with U.S. standards for world acceptance. For any vendor, it is much easier to design to home standards than foreign standards. The net result of these changes is that the European and Japanese vendors have become the largest nuclear power reactor vendors.

Simultaneously, to reduce business risk and expand markets, all major corporations in the business (with the exception of the Russian vendors) have formed international joint ventures or equivalent business structures.

4. DESCRIPTION OF PRODUCTS

4.1 INTRODUCTION

The design of existing and future nuclear reactor products is driven by the needs of the utility customer within the constraints of vendor capabilities. The purpose of this section is to provide a brief description of the nuclear reactor products in terms of the markets the products serve. Detailed technical information on the products is given in Appendix B.

4.2 DESIGN OBJECTIVES

The design objectives of a particular reactor product are determined by the requirements of the product users. These user requirements provide the incentives for the development of a reactor design. The four broad categories of user requirements are briefly described below: (1) economic requirements, (2) operational/infrastructure requirements, (3) safety/public acceptance requirements, and (4) regulatory requirements.

4.2.1 Economic Requirements

Vendors marketing nuclear power plants must consider what competitive energy resources are available to a particular customer (e.g., coal, oil, gas, hydro, etc.). The distribution of a country's energy resources will be a major determining factor of the demand for nuclear power. A country with an abundant source of nonnuclear energy is unlikely to invest heavily in the development of a nuclear power plant. The distribution of energy resources by country is more fully described in Sect. 5.2.

Different nuclear reactor designs will have variability in such economic factors as plant design life, construction time, construction costs, fuel costs, and operating and maintenance costs. Historically, nuclear reactors have been designed to take advantage of economies of scale with large reactors being built in well-developed countries but having a limited market in smaller, less-developed countries. The large size of most nuclear reactors has restricted their use to countries with larger electric grids or rapid growth in electrical demand.

Some vendors have attempted to open new markets by developing smaller reactor designs that are still economically competitive. These vendors believe that cost reduction is achievable through plant design simplification. Significant cost reductions may be realized by simplifying safety systems and reducing the number of active safety system components.

The financing of a nuclear power plant is similar to a hydroelectric facility but different than fossil-fueled facilities. In comparison to fossil-fuel plants, the capital costs of a nuclear power plant are higher but the fuel costs are significantly lower. Thus, a customer must be able to bear the initial capital expenditures in order to reap the long-term benefits of lower operating costs. The capital-intensive nature of nuclear power, along with lower operating costs, make nuclear attractive for base load plants as opposed to load-following plants. The availability of capital will, in part, determine the demand for nuclear power.

4.2.2 Operational/Infrastructure Requirements

A number of operational requirements affect the choice of power plant and its characteristics. The size and strength of the electrical grid determines the maximum size of the power plant. Nuclear power plants must be refueled, require routine maintenance, and occasionally shut down due to equipment failure. Typically, if an electrical grid suddenly loses more than about 10% of its electric generating capacity, there is a significant possibility that the electric grid will fail with loss of power to all customers. For this reason, utilities typically do not order power plants with generating capacities exceeding 10% of their total needs.

Larger utilities with more expansive electrical grids generally prefer a large power reactor. Small- and medium-sized power reactors generally appeal to smaller utilities or a utility that is replacing a fossil-fuel plant with a nuclear plant since fossil plants tend to be smaller in size than their nuclear counterparts.

Some electric grids have special requirements that limit the choice of power plants. For example, in the Nordic grid (Norway, Sweden) much of the electric power is generated by hydroelectric plants in the far north while the population centers are in the south. A major concern is the reliability of the grid and the potential for electric grid failure due to winter storms. Because of the cold climate, very high reliability of the electric grid is required. If the grid fails due to a winter storm, it is required that the fossil and nuclear power stations be restarted rapidly to provide essential electricity while the power lines to the north are repaired. This grid requirement is reflected in some of the unique technical characteristics of ABB BWRs and limits the choices of reactors for this region. Other countries have other specific grid requirements that impact the product requirements.

Infrastructure requirements include the compatibility of any future reactor with existing reactors. There are economic benefits if existing operational experience and equipment can be shared among reactors. Utilities who buy a single reactor from a particular vendor will prefer to buy similar reactors from the same vendor in the future if other factors are equal. Another infrastructure consideration is the need for support facilities to supply the reactors with fuel and equipment. Support facilities to supply enriched fuel would be costly to design and build, if not already available, or alternatively, the product user would have to rely upon another supplier for the fuel. Reactors that use natural uranium fuel, such as CANDU, are more attractive to users that are not willing to depend on foreign fuel suppliers and not able or willing to build uranium enrichment facilities.

4.2.3 Safety/Public Acceptance Requirements

Safety requirements must be addressed in order to ensure safe operation of the reactor and to enhance public acceptance of the design. In countries with few power reactors, the utility and/or national regulator usually requires that purchased reactors be "licensable" in the country of origin with modifications for local conditions.

Several vendors, as a product development strategy, are designing future reactor products with safety characteristics to simplify licensing and improve public acceptance. In this context, the reactor industry is taking steps similar to certain automobile manufacturers (such as Volvo) that use safety features to increase sales.

The term "design type" is used to categorize reactor designs based on their safety characteristics. Existing and proposed reactor designs can be divided into four design types: evolutionary plant reactors, evolutionary technology reactors, liquid-metal breeder reactors, and PRIME reactors. A more detailed description of these reactor design types and the associated safety systems can be found elsewhere (Forsberg 1991).

Evolutionary plant (E. P.) reactors are similar in overall plant design to existing LWRs or CANDU reactors but have refined and modernized design. Safety of E. P. reactors depends on a variety of active safety systems with power supplied by diesel generators or equivalent power sources. In the event of an accident, the safety systems must start up and continue to operate in order to prevent reactor core damage.

Evolutionary technology (E. T.) reactors are proposed advanced reactors that use the technology of current reactors but have significant changes in plant design, particularly in the safety systems. Most of the proposed safety systems for these reactors require power to initiate safety operations (such as opening a valve) but do not require power for continued operation. Safety system operation after initiation is passive. Vendors expect such reactors to be more economical than evolutionary plant designs in smaller sizes [600 MW(e)], thus increasing the number of utilities that could buy nuclear power plants. Improvement in safety with easier operation is also expected. Multiple vendors are developing such plants including Westinghouse (AP-600), Mitsubishi (MS-600) and General Electric (SBWR) for sale in the mid-1990s.

PRIME reactors are proposed where the design goals are to make radical improvements in safety and public acceptance (not dependant on operator for safety, etc.) with the potential for major improvements in economics. The vendor interest is to develop a unique product with greater public acceptance, which would translate into a unique competitive advantage (nuclear power equivalent to development of jet engine or transistor). Because the goals are aggressive, new technologies are required for the reactor designs. The term, PRIME, provides a reasonable description of these goals. PRIME is an acronym for passive safety, resilient operation, inherent safety, malevolence resistance, and extended safety. The PRIME reactor closest to commercialization is the PIUS reactor of ABB. Commercialization is not expected before the late 1990s.

Breeder reactors, of which the dominant type is the liquid-metal reactor (LMR), convert cheap, fertile, nonfuel materials (such as ^{238}U) into valuable fissile fuels (such as ^{239}Pu). This would lower fuel costs. Earlier LMR prototype plants and designs relied upon active safety systems. Newer breeder reactor designs, such as the Power Reactor Inherently Safe Module (PRISM®), depend primarily on passive safety systems. These reactors are a long-term nuclear power option under development by national governments and are not near-term commercial products. Low uranium prices have reduced the economic incentives to develop such reactors.

4.2.4 Regulatory Requirements

Nations regulate nuclear power to ensure safety. Different technical, economic, and cultural factors result in significant differences in regulations across national boundaries. Regulations define minimum standards for safety. Vendors and utilities may exceed regulatory minimums to minimize financial risk, improve public acceptance, meet corporate philosophies, or improve operability. This variation, in turn, implies that some details of a particular reactor design will change depending upon where it is built. The following examples illustrate this fact.

- In Japan, very tight regulatory requirements exist to ensure reactor safety in the event of an earthquake. In Germany, power reactors must have containment buildings that can withstand the crash of a military jet. Such requirements reflect local technical safety issues. Earthquakes are common in Japan and are a potential cause of a nuclear power plant accident. During the cold war, the highest density of military aircraft in the world operated over Germany, thus, the heightened (and real) technical concern about possible crashes of military aircraft.

- Levels of safety vary from country to country depending upon local economic conditions and cultural beliefs. These cultural factors can influence regulations. For example, some countries have long traditions in the use of concrete or steel. In such countries, particular materials of construction for buildings are preferred because the regulator is technically more knowledgeable and has higher confidence in the use of the materials. Regulations may impose much higher safety margins for technologies and materials with which the regulator is unfamiliar.

4.3 PRODUCT DESCRIPTIONS

A summary of general product characteristics and the markets they serve is given in Table 4.1. The products are listed in alphabetical order by product name. The five reactor types listed are BWR, pressurized-water reactor (PWR), HWR, liquid-metal fast breeder reactor (LMFBR), and high temperature gas-cooled reactor (HTGR). The design type of a product is based on the functional characteristics of the reactor safety systems as described in Sect. 4.2.3.

The developmental status indicates the degree of commercial development as follows.

- **In-use** A commercial reactor of this design is currently operating.
- **Construction** Construction of this reactor design is currently taking place in one or more locations.
- **Design** Research and development has advanced into the design of the reactor concept.
- **Research** Preliminary studies to evaluate the feasibility of the reactor design have begun.
- **Concept** Conceptual idea.

The availability indicates when the particular reactor product will be available to order from the vendor.

Table 4.1. Summary of general product characteristics

Product name	Reactor type	Design type	Electrical power [MW(e)]	Develop-mental status	Availability	Main vendors marketing product	Country/utility using product
Products currently available							
Advanced BWR	BWR	E. P.	1,356	Const.	Current	GE, Hitachi, Toshiba	Japan/TEPCO
Advanced BWR 90	BWR	E. P.	1,050	Design	Current	ABB-Atom	
Advanced PWR	PWR	E. T.	1,050	Design	1993	Mitsubishi, Westinghouse	
CANDU 3	HWR	E. P.	450	Design	Current	AECL	Canada
CANDU 6	HWR	E. P.	665	In use	Current	AECL	Canada
N4	PWR	E. P.	1,528	In use	Current	Framatome	France/EdF
Sizewell B	PWR	E. P.	1,250	Const.	Current	NNC, Westinghouse	UK/NE
SNERDI PWR	PWR	E. P.	300	In-use	Current	CNNC	China/MNI
System 80/80+	PWR	E. P.	1,345	Const.	Current	ABB-CE	Korea/KEPCO
Products that may be available within several years							
Advanced Passive-600	PWR	E. T.	600	Design	1994	Westinghouse	
CAREM	PWR	E. T.	150	Research	TBD	INVAP	
European PWR	PWR	E. T.	1,450	Design	1998	NPI (Siemens/ Framatome)	
Hitachi Small BWR	BWR	E. T.	600	Design	TBD	Hitachi	
Mitsubishi Simplified PWR	PWR	E. T.	1,200	Design	TBD	Mitsubishi	
PIUS	PWR	PRIME	640	Design	1998	ABB Atom	

Table 4.1 Summary of general product characteristics (continued)

Product name	Reactor type	Design type	Electrical power [MW(e)]	Develop-mental status	Availability	Main vendors marketing product	Country/utility using product
Safe Integral Reactor	PWR	E. T.	320	Design	TBD	ABB-CE, Rolls Royce	
Simplified BWR	BWR	E. T.	640	Design	1995	GE, Hitachi, Toshiba	
Toshiba 900	BWR	E. T.	310	Design	TBD	Toshiba	
VVER 88/91/92	PWR	E. P.	1,000	Design	Late 1990s	MTM	
Longer term nuclear power plant options							
Advanced CANDU Reactor	HWR	PRIME	900	Research	TBD	AECL	
ALMR	LMFBR	Breeder	1440	Design	2005	General Electric	
European Fast Reactor	LMFBR	Breeder	1450	Design	1998	Framatome, NNC, Siemens	
MHTGR/Gas Turbine	HTGR	PRIME	100	Research	TBD	MIT/USA	
MHTGR/U.S.	HTGR	PRIME	538	Design	2001	General Atomics	
System Integrated PWR	PWR	E. T.	350	Design	TBD	JAERI	

5. THE CUSTOMER SIDE OF THE MARKET

Electric utilities, the customer side of the nuclear power reactor market, are discussed in this section. Because of the large number of utilities throughout the world, the discussion is initially at the country (rather than individual utility) level. Nuclear-related decisionmaking in countries with different numbers of utilities is compared.

A screening process, described in more detail in the next section, was used to categorize each country as one of three types: (1) those that do not presently have nuclear power reactors and are not expected to develop nuclear capability due to restraining factors (72 nonnuclear countries); (2) those that do not presently have nuclear power reactors, but are potential candidates over the medium term (25 candidate countries); and (3) those that presently have operating commercial nuclear power plants or have such plants under construction (28 nuclear countries).

The screening process began by choosing 125 countries having a population greater than 1 million. Section 5.1 describes the initial screening process based upon electrical demand and total income for each country. In Sect. 5.2, the number of candidate countries is reduced even further by discussing factors that make the nuclear option unattractive to policymakers in many countries. In the final section, the decisionmaking processes for candidate and nuclear countries are compared.

5.1 INITIAL SCREENING OF COUNTRIES

Ideally, one would like to examine the characteristics of all existing and potential customers of commercial nuclear reactors (i.e., electric utilities). Practically, of course, such an examination is not possible, and, even if it were, it is probably not necessary. Many countries (and, therefore, electric utilities) do not currently have sufficient electric demand or total income to justify construction of nuclear power plants.

The most obvious countries are eliminated in Table C.1 in Appendix C. The table lists 125 countries in the world classified into four income categories that the World Bank uses to characterize countries: (1) low income economies (i.e., $610 per year or less, 43 economies), (2) lower middle income economies, (3) upper middle income economies, and (4) high income economies ($7,620 per year or more, 24 economies). Along with three other socioeconomic measures, the table includes the existing nuclear power reactors and their capacities and the corresponding amounts for reactors under construction.

From this table, it can be concluded that a candidate country is one that currently does not operate nuclear power plants and had a total income (i.e., GNP) of at least $30 billion in 1990. The $30 billion threshold was selected because, with the exception of Bulgaria, it is the lowest total income of any of the countries currently operating or constructing nuclear power plants. In Table 5.1, the candidate countries are the ones that do not have existing nuclear capacity or do not have any nuclear power plants under construction in those respective columns under the category, "Generating capacity."

Table 5.1. Socioeconomic and nuclear indicators for nuclear and candidate countries

Income level,[a] country	Population (Millions)	Per-capita GNP (1990 $US)	Generating capacity (GW)[b]			Utility organization[c]	Elimination criteria[d]		
			Total	Nuclear	Construct		Resources	Acceptance	Finances
Low income									
Nigeria	115.5	290	4.0	0.0	0.0	N1	X		
India	849.5	350	69.9	1.4	1.5	NM,RM			
China	1,133.7	370	98.0	0.0	2.1	N1,RM			
Pakistan	112.4	380	8.5	0.1	0.0	N1,R1			
Indonesia	178.2	570	11.0	0.0	0.0	N1			
Egypt	52.1	600	11.0	0.0	0.0	N1,RM			X
Cuba			3.2	0.0	0.8	N1			
Lower middle income									
Philippines	61.5	730	6.6	0.0	0.6	N1,RM			X
Peru	21.7	1,160	2.7	0.0	0.0	N1,R8	X		
Colombia	32.3	1,260	8.9	0.0	0.0	N3,RM	X		
Thailand	55.8	1,420	7.9	0.0	0.0	N1,R2			
Turkey	56.1	1,630	14.6	0.0	0.0	N1,P1			
Romania	23.2	1,640	22.9	0.0	3.1	N1			
Poland	38.2	1,690	32.0	0.0	0.0	N1		X	X
Algeria	25.1	2,060	3.8	0.0	0.0	N1,R1	X		
Bulgaria	8.8	2,250	11.1	2.6	1.9	N1			
Malaysia	17.9	2,320	4.4	0.0	0.0	R3			
Argentina	32.3	2,370	16.6	0.9	0.7	NM,RM			
Iran	55.8	2,490	13.8	0.0	2.4	N1			
Mexico	86.2	2,490	28.0	0.7	0.7	N1,P1			
South Africa	35.9	2,530	26.5	1.8	0.0	N1,RM			

Table 5.1 Socioeconomic and nuclear indicators for nuclear and candidate countries (continued)

Income level,[a] country	Population (Millions)	Per-capita GNP (1990 $US)	Generating capacity (GW)[b]			Utility organization[c]	Elimination criteria[d]		
			Total	Nuclear	Construct		Resources	Acceptance	Finances
Upper middle income									
Venezuela	19.7	2,560	17.7	0.0	0.0	N6,P7	X		
Brazil	150.4	2,680	52.1	0.6	1.2	NM,PM			
Hungary	10.6	2,780	6.4	1.6	0.0	N1			
Yugoslavia	23.8	3,060	15.8	0.6	0.0	WAR			
Czechoslovakia	15.7	3,140	17.7	3.3	3.3	N1			
Former USSR	290.0	4,600	341.0	34.7	21.3	R12			
Portugal	10.4	4,900	6.8	0.0	0.0	N1			
Korea	42.8	5,400	23.5	7.2	1.9	N1,P1			
Greece	10.1	5,990	8.2	0.0	0.0	N1,N1			
Saudi Arabia	14.9	7,050	16.5	0.0	0.0	N1,PM	X		
High income									
Ireland	3.5	9,550	3.7	0.0	0.0	N1			
Israel	4.7	10,920	4.1	0.0	0.0	N1			
Spain	39.0	11,020	42.7	7.1	0.0	NM,RM			
Singapore	3.0	11,160	3.4	0.0	0.0	N1			
Hong Kong	5.8	11,490	7.5	0.0	0.0	P2			
New Zealand	3.4	12,680	7.0	0.0	0.0	N1,RM	X		
Belgium	10.0	15,540	13.4	5.5	0.0	N1,R2,P3			
United Kingdom	57.4	16,100	71.4	11.5	1.2	PM			
Italy	57.7	16,830	50.0	0.0	0.0			X	
Australia	17.1	17,000	35.0	0.0	0.0	R8	X		

Table 5.1 Socioeconomic and nuclear indicators for nuclear and candidate countries (continued)

Income level,[a] country	Population (Millions)	Per-capita GNP (1990 $US)	Generating capacity (GW)[b]			Utility organization[c]	Elimination criteria[d]		
			Total	Nuclear	Construct		Resources	Acceptance	Finances
High income (cont.)									
Netherlands	14.9	17,320	17.3	0.5	0.0	NM,RM			
Austria	7.7	19,060	15.2	0.0	0.0	N1,RM		X	
France	56.4	19,490	91.8	55.8	8.3	N1			
Canada	26.5	20,470	102.2	14.0	1.8				
United States	250.0	21,790	684.7	100.6	1.2	NM,RM,PM			
Denmark	5.1	22,080	8.7	0.0	0.0	MM			
Germany	79.5	22,320	99.0	24.4	3.3	PM			
Norway	4.2	23,120	26.7	0.0	0.0	NM,RM,PM	X		
Sweden	8.6	23,660	31.5	9.8	0.0	N2,RM			
Japan	123.5	25,430	181.9	30.9	9.0	N1,RM,P10			
Finland	5.0	26,040	11.0	2.3	0.0	N1,RM,P12			
Switzerland	6.7	32,680	15.3	3.0	0.0	N1,RM,PM			

SOURCE: Adapted from Tables C.1 through C.9 in Appendix C.

[a]Based on the World Bank's classification of countries on the basis per-capita income. Countries with per-capita income of $610 or less are low-income; those with $7,620 or more are classified as high income.

[b]Total and nuclear refer to total electric generating capacity and nuclear capacity, respectively, in 1990. Construct means the amount of nuclear capacity under construction.

[c]The entries in this column designate the organizational structure of the electric power sector in each of the countries. The first character in any two-character sequence refers to the ownership of the electric utilities: N = owned by the national government, R = owned by a regional (city, county, district) government, P = owned by the private sector, M = mixed, public-private ownership. The second character refers to the number of utilities in the country with that type of ownership, with M meaning many or multiple. A designation N1,R3, for example, means that the country has 1 utility owned by the national government and 3 owned by regional governments. In this example, the country has no privately owned utilities.

[d]Elimination criteria refer to the reasons why a country is eliminated as a candidate for adopting nuclear power. An 'X' in the 'Resources' column means that the country has sufficient energy resources to preclude using nuclear power. Similarly, countries with an 'X' in the acceptance column have enacted antinuclear legislation or have strong antinuclear public sentiment. Countries with an 'X' in the finances column may not have a lot of indigenous energy resources, may not have a particularly difficult problem with public acceptance of nuclear power, but probably are not able to generate the funding for nuclear power plants.

Summary statistics for the 28 nuclear and 25 candidate countries are provided in Table 5.1, condensing much of the information contained in the tables of Appendix C. The table shows the wide range of characteristics of nuclear and candidate countries in terms of population, income, and the industrial structure of their electric power industries. India, Pakistan, Cuba, and China are the only low-income, nuclear countries. With the exception of Italy, all of the G-7 countries* operate nuclear power plants. Generally, the low- and middle-income countries have one dominant national utility. With the exception of Poland, all of the European members of the Council for Mutual Economic Assistance (Comecon) have operating nuclear power plants.** In fact, of the 28 nuclear countries, Bulgaria, a former member of Comecon, is the one with the lowest population. Cuba has the least amount of total generating capacity (3.2 GW) for a nuclear country attempting to construct its first nuclear power station [work has been currently suspended on this facility]. On the basis of capacity, the United States is the largest nuclear country with more than 100 GW of nuclear generating capacity. However, the republics of the FSU have the most capacity under construction (more than 21 GW). Finally, the structure of electric power industries varies widely across countries. The electric power sectors of higher-income countries generally are much more complicated than those of lower-income countries, involving many different types of ownership arrangements.

5.2 COMPLICATING FACTORS

Table 5.1 also serves as a bridge between the initial screening for candidate nuclear countries on the basis of income and a more in-depth screening on the basis of three issues. The three issues are shown as elimination criteria in Table 5.1, providing plausible reasons why some nuclear and candidate countries will not construct nuclear power plants over the short to medium term. After comparing the economics of nuclear power with other alternatives, the three elimination criteria are discussed in more detail.

5.2.1 Economics

Nuclear power plants have strong competitors to supply new load requirements from both the supply and demand side. On the supply side, as the real price of fossil fuels declined in recent years, the financial attractiveness of nuclear power in comparison with fossil fuel generating alternatives also declined. Also, in some countries, the promise of lower operating costs for nuclear power generation (i.e., compensating for higher, up-front, capital costs) never materialized. For example, a recent study showed that, under the best

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*The G-7 countries are the western industrialized countries with the largest economies. The leaders of these countries regularly meet to coordinate economic policies.

**Comecon (founded in 1949) included the former Soviet Union and the East European countries of Czechoslovakia, Hungary, Poland, Romania, Bulgaria, and the former East Germany. Yugoslavia was an associate member. Cuba, Mongolia, and Vietnam were the other full-standard members. Although the historical trading relationships in Comecon were to formally end on February 1, 1991, many *ad hoc* barter agreements have been negotiated among Comecon members.

circumstances for all types of plants (i.e., short lead times for constructing nuclear power plants and low-end fuel price assumptions for oil, gas, and coal plants), the total cost of providing electricity using nuclear power would be cheaper than only two 600 MW oil plants (*Petroleum Economist* 1992). However, the recent movement toward internalizing the costs of environmental externalities will make nuclear plants relatively more attractive.

On the demand side, additional generating capacity requirements have been reduced with the recent push for demand-side management (DSM) measures on the part of electric utilities. Utilities throughout the world are increasingly urged to implement DSM measures, substituting for traditional supply resources. Estimates of the degree of this substitution are substantial in some countries. In the United States, for example, some estimates show that utilities will obtain as much as a third of their additional resource requirements from the demand side by the year 2000.

5.2.2 Indigenous Energy Resources

As Table 5.1 shows, the rich energy resource base of many countries eliminates them as nuclear candidates over the near to medium term. Those countries include Nigeria (vast oil and gas reserves), Algeria (vast oil and gas reserves), Colombia (large oil reserves and large, untapped, hydropower potential), Peru (oil reserves and large, untapped, hydropower potential), Saudi Arabia (vast oil and gas reserves), Venezuela (oil and large, untapped, hydropower potential), Australia (oil, gas, and coal reserves), and New Zealand (large, untapped, hydropower potential).

Some countries can be considered serious candidates for constructing nuclear power over the medium term because of dwindling energy resources. Perhaps the most important is Indonesia. Presently an oil exporter, Indonesia generates 83.6% of its electricity from conventional thermal sources (Table C.2) and nearly three quarters of that from oil (Table C.3). However, at its 1991 production level (1.4 million barrels/d), it will exhaust its oil resource base (6.6 billion barrels) around the year 2000 (Table C.4). Recognizing this inevitability, the government recently decided to explore construction of Indonesia's first nuclear power plant.

5.2.3 Public Acceptance

Political reality in some countries suggests that nuclear power is not a viable option. In Italy, for example, the prospects for nuclear power remain uncertain for political reasons. Construction and operation of nuclear power plants has been suspended by the government through 1992. The country's last two nuclear power stations were permanently shut down in 1990.

There is growing resistance to nuclear power in the historically closed economies of Eastern Europe and the former Soviet Union. The European countries comprising Comecon currently have 13% of the world's nuclear generating capacity and more than 40% of the world's nuclear capacity under construction. However, plans to complete the nuclear capacity under construction and to continue to operate existing plants in the region are meeting increasing resistance. The Ukrainian government, for example, declared the republic an ecological disaster zone in the aftermath of Chernobyl. Environmental groups in Eastern Europe have increasingly protested construction of more nuclear power plants. Public reaction in Hungary to the Chernobyl accident was instrumental in the government's decision to cancel 2,000 MW of new nuclear generating capacity. The problem is even more severe in Czechoslovakia, which generates nearly one-third of its electricity from nuclear plants (8 units, 3,264 MW currently) and has eight nuclear units consisting of 5,120 MW capacity under construction. Czechoslovakia is the only country outside the former Soviet Union to build and export Soviet-designed nuclear power stations. The safety of some of those reactors is now under question. More recently, the Austrian government, which has a nuclear-free energy policy, has offered Czechoslovakia 800 MWh of free electricity annually if the Czech government will retire a troubled plant on the border between the two countries, less than 50 miles from Vienna.

5.2.4 Financial Cost

Because of their debt exposure and resulting difficulty in borrowing from abroad, some countries cannot afford the high up-front costs of nuclear power. As shown in Table 5.1, Egypt, the Philippines, and Poland are in that category. Egypt, however, signed a nuclear cooperation agreement with Argentina in 1988 in anticipation of developing a nuclear program, and the Philippines are negotiating with Westinghouse to complete and operate a nuclear power plant that was nearing operation before a variety of circumstances stopped construction.

5.3 NUCLEAR POWER DECISIONMAKING

Three levels of decisionmakers must be considered when discussing the construction of commercial nuclear power plants: (1) international, (2) national, and (3) individual utility. The international decisionmaking process is often a barrier to the adoption of nuclear power for certain countries where there are particular concerns about nonproliferation or political stability. There is no set pattern to the relationship between national and utility decisionmaking across the globe. Many variants exist. In many countries, national decisionmaking is equivalent to utility decisionmaking because of the structure of the electric power industry. Decisionmaking in South Korea illustrates this well. Although Korea Electric Power Corporation, the national electric monopoly, is a stock company, it has historically been majority-owned by the South Korean government. Decisions about generating alternatives, therefore, always rest with the government. Decisionmaking in the United States is at the other extreme. Individual utilities make choices about generating alternatives within a regulatory environment established at the national (and state) level.

In addition to levels of decisionmaking, the types of decisions are important—two types dominate. The first relates to an electricity generating strategy. That strategy could be for a nation, a region, or an individual utility. Given the first decision, the vendors for supplying the generating units must be chosen. That choice includes consideration of commercial nuclear power plants.

In the remainder of this section, this decisionmaking process is explored in greater detail. First, how the decisionmaking process affects generating alternatives in nuclear companies is examined. Then, the countries that are the most likely candidates to adopt nuclear power over the medium term are evaluated.

5.3.1 Nuclear Countries

The United States is an example of a country with very decentralized decisonmaking with respect to the selection of generating alternatives. It has perhaps the most diverse ownership of electric utilities with more than 2,200 utilities either (a) privately owned with shares traded on stock exchanges, (b) publicly owned by the federal government (Tennessee Valley Authority, five federal power marketing agencies), (c) publicly owned by subnational governments (i.e., state, country, or city-owned), or (d) organized as rural electric cooperatives. Broad government policy toward nuclear power—primarily related to licensing and safety—either promotes or inhibits the decision by utilities to adopt it. Once a decision is made to construct a nuclear power plant, the selection of a vendor is a decentralized decision. As is shown in Table 5.1, many of the high income countries have electric power sectors as diverse as that in the United States.

France is an example of a country on the opposite end of the spectrum from the United States. EdF, a government monopoly producer, transmitter, and distributor of electricity, has sole authority for nuclear power purchases in the country. Another government-owned corporation, Framatome, is the exclusive supplier of reactors to EdF.

Japan is an example of a country whose decisionmaking on nuclear power falls between the extremes of France and the United States. There is strong central direction with national energy policy long favoring the adoption of nuclear power, but ten privately owned utilities respond not only to the policy directions of the government, but also to the demands of stockholders when deciding on generating alternatives. As in France, however, nuclear power reactor vendors are government-owned and controlled.

5.3.2 Candidate Countries

For candidate countries, the rapidly growing economies of the Pacific Rim are the most likely candidates for building nuclear power plants: Malaysia, Thailand, Indonesia, Singapore, and Hong Kong. Many energy-short countries in that region already have substantial commercial nuclear power programs. South Korea, for example, currently generates more than one-half of its electricity with nuclear power (Table C.6) and has 1,900 MW of nuclear capacity under construction (Table C.1). Japan generates more than a quarter of its electricity from nuclear sources and has more than 9,000 MW under construction. Taiwan has decided to proceed with construction of its fourth nuclear power plant.

As noted above, of the candidate countries on the rim, perhaps the most likely to be the first to construct a nuclear power plant is Indonesia. That decision was made by the national government in response to Indonesia's dwindling supplies of oil.

Of the remaining candidate countries on the rim, Thailand has the largest electricity generation (37.4 tWh), but the lowest per-capita income ($1,420 per year). Of the remaining Pacific rim countries, Singapore would seem an ideal candidate except for its small population, land area, and electricity generation (14.0 tWh). Singapore's economy has been growing rapidly, mirrored by the growth in energy consumption. Over the last decade, energy consumption has increased at the rate of nearly 6% annually. More important, energy imports were 15% of Singapore's exports in 1990—a significant drain on its economy.

Decisionmaking for the adoption of generating alternatives in lower-income countries is generally centralized at the national level. As shown in Tables C.5 and C.9, these countries are typically dominated by one or two utilities—and major decisions are made at the national level.

6. CURRENT STRUCTURAL ARRANGEMENTS—WHO IS CONNECTED TO WHOM, WHY, AND IMPLICATIONS FOR THE FUTURE

This section provides a broader perspective of the nuclear power industry with observations on future directions. Associated with this section, Appendix D lists nuclear power plants, the utilities, and the vendors. It shows the historical relationships between vendor and customer.

6.1 KEY PLAYERS IN THE WORLD NUCLEAR BUSINESS

There are four major groupings of vendors, governments, and utilities that have dominated the nuclear power industry in the 1980s and are the major players in today's market. These groupings are identified by the vendors, but also involve utilities and governments.

6.1.1 Nuclear Power Incorporated

NPI is the largest grouping in the nuclear power industry today; it includes: (1) Nuclear Power Incorporated [a joint venture of Framatome (France) and Siemens (Germany)]; (2) Siemens, which controls the reactor vendors Kraftwerk Union (Germany) and is purchasing Skoda Energo (Czechoslovakia); and (3) French reactor vendor Framatome, which controls Babcock and Wilcox (United States). Siemens also controls Siemens Power in the United States, which fabricates nuclear fuel but has not been a vendor, historically. Since 1980, this group of companies sold ~23% of the nuclear reactors worldwide and has been responsible for ~23% of the reactors under construction. NPI as a consortium (Vignon and Shneider 1992) emphasizes nuclear markets in the industrialized countries. NPI has also initiated discussions with industrial organizations in other European countries as potential partners. Siemens and Framatome are partners in some markets and competitors in others.

In the past decade, NPI partners have been the exclusive suppliers for all power reactors in France, Germany, and Czechoslovakia. Both the French utility and Framatome (the reactor vendor) are controlled by the French government. There are not strong direct financial connections between Siemens and the German utilities, but very long-term business relationships do exist. The unification of Germany and the rebuilding of the former East German infrastructure (electrical grid, communications) provide major near-term markets that strengthen Siemens' position. The group clearly has the support of the major national governments with a goal for NPI to create a standard large evolutionary European nuclear power plant that meets all codes and standards across Europe.

Following the recent formation of NPI, there have been major agreements between the German utilities, the French utility, and NPI. The EVU (association of German nuclear utilities) Planungsauftrag program and the EdF (national utility) REP-2000/N4+ programs are being combined with input from NPI to produce a single set of specifications and requirements for new reactors. Conceptual design is nearing completion of the proposed NPI European EPR. Parallel efforts are under way between French and German regulators to "achieve some harmonization of their requirements" (Joint 1992). This combining of efforts is a complex task given the historically different structures of the German and French industries. In France, the French utility is responsible for overall design and integration of the plant with the vendor, Framatome, providing the reactor system. In Germany, the vendor Siemens is responsible for the entire plant. For NPI, the nuclear island design responsibility is a joint effort of Siemens and Framatome, while the balance of plant/overall AE is a joint responsibility of Siemens and the French utility, EdF.

6.1.2 Asea Brown Boveri

The Swedish-Swiss company, Asea Brown Boveri, owns multiple reactor vendors including ABB Combustion Engineering in the United States and ABB-Atom in Sweden. It is a major reactor supplier in Scandinavia, the United States, and South Korea, but does not have exclusive domestic markets. Recent multiple sales to South Korea have expanded its market share. It has the broadest range of nuclear power plant products of any vendor.

ABB is the largest industrial equipment manufacturer (steam turbines, electrical equipment, etc.) in the world. It has also grown very rapidly in the last decade. While it is not first in nuclear reactor power sales, its sales of other equipment to utilities provide it with unique broad access to utilities worldwide.

6.1.3 Hitachi, General Electric, and Toshiba

Hitachi, General Electric, and Toshiba (HGET) have joint agreements for development of BWRs. Since 1980, this group has sold ~11% of the world's reactors and has been responsible for ~11% of the nuclear power construction. Most of these sales have been in Japan, where Japanese utilities traditionally buy from one or two favored reactor vendors. The major development program of this group in the 1980s has been the advanced boiling-water reactor (ABWR), where the largest utility in Japan—Tokyo Electric Company (TEPCO)—is a major partner with HGET. The first two ABWRs are currently under construction at a TEPCO site. This close utility-vendor relationship is one of the identifying characteristics of the Japanese utility-vendor structure.

6.1.4 Atomic Energy of Canada Limited

Atomic Energy of Canada (AECL) is a government-owned vendor that has successfully continued to fill a niche market for nuclear power reactors. The CANDU reactor uses natural uranium, which greatly simplifies the nuclear fuel cycle and allows small countries to produce their own nuclear fuel. AECL has recently sold another reactor to South Korea and has a continued partnership on fuel development with South Korea (Doust 1992; KEPCO 1992). Thus, the ties between AECL and South Korea are strengthening.

The South Koreans and AECL are considering recycle of spent LWR fuel into CANDU reactors (Pillay 1992). If successful, this recycling effort would allow the waste from one reactor type to become the fuel for a second reactor type with significant savings in fuel costs. There are many uncertainties, but if this effort is successful, it would create a second niche market for heavy-water power reactors for South Korea and AECL.

6.2 EMERGING NUCLEAR GROUPS

There are a number of countries and other organizations that are building large commercial nuclear power supplier organizations with capabilities to become international nuclear reactor vendors. This is a slow process requiring a decade or more.

6.2.1 Mitsubishi

Historically, Mitsubishi supplied PWRs under a Westinghouse license exclusively to Japanese utilities. It is the vendor for 9% of the power reactors under construction worldwide since 1980. In Japan, each utility buys from one or two vendors with very close utility-vendor relationships. The earlier license agreements with Westinghouse have expired. In the last year, Mitsubishi has entered the international nuclear power business with bids on components and plants worldwide. It has also won major contracts for replacement equipment (NEIb 1992). The Mitsubishi family of companies includes ~190 members with annual sales of $\$300 \times 10^9$, which makes the group one of the largest in the world with extraordinary financial and technical capabilities. Thus, a new, large nuclear reactor vendor has entered the world market.

On March 24, 1992, Mitsubishi signed a 10-year-cross-licensing and joint-development agreement covering nuclear power technology with Westinghouse where both partners are **equal** partners. Given the different and complimentary strengths of the two companies, this partnership has the potential of being an important venture. The "lead" vendor for sales to third countries may be based on customer preferences.

6.2.2 South Korea

South Korea does not have a reactor vendor, but the government is encouraging the rapid development of vendor capabilities (Kim 1992, Taylor 1992[b]) through the government-controlled national utility. With rapid economic growth, nine additional power plants are to be built by 2001 with an additional nine units by 2006, making the Korean program one of the largest nuclear power programs in the world. Each subsequent power reactor purchased by the South Korean utility—Korean Electric Power Company (KEPCO)— has had associated with it a greater technology transfer and increasing domestic manufacturing content for South Korean suppliers. This indicates that within a decade, South Korea will fully manufacture its own nuclear power reactors. The utility estimates that for PWRs, Korea supplies 88.2% of the technology in the current plants and will supply 95% by 1995. It is planned to build Korean Standard Nuclear (KSN) 1000 Mw(e) PWRs based on the ABB-Combustion Engineering System 80 design. South Korea has constructed PWRs and CANDU reactors with a long-term goal of three PWRs to each PHWR.

As in France, many of the nuclear companies are controlled or partly owned by the utility. Korea Heavy Industries and Construction Company, Ltd., (KHIC) supplies the nuclear system. Korea Power Engineering Company, Inc., (KOPEC) is responsible for overall power plant design and engineering. It is 98% owned by KEPCO. Another KEPCO company—Korea Electric Power Operating Services Company, Ltd., (Kepos) does nuclear power plant maintenance, overhaul, and refuelling. Last, Korea Nuclear Fuel Company, Ltd., (KNFC), 95% owned by the utility, provides fuel fabrication services for their PWRs.

6.2.3 People's Republic of China

China has a centrally planned economy with the utility and vendor owned and controlled by the government. China recently completed its first Chinese-designed nuclear power plant, has several larger nuclear power stations under construction, and announced a recent sale of a power reactor to Pakistan (NEIa 1992; NNd 1992). This is in addition to the purchase of two power reactors from Framatome that are now under construction. The internally manufactured power plants contain a significant number of components from western suppliers with Framatome (France) the largest supplier. The potential domestic market for nuclear power plants is very large; thus, there is the potential for China to internally develop a large nuclear power industry that could also export nuclear power reactors.

6.3 OTHER NUCLEAR INDUSTRIAL GROUPS

6.3.1 Westinghouse

Historically, the largest vendor in the world was Westinghouse, which dominated the market before 1980. Since 1980, 2.3% of the power reactors under construction have been Westinghouse reactors. Several former licensees are now competitors, and Mitsubishi is now an equal partner. The large number of Westinghouse reactors built before 1980 provides the company with a significant customer base, but the financial difficulties of recent years (Schroeder 1992; Baker 1992) and its relatively small size are significant constraints. The traditional market for Westinghouse has been the United States, and the lack of orders in the United States has limited sales. Furthermore, Westinghouse does not have an assured domestic market. Currently, Westinghouse is providing much of the technology for the Sizewell nuclear power station which is under construction in Great Britain. There are serious discussions for additional power plants (NNc 1992) of this type.

Recently, Westinghouse signed a 10-year agreement with Mitsubishi Heavy Industries, Ltd., to cooperate on development of nuclear technologies and offer them to markets in "third countries" (NNa 1992; Westinghouse 1992). It also has agreements with Britain's Nuclear Electric and has announced plans for a joint bid to Taiwan Power Company for their next two nuclear power reactors (Airozo 1992).

6.3.2 Russia

The recent independence of Eastern European countries and the breakup of the FSU are rapidly altering the structure of the utilities and the Russian nuclear power industry. To understand these changes, some history must be understood.

- Eastern Europe and the FSU were centrally planned economics with the additional characteristic that much of the electric sector of Eastern Europe and the FSU was operated as a single unit across national boundaries. For example, in Bulgaria, 40% of the electric power is from a single station. No national utility would put such a large fraction of its total capacity at a single site because of the reliability concerns in the event of an accident at a single site.

- The FSU had effectively two and a half reactor vendors with the technical infrastructure located in Russia and Czechoslovakia.

  - One Russian "vendor" manufactured the RBMK—the Soviet graphite, water-cooled reactor type at Chernobyl.

  - A second Russian "vendor" produced the VVER, the Soviet version of the PWR used in most western countries.

  - The third "vendor," with most but not all capabilities, was Skoda Works of Czechoslovakia. It manufactured later versions of the 440 MW(t) VVER and was beginning to manufacture large VVER reactor components.

- With the exception of sale of power reactors to Finland, the FSU was not an international reactor vendor (i.e., no sales to foreign countries outside the communist block).

Two events continue to change the characteristics of the nuclear industry of the FSU—Chernobyl and the breakup of the FSU. While the ultimate structure of the industry is uncertain, several observations can be made.

- A major world-class industrial accident (Bhopal, Three Mile Island, Comet Aircraft) usually results in a product being discontinued and the organization responsible being radically downsized or eliminated. Chernobyl effectively eliminated the RBMK as a future reactor type and the "vendor."

- Significant new nuclear power plant construction in the FSU and most of Eastern Europe (except for completion of nuclear power plants that are almost complete) is likely to be limited for four different reasons:

  1. political impact of the Chernobyl accident;

  2. economic difficulties that limit capital for new power plants and that ultimately reduce power demand;

  3. inefficient use of energy, which will limit electrical demand growth as more energy efficient technologies are adopted; and

  4. the structure of the electrical grid. (With the breakup of the FSU and Eastern Europe, individual countries will develop independent national utilities. From a national planning basis, multiple power stations are desired for reliability. The size of the national grids will limit the demand for large power stations of any type which, in turn, limits demand for new nuclear power stations.)

- The market for nuclear power plant services by the Russian VVER reactor vendor will become highly competitive in the nations of the FSU and Eastern Europe outside Russia. This competition will reduce Russian vendor activity. The major strength of the vendor will be the low-cost but knowledgeable work force.

One special characteristic of the nuclear industry of Eastern Europe and the FSU is the likely future presence of the German reactor vendor Siemens and, through NPI, the French vendor Framatome. Two separate activities are responsible for this increased presence.

1. There has been one internationally recognized success of the Russian nuclear power industry: the Finnish power plant at Louisia. This is a unique station that houses two Russian reactors with Siemens control systems and other western safety features. In many years this station has been the most reliable nuclear power station in the world. Among other things, it is a powerful advertisement for Siemens ability to upgrade VVER reactors.

2. Siemens is purchasing controlling interest in Skoda Energo (Kralovec 1992) of Czechoslovakia, which built many of the VVER reactors in Eastern Europe and has the greatest understanding of these power reactors outside Russia.

The above factors provide Siemens with a very strong position to upgrade VVER reactors in Eastern Europe and the FSU.

It will be some time before definitive conclusions on the directions of the Russian nuclear program can be made and an understanding of what capabilities will survive is attained. It is noteworthy that the Russian vendor is the only significant vendor in the world that does not have long-term agreements with other reactor vendors to reduce costs and spread risks.

6.3.3 India

The Indian nuclear power program is controlled by the government (Wood 1991) and has slowly expanded in the last decade. Continuing financial troubles have and continue to restrict the program. While a substantial number of power reactors have been built, it is noted that these reactors are relatively small compared to those built elsewhere (Appendix D); thus, the industrial infrastructure requirements are substantially less. No significant efforts have been made to export nuclear power products.

6.3.4 New Vendors

Several countries have industrial organizations which, at one time, appeared to be likely future reactor vendors, but where the transition did not occur. In each case, specific local conditions prevented the emergence of a full-scale nuclear power reactor vendor. In each case, a shift in specific policies could result in an emerging reactor vendor.

- Italy. The Chernobyl accident resulted in a 5-year moratorium on nuclear power in Italy. Vendor capabilities were being developed by Ansaldo.

- Spain. Reduced growth in electric demand, the Chernobyl accident, and concerns about separatists movements have stopped creation of a Spanish reactor vendor.

- United States. In the United States, one vendor, General Atomics, has been developing a different type of advanced reactor, the modular high-temperature gas-cooled reactor. The reactor has potential safety advantages. Several prototypes have been built. While this technology is still under development, it has not been commercialized. Whether General Atomics becomes a vendor depends upon the success of this specific product.

6.4 COUNTRIES WITH SIGNIFICANT NUCLEAR POWER PROGRAMS BUT LIMITED DOMESTIC SUPPLY INDUSTRY

There are a number of countries with multiple nuclear power plants that have chosen not to create a local supply industry. This generalization includes countries such as Finland, Taiwan, and Belgium.

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Appendix A. DATA SHEETS ON THE VENDORS, SUPPLIERS, AND SIGNIFICANT ORGANIZATIONS IN THE NUCLEAR POWER INDUSTRY

Appendix A. DATA SHEETS ON THE VENDORS, SUPPLIERS, AND SIGNIFICANT ORGANIZATIONS IN THE NUCLEAR POWER INDUSTRY

This appendix is a collection of information about reactor vendors. These data are interpretations of articles from the technical press plus data from financial and business summary documents. The composite of this information is thought to provide a representative picture of the reactor vendors. The sources of the individual statements are usually provided; however, the accuracy of each statement has not been verified.

The data are provided in two forms:

1. a summary table that identifies the reactor vendors and their parent organizations [i.e., a corporation, a group of companies (keiretsu), or government agencies] plus other relevant information and

2. reactor vendor data sheets (a page, or in some cases two or three pages, of selected background information on particular vendors).

Table A.1 Reactor vendors and their organizational relationships

Organization or group	Major • **Vendors** • Subsidiaries • Corporations	Size Employees (10^3)	 Net revenue[a] / assets ($ Billions)	 Number of reactors[b] *Con started* / *operating*	Ownership	Products	Comments
Asea Brown Boveri (ABB) Sweden & Switzerland		215(90)[c]	26.7(90)[c] 20.0(90)[c] —	Pre-1980 *34/25* post-1980 *6/1*	Private 50% Asea 50% Brown Boveri	Large industrial plants and equipment	ABB incorporated in 1988—formerly fierce competitors in heavy-electrical and power generation fields, Sweden's Asea & Switzerland's Brown Boveri joined forces.
	Asea (ABB-Atom)	73(87)[c]		Pre-1980 *12/10* post-1980 *1/1*	Private Traded on Sweden's Stock Exchange	• Reactors • Industrial & electrical equipment	ASEA designed the PIUS reactor.
	Brown Boveri Company (BBC)			Pre-1980 *2/0* post-1980 *0/0*	Private Traded on Swiss Stock Exchange	• Industrial & electrical equipment	
	Combustion Engineering (CE)	28(87)[c]	3.0(87)[c] 2.7	Pre-1980 *20/15* post-1980 *5/0*	Private ABB bought control of CE for $\$1.6 \times 10^9$	• Reactors • Nuclear components • Industrial equipment • Nuclear service	Designer and builder of numerous reactor plants in the United States and foreign countries. Joint venture with Rolls Royce designing the SIR reactor prior to CE acquisition by ABB.
	Many companies throughout the world			N/A			

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major • **Vendors** • Subsidiaries • Corporations	Size: Employees (10^3)	Size: Net revenue[a] assets ($ Billions)	Size: Number of reactors[b] *Con started* / *operating*	Ownership	Products	Comments
Minatom Russia				Pre-1980 *54/41* post-1980 *51/15*	Russian Government	Nuclear power plants	Future structure and size of Russian nuclear program and vendor unclear due to Chernobyl nuclear power accident and breakup of the Soviet Union.
	Mintyazhmash **MTM**			Pre-1980 *54/41* post-1980 *51/15*	Russian Government	Reactors vessels and core internals	
Atomic Energy of Canada, Ltd. (AECL)				Pre-1980 *23/21* post-1980 *5/3*	Owned by the Canadian Government	Nuclear plants, equipment, and services	AECL has built all Canadian reactors. AECL is building two reactors for Korea and is negotiating for a third.
Peoples Republic of China				Pre-1980 *0/0* post-1980 *3/2*	China	Nuclear power plants	China started its first plant December 15, 1991, and contracted to build another for Pakistan on December 31, 1991—16 days later.
	China National Nuclear Corporation CNNC			Pre-1980 *0/0* post-1980 *1/1*	Owned by the Chinese Government	Nuclear power plants	China's first commercial nuclear power plant [300 MW(e)] started operation 12/15/91. The vessel was supplied by Mitsubishi.
	Guangdong Nuclear Power Joint Venture Company (GNPJVC)			Pre-1980 *0/0* post-1980 *2/1*			China's 900 MW(e) reactors have had Framatome reactor systems vessels, core, and internals. The French utility (EdF) is heavily involved in the construction.

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major · **Vendors** · Subsidiaries · Corporations	Size: Employees (10^3)	Size: Net revenue[a] assets ($ Billions)	Size: Number of reactors[b] *Con started* *operating*	Ownership	Products	Comments
France					France		
	Compagnie Generale d'Electricita (CGE)				French Government Agency	Electricity	CGE is responsible for France's electric power.
	Commissariat a l'Energie Atomique (CEA)			Pre-1980 *13/5* post-1980 *0/0*	French Government Agency	Nuclear energy	CEA is responsible for France's nuclear power.
	Electricite de France (EDF)	120			Stock FG 100% French Government	· Electricity · Transmission of Electricity	EdF supplies ~ 90% of France's electricity. EdF designs the power plant with Framatome providing nuclear reactor. In foreign sales, EdF is often the project manager.
	Framatome (FRAMA)			Pre-1980 *46/45* post-1980 *24/13*	Stock FG 40% CGE 35% CEA 10% EdF 15% other	· Reactors · Nuclear equipment and service	Initially Framatome built PWRs with Westinghouse licensing agreements. In 1981, a new relationship was established with Westinghouse based on the maturity of the French nuclear industry. Framatome is marketing throughout the world.

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major · **Vendors** · Subsidiaries · Corporations	Size			Ownership	Products	Comments
		Employees (10^3)	Net revenue[a] assets ($ Billions)	Number of reactors[b] *Con started* *operating*			
	Babcock & Wilcox Nuclear Technology (B&WNT)			Pre-1980 *12/8* post-1980 *0/0*	Private stock now owned by Framatome	Reactors Nuclear equipment and service	B&WNT is now owned by Framatome. B&W Nuclear Service (BWNS) 75% owned by BWNT--fully owned by mid 1993 Virginia Fuel Inc. (Framatome; Cogema & Uranium Peckiney). B&W Fuel Company (BWFC) owns 75% Virginia Fuel Inc.
	Nuclear Power International (NPI)		N/A	N/A	Joint venture of Framatome and Siemens	LWR power plants	NPI is a Framatome/Siemens effort to design and build a nuclear plant aimed at the European market. Four bids submitted to Finnish utilities for 1,100 and 1,380 MW PWRs and BWRs.
	Many nuclear component, fuel and service companies			N/A			
Dai - Ichi Kangyo Bank DKB Japan	688 Subsidiaries[d]				A keirestu group not a company	A broad base of products and banking	The zaibatsu (family) organizations were disbanded after World War II. They remained dormant for many years but have emerged as industrial groups. The Dai-ichi Kanayo Bank (DKB) is the group that includes Hitachi.

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major • **Vendors** • Subsidiaries • Corporations	Size: Employees (10^3)	Size: Net revenue[a] / assets ($ Billions)	Size: Number of reactors[b] *Con started / operating*	Ownership	Products	Comments
	Hitachi Ltd.	310(91)[e]	54.9[c](91) / 60.0[c](91)	Pre-1980 *6/6* post-1980 *5/3*	Private and part of DKB group	Power systems electronics Industrial cable chemicals	HITACHI is part of a joint venture with GE and TOSHIBA building two ABWRs for TEPCO. Power systems is 15% of sales.
	Hitachi Heavy Electric Machinery	83(92)[f]	59 / 65 130¥/$		Private and part of DKB group		Japan's largest comprehensive electric machinery manufacturer.[e] Electric power equipment is 20% of sales. R&D expenditure in 1992 was 410×10^9¥.
	Dai-ichi Kangyo Bank	19.4(92)[f]	38 / 496 130¥/$	N/A	Private and part of DKB group	Banking	Largest city bank in volume of funds. Member of U.S. Futures Market Outlook (with decline of interest for funds) is that the fund management profit is rising sharply.
	Fuji, Isuzu, Kawasaki, Asahi, Chemical & many others			N/A			

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major • **Vendors** • Subsidiaries • Corporations	Size: Employees (10^3)	Size: Net revenue[a] assets ($ Billions)	Size: Number of reactors[b] *Con started* *operating*	Ownership	Products	Comments
Department of Atomic Energy (DAE) India				Pre-1980 *8/8* post-1980 *8/0*	Government agency	Atomic energy	India built reactors with the help of many other nations (two with the United States, one with France, one with Great Britain, and two with Canada).
	Reactor Research Center and CEA RRC/CEA			Pre-1980 *1/1* post-1980 *8/0*	Government agency	Reactor technology	The French CEA has been involved in the commercial power plants.
	Department of Atomic Energy DAE			Pre-1980 2/2 post-1980 *0/0*	Government agency	Atomic energy	
	DAE and Nuclear Power Corporation (GB) DAE/NPC			Pre-1980 *1/1* post-1980 *2/0*	Government agency	Reactors plants	
	Canada & India AECL/DAE			Pre-1980 *2/2* post-1980 *0/0*	Joint venture	Reactor plants	

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major • **Vendors** • Subsidiaries • Corporations	Size: Employees (10^3)	Size: Net revenue[a] / assets ($ Billions)	Size: Number of reactors[b] *Con started* / *operating*	Ownership	Products	Comments
General Electric (GE) United States		298(88)[g] 302(87)[c]	50.1(88)[g] 40.5(87)[c] / 38.9(87)		Private	Power systems, electrical equipment, electronics, and plastics	GE is building their next generation nuclear plants (ABWR) as part of a joint venture with Hitachi and Toshiba. The plants are Units 6 & 7 at Kashiwazaki-Kariwa site of Tokyo Electric Power Company. R&D Expenditures in 87 were $\$3.0\times10^9$.[c]
	Power Systems Division			Pre-1980 *66/53* post-1980 *2/0*	Corporate division	Nuclear plants and services	Power Systems contributed 12% of GE sales in 1987.[g]
Korean Electric Power Corporation (KEPCO) South Korea					Government	Power plants	Prior to 1980, Korea bought reactors from Westinghouse and Framatome. Since 1980, Korea has used ABB-CE and AECL. There is a clear national policy to develop a nuclear power vendor capability with greater Korean involvement with each subsequent reactor project.
Mitsubishi Group (MITGR) Japan	190 Companies[f] 459 subsidiaries[h]		300[h]		A keirestu group not a corporation	A broad base of products and banking	When the Mitsubishi zaibatsu was broken in the 1940s, about a dozen companies maintained contact and developed into the Mitsubishi Group (banking, chemicals, shipbuilding, power plants, aircraft, industrial and consumer products).

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major • **Vendors** • Subsidiaries • Corporations	Size Employees (10^3)	 Net revenue[a] assets ($ Billions)	 Number of reactors[b] *Con started* *operating*	Ownership	Products	Comments
	Mitsubishi Electric Corporation[f]	50.4[f](92)	25[f] 25[f] 130¥/$	Pre-1980 *9/9* post-1980 *11/6*	Private Part of the Mitsubishi Group		Third among comprehensive electric machine makers. Top in defense electronics. Has agreements with Westinghouse in nuclear power.
	Mitsubishi Heavy Industry	45.4[f](92)	20[f] 28[f] 130¥/$		Private Part of the Mitsubishi Group	Ship building, power plants, aerospace, and heavy machinery	Japan's largest comprehensive heavy machinery maker. The leader in nuclear power. Prime Movers is 29% of sales.
	Mitsubishi Bank	15.1[f]	33[f] 457[f] 130¥/$	N/A	Private Part of the Mitsubishi Group	Banking	Third ranking city bank in terms of fund volume. Nucleus of Mitsubishi Group. Listed on NESE First Japanese Bank. Major stockholders are the insurance companies or ranks of the named groups. Data per JCH, summer 1992.
	Many companies in Japan and throughout the world			N/A			
Mitsui Taiyo Kobe MITSUI	513 subsidiaries[h]				A keirestu group, not a company	A broad base of products and banking	MITSUI is the keirestu that has regrouped since World War II and includes TOSHIBA.

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major · **Vendors** · Subsidiaries · Corporations	Size: Employees (10^3)	Size: Net <u>revenue</u>[a] assets ($ Billions)	Size: Number of reactors[b] <u>*Con started*</u> *operating*	Ownership	Products	Comments
	TOSHIBA	75[f](92)	<u>36</u>[f] 42[f] 130¥/$	Pre-1980 *8/8* post-1980 *5/3*	Private Part of the Mitsui Group		Japan's second all-around electric machinery maker. TOSHIBA cooperates with GE in nuclear power generation.
	MITSUI and Company	9.3[f]	<u>160</u> 75 130¥/	N/A	Private Part of the Mitsui Group	Steel, machinery, chemicals, food, and petroleum	Commercial trader vying with Mitsubishi Corporation. Leader of Mitsui group ranks second (next to Mitsubishi Corporation). Outlook—main profit earnings, machinery going strong, apparel, domestic constrictions, etc. are depressed. Data per JCH, Summer 1992.
	Mitsui Sanki Engineering Toray Industry Mitsukoshi Japan Steel Wks & many others						

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major · **Vendors** · Subsidiaries · Corporations	Size: Employees (10^3)	Size: Net revenue[a] assets ($ Billions)	Size: Number of reactors[b] *Con started* / *operating*	Ownership	Products	Comments
United Kingdom[k] **National Nuclear Corp. (NNC)**				Pre-1980 *39/34* post-1980 *5/4*	Government		NNC currently has the reactor vendor strength of Great Britain. However, Rolls Royce was in a joint venture with CE when ABB acquired CE.
	National Nuclear Corporation (NNC)			Pre-1980 *4/4* post-1980 *4/4*			NNC is the sole surviving nuclear reactor vendor in the United Kingdom. The reactor resources and capabilities of the design and construction organization of APC, TNPG, UKAEA, EE, BW, and TW have been absorbed by NNC.
	Atomic Power Construction (APC)			Pre-1980 *4/4* post-1980 *0/0*			APC is not currently supplying nuclear power plants, and NNC has absorbed their nuclear scopes.
	The Nuclear Power Group (TNPG)			Pre-1980 *12/10* post-1980 *0/0*			TNPG is not supplying nuclear power plants NNC has absorbed their nuclear scopes.
	United Kingdom Atomic Energy Commission (UKAEA)			Pre-1980 *11/9* post-1980 *0/0*			UKAEA was involved in the design, fabrication, and construction of plants prior to 1980. These capabilities of the UKAEA have been moved to NNC.
	Babcock & Wilcox (GB) Taylor Woodrow Construction (EE/BW/TW)			Pre-1980 *6/6* post-1980 *0/0*			BW(GB) is not currently supplying nuclear power plants NNC has absorbed their nuclear scopes.

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major · **Vendors** · Subsidiaries · Corporations	Size Employees (10^3)	 Net revenue[a] / assets ($ Billions)	 Number of reactors[b] *Con started* / *operating*	Ownership	Products	Comments
Siemens (SIEME) Germany	418 subsidiaries[d]	353[e](89)	41[e] 43[e] 1.5 DM/$		Private	Large industrial plants, electrical equipment, medical equipment, chemicals, and automation	Siemens is engaged in the entire field of electrical engineering & electronics. Siemens and Halske AG started in 1847. Siemens acquired KWU in 1977. KWU contributed 12% of Siemens' sales in 1987.
	Kraft Works Union (KWU)			Pre-1980 *25/18* post-1980 *8/5*	Owned by Siemens	Power plants and processing plants	
	Nuclear Power International (NPI)		N/A	N/A	Joint venture of Framatome and Siemens	LWR power plants	NPI is a Framatome/Siemens effort to design and build a nuclear plant aimed at the European market. Four bids submitted to Finnish utilities for 1,100 and 1,380 MW PWRs and BWRs.

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major • **Vendors** • Subsidiaries • Corporations	Size: Employees (10^3)	Size: Net revenue[a] assets ($ Billions)	Size: Number of reactors[b] *Con started* *operating*	Ownership	Products	Comments
	SKODA (of Czechoslovakia) (SKODA)	37		Pre-1980 *9/8* post-1980 *8/0*	Siemens plans to purchase 67% of SKODA group for production of power equipment		SKODA has 1,937 employees involved in nuclear divisions (out of 37,000 employees). Framatome is expected to acquire 10% from Siemens, leaving them with 57%. SKODA is reported to have considered Westinghouse, Framatome, GE, and ABB before the agreement to join Siemens. SKODA data from Nuclear Week December 5, 1991.
	Many support companies throughout the world			N/A	Owned by Siemens	All sorts of industrial and medical equipment	
Westinghouse (W) United States	26 Nuclear associates in nine countries	120(88)[g] 112[c]87	12(88)[g] 10.7[c](87) 9.9 (87)		Private	Electric equipment, power equipment, waste systems, fuel cells, and solar power	First builder of AC equipment, naval reactors, and commercial nuclear power plants. R&D expenditures \$808 x 10^6 in 1987[c]

Table A.1 Reactor vendors and their organizational relationships (continued)

Organization or group	Major • **Vendors** • Subsidiaries • Corporations	Size: Employees (10^3)	Size: Net revenue[a] assets ($ Billions)	Size: Number of reactors[b] *Con started / operating*	Ownership	Products	Comments
	Nuclear Energy Systems Division		Energy and utility systems 24%(87)[c] in sales	Pre-1980 *94/86* post-1980 *3/2*	Corporate division		Designer of the AP600 PWR Designer and builder of the largest number of nuclear plants. W has put two reactors into operation that were started since 1980 (one in Spain and one in Korea). W APWR 1300 was developed with the aid of funding from Japanese utilities. It will be Japan's next PWR project.[i]
	NES Division						

a. Net revenue and total assets values in 10^9 U.S. dollars unless otherwise specified.

b. *World Nuclear Industry Handbook 1992*. Reactors are shown as pre-1980 construction starts over currently operating 1980 and post-1980 construction starts over currently operating plants. The differences include cancelled plants, plants under construction, and plants that have been shut down.

c. *Directory of MULTINATIONALS*, D.C. Stafford, R.H.A. Purkis, ed John M. Stopford, published in the United Kingdom by MacMillan Publishers Ltd (Journals Division), 1989.

d. "Japan's Industrial Structure," *The Economist*, January 1991.

e. Data from *Moodys 1991*.

f. Data from *Japan Company Handbook*, First Section, Summer 1992.

g. Data from *International Directory of Company Histories* - St. James Press.

h. "Why Japan Keeps on Winning," *Fortune* July 15, 1991.

i. "Nuclear Engineering International" May 1992 p. 52.

j. The data shown is from the *Japan Company Handbook*, first section, Summer 1992. Other data for Mitsubishi Electric Company included: 97,000 people (91) and $23.7 billion in sales (*Moodys* 1991); 85,700 people (88) and $21.7 billion sales (*International Directory of Company Histories*); and 73,500 people (87) and $16 billion sales per *Directory of Multinationals*. The identification of data for Keirestu corporations is difficult because many sources lump many of the companies of a kieretsu without a clear definition of what companies are included. Other data for Toshiba includes 122,000 people (87) and $28 billion sales per *Directory of Multinationals*.

k. Most of the work in Great Britain appears to be currently consolidated with NNC. The other companies (APC, TNPC, UKAEA, B&W, and TW) provide support.

VENDOR DATA SHEET

ORGANIZATION: ABB & CE

Name	ABB ASEA Brown Boveri LTD
Address	P. O. Box 8131 CH-8050 Zurich, Switzerland
Phone #	(41-1) 317 71 11
Fax #	(41-1) 311 4897

TYPE/PURPOSE:

SIZE: 215,154 Employees/Total current assets \$19,961 x 10^6—1990 Balance Sheet[a]

HISTORY/LINKAGES:

- Established in Switzerland on January 5, 1988, by ASEA ABB 50% (Sweden) and Brown Boveri Ltd. (BBC) 50% (Switzerland) as a jointly held holding company for approximately 800 electrotechnical subsidiaries.
- ABB acquired Combustion Engineering in 1990.

COMMENTS:

♦ ABB Atom submitted bids for BWR for BWR-90 designs 1170 MW and 1350 MW (the cost of ABB Atom's plant was estimated at \$2 billion) for proposed Finnish plant.

□ ABB Atom has won an order to supply some of the reload fuel for French 1300 MW(e) PWR reactors. The order covers the delivery of four lead assemblies in 1992 and four demonstration assemblies in 1993, which should lead to the supply of two complete reloads. EdF has a policy of developing alternate suppliers, but this is the first time they placed an order for 1300 MW(e) fuel outside of France.

o ABB C-E is gearing up to compete in BWR outage services with GE. When ABB bought CE for $\$1.6 \times 10^9$, it was in primary competition with Westinghouse and B&W/Framatome in nuclear service and PWR fuel.

o ABB is also a BWR vendor, and CE provides the mechanism for them to compete in the U.S. BWR market share, GE has been the sole U.S. supplier. Swedish plants have consistently shorter refueling outages, and ABB is "wooing" utility executives with trips to Sweden to view outage operations. They claim to be going for half the $\$1\times10^9$ annual nonfuel BWR service market in the United States.

[a] *Moody's* 1991
♦ *NW* 10/31/91
□ *NN* 12/91/ page 68

VENDOR DATA SHEET

ABB & CE (Con't)

- ▵ ABB-CE Yonggwang Unit #3 (Korea Electric Power Company) will start up in 1995, which is proof that nuclear power stations can be built in 5 years. Yonggwang Unit #4 will follow a year later. Last year, ABB-CE received an order for two additional units to be built at Ulchin (Ulchin 3 & 4) also on 5-year schedules. Short schedules result in very economic nuclear power plants.

- ♠ ABB-CE is expected to bid on building two 1000-MW reactors for Taiwan (Taipower 7 & 8). GE, Westinghouse, and Framatome are also expected to bid.

VENDOR DATA SHEET

ORGANIZATION: AECL

Name Atomic Energy of Canada, Ltd.
Address Sheridan Park Research Community
2251 Speakman Drive
Mississauga, Ontario L5K 1B2
Canada
Phone #
Fax #

TYPE/PURPOSE:
- Government-owned company.
- Design, build, and operate reactors in Canada.

SIZE:

HISTORY/LINKAGES:

COMMENTS:
- Korean Electric Power Corporation (KEPCO) has invited AECL CANDU Ltd. to bid on providing the nuclear steam supply systems for the third and fourth 680-MW CANDU units at Wolsung. AECL is the only invited bidder.
- AECL supplied Wolsung-1, which is still among the world's top performing reactors and is building a second 680-MW Wolsung unit. The Wolsung-1 unit was built in 61 months and within budget of $600 million (1976 Canadian dollars).

* AECL announced the establishment of a program that will see Indonesian engineers and scientists gaining experience at operating CANDU stations.

□ The CANDU 600 is one of the candidate reactor designs being considered for the first reactor to be built in Indonesia.

* As a result of current technology transfer, Korea now fabricates its own CANDU fuel, and a percentage (at least 60%) of locally produced fuel for the Wolsung unit 2 currently under construction.

• *NW* 2/9/92 also NN 3/92

* *Nuclear Plant Journal* Jan-Feb 1992

□ *The World Nuclear Industry Handbook* December 1991

VENDOR DATA SHEET

AEE

ORGANIZATION:
Name Atomenergoexport
Address Soviet Union
Phone #
Fax #

AREA:
Russia

TYPE/PURPOSE:

SIZE:

HISTORY/LINKAGES:

COMMENTS:
- AEE submitted a single (December 1991) bid to supply its latest 1000-MW(e) PWR design to Finnish utilities.
- AEE supplied two VVER-440 reactors at IVO's Loviisa power station.

- NN 2/91

VENDOR DATA SHEET

ORGANIZATION: B&W

Name Babcock & Wilcox - Also see FRAMATOME **AREA:**

Address

Phone #

Fax #

TYPE/PURPOSE:

- Major segment of B&W is owned by Framatome.

SIZE:

HISTORY/LINKAGES:

- B&W Fuel Company—49% Framatome, 51% B&W.
  B&W Nuclear Service Company—75% Framatome, 25% B&W.
  Plans for Reactor technical company with Framatome, Siemens/KWU.
- The French now (January 1992) have controlling interest in two B&W Nuclear Technology subsidiaries.
- B&W Nuclear Technology (BWNT), formerly an unincorporated division of B&W Company is now a wholly owned corporation of Framatome, U.S.A.

  Framatome, through BWNT, increased its ownership in B&W Co. subsidiary, B&W Nuclear Services, Inc., from 50% to 75%.

  Virginia Fuel, Inc., which is composed of Framatome, Cogema, and Uranium Peckiney, increased its share of B&W Fuel Co. (BWFC) from 49 to75%.

  McDermott International, Inc., (which owned 50% stakes in the B&W subsidiaries) is in the midst of a financial program to raise money to pay debts.

  By the end of 1993, all of the B&W commercial companies will be fully owned .Framatome subsidaries

COMMENTS:

- Discussions
- *NW* 12/12/91

VENDOR DATA SHEET

ORGANIZATION: CNNC

Name China National Nuclear Corporation

Address

Phone #

Fax #

AREA:
- Asia

TYPE/PURPOSE:
- Government owned organization.

SIZE:

HISTORY/LINKAGES:
- The Pakistan contract made China a nuclear power exporter 16 d after it first became a nuclear power producer (December 1991).

COMMENTS:

• On December 31, 1991, the governments of Pakistan and China ended more than a year of negotiations with a contract under which China will provide a 300-MW(e) PWR to Pakistan. The plant is to be built and operated under IAEA safeguards. No financial agreements were provided. Pakistan has a 125-MW(e) Kanupp pressurized HWR that is nearly 20-years old. The reactor from China will be similar to the 300-MW(e) PWR that went on-line in December 1991 at Qinshan in Zhejiang Province.

• China considers Qinshan-1 to be its own indigenous design, even though much of the hardware was produced in other nations.

* Qinshan-1 was based on technology developed in China for submarine reactors.

♦p. 4 Two subsidiary agreements relating to the supply of a 300-MW(e) PWR to Pakistan were formalized. The contracts were signed by Jiang Xinxiong, president of CNNC, and Dr. Ishfaq Ahmed, chairman of Pakistan's Atomic Energy Commission.

♦p. 10 About 70% of the equipment for Qinshan was fabricated in China. Large components were imported (the vessel from Mitsubishi).

• *NN* 2/92
* *NW* 1/2/92
♦ *NEI* April 1992 p.4, p.10

VENDOR DATA SHEET

ORGANIZATION: **FRAMA**

Name Framatome (also see Babcock & Wilcox)
Address France
Phone #
Fax #

TYPE/PURPOSE:

SIZE:

HISTORY/LINKAGES:

- • Created in 1958 by decree of the French Government. Previously, this was essentially the Westinghouse operation in France. In 1958, Framatome began activity with a license from Westinghouse on PWR technology.
- • In 1981, a new relationship was established with Westinghouse based on the maturity of French PWR technology.
- • Framatome ownership in 1986—40% CGE, 35% CEA, 10% EdF, 12% DUMEX, 3%. The organization was offered for sale to the personnel of Framatome.

COMMENTS:

- * Has built 55 currently operating nuclear plants.
- • Framatome designs, manufactures, and sells 600-, 900- to 1000-, and 1300-MW(e) plants. They have sold two 1450-MW(e) units.
- * Framatome's products are:
  - basic design,
  - design of key nuclear components,
  - manufacturer of key components (reactor vessels [6-8/year], steam generators [18-24/year], pressurizers [8/year], in-core instrumentation [8 systems/year]),
  - enriched uranium fuel assemblies (first core and initial reload), and
  - procurement, transportation, erection, testing, and startup.
- • Framatome can supply any of the following:
  - NSSS (nuclear steam supply system),
  - installation and startup of NSSS,
  - nuclear islands,
  - complete nuclear power plants (in conjunction with industrial partners), and
  - nuclear fuel.
- o See Nuclear Power International (NPI) a joint venture Siemens & Framatome.

• Draft of 1986 MIT Report by Beckjord, Golay, Gyftopoulos, Hansen, Lester.
* *NN* 1992 List of World Plants.
o *NW* 10/31/91

VENDOR DATA SHEET

- ◘ Chinese agency, quoted by Agencé France Pressé, reported a delay in the startup of the 900-MW(e) Daya Bay-1 PWR in Guangdong Province near Hong Kong until the summer of 1993. The Daya Bay units are being supplied by Framatome and GEC Alsthom, respectively, with technical project supervision by EdF with Guangdong Nuclear Power Joint Venture Company (a partnership of Hong Kong and Guangdong utilities).
- See association with SKODA and Siemens (SKODA).
- Framatome is expected to bid on two 1000-MW reactors for Taiwan (Taipower 7&8). ABB-CE, GE, and Westinghouse are also expected to bid.

◘ *NW* 2/2/92

VENDOR DATA SHEET

ORGANIZATION: GA

Name General Atomics
Address California
Phone #
Fax #

TYPE/PURPOSE:

- General Atomics has been developing the Modular High-Temperature Gas-Cooled reactor. The success of this advanced reactor will determine if it becomes a vendor.

SIZE:

HISTORY/LINKAGES:

COMMENTS:

- 1992 is the thirtieth anniversary of the first nuclear chain reaction in Korea. The 100 KW thermal TRIGA (GA) research reactor went critical in 1962 at the Korea Atomic Energy Research Institute in Seoul. Its operation in the 1960s and 1970s helped Korea develop its nuclear knowledge and infrastructure.

- *NEI* April 1992 p.30

VENDOR DATA SHEET

ORGANIZATION: GE

Name General Electric Company
Address Schenectady, NY
U.S.A.

Phone #
Fax #

TYPE/PURPOSE:
- Public Company

SIZE: Dollar Volume - $\$58.4 \times 10^9$
Number of Employees -

HISTORY/LINKAGES: - Incorporated 4/15/1892
- Joint ventures SDRC; Quadrex Corp.; Big Three Industries, Inc.; Coherent, Inc.; PPG, with Stone & Webster with GE - Nuclear Parts Associates $30M contract with Gulf States Utilities, with Fuji Elec. Co., Strategic Alliance Agreement; with GE of the United Kingdom (an unrelated company) for European business interest, with Turigsram Co., LTD, of Hungary Lighting.

COMMENTS:
- Decentralized: industry, aerospace, aircraft engineers, appliances, broadcasting, industrial, materials, power systems, technical products and services.
- 177 manufacturing plants in 35 states and Puerto Rico. Some 103 manufacturing plants in 23 other countries.

  Welch (Chairman) to shareholders 1990:

  Revenues of $58.4B plus contribution to balance of trade of $4.5B. R&D expenditure up 9% to $4.3B and $9.9% of sales record, 20% of the European lamp business and number one in the world.
- Two new GE nuclear power plants are under construction (groundbreaking September 1991) employing an advanced "evolutionary" design. They are units 6 and 7 at the Kashwazaki - Kariwa station 140 miles Northwest of Tokyo. The other five units are also GE BWRs. These plants will be the first 1356-MW(e) advanced boiling water reactors (ABWR). GE is also seeking certification of the ABWR use in the United States (Reference USCEA #269 10/91). GE claimed they met their goal of 15 to 20% improvement in overnight capital cost relative to previous BWRs. Operation and maintenance are also expected to be significantly lower. GE's share of the project was $1.4B, which helps the U.S. Japan deficit problem.
- GE is currently developing an advanced 600-MW BWR (SBWR).[1]

o The GE SBWR is one of the candidate reactor designs being considered for the first reactor to be built in Indonesia.

- *Moody's* 1992

[1] DOE has 26 million in the '93 Budget for ALWRs (AP600 and SBWR) NN 3/92.

o *World Nuclear Industry Handbook* December 1991.

VENDOR DATA SHEET

GE (Con't)

- ◘ GE Nuclear Energy and three Japanese manufacturing firms have agreed to extend their 25-year technical cooperation agreements by another 10 years. The Japanese firms are Hitachi, Toshiba, and Japan Nuclear Fuel Company, with the latter jointly owned by GE, Hitachi and Toshiba. The technology collaboration with GE was initiated in 1967. This method of technology exchange gives the participants access to each firm's BWR engineering and manufacturing technical information. Areas for joint R&D technology collaboration include development, testing, and manufacturing of high performance BWR components, such as nuclear fuel, control rods, and other reactor internals; the creation, qualification, and characterization of new nuclear-grade materials; and the development and evaluation of new analytical models and calculational methods to more accurately simulate and predict BWR performance.
- ♠ GE is expected to bid on two 1000-MW reactors for Taiwan (Taipower 7&8). ABB-CE, Westinghouse and Framatome are also expected to bid.

REACTOR PLANTS

BWR - numerous BWR in all sizes (1960s, 70s & 80s)
BWR - [large ~1300 to 1500 MW(e) (ABWR)]
BWR - [medium ~600 MW(e) (SBWR)]
Government plants

◘ *Nuclear Plant Journal*, Jan. - Feb. 1992.
♠ *USCEA INFO*, June/July 1992

VENDOR DATA SHEET

ORGANIZATION: HITAC

Name HITACHI, LTD.
Address
Phone #
Fax #

TYPE/PURPOSE:
- Public company.
- Manufacturing and marketing of consumer products, power systems and equipment, information and communication systems, electronic devices, industrial machinery and plants, wire, cable, metals, chemicals, and other products.

SIZE:

• Net sales	$54,872,000,000
• Stockholders	369,717
• Employees	309,757
• Net income	$ 1,632,518K
• Earn per share	$0.47 (¥65.96)
• Assets/liabilities	8,526,121Y ($60.5 x 10^9)
• Long-term debt	¥247 x 10^9 ?
• Stock price range	$77 to 108 Div. $.429

HISTORY/LINKAGES:
- Founded in Japan in 1910 and incorporated in 1920.
- Established Hitachi Data Systems Corporation 1989.
- Founded Advanced Interconnection Technology, Inc., in New York. 1990
- Established Hitachi Electronic Devices (USA) in South Carolina. 1990
- Established Hitachi Home Electronics (America), Inc. 1991
- Established Open System Business Center in America. 1991
- Established Hitachi Computer Products (America) and HCP (Europe) in France. 1991
- Established Hitachi Cable Ltd. in Malaysia. 1991
- Joint Ventures:
  - Electronic Data Systems Corporation (Electronic Data 20%). 1989
  - Joint with Deere & Co. & Fiat Geotech (hydraulic elevators in the United States and Europe). 1988
  - Joint ventures with GE.[1] 1967
- Sixty consolidated subsidiaries.

COMMENTS:

- *Moody's* 1992

[1] *Nuclear Plant Journal*, (Jan.-Feb. 1992)

VENDOR DATA SHEET

PRODUCT LINES:

Nuclear equipment
Heavy electric equipment
Electronics
Construction Equipment
Other

VENDOR DATA SHEET

ORGANIZATION: MITEC

Name	Mitsubishi Electric Corporation
Address	Denki Bldg., 2-3 Marunouchi 2-Chrome, Chiyoda-Ku, Tokyo 100 Japan
Phone #	(03) 32118-2111
Fax #	

AREA:
- 28 locations in Japan

TYPE/PURPOSE:
- Public company.
- Manufacturing and marketing electronic and electrical, information processing, communication, satellite relay and optical fiber equipment.
- Products space development, communication information processing, electronic devices, energy, transportation, building equipment and systems, heavy machinery, industrial equipment, audio-visual and home electronics.

SIZE:

• Net sales	3,316,243 x 10^6¥ (1991) [$23.7 x 10^9]
• Number of employees	97,002
• Net income	79,760 x 10^6¥ [569 x 10^6]
• Earn per share	¥34.19
• Assets/liabilities	3,318,058 x 10^6¥ [$23.7 x 10^9]
• Long-term debt	615,664,000,000¥ (1.3% to 9.3%)
• ○ Dividends paid	8.5 offered at ¥390 1985
○ Stock authorized	8 x 10^9 shares - 2.14 x 10^9 shares outstanding.

HISTORY/LINKAGES:
- Established in 1921. Changed to present name in 1963.
- Joint ventures in Mexico, Brazil, Colombia, Venezuela, France, Saudi Arabia, Nigeria, Singapore, Malaysia, Philippines. Korea, United Arab Emirates, Australia, New Zealand and the United States.
- Principle subsidiaries: 19 in Japan, 4 in the United States, 2 in Canada, 1 in the Netherlands, 1 in the United Kingdom, 1 in Singapore, 1 in Germany, and 1 in France.

COMMENTS:

* The Mitsubishi MS-600 is one of the candidates for the first reactor design to be used in Indonesia.

- *Moody's*, 1992

* *World Nuclear Industry Handbook*, December 1991

VENDOR DATA SHEET

ORGANIZATION: NJEC

Name New Japan Engineering Company
Address
Phone #
Fax #

TYPE/PURPOSE:

- A subsidiary of Kansi Electric Power Company

SIZE:

HISTORY/LINKAGES:

COMMENTS:

- NJEC will conduct a feasibility study for a possible nuclear power plant in the Muria Peninsula region of Indonesia to be completed in 1993. Contracts may be awarded in 1996-1997. Next step will be geological and environmental studies to be completed by March 1996. Indonesia projects a need for 3,500 MW(e) and generation of 7,500 MW by nuclear power.

VENDOR DATA SHEET

ORGANIZATION: NPI

Name Nuclear Power International **AREA:** Europe
Address
Phone #
Fax #

TYPE/PURPOSE:

- A joint venture of Siemens and Framatome.

SIZE:

HISTORY/LINKAGES:

COMMENTS:

- • NPI is offering 1110-MW and 1380-MW PWR designs for the Loviisa site and BWRs of the same size for the Olkilnoto Finnish System. One ton of documentation was delivered to the utilities for each alternative. NPI believes that 50% is construction work that can be performed by the Finns. NPI has studied 45 Finnish companies for possible partnerships. The former Soviet Union's Atomenergoerport (AEE) is also competing with a 1040-MW PWR.
- * Sites will be selected in Germany and France in 1994 for construction of an advanced PWR designed by NPI. Construction of one reactor could get underway in each country by 1998. The utility consortium led by EdF have agreed on a large evolutionary type reactor of about 1500-MW. The extent of the utilities contribution to the design is still to be resolved. Basic design phase in 1993-94 will include all design documentation independent of the site. Forum in Bonn said that NPI is confident that "licensing applications for the plant will be placed simultaneously in Germany and France in mid-1995."
- * Design features of the NPI are to include: simpler instrumentation and controls, prestressed concrete cylindrical containment with steel lines, and the spent-fuel pool in the annular building surrounding the outer containment. NPI has rejected most passive safety approaches, but some are used in the secondary side of the new PWR, including a new safety condenser for decay heat removal. How much of the design role the vendor is willing to relinquish to EdF and its utility associates is not clear. EdF is not prepared to accept the "failures" that utilities have paid for due to lack of close control of nuclear plant construction in America.
- □ NPI has formed a Finnish subsidiary to promote its bid for building a fifth nuclear reactor in Finland.
- ♣ Summary of NPI design concept stressed the use of a safety condenser, an evolutionary approach ("four-train" concept using four fully separated safety systems without headers), and material with high embrittlement resistance for the vessel that will retain its ductility throughout the life of the unit.

• *NW* 10/31/91
* *NW* 02//06/92
□ *NW* 03/05/92
♣ *NEI* 4/92

VENDOR DATA SHEET

ORGANIZATION: SIEME

Name	Siemens AG	Siemens Power Corporation
Address	Wittelsbacher 2 D-8000	P. O. Box 90777
	Mantch 2	Bellevue, WA 98009-0777
	Germany	U.S.A.
Phone #	(089) 234-0	
Fax #	52 100-0	

TYPE/PURPOSE:
- Public company
- Engaged in the entire field of electrical engineering and electronics.
- Manufacturing and marketing of components, communication and information systems, power engineering and automatron, telecommunications and security systems, and medical engineering.

SIZE:

• Employees	353,000 - 1989
• Net sales	61.1 x 10^9 DM
• Net income	1.58 x 10^9 DM
• Assets/liabilities	64.4 x 10^9 DM
• Long-term debt	4.22 x 10^9 DM (4.75 to 15%)
• Stock Range $65 to 94	1990 dividends $1.071

HISTORY/LINKAGES:
- Siemens and Halske AG 1847
- Acquired remaining 50% of Kraftwork Union in 1977

COMMENTS:

* Siemens has consolidated its U.S. power generating products and services into one operating company (Siemens Power Corporation). These products and services include fossil, gas turbines, generators, nuclear services and fuel, and related electrical components. It will also hold the U.S. interest in the remaining Siemens KWU affiliates. For 20 years, these affiliates were part of Advanced Nuclear Fuel Corp. prior to being bought by Siemens KWU.

* Siemens AG's Power Generation Group (KWU) will provide instrumentation and controls for Mochovce Units 3 & 4 in Czecho-Slovakia.
Siemens Power Corporation has joint operations with Czech Works.

o See Nuclear Power International (NPI) joint venture Siemens and Framatome.

[1] See discussion on SKODA vendor sheet regarding Siemens joint venture with Skoda and Framatome.

* *NN* 2/92 pages 83, 84, 86
• *Moody's*
o *NW* 10/31/91
[1] *NW* 12/5/91

VENDOR DATA SHEET

ORGANIZATION: SKODA

Name Skoda Energy
Address Czechoslovakia
Phone #
Fax #
TYPE/PURPOSE:

SIZE:
- Skoda Pilsen 37 x 10^3 employees 1990 (1,937 engaged in nuclear division work).
- Sales \$3.3 x 10^6 for nuclear division 0.8% of total Skoda Pilsen sales.
- Turbine sales accounted for 6.3% of total sales.
- Sales in 1991 maybe 50% of 1990 sales.

HISTORY/LINKAGES:
- Skoda Concern, Pilsen, and Siemens AG's KWU formed (fall 1991) a joint venture partnership in nuclear, fossil, and hydroelectric generating equipment (Skoda 33%, Siemens 67%).
- Framatome will acquire 10% of the Siemens share leaving Siemens with 57%.

COMMENTS:
- Skoda Energy is seen in Germany as giving Siemens a decided edge in future nuclear equipment competition in Eastern Europe, including any new Western PWRs the Czechs may order for the Temelin site where two Soviete-design VVER-1000s are awaiting completion.
- Framatome said this agreement does not change the plans for NPI. The new company's nuclear business is expected to be small. Its prime work will be modernization of fossil-fired plants.
- Skoda, long a key supplier of heavy components for Soviet PWRs, began the search for a Western partner in early 1990. Czechs considered Westinghouse, Framatome, Siemens, GE, and ABB before joining Siemens.
- The joint venture is expected to assure Siemens a major role in upgrading as many as sixteen Czechoslovakian PWRs that are either operating or under construction.
- Since Skoda is the most important power equipment supplier in the country, which has the regions largest nuclear infrastructure. This venture should give the German vendor an advantage in marketing power equipment in Eastern Europe.

▵ Western and Far Eastern vendors have a new competitor "Skoda Pilsen." SKODA has received certification from ASME. The ASME certification guarantees that their products meet the high quality demanded by nuclear operators and licensing authorities in the West.

* According to its statement, SKODA chose Siemens (and Framatome) as partners not only to maintain high technical standards for the domestic nuclear plants in Northern Bohemia, but also to help the company meet international standards that will allow it to participate in the world market. Skoda has 7,000 people in this field.

• *NW* 12/05/91
▵ *Nuclear Energy INFO* May 1992
* *Nuclear News* January 1992

VENDOR DATA SHEET

TOSHI

ORGANIZATION:

Name	TOSHIBA Machine Company
Address	№ 2-11, Gunza 4-Chome Chus-Ku Tokyo 104 Japan
Phone #	03-567-0511
Fax #	03-535-2570

AREA:
- Nuzamu
- Sazami
- Gotemba

TYPE/PURPOSE:
- Public stock.
- Engaged in machinery, plastics, semiconductor manufacturing equipment, electric controls, and food service equipment.
- Nine major subsidiaries and joint ventures.

SIZE (as of 1989):

• Number of employees	3,300?
• Net sales	$\$824 \times 10^6$
• Net earnings	$\$11.1 \times 10^6$
• Earnings per common share	$3.75
• Assets/liabilities	$\$912 \times 10^6$
• Long-term debt	¥5,289,000,000
• Number of stockholders	13,860

HISTORY/LINKAGES:
- Established in Japan in 1938.

COMMENTS:

PRODUCT LINES:

Nuclear equipment and electronics.

- *Moody's*

VENDOR DATA SHEET

ORGANIZATION: W

Name Westinghouse Electric Corporation
Address Pittsburgh, Pennsylvania
Phone #
Fax #

TYPE/PURPOSE:

- Public company.
- Manufacturing and marketing of electrical equipment, power generating equipment, transmission equipment, waste management systems, instrumentation, fuel cells, solar power elements.

SIZE:

HISTORY/LINKAGES: France - Framatome
Japan - Mitsubishi

- Designers and builders of the first AC machinery in the late 1800s.
- Designers and builders of the reactor for the first nuclear submarine in the 1950s.
- Designers and builders of the first nuclear power plant in the 1950s.
- Licensed Framatome to build the W PWRs in the 1960s.

COMMENTS:

- Currently developing an advanced 600-MW(e) PWR (AP600)[1] with active NRC licensing work and interaction.

* W has reached an agreement to proceed with putting PNNI [620 MW(e)] on line in 1995 and pay $100M in cash and services to the Philippines.

- Working agreement with Mitsubishi in 1992.

o The AP600 is one of the candidates for the first reactor design to be used in Indonesia.

△ Dozens of engineers from Indonesia, Italy, and Spain are in Pittsburgh working on the AP-600. In addition, nuclear companies in France, Japan, and Spain have committed money to the design (in the millions $). W also has "serious expression of interest" in the AP-600 from Poland, Mexico, South Korea, Argentina, Bulgaria, and Egypt.

♣ A *Business Week* article last November claimed that a Senior Management Group, including Lego (W president), went to Tokyo to renegotiate licensing agreements with Mitsubishi and also (according to a source involved in the talks) explored the idea of selling Mitsubishi the whole company for a premium of 20% over its $3.7 billion book value. W denies such talks ever took place.

- General information.

1 DOE has 26 million in 1993 Budget for AP600 and SBWR NN, 3/92.

* *USCEA INFO*, 3/92.

o *World Nuclear Industry Handbook*, December 1991.

△ *Nuclear Energy INFO*, May 1992

♣ *Business Week*, May 11, 1992

VENDOR DATA SHEET

- ♠ W president (Lego) sent a letter to *Business Week* stating that the allegations made in their May 11 article are incorrect and irresponsible.
- ♥ W is expected to bid on two 1000-MW reactors for Taiwan (Taipower 7 & 8). ABB-CE, GE, and Framatome are also expected to bid.
- ∝ In 1991 *W*'s APWR 1300 earned its preliminary design authorization from the NRC. Developed with the aid of funding from Japanese utilities, it will be Japan's next PWR project. An APWR 1000 has also been developed.

REACTOR PLANTS:

PWR - Numerous PWRs in all sizes built in 1950s, bulb & 70s.
Government Plants - Hanford, Savannah River, Idaho
New Designs - Large Evolutionary LWR
- Medium Advanced LWR, AP-600

- ♠ Letter from Lego, W President, to Business Week
- ♥ *USCEA INFO*, June/July 1992
- ∝ *Nuclear Engineering International*, May 1992, p. 52

Appendix B. REACTOR PRODUCTS

Appendix B. PRODUCT DATA SHEETS

B.1 INTRODUCTION

This appendix provides the detailed technical characteristics of each reactor product. The product data sheets are ordered alphabetically by product name within each design class. Each product data sheet is divided into two parts: general product characteristics and technical product characteristics.

The general product characteristics were summarized earlier in Table 4.1. The technical product characteristics include the reactor thermal and electrical power, coolant temperatures, fuel design parameters, power density, fuel-cycle length, steam generator design, safety system descriptions, plant design life, construction time, and other pertinent product characteristics.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Advanced Boiling-Water Reactor
Reactor Type: BWR
Electrical Power: 1356 MW(e)
Design Type: Evolutionary Plant
Developmental Status: Construction
Availability: Current

Vendor organization:

- General Electric, U.S.A.
- Hitachi, Ltd., Japan
- Toshiba Corporation, Japan

Utilities using product:

- Tokyo Electric Power Co., Inc. (TEPCO)
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 3926 MW(t)
Electrical power: 1356 MW(e)
Coolant inlet temp: 216°C
Coolant outlet temp: 288°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size: 8x8 or 9x9
No. of fuel assemblies: 872
Core loading (MTU):
Av fuel burnup:
Power density: 50.6 kW/L
Operating cycle: 18 months

Steam Generator Design:
SG type: N/A
No. of SGs: N/A

Safety System Design:
Containments: lined, reinforced concrete with pressure suppression
ECCS design: high & low pressure injection plus passive injection
List of unique safety systems: no external recirculation piping, RHR system

Scheduling:
Construction time: 48 months
Construction cost:
Plant design life:

Comments: TEPCO has ordered two units, currently under construction, at the Kashiwazaki-Kariwa Nuclear Power Station 140-miles NW of Tokyo with commercial operation set for 1996 and 1997, respectively.

References: GE Advanced Boiling Water Reactors, D. R. Wilkins, GE Nuclear Energy, April 1990.
Nuclear News, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Advanced Boiling-Water Reactor 90
Reactor Type: BWR
Electrical Power: 1050 MW(e)
Design Type: Evolutionary Plant
Developmental Status: Design
Availability: Current

Vendor organization:
- ABB-Atom
-
-

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 3020 MW(t)
Electrical power: 1050 MW(e)
Coolant inlet temp: 215°C
Coolant outlet temp: 286°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size:
No. of fuel assemblies: 676
Core loading (MTU): 120
Av fuel burnup:
Power density: 50 kW/L
Operating cycle:

Steam Generator Design:
SG type: N/A
No. of SGs: N/A

Safety System Design:
Containments: steel primary with reinforced concrete secondary
ECCS design: four independent systems
List of unique safety systems: containment venting and forced flooding

Scheduling:
Construction time: <57 months
Construction cost:
Plant design life:

Comments: Basis for commercial bid to Finnish power companies. The ABWR 90 is a moderate design modification of the two existing plants, Forsmark 3 and Oskarshamn 3, in Sweden.

References: BWR 90 — The Advanced Alternative, ABB Atom, 1988.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Advanced Pressurized-Water Reactor
Reactor Type: PWR
Electrical Power: 1050 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: Preliminary design in July 1993

Vendor organization:

- Westinghouse, U.S.A.
- Mitsubishi, Japan
-

Utilities using product:

-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 3150 MW(t)
Electrical power: 1050 MW(e)
Coolant inlet temp: 287°C
Coolant outlet temp: 325°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size: 17x17
No. of fuel assemblies: 193
Core loading (MTU):
Av fuel burnup:
Power density: 96.2 kW/L
Operating cycle: 17 months

Steam Generator Design:
SG type:
No. of SGs: 3

Safety System Design:
Containments: Cylindrical steel
ECCS design:
List of unique safety systems:

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Zircaloy-4 cladding. Design work on larger APWR 1300 is under way and includes 1300 MW(e), 3900 MW(t), 19x19 fuel assembly array size with similar coolant temperatures and four steam generators.

References: *Nuclear News*, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: CANDU 3
Reactor Type: HWR
Electrical Power: 450 MW(e)
Design Type: Evolutionary Plant
Developmental Status: Design
Availability: Current

Vendor organization:
- AECL, Canada
-
-

Utilities using product:
- Canada
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 1440 MW(t)
Electrical power: 450 MW(e)
Coolant inlet temp: 260°C
Coolant outlet temp: 310°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment: natural
Array size: 37-element bundle
No. of fuel assemblies: 232
Core loading (MTU): 53.2
Av fuel burnup:
Power density: 12.8 kW/L
Operating cycle: continuous, on-line refueling.

Steam Generator Design:
SG type: vertical U-tube with integral steam drum and preheater
No. of SGs: 2

Safety System Design:
Containments: dual containment carbon steel liner inside reinforced concrete building
ECCS design: passive high-pressure injection
List of unique safety systems: PCCS, PRHR

Scheduling:
Construction time: 38 months
Construction cost:
Plant design life: 40 years

Comments: Heavy water moderator and coolant. Core loading was calculated as 232 fuel channels x 12 fuel bundles/channel x 19.1 KgU/bundle x 1 MT/1000 Kg=53.2 MTU. Zircaloy-4 cladding.

References: CANDU 3—The Right Product for the Times, Atomic Energy of Canada Limited.
Nuclear News, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: CANDU 6
Reactor Type: HWR
Electrical Power: 665 MW(e)
Design Type: Evolutionary Plant
Developmental Status: In use
Availability: Current

Vendor organization:

- AECL, Canada
-
-

Utilities using product:

- Canada
- KEPCO, Korea
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power:
Electrical power: 665 MW(e)
Coolant inlet temp:
Coolant outlet temp:

Fuel Design:
Fuel composition: UO_2
Fuel enrichment: natural
Array size: 37-element bundle
No. of fuel assemblies: 380
Core loading (MTU):
Av fuel burnup:
Power density:
Operating cycle: continuous, on-line refueling

Steam Generator Design:
SG type: vertical U-tube
No. of SGs: 4

Safety System Design:
Containments:
ECCS design:
List of unique safety systems:

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: AECL has sold 12 of the CANDU 6 reactors in Canada, South Korea, Argentina and Romania. Heavy water moderator and coolant.

References: *Nuclear Engineering International*, Vol. 35, 430, pg. 22-25, May 1990. *The Energy Daily*, pg. 1, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: N4
Reactor Type: PWR
Electrical Power: 1528 MW(e)
Design Type: Evolutionary Plant
Developmental Status: In use
Availability: Current

Vendor organization:

- Framatome, France
-
-

Utilities using product:

- EdF, France
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 4270 MW(t)
Electrical power: 1528 MW(e)
Coolant inlet temp: 292°C
Coolant outlet temp: 330°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment: 1.5%, 2.4%, 2.95%
Array size:
No. of fuel assemblies: 205
Core loading (MTU):
Av fuel burnup: 36000 MWd/MT
Power density: 44.8 kW/m
Operating cycle:

Steam Generator Design:
SG type: vertical U-tube
No. of SGs: 4

Safety System Design:
Containments: dual, prestressed concrete
ECCS design:
List of unique safety systems:

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Chooz B in the Ardennes region of France was the first model N4 series of French nuclear reactors.

References: *Nuclear Engineering International*, Vol. 30, 365, pg. 26-32, February 1985.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Sizewell B
Reactor Type: PWR
Electrical Power: 1250 MW(e)
Design Type: Evolutionary Plant
Developmental Status: Construction
Availability: Current

Vendor organization:

- Westinghouse, USA
- NNC, Great Britain
-

Utilities using product:

- Nuclear Electric (UK)
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 3411 MW(e)
Electrical power: 1250 MW(e)
Coolant inlet temp: 294°C
Coolant outlet temp: 326°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment: 2.1%, 2.6%, 3.1%
Array size:
No. of fuel assemblies: 193
Core loading (MTU):
Av fuel burnup: 33000 MWd/MT
Power density: 41.3 kW/m
Operating cycle:

Steam Generator Design:
SG type: vertical U-tube
No. of SGs: 4

Safety System Design:
Containments: dual, steel-lined concrete
ECCS design: accumulators, RHR pumps
List of unique safety systems: containment spray/fan, emergency boration system

Scheduling:
Construction time: 5 years
Construction cost:
Plant design life:

Comments:

References: *Nuclear Engineering International*, Vol. 37, 454, pg. 53, May 1992.
"The British PWR," *Nuclear Engineering International Special Publications*, 1988.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: SNERDI PWR
Reactor Type: PWR
Electrical Power: 300 MW(e)
Design Type: Evolutionary Plant
Developmental Status: In-use
Availability: Current

Vendor organization:

- China National Nuclear Co.
-
-

Utilities using product:

- MNI, China
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 966 MW(t)
Electrical power: 300 MW(e)
Coolant inlet temp: 289°C
Coolant outlet temp: 315°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size:
No. of fuel assemblies: 121
Core loading (MTU):
Av fuel burnup:
Power density:
Operating cycle:

Steam Generator Design:
SG type: U-tube design
No. of SGs: 1

Safety System Design:
Containments:
ECCS design:
List of unique safety systems:

Scheduling:
Construction time: 6.5 years
Construction cost:
Plant design life:

Comments: First reactor started operation on December 15, 1991, and is located at Qinshan, 100 km from Shanghai. Designed by Shanghai Nuclear Engineering Research and Design Institute (SNERDI).

References: *Nuclear Engineering International*, Vol. 37, 453, pg. 39-41, April 1992.
Nuclear Engineering International, Vol. 37, 454, pg. 53, May 1992.
Nuclear Engineering International, Vol. 37, 455, pg. 38-39, June 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: System 80/80+
Reactor Type: PWR
Electrical Power: 1345 MW(e)
Design Type: Evolutionary Plant
Developmental Status: Construction
Availability: Current, U.S. NRC design certification in 1994.

Vendor organization:
- ABB-CE, USA
-
-

Utilities using product:
- Korea Electric Power Co.
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 3817 MW(t)
Electrical power: 1345 MW(e)
Coolant inlet temp: 292°C
Coolant outlet temp: 324°C

Fuel Design:
Fuel composition: UO_2 or PuO_2
Fuel enrichment: 3.3, 2.8, and 1.9%
Array size: 16x16
No. of fuel assemblies: 241
Core loading: 116.6 MT UO_2
Av fuel burnup:
Power density: 95.5 kW/L
Operating cycle: 18 to 24 months

Steam Generator Design:
SG type:
No. of SGs: 2

Safety System Design:
Containments: dual, steel sphere inside reinforced concrete building
ECCS design:
List of unique safety systems: PCCS

Scheduling:
Construction time: 48 months
Construction cost:
Plant design life:

Comments: Korea Electric Power Co. has reactor projects in Yongwang and Ulchin, Korea. Zircaloy-4 cladding.

References: System 80+ Standard Design, "THE Nuclear Option for the 90s . . .", ABB-CE, Inc., 1991.
Nuclear Engineering International, Vol. 37, 453, pg. 49-50, April 1992.
Nuclear News, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Advanced Passive-600
Reactor Type: PWR
Electrical Power: 600 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: U. S. NRC design certification in November 1994

Vendor organization:
- Westinghouse Electric Co, U.S.A.
-
-

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 1812 MW(t)
Electrical power: 600 MW(e)
Coolant inlet temp: 276°C
Coolant outlet temp: 312°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size: 17x17 WE OFA
No. of fuel assemblies: 145
Core loading (MTU): 61.0
Av fuel burnup:
Power density: 78.8 kW/L
Operating cycle: 18 or 24 months

Steam Generator Design:
SG type: Westinghouse Model F-1000, vertical U-tube type
No. of SGs: 2

Safety System Design:
Containments: steel primary with reinforced concrete secondary
ECCS design: high & low pressure borated coolant injection
List of unique safety systems: PCCS, ADS, passive containment spray, containment flooding with long-term, passive, RHR

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Zircaloy decladding.

References: *The Energy Daily*, pg. 3, April 23, 1992.
Conway, L. E., Westinghouse Electric Company, "Westinghouse AP600 Passive Safety Systems—Key to a Safer, Simplified PWR," *American Nuclear Society International Topical Meeting—Safety of Next Generation Power Reactors*, Seattle, Washington, May 1-5, 1988.
Nuclear News, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: CAREM
Reactor Type: PWR
Electrical Power: 150 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Research
Availability: TBD

Vendor organization:

- INVAP, Argentina
-
-

Utilities using product:

-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power:
Electrical power: 150 MW(e)
Coolant inlet temp:
Coolant outlet temp:

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size:
No. of fuel assemblies:
Core loading (MTU):
Av fuel burnup:
Power density:
Operating cycle:

Steam Generator Design:
SG type: Once-through, helical tube
No. of SGs: 1

Safety System Design:
Containments: steel vessel
ECCS design: actively initiated, passively operated water injection system
List of unique safety systems: PCCS

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Modular reactor design, factory fabrication, preassembled and tested reactor modules. General Atomics and state-owned Investigaciones Aplicadas (INVAP) of Argentina have memorandum of understanding for nuclear research.

References: INVAP, 1991. "CAREM Aims to Make Very-Low-Power Reactors Economic," *Nucl. Eng. International*, April 1991, 49-51.
Nucleonics Week, 1992. "General Atomics, INVAP Explore Research Reactor, Nuclear Ties.", pg. 15, April 2, 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: European Pressurized-Water Reactor
Reactor Type: PWR
Electrical Power: 1450 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: Final design in 1998

Vendor organization:
- Nuclear Power International
- Framatome, France
- Siemens, Germany

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 4250 MWT
Electrical power: 1450 MWe
Coolant inlet temp: 291°C
Coolant outlet temp: 325°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size: 17x17
No. of fuel assemblies: 205
Core loading (MTU):
Avg fuel burnup:
Power density: 107 kW/L
Operating cycle: 12 to 18 months

Steam Generator Design:
SG type:
No. of SGs: 4

Safety System Design:
Containments: steel primary with reinforced concrete secondary
ECCS design: high & low pressure borated coolant injection
List of unique safety systems: PRHR, PCCS

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Successor of the French N4 Reactor and the Konvoi plants in Germany. Zircaloy cladding.

References: *Nuclear Engineering International*, Vol. 37, 453, pg. 48-49, April 1992.
NN, Vol. 35, No. 10, Aug. 1992, pg. 52-53.
Nuclear News, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Hitachi Small Boiling-Water Reactor
Reactor Type: BWR
Electrical Power: 600 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: TBD

Vendor organization:

- Hitachi, Ltd, Japan
-
-

Utilities using product:

-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 1800 MWt
Electrical power: 600 MWe
Coolant inlet temp:
Coolant outlet temp:

Fuel Design:
Fuel composition: UO_2
Fuel enrichment: 3.6%
Array size: 8x8
No. of fuel assemblies: 708
Core loading (MTU):
Av fuel burnup: 39,000 MWd/MT
Power density: 34.2 kW/L
Operating cycle: 23 months

Steam Generator Design:
SG type: N/A
No. of SGs: N/A

Safety System Design:
Containments: steel vessel
ECCS design: natural circulation
List of unique safety systems: steam-driven reactor core isolation cooling, suppression pool, ADS, PCCS

Scheduling:
Construction time: 36 months
Construction cost:
Plant design life:

Comments:

References: Kataoka, Y., Suzuki, H., Murase, M., Sumida, I., Horiuchi, T., Mike, M., 1988. "Conceptual Design and Thermal-Hydraulic Characteristics of Natural Circulation Boiling Water Reactors," *Nucl. Technol.*, 82:147-156.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Mitsubishi Simplified Pressurized-Water Reactor
Reactor Type: PWR
Electrical Power: 600/1200 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: TBD

Vendor organization:

- Mitsubishi Heavy Industries, Japan
-

Utilities using product:

-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 1825/3650 MW(t)
Electrical power: 600/1200 MW(e)
Coolant inlet temp: 291°C
Coolant outlet temp: 325°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size: 15 x 15 (MS-600)
No. of fuel assemblies: 157 (MS-600)
Core loading (MTU):
Av fuel burnup:
Power density:
Operating cycle: 24 months

Steam Generator Design:
SG type: horizontal, U-tube
No. of SGs: 2

Safety System Design:
Containments: steel primary with concrete-filled, steel secondary
ECCS design: active and passive water injection systems, natural coolant circulation
List of unique safety systems: PCCS, ADS, gravity-feed containment flooding

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Includes data for both MS-600 and MS-1200 designs. Horizontal steam generators provide significant improvements in natural coolant circulation & prevention of crud buildup. Hybrid safety system with active safety systems to terminate credible accidents and passive safety systems to terminate improbable, severe accidents.

References: Matsuoka, T., 1991. "A Simplified Japanese PWR," *Nucl. Eng. Int.*, 36(443):47.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: PIUS
Reactor Type: PWR
Electrical Power: 640 MW(e)
Design Type: PRIME
Developmental Status: Design
Availability: 1998

Vendor organization:
- ABB Atom
-
-

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 2000 MW(t)
Electrical power: 640 MW(e)
Coolant inlet temp: 260°C
Coolant outlet temp: 290°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size: 18x18
No. of fuel assemblies: 213
Core loading (MTU):
Av fuel burnup:
Power density: 72.3 kW/L
Operating cycle: 11-12 months

Steam Generator Design:
SG type:
No. of SGs: 4

Safety System Design:
Containments:
ECCS design:
List of unique safety systems:

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Zircaloy-4 cladding.

References: *Nuclear News*, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Safe Integral Reactor
Reactor Type: PWR
Electrical Power: 320 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: TBD

Vendor organization:
- ABB-CE, U.S.A
- Stone & Webster
- Rolls Royce & Associates, Ltd.,
- U.K. Atomic Energy Authority

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 1000 MW(t)
Electrical power: 320 MW(e)
Coolant inlet temp: 295°C
Coolant outlet temp: 318°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment: 3.3-4.0%
Array size:
No. of fuel assemblies:
Core loading (MTU):
Av fuel burnup:
Power density: 55 kW/L
Operating cycle:

Steam Generator Design:
SG type: modular once-through
No. of SGs: 12

Safety System Design:
Containments:
ECCS design: gravity- and steam-driven coolant injection
List of unique safety systems: passive pressurizer system using fluidic diodes, ADS, natural circulation condensers for RHR

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: The entire primary nuclear system (core, steam generators, pressurizer, etc.) is located within a very large pressure vessel that provides a large water inventory similar to PRIME reactor concepts. The developmental program is currently on hold.

References: NEA, 1991. Small and Medium Nuclear Reactors, Organization for Economic Cooperation and Development/Nuclear Energy Agency.
Andrews, P.J., Hall, S. F., and Gibson, I. H., 1991. "SIR Reactor Safety and Decommissioning," *Journal of the British Nuclear Energy Society.*

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Simplified Boiling-Water Reactor
Reactor Type: BWR
Electrical Power: 640 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: U. S. NRC design certification in January 1995

Vendor organization:
- General Electric, U.S.A.
- Hitachi Ltd., Japan
- Toshiba Co., Japan
-
-

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 2000 MW(t)
Electrical power: 640 MW(e)
Coolant inlet temp: 216°C
Coolant outlet temp: 288°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size: 8x8 or 9x9
No. of fuel assemblies: 732
Core loading (MTU):
Av fuel burnup:
Power density: 41.0 kW/L
Operating cycle: 24 months

Steam Generator Design:
SG type: N/A
No. of SGs: N/A

Safety System Design:
Containments: steel primary with reinforced concrete secondary
ECCS design: gravity-driven, low-pressure coolant injection
List of unique safety systems: suppression pool, PCCS, isolation condenser to remove decay heat, ADS

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Uses a hybrid safety system. The PCCS consists of a "water wall" that removes decay heat from the PV using natural circulation water flow similar to the Toshiba 900 Seawater Coolant System. Zircaloy-2 cladding.

References: GE Advanced Boiling Water Reactors, D. R. Wilkins, GE Nuclear Energy, April 1990.
The Energy Daily, pg. 3, April 23, 1992.
Nuclear News, "The New Reactors," Vol 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Toshiba 900
Reactor Type: BWR
Electrical Power: 310 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: TBD

Vendor organization:
- Toshiba Corporation, Japan
-
-

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 900 MW(t)
Electrical power: 310 MW(e)
Coolant inlet temp:
Coolant outlet temp:

Fuel Design:
Fuel composition:
Fuel enrichment:
Array size: 8 x 8
No. of fuel assemblies: 388
Core loading (MTU):
Av fuel burnup:
Power density: 40 kW/L
Operating cycle:

Steam Generator Design:
SG type: large, external steam drums
No. of SGs: 2 steam drums

Safety System Design:
Containments: steel primary with reinforced concrete secondary
ECCS design: high and low pressure accumulators, gravity-driven coolant injection
List of unique safety systems: ADS, PCS, PCCS

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: No steam separators or dryers in the reactor pressure vessel (to enhance natural water circulation). Top-mounted, gravity-driven, control-rod drive mechanism. Natural circulation seawater coolant system.

References: Oka, Yoshiaki, 1989. "Research and Development of Next Generation Light Water Reactors in Japan," *International Atomic Energy Agency Technical Committee Meeting on Passive Safety Features in Current and Future Water-Cooled Reactors*, Moscow, USSR, March 21-24, 1989.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: VVER 88/91/92
Reactor Type: PWR
Electrical Power: 1000 MW(e)
Design Type: Evolutionary Plant
Developmental Status: Design
Availability: Late 1990s for VVER 92, earlier for other designs

Vendor organization:
- MTM
-
-

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 3000 MW(t)
Electrical power: 1000 MW(e)
Coolant inlet temp: 290°C
Coolant outlet temp: 320°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment: 2%, 3%, 4.4%
Array size:
No. of fuel assemblies: 163
Core loading (MTU): 80.1
Av fuel burnup: 42 GWd/MT
Power density: 12.9 kW/m
Operating cycle: 3 years

Steam Generator Design:
SG type: horizontal design
No. of SGs: 4

Safety System Design:
Containments: dual steel-lined concrete
ECCS design: passive injection system
List of unique safety systems: PRHR, PCCS

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: VVER-88 (also V-392) is basically a VVER-1000 with added passive heat removal systems and containment venting. VVER 91 is being developed for Finland. VVER-92 (also V-410) is further refined to simplify design and improve economics. Other advanced VVER concepts are being developed.

References: *Nuclear News*, Vol. 35, 14, pg. 57, November 1992.
Nuclear Engineering International, Vol. 36, 440, pg. 17-33, March 1991.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: Advanced CANDU Reactor
Reactor Type: HWR
Electrical Power: 900 MW(e)
Design Type: PRIME
Developmental Status: Research
Availability: TBD

Vendor organization:

- AECL, Canada
-
-

Utilities using product:

-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power:
Electrical power: 900 MW(e)
Coolant inlet temp:
Coolant outlet temp:

Fuel Design:
Fuel composition: UO_2
Fuel enrichment: natural
Array size:
No. of fuel assemblies:
Core loading (MTU):
Av fuel burnup:
Power density:
Operating cycle: continuous, on-line refueling

Steam Generator Design:
SG type:
No. of SGs:

Safety System Design:
Containments: reinforced concrete
ECCS design: calandria with heat pipe
List of unique safety systems: PCCS, PRHR

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: AECL has begun research and development at the Chalk River Laboratory. The insulated pressure tubes become highly conductive at elevated temperatures to provide passive core cooling.

References: Forsberg, C. W., Reich, W. J., "Worldwide Advanced Nuclear Power Reactors with Passive and Inherent Safety: What, Why, How, and Who," ORNL/TM-11907, Oak Ridge National Laboratory, September 1991.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: ALMR
Reactor Type: LMFBR
Electrical Power: 1440 MW(e)
Design Type: Breeder
Developmental Status: Design
Availability: Design certification targeted for 2005

Vendor organization:

- General Electric, U.S.A.
-
-

Utilities using product:

-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 4245 MW(t)
Electrical power: 1440 MW(e)
Coolant inlet temp: 338°C
Coolant outlet temp: 485°C

Fuel Design:
Fuel composition: U-Pu-Zr metal
Fuel enrichment:
Array size: 217 pins in hex bundle
No. of fuel assemblies: 66
Core loading (MTU):
Av fuel burnup:
Power density: 180 kW/L avg.
Operating cycle: 24 months

Steam Generator Design:
SG type: N/A
No. of SGs: N/A

Safety System Design:
Containments:
ECCS design:
List of unique safety systems:

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: The U.S. DOE program to develop an Advanced Liquid Metal Reactor (ALMR) involves applying Argonne National Laboratory's Integral Fast Reactor concept to GE's PRISM (Power Reactor Innovative Small Module) breeder reactor design. Liquid sodium coolant. HT-9 ferritic alloy cladding.

References: *Nuclear News*, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: European Fast Reactor
Reactor Type: LMFBR
Electrical Power: 1450 MW(e)
Design Type: Breeder
Developmental Status: Design
Availability: Basic design completed in 1998

Vendor organization:

- EFR Associates
-
-

Utilities using product:

-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 3600 MW(t)
Electrical power: 1450 MW(e)
Coolant inlet temp: 395°C
Coolant outlet temp: 545°C

Fuel Design:
Fuel composition: Mixed UO_2 and PuO_2
Fuel enrichment:
Array size: 331 pins in triangle
No. of fuel assemblies: 387
Core loading (MTU):
Av fuel burnup:
Power density: 290 kW/L
Operating cycle: 12 months

Steam Generator Design:
SG type: N/A
No. of SGs: N/A

Safety System Design:
Containments:
ECCS design:
List of unique safety systems:

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: European Fast Reactor (EFR) Associates is a joint design organization made up of Novatome, a division of Framatome of France; Siemens KWU of German; and NNC, Ltd., of Great Britain. Austenitic stainless steel cladding.

References: *Nuclear News*, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1992.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: MHTGR/Gas Turbine
Reactor Type: HTGR
Electrical Power: 100 MW(e)
Design Type: PRIME
Developmental Status: Research
Availability: TBD

Vendor organization:

- MIT, USA
-
-

Utilities using product:

-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 350 MW(t)
Electrical power: 100 MW(e)
Coolant inlet temp: 576°C
Coolant outlet temp: 850°C

Fuel Design:
Fuel composition: UCO, THO_2
Fuel enrichment:
Array size:
No. of fuel assemblies:
Core loading (MTU):
Av fuel burnup:
Power density: 5.9 kW/L
Operating cycle:

Steam Generator Design:
SG type: N/A
No. of SGs: N/A

Safety System Design:
Containments:
ECCS design:
List of unique safety systems:

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: This direct cycle MHTGR developed at MIT uses helium as both the reactor coolant and the working fluid to drive a gas turbine to produce electric power. the design is modular with data shown for one modular reactor unit.

References: *Proceedings of the International Workshop on the Closed-Cycle Gas-Turbine Modular High-Temperature Gas-Cooled Reactor*, Gas-Cooled Reactor Associates, Massachusetts Institute of Technology (MIT), June 17-19, 1991.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: MHTGR/U.S.
Reactor Type: HTGR
Electrical Power: 538 MW(e)
Design Type: PRIME
Developmental Status: Design
Availability: Estimated final design in 2001

Vendor organization:

- General Atomics, U.S.A.
-
-

Utilities using product:

-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 1400 MW(t)
Electrical power: 538 MW(e)
Coolant inlet temp: 258° C
Coolant outlet temp: 687° C

Fuel Design:
Fuel composition: UCO, THO_2
Fuel enrichment: 19.9%
Array size: Hexagonal graphite blocks
No. of fuel assemblies: 660
Core loading (MTU):
Av fuel burnup:
Power density: 5.9 kW/L
Operating cycle: 19 months

Steam Generator Design:
SG type: N/A
No. of SGs: N/A

Safety System Design:
Containments:
ECCS design:
List of unique safety systems:

Scheduling:
Construction time:
Construction cost:
Plant design life: 40 years

Comments: Helium coolant and graphite moderator. Refractory coating on fuel particles serves as cladding. The technical characteristics are shown for four combined reactor modules. There will be four modules, 350 MW(t) each, per nuclear power plant.

References: *Nuclear News*, "The New Reactors," Vol. 35, 12, pg. 65-90, September 1990.

PRODUCT DATA SHEET

GENERAL CHARACTERISTICS

Product Name: System Integrated Pressurized-Water Reactor
Reactor Type: PWR
Electrical Power: 350 MW(e)
Design Type: Evolutionary Technology
Developmental Status: Design
Availability: TBD

Vendor organization:
- JAERI
-
-

Utilities using product:
-
-
-

TECHNICAL CHARACTERISTICS

Reactor:
Thermal power: 1100 MW(t)
Electrical power: 350 MW(e)
Coolant inlet temp: 280°C
Coolant outlet temp: 310°C

Fuel Design:
Fuel composition: UO_2
Fuel enrichment:
Array size:
No. of fuel assemblies:
Core loading (MTU):
Av fuel burnup:
Power density: 84 $MW(t)/m^3$
Operating cycle:

Steam Generator Design:
SG type: once-through, helical coil
No. of SGs: 4

Safety System Design:
Containments:
ECCS design: natural circulation boron injection
List of unique safety systems: passive, hydraulic valves for boron tank

Scheduling:
Construction time:
Construction cost:
Plant design life:

Comments: Fully-integrated primary cooling system within the RPV and no openings or pipes below the core. Designed by Japan Atomic Energy Research Institute (JAERI). This is an advanced reactor concept still in the early design stages.

References: NEA, 1991. Small and Medium Nuclear Reactors, Organization for Economic Cooperation and Development/Nuclear Energy Agency.

Appendix C. CUSTOMER BASE FOR NUCLEAR POWER PLANTS

Table C.1. Socioeconomic and nuclear indicators for major countries of the world, 1990

					Nuclear power reactors				
					In operation		Under construction		
	Population[a]	Area[b]	Per-capita GNP[c]	GDP[d]	No.	Capacity	No.	Capacity	Consider further[e]
Low-income									
Mozambique	15.7	802	80	1,320					
Tanzania	24.5	945	110	2,060					
Ethiopia	51.2	1,222	120	5,490					
Somalia	7.8	638	120	890					
Nepal	18.9	141	170	2,890					
Chad	5.7	1,284	190	1,100					
Bhutan	1.4	47	190	280					
Lao PDR	4.1	237	200	870					
Malawi	8.5	118	200	1,660					
Bangladesh	106.7	144	210	22,880					
Burundi	5.4	28	210	1,000					
Zaire	37.3	2,345	220	7,540					
Uganda	16.3	236	220	2,820					
Madagascar	11.7	587	230	2,750					
Sierra Leone	4.1	72	240	840					
Mali	8.5	1,240	270	2,450					
Nigeria	115.5	924	290	34,760					X
Niger	7.7	1,267	310	2,520					
Rwanda	7.1	26	310	2,130					
Burkina Faso	9.0	274	330	3,060					
India	849.5	3,288	350	254,540	7	1,374	7	1,540	
Benin	4.7	113	360	1,810					

Table C.1 Socioeconomic and nuclear indicators for major countries of the world, 1990 (continued)

					Nuclear power reactors				
					In operation		Under construction		
	Population[a]	Area[b]	Per-capita GNP[c]	GDP[d]	No.	Capacity	No.	Capacity	Consider further[e]
China	1,133.7	9,561	370	364,900	0	0	3	2,148	
Haiti	6.5	28	370	2,760					
Kenya	24.2	580	370	7,540					
Pakistan	112.4	796	380	35,500	1	125	0	0	
Ghana	14.9	239	390	6,270					
Cent. Afr. Rep.	3.0	623	390	1,220					
Togo	3.6	57	410	1,620					
Zambia	8.1	753	420	3,120					
Guinea	5.7	246	440	2,820					
Sri Lanka	17.0	66	470	7,250					
Mauritania	2.0	1,026	500	950					
Lesotho	1.8	30	530	340					
Indonesia	178.2	1,905	570	107,290					X
Honduras	5.1	112	590	2,360					
Egypt	52.1	1,001	600	33,210					X
Afghanistan	-	652	-	-					
Cambodia	8.5	181	-	-					
Liberia	2.6	111	-	-					
Myanmar	41.6	677	-	-					
Sudan	25.1	2,506	-	-					
Vietnam	66.3	330	-	-					
Lower middle-income									
Bolivia	7.2	1,099	630	4,480					
Zimbabwe	9.8	391	640	5,310					

Table C.1 Socioeconomic and nuclear indicators for major countries of the world, 1990 (continued)

					Nuclear power reactors				
					In operation		Under construction		
	Population[a]	Area[b]	Per-capita GNP[c]	GDP[d]	No.	Capacity	No.	Capacity	Consider further[e]
Senegal	7.4	197	710	5,840					
Philippines	61.5	300	730	43,860					X
Cote d'Ivoire	11.9	322	750	7,610					
Dominican Rep.	7.1	49	830	7,310					
Papua New Guinea	3.9	463	860	3,270					
Guatemala	9.2	109	900	7,630					
Morocco	25.1	447	950	25,220					
Cameroon	11.7	475	960	11,130					
Ecuador	10.3	284	980	10,880					
Syria	12.4	185	1,000	14,730					
Congo	2.3	342	1,010	2,870					
El Salvador	5.2	21	1,110	5,400					
Paraguay	4.3	407	1,110	5,260					
Peru	21.7	1,285	1,160	36,550					X
Jordan	3.2	89	1,240	3,330					
Colombia	32.3	1,139	1,260	41,120					X
Thailand	55.8	513	1,420	80,170					X
Tunisia	8.1	164	1,440	11,080					
Jamaica	2.4	11	1,500	3,970					
Turkey	56.1	779	1,630	96,500					X
Romania	23.2	238	1,640	34,730	0	0	5	3,125	
Poland	38.2	313	1,690	63,590					X
Panama	2.4	77	1,830	4,750					
Costa Rica	2.8	51	1,900	5,700					
Chile	13.2	757	1,940	27,790					
Botswana	1.3	582	2,040	2,700					

Table C.1 Socioeconomic and nuclear indicators for major countries of the world, 1990 (continued)

					Nuclear Power Reactors				
					In operation		Under construction		
	Population[a]	Area[b]	Per-capita GNP[c]	GDP[d]	No.	Capacity	No.	Capacity	Consider further[e]
Algeria	25.1	2,382	2,060	42,150					X
Bulgaria	8.8	111	2,250	19,910	5	2,585	2	1,906	
Mauritius	1.1	2	2,250	2,090					
Malaysia	17.9	330	2,320	42,400					X
Argentina	32.3	2,767	2,370	93,260	2	935	1	692	
Iran	55.8	1,648	2,490	116,040	0	0	2	2,392	
Albania	3.3	29	-	-					
Angola	10.0	1,247	-	7,700					
Lebanon	-	10	-	-					
Mongolia	2.1	1,565	-	-					
Namibia	1.8	824	-	-					
Nicaragua	3.9	130	-	-					
Yemen	11.3	528	-	6,690					
Upper middle income									
Mexico	86.2	1,958	2,490	237,750	1	654	1	654	
South Africa	35.9	1,221	2,530	90,720	2	1,842	0	0	
Venezuela	19.7	912	2,560	48,270					X
Uruguay	3.1	177	2,560	8,220					
Brazil	150.4	8,512	2,680	414,060	1	626	1	1,245	
Hungary	10.6	93	2,780	32,920	4	1,645	0	0	
Yugoslavia	23.8	256	3,060	82,310	1	632	0	0	
Czechoslovakia	15.7	128	3,140	44,450	8	3,264	6	3,336	
Gabon	1.1	268	3,330	4,720					
Trinidad & Tobago	1.2	5	3,610	4,750					

Table C.1 Socioeconomic and nuclear indicators for major countries of the world, 1990 (continued)

	Population[a]	Area[b]	Per-Capita GNP[c]	GDP[d]	Nuclear power reactors In operation No.	In operation Capacity	Under construction No.	Under construction Capacity	Consider further[e]
Former USSR	290.0		4,600		45	34,673	25	21,255	
Portugal	10.4	92	4,900	56,820					X
Korea	42.8	99	5,400	236,400	9	7,220	2	1,900	
Greece	10.1	132	5,990	57,900					X
Saudi Arabia	14.9	2,150	7,050	80,890					X
Iraq	18.9	438	-	-					
Libya	4.5	1,760	-	-					
Oman	1.6	212	-	7,700					
High income									
Ireland	3.5	70	9,550	42,500					X
Israel	4.7	21	10,920	53,200					X
Spain	39.0	505	11,020	491,240	9	7,067	0	0	
Singapore	3.0	1	11,160	34,600					X
Hong Kong	5.8	1	11,490	59,670					X
New Zealand	3.4	269	12,680	42,760					X
Belgium	10.0	31	15,540	192,390	7	5,500	0	0	
United Kingdom	57.4	245	16,100	975,150	37	11,506	1	1,188	
Italy	57.7	301	16,830	1,090,750					X
Australia	17.1	7,687	17,000	296,300					X
Netherlands	14.9	37	17,320	279,150	2	508	0	0	
Austria	7.7	84	19,060	157,380					X
France	56.4	552	19,490	1,190,780	56	55,778	6	8,304	
U. Arab Emirates	1.6	84	19,860	28,270					
Canada	26.5	9,976	20,470	570,150	20	13,993	2	1,762	
United States	250.0	9,373	21,790	5,392,200	112	100,630	1	1,165	

Table C.1 Socioeconomic and nuclear indicators for major countries of the world, 1990 (continued)

					Nuclear Power Reactors				
					In Operation		Under Construction		
	Population[a]	Area[b]	Per-capita GNP[c]	GDP[d]	No.	Capacity	No.	Capacity	Consider further[e]
Denmark	5.1	43	22,080	130,960					X
Germany	79.5	357	22,320	1,488,210	26	24,430	6	3,319	
Norway	4.2	324	23,120	105,830					X
Sweden	8.6	450	23,660	228,110	12	9,817	0	0	
Japan	123.5	378	25,430	2,942,890	41	30,917	10	9,012	
Finland	5.0	338	26,040	137,250	4	2,310	0	0	
Switzerland	6.7	41	32,680	224,850	5	2,952	0	0	
Kuwait	2.1	18		23,540					
Cuba					0	0	2	816	

SOURCES: World Bank, *World Development Report 1992*, Washington, D.C., 1992.

[a]In millions, midyear 1990.

[b]In thousands of square kilometers.

[c]In 1990 U.S. dollars.

[d]In millions 1990 U.S. dollars.

[e]Total income exceeds $30 billion; will be considered further as a candidate country.

Table C.2. Electricity generation by fuel type,[a] candidate countries, 1989

	% composition				Total generation (tWh)
	Thermal[b]	Hydro	Nuclear	Other[c]	
Low income					
Egypt	81.9	18.1	0.0	0.0	35.3
Indonesia	83.6	15.6	0.0	0.7	27.5
Nigeria	76.8	22.2	0.0	0.0	9.9
Lower-middle income					
Algeria	98.6	1.4	0.0	0.0	14.5
Colombia	18.5	81.5	0.0	0.0	36.2
Malaysia	70.0	30.0	0.0	0.0	20.7
Peru	9.4	90.6	0.0	0.0	9.6
Philippines	52.8	26.0	0.0	21.2	25.0
Poland	97.2	2.8	0.0	0.0	136.9
Thailand	85.0	15.0	0.0	0.0	37.4
Turkey	63.1	36.7	0.0	0.2	48.8
Upper-middle income					
Greece	93.5	6.5	0.0	0.0	33.7
Portugal	76.1	23.9	0.0	—	24.3
Saudi Arabia	100.0	0.0	0.0	0.0	45.0
Venezuela	37.8	62.2	0.0	0.0	55.0
High income					
Australia	88.9	10.5	0.0	0.6	137.4
Austria	22.4	77.6	0.0	0.0	43.3
Denmark	99.5	—	0.0	0.5	22.0
Hong Kong	100.0	0.0	0.0	0.0	27.4
Ireland	92.6	7.4	0.0	0.0	13.6
Israel	100.0	0.0	0.0	0.0	19.8
Italy	82.8	15.5	0.0	1.8	181.2
New Zealand	18.1	77.7	0.0	4.3	28.2
Norway	0.2	99.8	0.0	0.0	105.1
Singapore	100.0	0.0	0.0	0.0	14.0

SOURCE: United Nations (1991).
A '—' signifies that the amount was <500 million kWh.
[a]Does not include the production of electricity for self-use (i.e., auto-producers).
[b]Electricity generated from oil, gas, and coal.
[c]Electricity generated from geothermal, solar, biomass, wind, and other renewable sources.

Table C.3. Production of conventional thermal electricity, candidate countries, 1988

	% Composition			Total
	Coal	Oil	Gas	(10^3 TOE)
Low income				
Egypt	0.0	64.4	35.6	7,834
Indonesia	25.7	72.6	1.7	7,911
Nigeria	0.0	13.5	86.5	2,601
Lower-middle income				
Algeria	0.0	7.2	92.8	4,754
Colombia	27.5	2.2	70.3	2,139
Malaysia	1.9	67.9	30.2	3,274
Peru	0.0	91.8	8.2	765
Philippines	21.3	78.7	0.0	2,886
Poland	93.2	3.9	2.9	50,466
Thailand	25.3	9.3	65.3	6,291
Turkey				
Upper-middle income				
Greece				
Portugal				
Saudi Arabia	0.0	58.8	41.2	15,135
Venezuela	0.0	24.0	76.0	4,928
High income				
Australia				
Austria				
Denmark				
Hong Kong	98.6	1.4	0.0	5,776
Ireland				
Israel	46.9	53.1	0.0	4,371
Italy				
New Zealand				
Norway				
Singapore	0.0	100.0	0.0	2,961

SOURCE: International Energy Agency (1990).

Table C.4. Energy resources, candidate countries

	Oil			Gas			Coal			Hydroelectric	
	Reserves (10^6 Bpd)	Production (10^3 Bpd)	(%)[a]	Reserves (-ft3 thru Oct.)	Production (109 cf)	(%)[a]	Reserves (10^6 Tons)	Production (10^3 Tons)	(%)[a]	Technical potential (MW)	1989 capacity (MW)
Low income											
Egypt	4,500.0	878.0	7.1	12.4	264.2	2.1	13	X[b]	X	3,210	2,445
Indonesia	6,581.3	1,431.0	7.9	64.8	1,360.3	2.1	1,000	4,553	0.5	141,800	1,850
Nigeria	17,899.8	1,867.0	3.8	104.7	115.8	0.1	21	130	0.6	12,400	1,900
Lower-middle income											
Algeria	9,200.0	803.0	3.2	116.5	1,618.4	1.4	43	15	0.0	287	285
Colombia	1,935.2	429.0	8.1	3.9	143.6	3.7	9,666	18,969	0.2	83,640	6,317
Malaysia	3,045.0	652.0	7.8	59.1	584.8	1.0	4	0	0.0	11,846	1,437
Peru	382.2	115.0	11.0	7.1	45.3	0.6	960	120	0.0	60,000	2,275
Philippines	38.0	3.0	2.9	0.1	X	X	X	1,360	X	6,598	2,154
Poland	30.0	2.0	2.4	4.5	X	X	28,700	177,633	0.6	2,400	1,976
Thailand	262.0	45.0	6.3	13.6	261.4	1.9	X	0	0.0	3,428	2,268
Turkey	540.4	87.0	5.9	0.7	7.2	1.0	175	3,200	1.8	43,000	6,598
Upper-middle income											
Greece	41.0	14.0	12.5	—	3.6	8.2	X	X	X	4,140	2,301
Portugal	0.0	0.0	0.0	0.0	0.0	0.0	3	258	8.6	7,184	3,360
Saudi Arabia	257,842.0	8,158.0	1.2	184.0	1,591.7	0.9	X	0	0.0	X	0
Venezuela	59,100.0	2,351.0	1.5	110.0	1,005.4	0.9	417	2,098	0.5	37,186	7,000

Table C.4 Energy resources, candidate countries (continued)

	Oil			Gas			Coal			Hydroelectric (MW)	
	Reserves (10^6 Bpd)	Production (10^3 Bpd)	(%)[a]	Reserves (-ft3 thru Oct.)	Production (10^9 cf)	(%)[a]	Reserves (10^6 Tons)	Production (10^3 Tons)	(%)[a]	Technical potential	1989 capacity
High income											
Australia	1,523.7	544.0	13.0	15.1	755.0	5.0	45,340	147,778	0.3	5,050	7,268
Austria	85.0	26.0	11.2	0.4	47.6	11.9	X	0	0.0	11,360	10,838
Denmark	755.0	142.0	6.9	4.1	133.3	3.3	X	X	X	14	10
Hong Kong	0.0	0.0	0.0	0.0	0.0	0.0	X	0	0.0	X	0
Ireland	0.0	0.0	0.0	1.7	88.6	5.2	5	43	0.9	X	512
Israel	1.3	0.2	5.6	—	X	X	X	X	X	X	0
Italy	692.2	84.0	4.4	11.4	713.0	6.3	X	74	X	13,000	18,237
New Zealand	170.2	40.0	8.6	3.4	146.8	4.3	X	2,462	X	12,182	4,287
Norway	7,609.4	1,848.0	8.9	60.7	869.1	1.4	X	360	X	34,000	26,465
Singapore	0.0	0.0	0.0	0.0	0.0	0.0	X	0	0.0	X	0

SOURCE: *Oil and Gas Journal*, December 30, 1991, and March 9, 1992; World Resources Institute (1990); United Nations (1991);
[a]The percentage refers to the annual rate of exhaustion of the resource.
[b]A '—' means that the value is less than one half of the unit of measure.
[c]A 'X' means that the amount is not available.

Table C.5. Electric utilities, candidate countries

Income level/ country	Generation[a]		Distribution[a]	
	Ownership	Name	Ownership	Name
Low income				
Egypt	National	Egyptian Electricity Authority	Regional	Multiple distribution agencies
Indonesia	National	Perusahaan Umum Listrik Negara (PLN)	National	Perusahaan Umum Listrik Negara (PLN)
Nigeria	National	Nigeria Electric Power Authority	National	Nigeria Electric Power Authority
Lower-middle income				
Algeria	Public	Societe Nationale d'Electricite et du Gaz	Regional	EEB
Colombia	National	ICEL	Regional	EPM
	National	ISA	Regional	Others
	National	Corelca		
	Regional	EEB		
	Regional	EPM		
Malaysia	Regional	National Electricity Board-Malaya	Regional	National Electricity Board-Malaya
	Regional	Sabah Electricity Board-Sabah	Regional	Sabah Electricity Board-Sabah
	Regional	Sarawak Electric Supply Corp.-Sarawak	Regional	Sarawak Electric Supply Corp.-Sarawak
Peru	National	Electroperu	Regional	Eight utilities
Philippines	National	National Power Corp.	Regional	Manila Electric Co.
			Regional	Cities, cooperatives
Poland	National	Ministry of Mining and Energy	National	Ministry of Mining and Energy
Thailand	National	Elec. Generating Auth. of Thailand (EGAT)	Regional	Metropolitan Electricity Authority (Bangkok+)
			Regional	Provincial Electricity Authority (Rest of country)
Turkey	National	Turkiye Elektrik Kurumu	National	Turkiye Elektrik Kurumu
	Private	Build/Operate/Transfer		
Upper-middle income				
Greece	National	Dimosia Epiheirisis Ilektrismou (DEI)	National	Dimosia Epiheirisis Ilektrismou (DEI)
Portugal	National	Electricidade de Portugal (EdP)	National	Electricidade de Portugal (EdP)
Saudi Arabia	National	General Electricity Corp. (Coordiantion)	Private	Saudi Consolidated Elec. Companies (Prod.)
	Private	Saudi Consolidated Elec. Companies (Prod.)		

Table C.5 Electric utilities, candidate countries (continued)

Income level/ country	Generation[a] Ownership	Generation[a] Name	Distribution[a] Ownership	Distribution[a] Name
Venezuela	National	Six companies	National	Six companies
	Private	Seven companies	Private	Seven companies
High income				
Australia	Regional	Electricity Trust of South Australia	Regional	Electricity Trust of South Australia
	Regional	Energy Authority of New South Wales	Regional	Energy Authority of New South Wales
	Regional	The Hydro-Electric Comm. (Tasmania)	Regional	The Hydro-Electric Comm. (Tasmania)
	Regional	Northern Territory Electricity Comm.	Regional	Northern Territory Electricity Comm.
	Regional	Queensland Electricity Commission	Regional	Queensland Electricity Commission
	Regional	Snowy Mtns. Hydro-Elec. (New So. Wales)	Regional	Snowy Mtns. Hydro-Elec. (New So. Wales)
	Regional	State Electricity Comm. of Victoria	Regional	State Electricity Comm. of Victoria
	Regional	State Energy Comm. of Western Australia	Regional	State Energy Comm. of Western Australia
Austria	National	Osterreichische Elektrizitatswirtschafts-AG	Public	Nine states, five major cities, municipalities
	Regional			
Denmark	Mixed	12 companies	Mixed	117 companies
Hong Kong	Private (?)	China Light and Power Co.	Private (?)	China Light and Power Co.
	Private (?)	Hong Kong Electric Co.	Private (?)	Hongkong Electric Co.
Ireland	National (?)	Electricity Supply Board	National (?)	Electricity Supply Board
Israel	National (?)	Israel Electric Co.	National (?)	Israel Electric Co.
Italy	National (?)	Ente Nazionale per l'Energia Elletrica	National (?)	Ente Nazionale per l'Energia Elletrica
New Zealand	National	Electricity Corp. of New Zealand	Regional	Boards and Supply Authorities
	Regional	Boards and Supply Authorities		
Norway	National	33%-State Water Resources and Elec. Auth	Same	
	Regional	50+%-municipalities, counties, cooperatives	Same	
	Private	10%		Same
Singapore	National (?)	Public Utilities Board	National (?)	Public Utilities Board

SOURCES: Catalano (1988).

[a]The following defines ownership types: (1) national means owned by the national government; (2) regional means owned by the government at a political subdivision under the national government, such as a municipality or county; and (3) private means ownership by other than the government.

Table C.6. Electricity generation by fuel type,[a] nuclear countries, 1989

	% Composition				Total generation (tWh)
	Thermal[b]	Hydro	Nuclear	Other[c]	
Low income					
China	81.2	18.8	0.0	0.0	582.0
India	71.0	26.0	3.0	0.0	245.2
Pakistan	52.0	48.0	—	0.0	35.4
Lower-middle income					
Argentina	55.7	32.3	12.0	0.0	46.5
Bulgaria	80.8	9.6	9.6	0.0	28.1
Iran	82.2	17.8	0.0	0.0	37.7
Romania	82.8	17.2	0.0	0.0	72.5
Upper-middle income					
Brazil	3.2	96.0	0.8	0.0	219.5
Czechoslovakia	63.8	5.2	31.1	0.0	79.1
Former USSR	73.6	13.5	12.9	0.0	1,649.0
Hungary	51.0	0.7	48.6	0.0	28.6
Korea (South)	45.0	4.9	50.2	0.0	94.5
Mexico	75.1	20.4	0.0	4.6	111.6
South Africa	97.0	0.5	2.5	0.0	157.5
Yugoslavia	61.8	28.4	5.6	4.1	83.5
High income					
Belgium	35.1	0.6	64.3	0.0	64.1
Canada	25.6	57.0	17.4	—	459.2
Finland	29.3	28.4	42.1	0.0	45.4
France	7.5	12.4	80.1	0.0	379.5
Germany	63.5	3.4	33.1	0.0	484.3
Japan	61.2	12.8	25.8	0.0	704.7
Netherlands	93.4	—	6.5	—	62.0
Spain	47.8	12.9	39.3	0.0	142.9
Sweden	1.9	49.7	48.4	0.0	136.1
Switzerland	1.4	52.5	45.9	0.0	49.7
United Kingdom	77.3	2.2	20.5	—	292.4
United States	71.0	9.5	19.0	0.4	2,780.8
Cuba	99.3	0.7	0.0	0.0	13.6

SOURCE: United Nations (1991).
[a]Does not include the production of electricity for self-use (i.e., auto-producers).
[b]Electricity generated from oil, gas, and coal.
[c]Electricity generated from geothermal, solar, biomass, wind, and other renewable sources.
[d]A '—' signifies that the amount was less than 500M kWh.

Table C.7. Production of conventional thermal electricity, nuclear countries, 1988

	% composition			Total (10^3 TOE)
	Coal	Oil	Gas	
Low income				
China	87.7	12.0	0.3	116,729
India	89.1	5.4	5.5	47,280
Pakistan	0.3	44.9	54.8	3,776
Lower-middle income				
Argentina	3.6	40.2	56.2	7,358
Bulgaria	85.3	14.7	0.0	13,033
Iran	0.0	55.2	44.8	10,713
Romania	48.3	22.9	28.8	20,142
Upper-middle income				
Brazil	37.1	62.9	0.0	2,584
Czechoslovakia	73.2	14.5	12.3	26,484
Former USSR	31.0	20.0	48.9	399,274
Hungary	46.1	16.4	37.5	7,807
Korea (South)	48.7	26.3	25.1	9,685
Mexico	10.0	76.2	13.8	18,223
South Africa	100.0	0.0	0.0	31,490
Yugoslavia	83.5	12.9	3.6	15,020
High income				
Belgium				
Canada				
Finland				
France				
Germany				
Japan				
Netherlands				
Spain				
Sweden				
Switzerland				
United Kingdom				
United States				
Cuba	0.0	100.0	0.0	3,723

Table C.8. Energy resources, nuclear countries

	Oil			Gas			Coal			Hydroelectric	
	Reserves (10^6 Bpd)	Production (10^3 Bpd)	(%)[a]	Reserves (1012 Cf)	Production (109 cf)	(%)[a]	Reserves (10^6 Tons)	Production (10^3 Tons)	(%)[a]	Technical potential (MW)	1989 capacity (MW)
Low income											
China	24,000.0	2,800.0	4.3	35.4	540.3	1.5	610,800	1,040,000	0.2	436,197	30,000
India	6,126.7	623.0	3.7	25.8	484.7	1.9	60,648	198,659	0.3	41,000	18,504
Pakistan	162.0	72.0	16.2	22.6	508.6	2.3	X[b]	2,619	X	3,106	2,897
Lower middle income											
Argentina	1,570.0	490.0	11.4	20.4	747.3	3.7	X	525	X	37,208	6,594
Bulgaria	15.0	—	0.0	0.2	—	—	30	193	0.6	5,282	1,975
Iran	92,860.0	3,358.0	1.3	600.4	779.1	0.1	193	1,200	0.6	11,200	1,804
Romania	1,150.0	140.0	4.4	3.7	920.0	24.9	X	8,289	X	7,600	5,583
Upper middle income											
Brazil	2,800.3	630.0	8.2	4.0	101.3	2.5	X	6,536	X	150,322	44,622
Czechoslovakia	15.0	—	—	0.5	—	—	1,870	24,681	1.3	2,165	2,920
Former USSR	57,000.0	10,300.0	6.6	1,750.0	28,619.0	1.6	104,000	502,844	0.5	766,200	64,100
Hungary	158.5	38.0	8.8	3.8	175.7	4.6	596	2,127	0.4	900	48
Korea (South)	0.0	0.0	0.0	0.0	0.0	0.0	158	20,785	13.2	2,000	2,339
Mexico	51,298.0	2,774.0	2.0	71.5	1,343.8	1.9	1,252	10,575	0.8	34,400	7,825
South Africa	0.0	0.0	0.0	1.8	—	—	55,333	174,711	0.3	X	592
Yugoslavia	240.0	43.0	6.5	2.9	65.1	2.2	70	293	0.4	13,600	7,000

Table C.8 Energy resources, nuclear countries (continued)

	Oil			Gas			Coal			Hydroelectric	
	Reserves (10^6 Bpd)	Production (10^3 Bpd)	(%)[a]	Reserves (1012 Cf)	Production (109 cf)	(%)[a]	Reserves (10^6 Tons)	Production (10^3 Tons)	(%)[a]	Technical potential (MW)	1989 capacity (MW)
High income											
Belgium	0.0	0.0	0.0	0.0	0.0	0.0	410	3,632	0.9	X	1,402
Canada	5,587.8	1,494.0	9.8	96.7	4,598.4	4.8	3,831	38,794	1.0	118,596	57,924
Finland	0.0	0.0	0.0	0.0	0.0	0.0	X	X	X	3,620	2,586
France	170.8	59.0	12.6	1.3	121.6	9.4	213	12,296	5.8	20,395	24,815
Germany	449.0	74.0	6.0	8.8	966.8	11.0	X	77,451	X	X	8,705
Japan	59.8	15.0	9.2	1.0	57.0	5.7	856	10,187	1.2	26,840	37,409
Netherlands	144.6	65.0	16.4	69.6	2,935.5	4.2	497	X	X	100	25
Spain	21.4	22.0	37.5	0.7	47.4	6.8	379	14,525	3.8	12,440	16,223
Sweden	0.0	0.0	0.0	0.0	0.0	0.0	X	0	0.0	19,000	15,616
Switzerland	0.0	0.0	0.0	0.0	0.0	0.0	X	X	X	8,200	11,580
United Kingdom	3,994.3	1,774.0	16.2	19.2	1,950.7	10.2	3,300	98,285	3.0	1,120	4,163
United States	26,250.0	7,372.0	10.3	169.3	18,675.0	11.0	112,972	810,034	0.7	183,287	88,746
Cuba	100.0	—	—	0.1	—		X	X	X	X	49

[a]The percentage refers to the annual rate of exhaustion of the resource.
[b]A 'X' means that the amount is not available.
[c]A '—' means that the value is less than one half of the unit of measure.
[d]**SOURCE:** *Oil and Gas Journal*, December 30, 1991 and March 9, 1992; World Resources Institute (1990); United Nations (1991).

Table C.9. Electric utilities, nuclear countries

Income level/ country	Generation[a]		Distribution[a]	
	Ownership	Name	Ownership	Name
Low income				
China	National	Ministry of Water Res. and Elec. Pwr.	National	Ministry of Water Res. and Elec. Pwr.
	Regional	Provincial governments	Regional	Provincial governments
India	National	Central Electricity Authority	Regional	Five Regional Electricity Boards
	National	National Thermal Power Corp.	Regional	21 State Electricity Boards
	National	National Hydroelectric Power Corp.		
	National	Dept. of Atomic Energy		
	Regional	Five Regional Electricity Boards		
	Regional	21 State Electricity Boards		
Pakistan	National	Water and Power Development Auth.	National	Water and Power Development Auth.
	National	Pakistan Atomic Energy Commission	Regional (?)	Karachi Electric Supply Corp.
	Regional (?)	Karachi Electric Supply Corp.		
Lower middle income				
Argentina	National	Multiple	National	Multiple
	Regional	Multiple	Regional	Multiple
Bulgaria	National		National	
Iran	National (?)	Iranian Electricity Co. (Tavanir Co.)	National (?)	Iranian Electricity Co. (Tavanir Co.)
Romania	National	Ministry of Electric Power	National	Ministry of Electric Power
Upper middle income				
Brazil	National	Eletrobas (+4 regional subs.)	National	25 concessionaires
			Private	575 concessionaires
Czechoslovakia	National	Federal Ministry of Fuels & Power	National	Federal Ministry of Fuels & Power
Former USSR	National		National	
Hungary	National	Hungarian Electric Power Trust	National	Hungarian Electric Power Trust
Korea (South)	National/Private	KEPCO	National/Private	KEPCO
	National	ISWACO		
	Private	Kyung In		

Table C.9 Electric utilities, nuclear countries (continued)

Income level/ country	Generation[a]		Distribution[a]	
	Ownership	Name	Ownership	Name
Mexico	National	Comision Federal de Electricidad (CFE)	National	Comision Federal de Electricidad (CFE)
	Private (?)	Compania de Luz y Fuerza	Private (?)	Compania de Luz y Fuerza
South Africa	National	Electricity Supply Comm. (Escom)	National	Electricity Supply Comm. (Escom)
	Regional	Municipalities	Regional	Municipalities
Yugoslavia	War		War	
High income				
Belgium	National	SPE	Private	EBES
	Private	EBES	Private	Intercom
	Private	Intercom	Private	Unerg
	Private	Unerg	Regional (?)	2 Municipalities
Canada				
Finland	National	IVO	National	IVO
	Regional	Municipalities	Regional	Municipalities
	Private	12 utilities	Private	12 utilities
France	National	Electricite de France	National	Electricite de France
Germany	Private (?)	Various	Private (?)	Various
Japan	National	Electric Power Development Co.	Private	10 EPCs
	National	Japan Atomic Power Co.	Regional	Municipalities
	Private	10 EPCs		
Netherlands	National	SEP	Regional (?)	Municipals
	National (?)	10 Generating Cos.		
Spain	National	Multiple	???	???
	Regional (?)			
	Private	Multiple		
Sweden	National	Swedish State Power Board	National	Swedish State Power Board
	National	Southern Sweden Power Supply	Regional	Municipalities
	Regional	Municipalities		
Switzerland	National (?)			
	Regional (?)	1,200 Utilities	Same as generators	
	Private (?)			

Table C.9 Electric utilities, nuclear countries (continued)

Income level/ country	Generation[a]		Distribution[a]	
	Ownership	Name	Ownership	Name
United Kingdom				
United States	National	Multiple	National	Multiple
	Regional	Multiple	Regional	Multiple
	Private	Multiple	Private	Multiple
Cuba	National		National	

[a]The following defines ownership types: (1) national means owned by the national government; (2) regional means owned by the government at a political subdivision under the national government, such as municipality or country; and (3) private means ownership by other than the government.

Appendix D. LIST OF NUCLEAR POWER REACTORS AND SUPPLIERS

Appendix D. WORLD LIST OF NUCLEAR POWER PLANTS OPERATING AND UNDER CONSTRUCTION

Table D.1 provides a list of nuclear power reactors in operation or under construction by country, the utility that owns the plant, the reactor vendor supplying the nuclear system, and other auxiliary information. Countries are listed alphabetically except for the Former Soviet Union which has been placed at the end of the table with a separate listing for each independent republic. The table empirically shows the historical relationships between specific vendors and utilities. It also provides an estimate of the relative sizes of various nuclear reactor vendors and their capabilities. A vendor that has sold many reactors within the last decade clearly has significant industrial capabilities. Similarly, if a vendor sold many reactors over a long time period, there will be some demand for replacement components that may provide a continuing income to that vendor. The original vendor has a competitive advantage for replacement parts. Since the objective of the table is to understand the current nuclear power industry, shutdown or decommissioned power reactors are not included. Such facilities provide no sales to a nuclear power plant supplier.

The names and general characteristics of countries, utilities, and nuclear power plants seldom change. The same is not true for vendors. Some vendors have merged. Other vendors have changed names. Finally, many vendors have created temporary partnerships to build nuclear power plants in particular countries. Typically, such partnerships include a reactor vendor plus a local company with much of the work subcontracted to the local company. Such partnerships often reflect local desires to maximize local employment. To understand who the major vendors are, Table D1 lists the current vendor organization based on those identified in Table S1. The historical vendor is listed in parenthesis. For some of the older power reactors, there is some uncertainty about the parent organization due to multiple mergers and name changes over a period of decades.

Table D.1 World list of nuclear power reactors operating and under construction[a]

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
ARGENTINA							
Operating	CANDU	Embalse, Cordoba	648	CNEA	AECL	73	01/84
	PHWR	Atucha 1	357	CNEA	Siemens	68	06/74
Construction	PHWR	Atucha 2	745	CNEA	Siemens (KWU)	81	95
BELGIUM							
Operating	PWR	Doel 1	412	Electrabel	WE (Acecowen)	69	02/75
	PWR	Doel 2	412	Electrabel	WE (Acecowen)	71	12/75
	PWR	Doel 3	945	Electrabel	Framatome (Framaceco)	74	10/82
	PWR	Doel 4	1065	Electrabel	WE (Acecowen)	78	07/85
	PWR	Tihange 1	920	Electrabel	WE (Acecowen)	69	10/75
	PWR	Tihange 2	941	Electrabel	Framatome (Framaceco)	75	06/83
	PWR	Tihange 3	1054	Electrabel	WE (Acecowen)	77	09/85
BRAZIL							
Operating	PWR	Angra 1	657	Furnas	WE	71	01/85
Construction	PWR	Angra 2	1309	Furnas	Siemens (KWU)	76	96
BULGARIA							
Operating	PWR	Kozloduy 1	440	NEC	MTM (AEE)	70	10/74
	PWR	Kozloduy 2	440	NEC	MTM (AEE)	70	11/75
	PWR	Kozloduy 3	440	NEC	MTM (AEE)	73	01/81
	PWR	Kozloduy 4	440	NEC	MTM (AEE)	73	06/82
	PWR	Kozloduy 5	1000	NEC	MTM (AEE)	80	01/88
	PWR	Kozloduy 6	1000	NEC	MTM (AEE)	82	91
CANADA							
Operating	CANDU	Bruce 1	825	Ont Hyd	AECL	70	09/77
	CANDU	Bruce 2	825	Ont Hyd	AECL	70	09/77
	CANDU	Bruce 3	825	Ont Hyd	AECL	72	01/78
	CANDU	Bruce 4	825	Ont Hyd	AECL	72	01/79
	CANDU	Bruce 5	915	Ont Hyd	AECL	78	03/85

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	CANDU	Bruce 6	915	Ont Hyd	AECL	78	09/84
	CANDU	Bruce 7	915	Ont Hyd	AECL	79	04/86
	CANDU	Bruce 8	915	Ont Hyd	AECL	79	05/87
	CANDU	Darlington 1	935	Ont Hyd	AECL	82	04/91
	CANDU	Darlington 2	935	Ont Hyd	AECL	81	09/90
	CANDU	Gentilly 2	685	Hyd-Quebec	AECL	74	10/83
	CANDU	Pickering 1	542	Ont Hyd	AECL	65	07/71
	CANDU	Pickering 2	542	Ont Hyd	AECL	65	12/71
	CANDU	Pickering 3	542	Ont Hyd	AECL	66	06/72
	CANDU	Pickering 4	542	Ont Hyd	AECL	66	06/73
	CANDU	Pickering 5	540	Ont Hyd	AECL	74	05/83
	CANDU	Pickering 6	540	Ont Hyd	AECL	74	02/84
	CANDU	Pickering 7	540	Ont Hyd	AECL	74	01/85
	CANDU	Pickering 8	540	Ont Hyd	AECL	74	02/86
	CANDU	Point Lepreau 1	680	NB Power	AECL	75	02/83
Construction	CANDU	Darlington 3	935	Ont Hyd	AECL	85	06/92
	CANDU	Darlington 4	935	Ont Hyd	AECL	86	03/92
CHINA							
Construction	PWR	Guangdong 1	900	GNPJVC	Framatome	86	10/92
	PWR	Guangdong 2	900	GNPJVC	Framatome	87	07/93
	PWR	Qinshan 1	300	MNI	CNNC	85	92
CUBA							
Construction	PWR	Juragua 1, Cienfuegos	440	MBI	MTM (AEE)	83	90
	PWR	Juragua 2, Cienfuegos	440	MBI	MTM (AEE)	85	95
CZECHOSLOVAKIA							
Operating	PWR	Bohunice V1-1	440	SPB	MTM (TPE/Skoda)	74	06/81
	PWR	Bohunice V1-2	440	SPB	MTM (TPE/Skoda)	74	01/81
	PWR	Bohunice V2-1	440	SPB	Siemens (Skoda)	76	02/85
	PWR	Bohunice V2-2	440	SPB	Siemens (Skoda)	76	12/85

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	Dukovany 1	432	CPB	Siemens (Skoda)	78	03/85
	PWR	Dukovany 2	432	CPB	Siemens (Skoda)	78	09/86
	PWR	Dukovany 3	432	CPB	Siemens (Skoda)	78	06/87
	PWR	Dukovany 4	432	CPB	Siemens (Skoda)	78	12/87
Construction	PWR	Mochovce 1	440	SPB	Siemens (Skoda)	83	12/93
	PWR	Mochovce 2	440	SPB	Siemens (Skoda)	83	09/94
	PWR	Mochovce 3	440	SPB	Siemens (Skoda)	85	09/95
	PWR	Mochovce 4	440	SPB	Siemens (Skoda)	85	04/96
	PWR	Temelin 1	1014	CPB	MTM (AEE/Skoda)	84	94
	PWR	Temelin 2	1014	CPB	MTM (AEE/Skoda)	85	96
FINLAND							
Operating	BWR	Olkiluoto 1	735	TVO	ABB (Atom)	74	10/79
	BWR	Olkiluoto 2	735	TVO	ABB (Atom)	75	07/82
	PWR	Loviisa 1	465	IVO	MTM (AEE)	71	05/77
	PWR	Loviisa 2	465	IVO	MTM (AEE)	72	01/81
FRANCE							
Operating	LMFBR	Creys-Malville, Super	1242	NERSA	Novatome/NIRA	77	86
	LMFBR	Phenix	250	CEA	Various	68	07/74
	GCR	Bugey 1	555	EdF	Citra	66	07/72
	PWR	Belleville 1	1363	EdF	Framatome	81	06/88
	PWR	Belleville 2	1363	EdF	Framatome	81	09/88
	PWR	Bugey 2	955	EdF	Framatome	72	03/79
	PWR	Bugey 3	955	EdF	Framatome	74	03/79
	PWR	Bugey 4	937	EdF	Framatome	74	07/79
	PWR	Bugey 5	937	EdF	Framatome	74	01/80
	PWR	Cattenom 1	1362	EdF	Framatome	79	04/87
	PWR	Cattenom 2	1362	EdF	Framatome	80	02/88
	PWR	Cattenom 3	1362	EdF	Framatome	82	02/91
	PWR	Chinon B1	919	EdF	Framatome	77	02/84

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	Chinon B2	919	EdF	Framatome	77	08/84
	PWR	Chinon B3	970	EdF	Framatome	81	03/87
	PWR	Chinon B4	970	EdF	Framatome	82	03/88
	PWR	Cruas Meysse 1	921	EdF	Framatome	78	04/84
	PWR	Cruas Meysse 2	956	EdF	Framatome	78	04/85
	PWR	Cruas Meysse 3	956	EdF	Framatome	78	09/84
	PWR	Cruas Meysse 4	921	EdF	Framatome	78	02/85
	PWR	Dampierre 1	937	EdF	Framatome	75	09/80
	PWR	Dampierre 2	937	EdF	Framatome	74	02/81
	PWR	Dampierre 3	937	EdF	Framatome	75	05/81
	PWR	Dampierre 4	937	EdF	Framatome	76	11/81
	PWR	Fessenheim 1	920	EdF	Framatome	71	12/77
	PWR	Fessenheim 2	920	EdF	Framatome	71	03/78
	PWR	Flamanville 1	1382	EdF	Framatome	79	12/86
	PWR	Flamanville 2	1382	EdF	Framatome	79	03/87
	PWR	Golfech 1	1363	EdF	Framatome	83	02/91
	PWR	Gravelines 1	951	EdF	Framatome	74	12/80
	PWR	Gravelines 2	951	EdF	Framatome	75	12/80
	PWR	Gravelines 3	957	EdF	Framatome	75	06/81
	PWR	Gravelines 4	957	EdF	Framatome	76	10/81
	PWR	Gravelines 5	951	EdF	Framatome	79	01/85
	PWR	Gravelines 6	951	EdF	Framatome	79	10/85
	PWR	Le Blayais 1	951	EdF	Framatome	76	12/81
	PWR	Le Blayais 2	951	EdF	Framatome	76	02/83
	PWR	Le Blayais 3	951	EdF	Framatome	77	11/83
	PWR	Le Blayais 4	951	EdF	Framatome	77	10/83
	PWR	Nogent 1	1363	EdF	Framatome	81	02/88
	PWR	Nogent 2	1363	EdF	Framatome	82	05/89
	PWR	Paluel 1	1382	EdF	Framatome	77	12/85

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	Paluel 2	1382	EdF	Framatome	77	12/85
	PWR	Paluel 3	1382	EdF	Framatome	77	02/86
	PWR	Paluel 4	1382	EdF	Framatome	77	06/86
	PWR	Penly 1	1382	EdF	Framatome	83	12/90
	PWR	Saint Alban 1	1381	EdF	Framatome	78	05/86
	PWR	Saint Alban 2	1381	EdF	Framatome	79	03/87
	PWR	St Laurent B1	921	EdF	Framatome	76	08/83
	PWR	St Laurent B2	921	EdF	Framatome	76	08/83
	PWR	Tricastin 1	955	EdF	Framatome	74	12/80
	PWR	Tricastin 2	955	EdF	Framatome	74	12/80
	PWR	Tricastin 3	955	EdF	Framatome	74	05/81
	PWR	Tricastin 4	955	EdF	Framatome	74	11/81
Construction	PWR	Cattenom 4	1362	EdF	Framatome	84	06/91
	PWR	Chooz B1	1516	EdF	Framatome	84	96
	PWR	Chooz B2	1516	EdF	Framatome	86	97
	PWR	Civaux 1	1516	EdF	Framatome	89	95
	PWR	Golfech 2	1363	EdF	Framatome	84	05/93
	PWR	Penly 2	1382	EdF	Framatome	84	03/92
GERMANY							
Operating	BWR	Brunsbuettel	806	KKB	Siemens (KWU)	70	02/77
	BWR	Gundremmingen B	1300	KRB	Siemens (KWU)	76	07/84
	BWR	Grundremmingen C	1308	KRB	Siemens (KWU)	76	01/85
	BWR	Isar 1	907	KKI	Siemens (KWU)	72	03/79
	BWR	Kruemmell	1316	KKK	Siemens (KWU)	74	03/84
	BWR	Philippsburg 1	900	KKP	Siemens (KWU)	71	03/80
	BWR	Wuergassen	670	PreussenElektra	AEG	68	11/75
	PWR	Biblis A	1204	RWE Energie	Siemens (KWU)	70	02/75
	PWR	Biblis B	1300	RWE Energie	Siemens (KWU)	72	01/77
	PWR	Brokdorf	1365	KBR	Siemens (KWU)	81	12/86

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	Emsland	1341	KKE	Siemens (KWU)	82	06/88
	PWR	Grafenrheinfeld	1300	Bayernwerk AG	Siemens (KWU)	75	06/82
	PWR	Grohnde	1394	KWG	Siemens (KWU)	76	02/85
	PWR	Isar 2	1400	KKI	Siemens (KWU)	82	04/88
	PWR	Neckar 1	840	GKN	Siemens (KWU)	72	12/76
	PWR	Neckar 2	1316	GKN	Siemens (KWU)	82	04/90
	PWR	Obrigheim	357	KWO	Siemens	65	03/69
	PWR	Philippsburg 2	1349	KKP	Siemens (KWU)	77	04/85
	PWR	Stade	672	KKS	Siemens	67	05/72
	PWR	Unterweser	1300	KKU	Siemens (KWU)	71	09/79
HUNGARY							
Operating	PWR	Paks 1	440	HPC	MTM (AEE)	74	08/83
	PWR	Paks 2	450	HPC	MTM (AEE)	74	11/84
	PWR	Paks 3	460	HPC	MTM (AEE)	79	12/86
	PWR	Paks 4	460	HPC	MTM (AEE)	79	12/87
INDIA							
Operating	BWR	Tarapur 1	160	NPCIL	GE	64	10/69
	BWR	Tarapur 2	160	NPCIL	GE	64	10/69
	FBR	FBTR	13	DAE	RRC	72	90
	PHWR	Madras, MAPS 1	235	NPCIL	DAE	70	01/84
	PHWR	Madras, MAPS 2	235	NPCIL	DAE	71	03/86
	PHWR	Narora 1	235	NPCIL	DAE/NPC	76	01/91
	PHWR	Rajasthan, RAPS 1	220	DAE	AECL	64	12/73
	PHWR	Rajasthan, RAPS 2	220	NPCIL	AECL	68	04/81
Construction	PHWR	Kaiga 1	235	NPCIL	DAE/NPC	88	12/95
	PHWR	Kaiga 2	235	NPCIL	DAE/NPC	88	06/96
	PHWR	Kakrapar 1	235	NPCIL	DAE/NPC	83	06/92
	PHWR	Kakrapar 2	235	NPCIL	DAE/NPC	83	06/93
	PHWR	Narora 2	235	NPCIL	DAE/NPC	76	01/92

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PHWR	Rajasthan, RAPP-3	235	NPCIL	DAE/NPC	88	11/95
	PHWR	Rajasthan, RAPP-4	235	NPCIL	DAE/NPC	88	05/96
	PHWR	Tarapur 3	500	NPCIL	DAE/NPC		
	PHWR	Tarapur 4	500	NPCIL	DAE/NPC		
	PWR	Koodankulam 1	953		MTM (AEE)	91	98
	PWR	Koodankulam 2	953		MTM (AEE)	91	00
JAPAN							
Operating	BWR	Fukushima Daiichi 1	460	TEPCO	GE	67	03/71
	BWR	Fukushima Daiichi 2	784	TEPCO	GE/Toshiba	69	07/74
	BWR	Fukushima Daiichi 3	784	TEPCO	Toshiba	70	03/76
	BWR	Fukushima Daiichi 4	784	TEPCO	Hitachi	72	10/78
	BWR	Fukushima Daiichi 5	784	TEPCO	Toshiba	71	04/78
	BWR	Fukushima Daiichi 6	1100	TEPCO	GE/Toshiba	73	10/79
	BWR	Fukushima Daini 1	1100	TEPCO	Toshiba	75	04/82
	BWR	Fukushima Daini 2	1100	TEPCO	Hitachi	79	02/84
	BWR	Fukushima Daini 3	1100	TEPCO	Toshiba	80	06/85
	BWR	Fukushima Daini 4	1100	TEPCO	Hitachi	80	08/87
	BWR	Hamaoka 1	540	Chubu	Toshiba	71	03/76
	BWR	Hamaoka 2	840	Chubu	Toshiba/Hitachi	74	11/78
	BWR	Hamaoka 3	1100	Chubu	Toshiba/Hitachi	82	09/87
	BWR	Kashiwazaki-Kariwa 1	1100	TEPCO	Toshiba	78	09/85
	BWR	Kashiwazaki-Kariwa 2	1100	TEPCO	Toshiba	83	09/90
	BWR	Kashiwazaki-Kariwa 5	1100	TEPCO	Hitachi	83	04/90
	BWR	Onagawa 1	524	Tohoku	Toshiba	79	06/84
	BWR	Shimane 1	460	Chugoku	Hitachi	70	03/74
	BWR	Shimane 2	820	Chugoku	Hitachi	84	02/89
	BWR	Tokai 2	1100	JAPCO	GE/Hitachi	72	11/78
	BWR	Tsuruga 1	357	JAPCO	GE/Hitachi	66	03/70
	LWCHWR	Fugen ATR	165	PNC	PNC/Hitachi	70	03/79

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	Magnox	Tokai Japco	166	JAPCO	GE	60	07/66
	PWR	Genkai 1	559	Kyushu	Mitsubishi	69	10/75
	PWR	Genkai 2	559	Kyushu	Mitsubishi	76	03/81
	PWR	Ikata 1	566	Shikoku	Mitsubishi	73	09/78
	PWR	Ikata 2	566	Shikoku	Mitsubishi	78	03/82
	PWR	Mihama 1	340	Kansai	Mitsubishi	67	11/70
	PWR	Mihama 2	500	Kansai	Mitsubishi	68	07/72
	PWR	Mihama 3	826	Kansai	Mitsubishi	72	12/76
	PWR	Ohi 1	1175	Kansai	WE/Mitsubishi	72	03/79
	PWR	Ohi 2	1175	Kansai	WE/Mitsubishi	72	12/79
	PWR	Sendai 1	890	Kyushu	Mitsubishi	79	07/84
	PWR	Sendai 2	890	Kyushu	Mitsubishi	81	11/85
	PWR	Takahama 1	826	Kansai	WE/Mitsubishi	70	11/74
	PWR	Takahama 2	826	Kansai	Mitsubishi	71	11/75
	PWR	Takahama 3	870	Kansai	Mitsubishi	81	01/85
	PWR	Takahama 4	870	Kansai	Mitsubishi	81	06/85
	PWR	Tomari 1	579	Hokkaido	Mitsubishi	84	06/89
	PWR	Tomari 2	579	Hokkaido	Mitsubishi	84	04/91
	PWR	Tsuruga 2	1160	JAPCO	Mitsubishi	82	02/87
Construction	BWR	Hamaoka 4	1137	Chubu	Toshiba/Hitachi	89	09/93
	BWR	Kashiwazaki-Kairwa 3	1100	TEPCO	Toshiba	87	07/93
	BWR	Kashiwazaki-Kairwa 4	1100	TEPCO	Hitachi	88	07/94
	BWR	Onagawa 2	825	Tohoku	Toshiba	89	02/96
	BWR	Shika 1	540	Hokuriku	Hitachi	88	03/93
	BWR	Kashiwazaki-Kairwa 6	1356	TEPCO	HGET	91	07/96
	BWR	Kashiwazaki-Kairwa 7	1356	TEPCO	HGET	92	07/97
	LMFBR	Monju	280	PNC	Toshiba	85	95
	PWR	Genkai 3	1180	Kyushu	Mitsubishi	85	07/93
	PWR	Genkai 4	1180	Kyushu	Mitsubishi	85	07/95

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	Ikata 3	890	Shikoku	Mitsubishi	86	03/95
	PWR	Ohi 3	1180	Kansai	Mitsubishi	87	12/91
	PWR	Ohi 4	1180	Kansai	Mitsubishi	87	08/93
KOREA							
Operating	CANDU	Wolsong 1	679	KEPCO	AECL	77	04/83
	PWR	Kori 1	595	KEPCO	WE	70	04/78
	PWR	Kori 2	650	KEPCO	WE	77	07/83
	PWR	Kori 3	950	KEPCO	WE	78	09/85
	PWR	Kori 4	950	KEPCO	WE	80	03/86
	PWR	Uljin 1	950	KEPCO	Framatome	82	09/88
	PWR	Uljin 2	950	KEPCO	Framatome	82	08/89
	PWR	Yeonggwang 1	966	KEPCO	WE	79	08/86
	PWR	Yeonggwang 2	966	KEPCO	WE	79	07/87
Construction	CANDU	Wolsong 2	663	KEPCO	AECL	92	06/97
	CANDU	Wolsong 3	700	KEPCO	AECL	92	98
	CANDU	Wolsong 4	700	KEPCO	AECL	92	99
	PWR	Uljin 3	950	KEPCO	ABB (CE)	92	06/98
	PWR	Uljin 4	950	KEPCO	ABB (CE)	92	06/99
	PWR	Yeonggwang 3	950	KEPCO	ABB (CE)	89	95
	PWR	Yeonggwang 4	950	KEPCO	ABB (CE)	89	96
MEXICO							
Operating	BWR	Laguna Verde 1	675	CFE	GE	75	07/90
Construction	BWR	Laguna Verde 2	675	CFE	GE	75	94

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
NETHERLANDS							
Operating	BWR	Dodewaard	58	NVGKN	GE	65	01/69
	PWR	Borssele	481	EPZ	Siemens (KWU)	69	10/73
PAKISTAN							
Operating	PHW	Kanupp	137	PAEC	GE	66	12/72
PHILIPPINES							
Construction	PWR	PNNP 1	651	PNPC	WE	76	95
ROMANIA							
Construction	PHW	Cernavoda 1	700	REA	AECL	80	93
	PHW	Cernavoda 2	700	REA	AECL	82	95
	PHW	Cernavoda 3	700	REA	AECL	84	97
	PHW	Cernavoda 4	700	REA	AECL	85	98
	PHW	Cernavoda 5	700	REA	AECL	86	99
SLOVENIA							
Operating	PWR	Krsko	664	NEK	WE	74	01/83
SOUTH AFRICA							
Operating	PWR	Koeberg 1	965	Eskom	Framatome	77	07/84
	PWR	Koeberg 2	965	Eskom	Framatome	77	11/85
SPAIN							
Operating	BWR	Cofrentes	990	Iberdrola	GE	75	03/85
	BWR	Santa Maria de Garona	460	Nuclenor	GE	66	05/71
	PWR	Almaraz 1	930	Central Nuclear	WE	73	10/81
	PWR	Almaraz 2	930	Central Nuclear	WE	73	02/84
	PWR	Asco 1	930	ANA	WE	74	09/84
	PWR	Asco 2	930	ANA	WE	75	03/86
	PWR	Jose Cabrera	160	Union Electrica	WE	65	02/69
	PWR	Trillo 1	1041	Central de Trillo	Siemens (KWU)	79	08/88
	PWR	Vandellos 2	992	ANV	WE	81	03/88

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
SWEDEN							
Operating	BWR	Barsebaeck 1	615	Sydkraft AB	ABB (Asea-Atom)	71	07/75
	BWR	Barsebaeck 2	600	Sydkraft AB	ABB (Asea-Atom)	73	07/77
	BWR	Forsmark 1	1004	Vattenfall AB	ABB (Asea-Atom)	73	12/80
	BWR	Forsmark 2	1004	Vattenfall AB	ABB (Asea-Atom)	75	07/81
	BWR	Forsmark 3	1090	Vattenfall AB	ABB (Asea-Atom)	79	08/85
	BWR	Oskarshamn 1	460	OKG	ABB (Atom)	66	02/72
	BWR	Oskarshamn 2	617	OKG	ABB (Atom)	70	12/74
	BWR	Oskarshamn 3	1200	OKG	ABB (Atom)	80	08/85
	BWR	Ringhals 1	780	Vattenfall AB	ABB (Asea-Atom)	69	01/76
	PWR	Ringhals 2	840	Vattenfall AB	WE	70	05/75
	PWR	Ringhals 3	960	Vattenfall AB	WE	73	09/81
	PWR	Ringhals 4	960	Vattenfall AB	WE	74	11/83
SWITZERLAND							
Operating	BWR	Leibstadt	1045	KKL	GE/ABB	75	12/84
	BWR	Muehleberg	336	BKW	GE/ABB	67	11/72
	PWR	Beznau 1	364	NOK	WE	65	12/69
	PWR	Beznau 2	350	NOK	WE	68	03/72
	PWR	Gösgen	970	KKG-D	Siemens (KWU)	73	11/79
TAIWAN							
Operating	BWR	Chin-shan 1	636	TPC	GE	72	12/78
	BWR	Chin-shan 2	636	TPC	GE	73	07/79
	BWR	Kuosheng 1	985	TPC	GE	75	12/81
	BWR	Kuosheng 2	985	TPC	GE	75	03/83
	PWR	Maanshan 1	951	TPC	WE	78	07/84
	PWR	Maanshan 2	951	TPC	WE	78	05/85
UNITED KINGDOM							

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
Operating	AGR	Dungeness B1	420	NE	NNC (APC)	66	04/85
	AGR	Dungeness B2	420	NE	NNC (APC)	66	88
	AGR	Hartlepool 1	560	NE	NNC	68	84
	AGR	Hartlepool 2	560	NE	NNC	68	85
	AGR	Heysham 1-1	560	NE	NNC	70	84
	AGR	Heysham 1-2	510	NE	NNC	70	85
	AGR	Heysham 2-1	660	NE	NNC	80	09/88
	AGR	Heysham 2-2	660	NE	NNC	80	89
	AGR	Hinkley Point B1	610	NE	NNC (TNPG)	67	10/78
	AGR	Hinkley Point B2	610	NE	NNC (TNPG)	67	09/76
	AGR	Hunterston B1	660	SNL	NNC (TNPG)	67	02/76
	AGR	Hunterston B2	660	SNL	NNC (TNPG)	67	03/77
	AGR	Torness 1	682	SNL	NNC	80	05/88
	AGR	Torness 2	682	SNL	NNC	80	04/89
	LMFBR	Dounreay PFR	270	AEA Technology	NNC (TNPG)	67	10/76
	Magnox	Bradwell 1(10)	129	NE	NNC (TNPG)	57	07/62
	Magnox	Bradwell 2(10)	129	NE	NNC (TNPG)	57	11/62
	Magnox	Calder Hall 1	61	BNFL	NNC (TWC)	53	56
	Magnox	Calder Hall 2	61	BNFL	NNC (TWC)	53	57
	Magnox	Calder Hall 3	61	BNFL	NNC (TWC)	53	58
	Magnox	Calder Hall 4	61	BNFL	NNC (TWC)	53	59
	Magnox	Chapelcross 1	60	BNFL	NNC (Mitchels)	56	59
	Magnox	Chapelcross 2	60	BNFL	NNC (Mitchels)	56	59
	Magnox	Chapelcross 3	60	BNFL	NNC (Mitchels)	56	60
	Magnox	Chapelcross 4	60	BNFL	NNC (Mitchels)	56	60
	Magnox	Dungeness A1(10)	220	NE	NNC (TNPG)	60	10/65
	Magnox	Dungeness A2(10)	220	NE	NNC (TNPG)	60	12/65
	Magnox	Hinkley Point A1(10)	249	NE	NNC (EE/BW/TW)	57	05/65
	Magnox	Hinkley Point A2(10)	240	NE	NNC (EE/BW/TW)	57	05/65

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	Magnox	Oldbury 1(10)	225	NE	NNC (TNPG)	62	01/68
	Magnox	Oldbury 2(10)	225	NE	NNC (TNPG)	62	04/68
	Magnox	Sizewell A1(10)	250	NE	NNC (EE/BW/TW)	61	03/66
	Magnox	Sizewell A2(10)	250	NE	NNC (EE/BW/TW)	61	04/66
	Magnox	Trawsfynydd 1(10)	236	NE	NNC (APC)	59	02/65
	Magnox	Trawsfynydd 2(10)	236	NE	NNC (APC)	59	04/65
	Magnox	Wylfa A1(10)	496	NE	NNC (EE/BW/TW)	63	11/71
	Magnox	Wylfa A1(10)	496	NE	NNC (EE/BW/TW)	63	01/72
Construction	PWR	Sizewell B	1258	NE	WE/NNC	88	05/94
USA							
Operating	BWR	Big Rock Point	75	CPC	GE	60	11/65
	BWR	Browns Ferry 1	1098	TVA	GE	67	08/74
	BWR	Browns Ferry 2	1098	TVA	GE	67	03/75
	BWR	Browns Ferry 3	1098	TVA	GE	68	03/77
	BWR	Brunswick 1	849	CPL/NCMPA	GE	70	03/77
	BWR	Brunswick 2	849	CPL/NCMPA	GE	70	11/75
	BWR	Clinton 1	985	IPC/SPC	GE	75	04/87
	BWR	Cooper	801	NPPD	GE	68	07/74
	BWR	Dresden 2	828	CEC	GE	66	06/70
	BWR	Dresden 3	828	CEC	GE	66	10/71
	BWR	Duane Arnold	565	IELP	GE	70	02/75
	BWR	Edwin I Hatch 1	810	SNOC	GE	68	12/75
	BWR	Edwin I Hatch 2	820	SNOC	GE	72	09/79
	BWR	Fermi 2	1154	DE	GE	69	01/88
	BWR	Grand Gulf 1	1306	Entergy	GE	74	07/85
	BWR	Hope Creek 1	1170	PSEG	GE	74	12/86
	BWR	James A FitzPatrick	849	NYPA	GE	68	07/75
	BWR	La Salle 1	1078	CEC	GE	73	12/82
	BWR	La Salle 2	1078	CEC	GE	72	10/84

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	BWR	Limerick 1	1092	PEC	GE	74	02/86
	BWR	Limerick 2	1092	PEC	GE	74	90
	BWR	Millstone 1	684	CLP	GE	66	12/70
	BWR	Monticello	576	NSP	GE	67	06/71
	BWR	Nine Mile Point 1	625	NMPC	GE	65	12/69
	BWR	Nine Mile Point 2	1166	NMPC	GE	75	04/88
	BWR	Oyster Creek 1	670	JCPL	GE	64	12/69
	BWR	Peach Bottom 2	1098	PEC	GE	68	07/74
	BWR	Peach Bottom 3	1098	PEC	GE	69	12/74
	BWR	Perry 1	1252	CEIC	GE	74	11/87
	BWR	Pilgrim 1	691	BEC	GE	67	12/72
	BWR	Quad Cities 1	833	CEC	GE	67	02/73
	BWR	Quad Cities 2	833	CEC	GE	66	03/73
	BWR	River Bend 1	991	GSU	GE	79	06/86
	BWR	Susquehanna 1	1100	PPL	GE	73	08/83
	BWR	Susquehanna 2	1100	PPL	GE	73	02/85
	BWR	Vermont Yankee	540	VYNPC	GE	66	11/72
	BWR	WNP 2	1154	WPPSS	GE	72	12/84
	FBR	EBR 2	20	DOE	ANL	58	08/64
	PWR	Arkansas Nuclear 1	883	Entergy	B&W	68	12/74
	PWR	Arkansas Nuclear 2	897	Entergy	ABB (CE)	72	03/80
	PWR	Beaver Valley 1	860	DLC	WE	69	03/77
	PWR	Beaver Valley 2	860	DLC	WE	74	11/87
	PWR	Braidwood 1	1175	CEC	WE	75	11/87
	PWR	Braidwood 2	1175	CEC	WE	75	10/88
	PWR	Byron 1	1175	CEC	WE	75	09/85
	PWR	Byron 2	1175	CEC	WE	75	08/87
	PWR	Callaway 1	1219	Union Electric	WE	75	12/84
	PWR	Calvert Cliffs 1	900	BGE	ABB (CE)	68	05/75

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	Calvert Cliffs 2	900	BGE	ABB (CE)	68	04/77
	PWR	Catawba 1	1205	Duke	WE	74	06/85
	PWR	Catawba 2	1205	Duke	WE	74	09/86
	PWR	Comanche Peak 1	1160	Texas Utilities	WE	74	08/90
	PWR	Crystal River 3	860	FPC	B&W	68	03/77
	PWR	Davis Besse 1	925	Toledo Edison Co.	B&W	69	11/77
	PWR	Diablo Canyon 1	1124	PG&E	WE	68	05/85
	PWR	Diablo Canyon 2	1137	PG&E	WE	70	03/86
	PWR	Donald C Cook 1	1056	IMPC	WE	69	08/75
	PWR	Donald C Cook 2	1100	IMPC	WE	69	07/78
	PWR	Fort Calhoun 1	510	OPPD	ABB (CE)	68	09/73
	PWR	H B Robinson 2	769	CPL	WE	67	03/71
	PWR	Haddam Neck	603	CYAPC	WE	64	01/68
	PWR	Indian Point 2	975	ConEd	WE	66	07/74
	PWR	Indian Point 3	1005	NYPA	WE	69	08/76
	PWR	Joseph M Farley 1	860	SNOC	WE	70	12/77
	PWR	Joseph M Farley 2	860	SNOC	WE	70	07/81
	PWR	Kewaunee	563	WPSC	WE	67	06/74
	PWR	Main Yankee	890	MYAPC	ABB (CE)	68	12/72
	PWR	Millstone 2	888	CLP	ABB (CE)	69	12/75
	PWR	Millstone 3	1209	CLP	WE	75	04/86
	PWR	North Anna 1	947	VPC	WE	71	06/78
	PWR	North Anna 2	947	VPC	WE	71	12/80
	PWR	Oconee 1	934	Duke	B&W	67	07/73
	PWR	Oconee 2	934	Duke	B&W	67	09/74
	PWR	Oconee 3	934	Duke	B&W	67	12/74
	PWR	Palisades	812	CPC	ABB (CE)	67	12/71
	PWR	Palo Verde 1	1303	ANPP	ABB (CE)	76	01/86
	PWR	Palo Verde 2	1303	ANPP	ABB (CE)	76	09/86

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	Palo Verde 3	1303	ANPP	ABB (CE)	76	01/88
	PWR	Point Beach 1	524	WEP	WE	66	12/70
	PWR	Point Beach 2	524	WEP	WE	68	10/72
	PWR	Prairie Island 1	534	NSP	WE	68	04/74
	PWR	Prairie Island 2	531	NSP	WE	68	04/75
	PWR	R E Ginna	498	RGE	WE	66	03/70
	PWR	Salem 1	1132	PSEG	WE	68	06/77
	PWR	Salem 2	1158	PSEG	WE	68	10/81
	PWR	San Onofre 1	456	SCEC	WE	64	01/68
	PWR	San Onofre 2	1127	SCEC	ABB (CE)	74	08/83
	PWR	San Onofre 3	1127	SCEC	ABB (CE)	74	04/84
	PWR	Seabrook 1	1194	PSNH	WE	76	08/90
	PWR	Sequoyah 1	1190	TVA	WE	69	07/81
	PWR	Sequoyah 2	1190	TVA	WE	69	06/82
	PWR	Shearon Harris 1	950	CPL	WE	78	05/87
	PWR	South Texas 1	1312	HLP	WE	76	08/88
	PWR	South Texas 2	1312	HLP	WE	76	06/89
	PWR	St. Lucie 1	872	FPL	ABB (CE)	69	12/76
	PWR	St. Lucie 2	892	FPL	ABB (CE)	77	08/83
	PWR	Slurry 1	848	VPC	WE	68	12/72
	PWR	Slurry 2	848	VPC	WE	68	05/73
	PWR	Three Mile Island 1	871	GPUN	B&W	67	09/74
	PWR	Trojan	1178	PortGE	WE	71	05/76
	PWR	Turkey Point 3	699	FPL	WE	67	12/72
	PWR	Turkey Point 4	699	FPL	WE	67	0973
	PWR	Virgil C Summer 1	933	SCEGC	WE	73	01/84
	PWR	Vogtle 1	1160	SNOC	WE	74	06/87
	PWR	Vogtle 2	1160	SNOC	WE	76	05/89
	PWR	W B McGuire 1	1220	Duke	WE	71	12/81

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	W B McGuire 2	1220	Duke	WE	71	03/84
	PWR	Waterford 3	1153	Entergy	ABB (CE)	74	09/85
	PWR	Wolf Creek 1	1192	WCNOC	WE	77	09/85
	PWR	Zion 1	1098	CEC	WE	68	12/73
	PWR	Zion 2	1098	CEC	WE	68	09/74
Construction	PWR	Bellefonte 1	1263	TVA	B&W	74	
	PWR	Bellefonte 2	1263	TVA	B&W	74	
	PWR	Comanche Peak 2	1160	Texas Utilities	WE	74	
	PWR	Watts Bar 1	1218	TVA	WE	72	
	PWR	Watts Bar 2	1218	TVA	WE	72	
FORMER SOVIET UNION							
KAZAKHSTAN							
Operating	FBR	BN 350, Shevchenko	150	SCUAE	MTM	64	07/73
LITHUANIA							
Operating	LWGR	Ignalina 1	1500	MAEP	MTM	77	05/85
	LWGR	Ignalina 2	1500	MAEP	MTM	78	12/87
RUSSIA							
Operating	BWR	Melekess VK50	62	SCUAE	MTM	62	01/66
	FBR	Beloyarsk 3, BN 600	600	MAEP	MTM	66	11/81
	FBR	Melekess BOR60	12	MPS	MTM	65	01/70
	FBR	Obninsk BR5	15	MPS	MTM	54	59
	LWGR	Bilibino 1	12	MAEP	MTM	70	04/74
	LWGR	Bilibino 2	12	MAEP	MTM	70	02/75
	LWGR	Bilibino 3	12	MAEP	MTM	70	02/76
	LWGR	Bilibino 4	12	MAEP	MTM	70	01/77
	LWGR	Kursk 1	1000	MAEP	MTM	72	10/77
	LWGR	Kursk 2	1000	MAEP	MTM	73	08/79
	LWGR	Kursk 3	1000	MAEP	MTM	78	03/84
	LWGR	Kursk 4	1000	MAEP	MTM	81	02/86

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	LWGR	Leningrad 1	1000	MAEP	MTM	70	11/74
	LWGR	Leningrad 2	1000	MAEP	MTM	70	02/76
	LWGR	Leningrad 3	1000	MAEP	MTM	73	06/80
	LWGR	Leningrad 4	1000	MAEP	MTM	75	08/81
	LWGR	Obninsk APS	5	SCUAE	MTM	51	12/54
	LWGR	Smolensk 1	1000	MAEP	MTM	75	12/83
	LWGR	Smolensk 2	1000	MAEP	MTM	76	07/85
	LWGR	Smolensk 3	1000	MAEP	MTM	84	
	LWGR	Tomsk 2	200	Unknown	Unknown		
	LWGR	Tomsk 3	200	Unknown	Unknown		
	LWGR	Tomsk 4	200	Unknown	Unknown		
	LWGR	Tomsk 5	200	Unknown	Unknown		
	LWGR	Troitsk 5	100	MPS	MTM	54	01/56
	OMR	Melekess Arbus	5	SCUAE	KTF		63
	PWR	Balakovo 1	1000	MAEP	MTM	80	05/86
	PWR	Balakovo 2	1000	MAEP	MTM	81	01/88
	PWR	Balakovo 3	1000	MAEP	MTM	82	04/89
	PWR	Kalinin 1	1000	MAEP	MTM	77	06/85
	PWR	Kalinin 2	1000	MAEP	MTM	82	03/87
	PWR	Kola 1	440	MAEP	MTM	70	12/73
	PWR	Kola 2	440	MAEP	MTM	70	02/75
	PWR	Kola 3	440	MAEP	MTM	77	12/82
	PWR	Kola 4	440	MAEP	MTM	76	12/84
	PWR	Novovoronezh 3	417	MAEP	MTM	67	06/72
	PWR	Novovoronezh 4	417	MAEP	MTM	67	03/73
	PWR	Novovoronezh 5	1000	MAEP	MTM	74	02/81
Construction	BWR	Voronezh 1	0	MAEP	MTM	83	
	BWR	Voronezh 2	0	MAEP	MTM	85	
	FBR	Beloyarsk 4, BN 800	800	MAEP	MTM		

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	LWGR	Kursk 5	1000	MAEP	MTM	85	93
	PWR	Balakovo 4	1000	MAEP	MTM	84	
	PWR	Balakovo 5	1000	MAEP	MTM	87	
	PWR	Balakovo 6	1000	MAEP	MTM	88	
	PWR	Kalinin 3	1000	MAEP	MTM	85	93
	PWR	Kalinin 4	1000	MAEP	MTM	86	95
	PWR	Kostroma 1	1000	MAEP	MTM	81	99
	PWR	Kostroma 2	1000	MAEP	MTM	88	
UKRAINE							
Operating	LWGR	Chernobyl 1	1000	Ukratom	MTM	72	05/78
	LWGR	Chernobyl 3	1000	Ukratom	MTM	77	06/82
	PWR	Khmelnitski 1	1000	Ukratom	MTM	81	08/88
	PWR	Rovno 1	392	Ukratom	MTM	76	09/81
	PWR	Rovno 2	416	Ukratom	MTM	77	07/82
	PWR	Rovno 3	1000	Ukratom	MTM	81	05/87
	PWR	South Ukraine 1	1000	Ukratom	MTM	77	10/83
	PWR	South Ukraine 2	1000	Ukratom	MTM	79	04/85
	PWR	South Ukraine 3	1000	Ukratom	MTM	85	
	PWR	Zaporozhe 1	1000	Ukratom	MTM	80	04/85
	PWR	Zaporozhe 2	1000	Ukratom	MTM	81	10/85
	PWR	Zaporozhe 3	1000	Ukratom	MTM	82	01/87
	PWR	Zaporozhe 4	1000	Ukratom	MTM	84	01/88
	PWR	Zaporozhe 5	1000	Ukratom	MTM	85	90
Construction	PWR	Khmelnitski 2	1000	Ukratom	MTM	85	94
	PWR	Khmelnitski 3	1000	Ukratom	MTM	86	
	PWR	Khmelnitski 4	1000	Ukratom	MTM	87	

Table D.1 World list of nuclear power reactors operating and under construction (continued)

Country Status	Reactor type	Reactor name	Electrical [MW(e)]	Utility	Current vendor (Historical vendor)	Const. start	Comm. operation
	PWR	Rovno 4	1000	Ukratom	MTM	86	
	PWR	South Ukraine 4	1000	Ukratom	MTM	87	
	PWR	Zaporozhe 6	1000	Ukratom	MTM	86	94

[a]NEI, 1992. World Nuclear Industry Handbook 1992, *Nuclear Engineering International*, 1992.
NN, 1992. World List of Nuclear Power Plants, *Nuclear News*, Vol. 35, No. 10, August 1992.