Massachusetts Institute of Technology

Center for Energy Policy Research

INTERNATIONAL COMPARISON OF LWR PERFORMANCE

by

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CHAPTER 1

INTRODUCTION

This report summarizes the large body of data and other information collected as part of a study on the International Comparison of LWR Performance. The object of the study is to quantify the causes of lost capacity in nuclear power plants in the Federal Republic of Germany, France, Japan, Sweden, Switzerland, and the United States, and to understand why losses vary with time, as well as from country to country.

Nuclear plant capacity losses for individual LWRs in each of the six countries were collected for the years 1975-1984, an interval that includes the Three Mile Island-2 accident. The data were limited to LWRs 300 MWe or larger and that entered commercial service before January 1, 1984. (Data for 1985 were not available when this study began.)

The capacity loss information has been aggregated into several categories and subcategories. The major categories are based upon the character of the loss, i.e., whether the loss was a forced loss, a scheduled loss, a regulatory loss, or of unknown character. Subcategories were used for forced and scheduled outages, and identified the part of the plant responsible for the loss. Table 1.1 summarizes the performance loss categories.

The vast bulk of the data collected is reported in a companion report(1). The report discusses in considerable detail the nature

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(1) C.T. Wilson, "A Numerical Comparison of International Light Water Reactor Performance, 1975 to 1984," MIT Center for Energy Policy Research Report No. MIT-EL 86-007, Cambridge, Massachusetts, May 1986.

of the data and the data collection process. The report also contains extensive analyses of the results on a country-by-country basis.

The object of the present report is to compare results between countries and analyze possible causes of differences. It is clear that the data alone are insufficient for meaningful analysis. There are enormous differences among the various environments in which nuclear power plants are built and operated. The differences in national environments may have a large impact on how the plants perform. Thus, a major element of the entire study was to reach some understanding about the context in which nuclear plants operate in each country.

Information about national contexts was obtained by direct interviews with members of the nuclear community in the six countries. The elements of interest included the following:

- the structure of the electric industry
- the structure of the supply industry
- utility internal organization
- economics of nuclear power
- economic regulation
- safety regulation
- public attitude and influence

The nine chapters that follow summarize findings on these matters. In addition, we have included some comments on the performance results reported for each country. In most cases we have replicated information included in Wilson's report.

Chapter 8 presents a comparison of results. The discussion is divided by reactor type: Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR). The comparisons are made on an overall basis, as well as by forced outages, scheduled outages, and regulatory outages.

Chapter 9 of the report contains tentative conclusions. These conclusions are based on the data and the national contexts. The results represent the views of the authors, based on the study, and based upon discussions held with various experts in the nuclear field.

Chapter 10 presents recommendations for further study.

Table 1.1

Performance Loss Categories

<u>Forced Outages</u>

- Nuclear Steam Supply System
    - Fuel
    - RCS
    - SG
    - Refuel
    - Other
- Balance of Plant
    - Turbine
    - Generator
    - Condenser
    - CW/SW/CCW
    - Other
- Economic
- Human
- Other

<u>Scheduled Outages</u>

- Nuclear Steam Supply System
    - Fuel
    - RCS
    - SG
    - Refuel
    - Other
- Balance of Plant
    - Turbine
    - Generator
    - Condenser
    - CW/SW/CCW
    - Other
- Economic
- Human
- Other

<u>Regulatory Outages</u>

<u>Unknown Outages</u>

Definitions and Comments on Data

We have tried to use standard definitions for symbols and abbreviations used in the report. The two most frequently used terms are "capacity factor" and "energy availability factor". We use the OPEC-2 definitions. Thus the capacity factor is defined as

$$CF \equiv \frac{\text{net electric MWH generated in a year}}{\text{net electric rating (MW) x hours in a year}}$$

The energy availability factor is

$$EAF = CF + \frac{\text{externally caused generation losses}}{\text{net electric rating (MW) x hours in a year}}$$

The externally caused generation losses are limited to losses caused by lack of demand, and would not include regulatory imposed shutdowns for example.

Data for different countries are reported as CF or EAF. For the data for Japan, Sweden, Switzerland, and the United States differences between CF and EAF are very small and ignorable. In France and West Germany differences may be significant and we use EAF for those countries.

Other symbols are defined below:

RCS - reactor coolant system
SC - steam generator
CW/SW/CCW - circulating water/service water/component cooling water
NSSS - nuclear steam supply system.

CHAPTER 2

THE FEDERAL REPUBLIC OF GERMANY

2.1 STRUCTURE OF THE ELECTRIC INDUSTRY

In 1984, the total installed electric generating capacity in the Federal Republic of Germany was 94,900 MWe. Public utilities, which supply the industrial and residential sectors, owned 79,542 MWe, with the remainder owned by private industry (13,972 MWe) and the Federal German Railway (1,392 MWe). Table 2.1 shows the share of capacity in the public utility sector by plant type.

Table 2.1

ELECTRIC GENERATING CAPACITY BY PLANT TYPE

Plant Type	1984	1984
Bituminous coal-fired plants	(22,954)	28.9%
Lignite coal-fired plants	(12,764)	16.1%
Oil-fired plants	(11,086)	13.9%
Gas-fired plants	(10,520)	13.2%
Hydro and other sources	(6,770)	8.5%
Nuclear power plants	(15,448)	19.4%
	(79,542)	100%

Figure 2.1 shows the flow of electricity in the Federal Republic of Germany in 1984. Although nuclear power accounted for only some 19.4 percent of total installed capacity, it generated approximately 27.6 percent of total electricity. The share of coal fell from 67.5 percent in 1970 to 57.7 percent in 1984 and oil from 12.6 percent to 1.1 percent

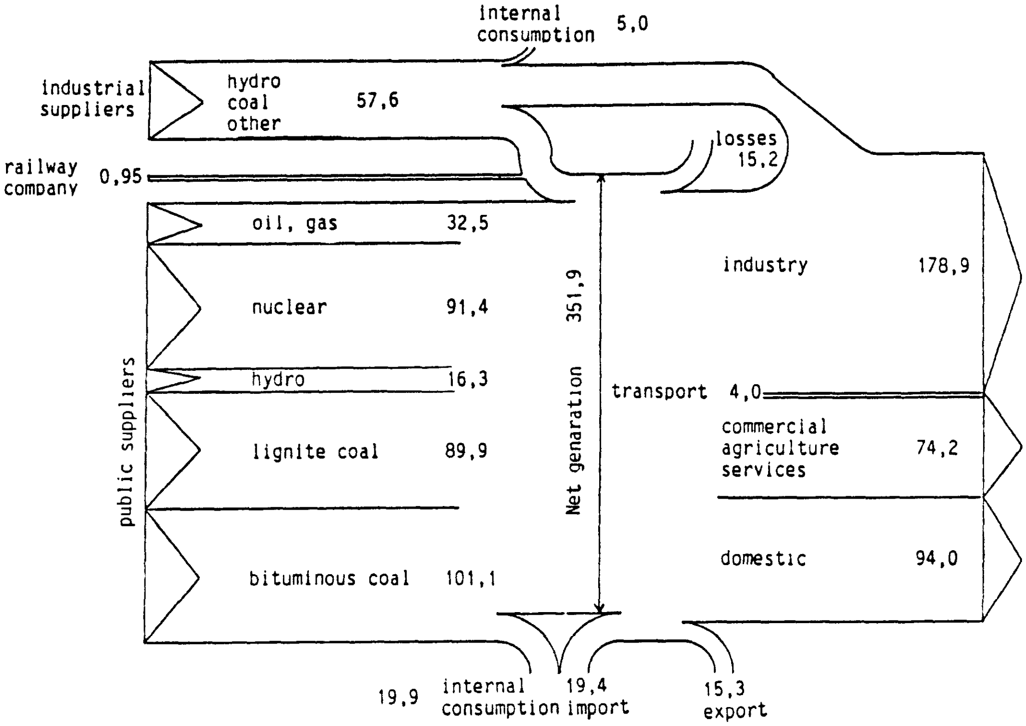


Figure 2.1 Electricity Flow Chart 1984 (TWh).

over the same period (see Figure 2.2). Figure 2.3 illustrates the capacity of public utility power plants by energy sources.

Total electricity consumption was 232.6 TWh in 1970 and 372.9 TWh in 1984, an average annual growth rate of 3.4 percent. The future annual growth rate for electricity demand is expected to be about 3 percent.

The nuclear power capacity (about 17,000 MWe) is provided by 19 units: 9 Pressurized Water Reactors (PWRs) and 7 Boiling Water Reactors (BWRs). Another 6 units are under construction, with a total additional 7,000 MWe expected, resulting in a total nuclear capacity of 24,000 MWe. Figure 2.4 shows the location of both operating and planned nuclear power plants, and Table 2.2 details their location, type, output, and first year of operation.

The structure of the electric industry consists of more than 1,100 companies, including:

(1) interregional operating utilities that generate electricity and transport it to end users; (2) regional utilities that supply electricity to end users; and (3) city and community utilities. Figure 2.5 shows this structure. Large interregional utilities, of which there are 9 supply electricity primarily to other utilities, while regional utilities, of which there are 45, and city and community utilities also generate some electricity but concentrate on distributing electricity to final customers.

The market for electricity is divided into regional monopolies. Interregional utilities generate the largest share of electricity, the five largest of which provide 52 percent. (See Figure 2.6.) Approximately 10 percent provided about 90 percent. The industrial sector often is supplied directly by large utilities; 9 utilities meet 50 percent of the industrial demand in 1984, RWE alone supplied 26 percent.

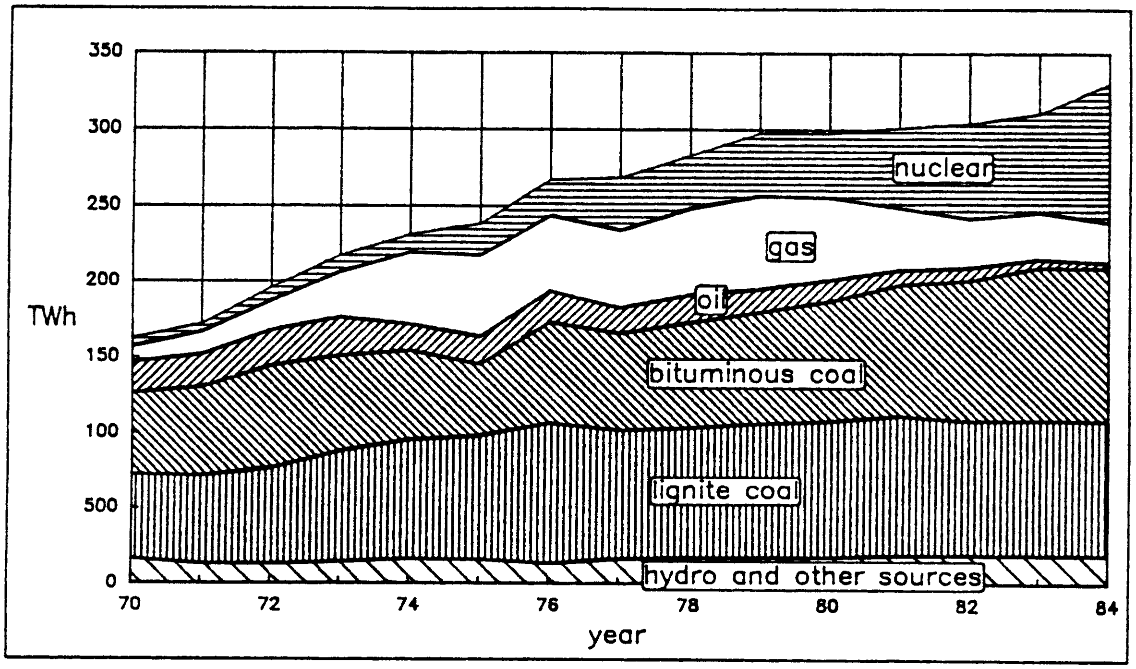


Figure 2.2 Electricity Generation of Public Utilities by Energy Sources.

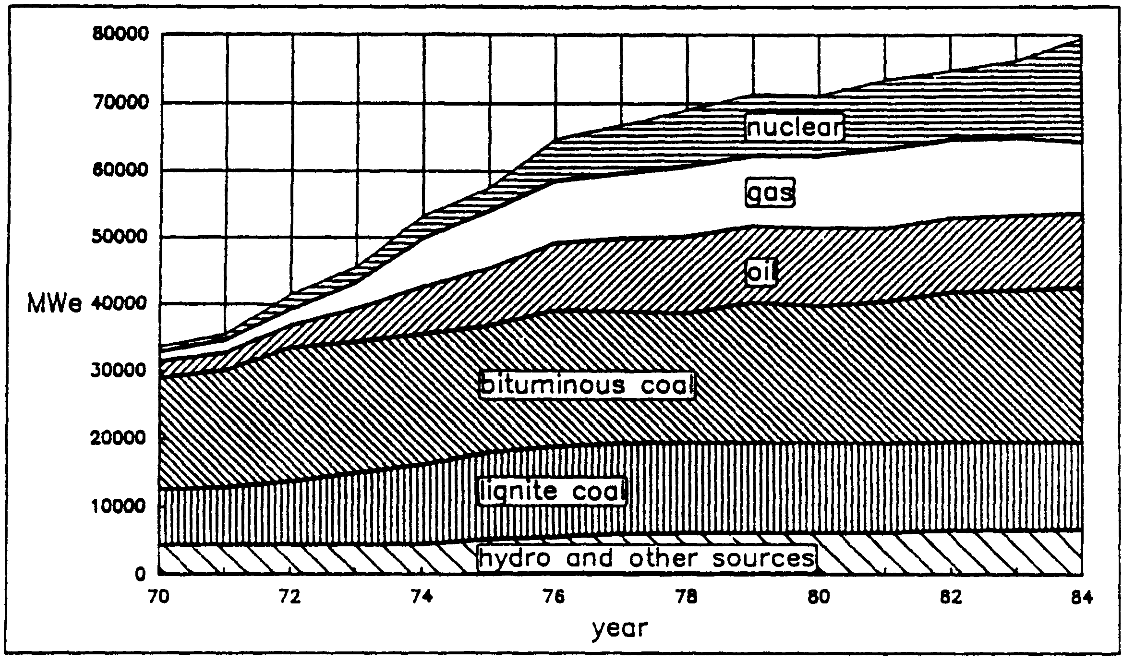


Figure 2.3 **Capacity** of public utility power plants by energy sources.

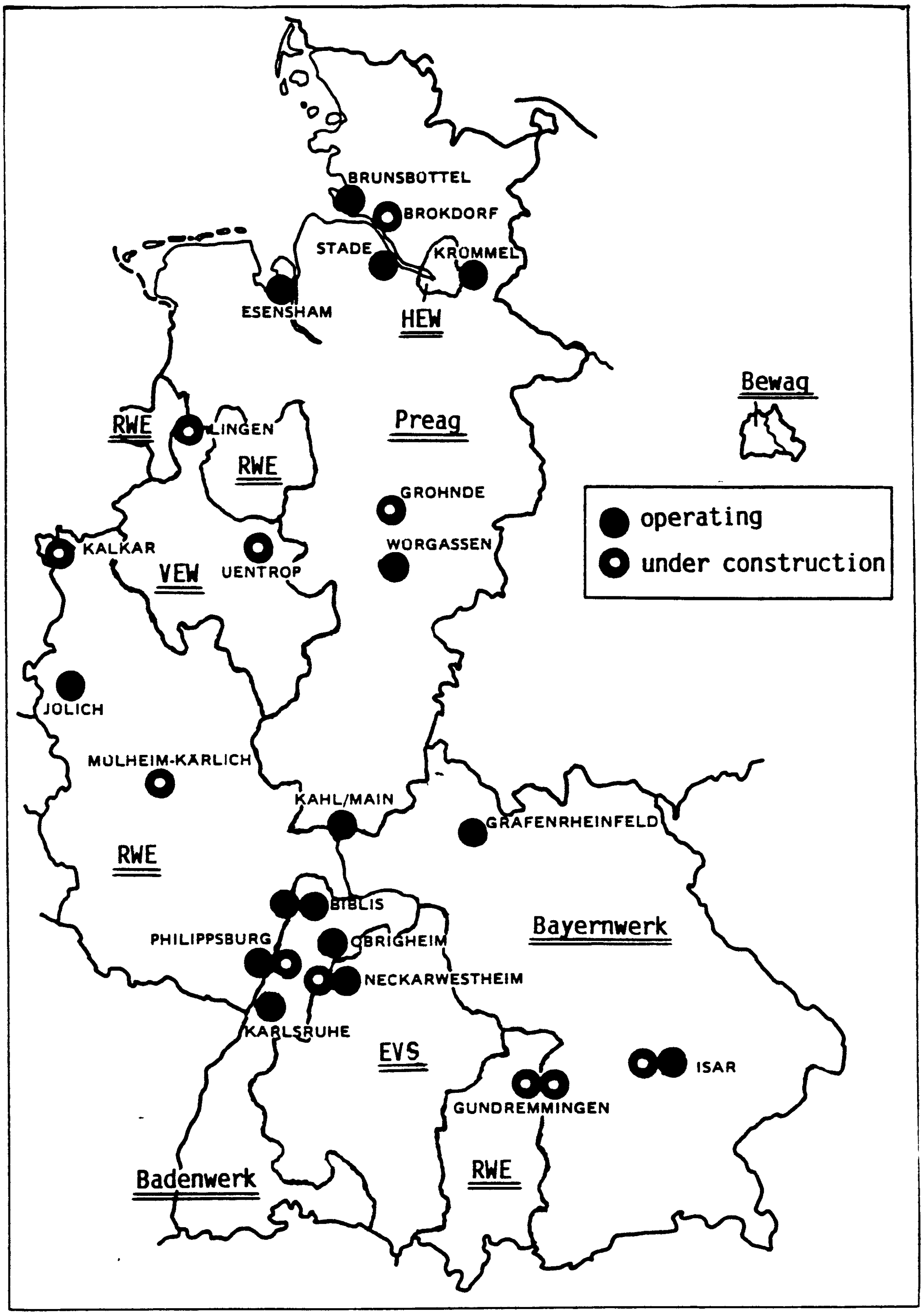


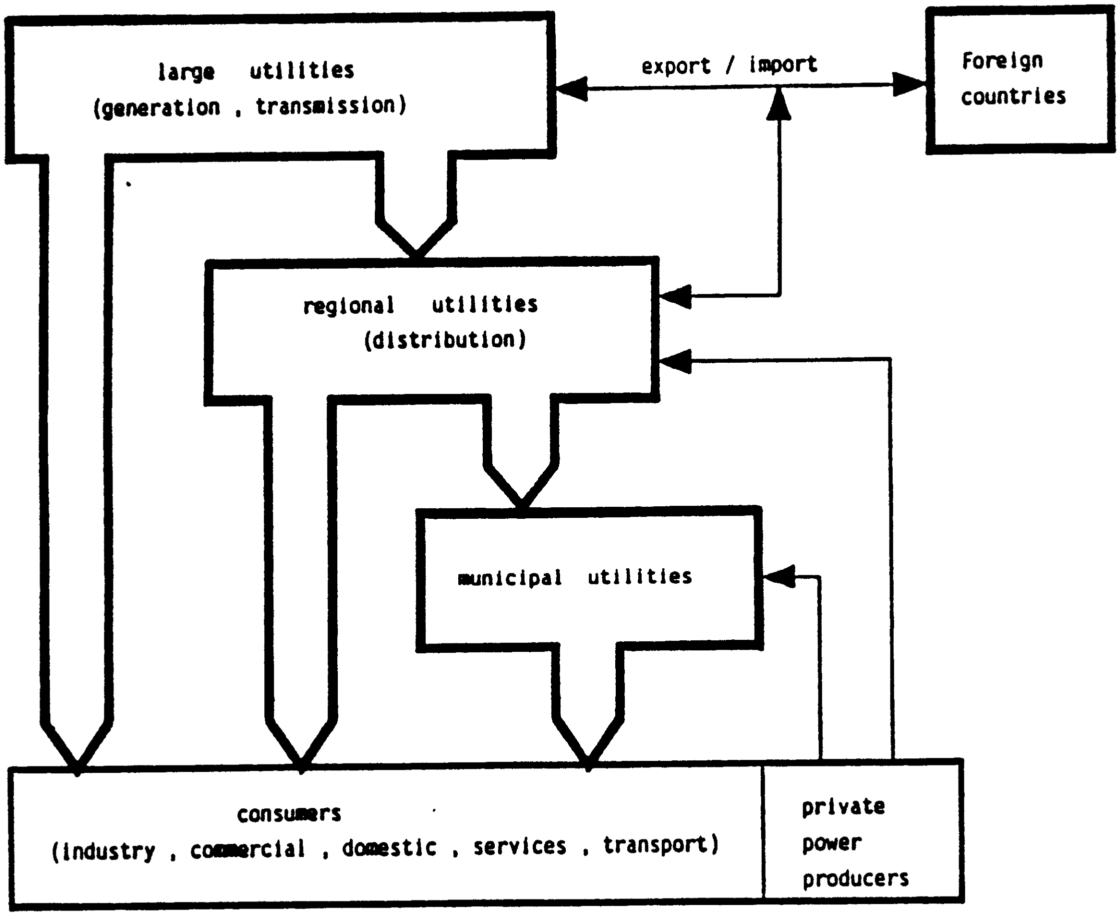
Figure 2.4 Location of Nuclear Power Plants.

Table 2.2 Nuclear Power Plants.

Name		Type	1.year of operation	Owner
AVR Jülich	15 MW	HTGR	1968	Arbeitsgemeinschaft Versuchsreaktor AVR
KNK Karlsruhe	20 MW	FBR	1979	Kernkraftwerk Betriebsgesellschaft
KWO Obrigheim	357 MW	PWR	1969	KWO Kernkraftwerk Obrigheim
KKS Stade	672 MW	PWR	1972	KKS Kernkraftwerk Stade
KKW Würgassen	670 MW	BWR	1975	Preag Preussische Elektrizitätswerke AG
Biblis A	1204 MW	PWR	1975	RWE Rheinisch-Westf. Elektrizitätswerke AG
Biblis B	1300 MW	PWR	1977	RWE Rheinisch-Westf. Elektrizitätswerke AG
GKN-1 Neckarwestheim	855 MW	PWR	1976	GKN Gemeinschaftskernkraftwerk Neckar
KKB Brunsbüttel	806 MW	BWR	1977	KKB Kernkraftwerk Brunsbüttel
KKI-1 Isar	907 MW	BWR	1979	KKI Kernkraftwerk Isar
KKU Unterweser	1300 MW	PWR	1979	Preag Preussische Elektrizitätswerke AG
KKP-1 Philippsburg	900 MW	BWR	1980	KKP Kernkraftwerk Philippsburg
KKP-2 Philippsburg	1349 MW	PWR	1985	KKP Kernkraftwerk Philippsburg
KKG Grafenrheinfeld	1300 MW	PWR	1982	Bayernwerk
KKK Krümmel	1316 MW	BWR	1984	KKK Kernkraftwerk Krümmel
KRB-B Gundremmingen	1310 MW	BWR	1984	KGB Kernkraftwerk Gundremmingen Verwaltungs-AG
KRB-C Gundremmingen	1310 MW	BWR	1985	KGB Kernkraftwerk Gundremmingen
KWG Grohnde	1365 MW	PWR	1985	KWG Kernkraftwerk Grohnde
THTR-300 Uentrop	308 MW	HTGR	1985	HKG Hochtemperatur Kernkraftwerk

Figure 2.5

Structure of Electric Utility Generation and Distribution System



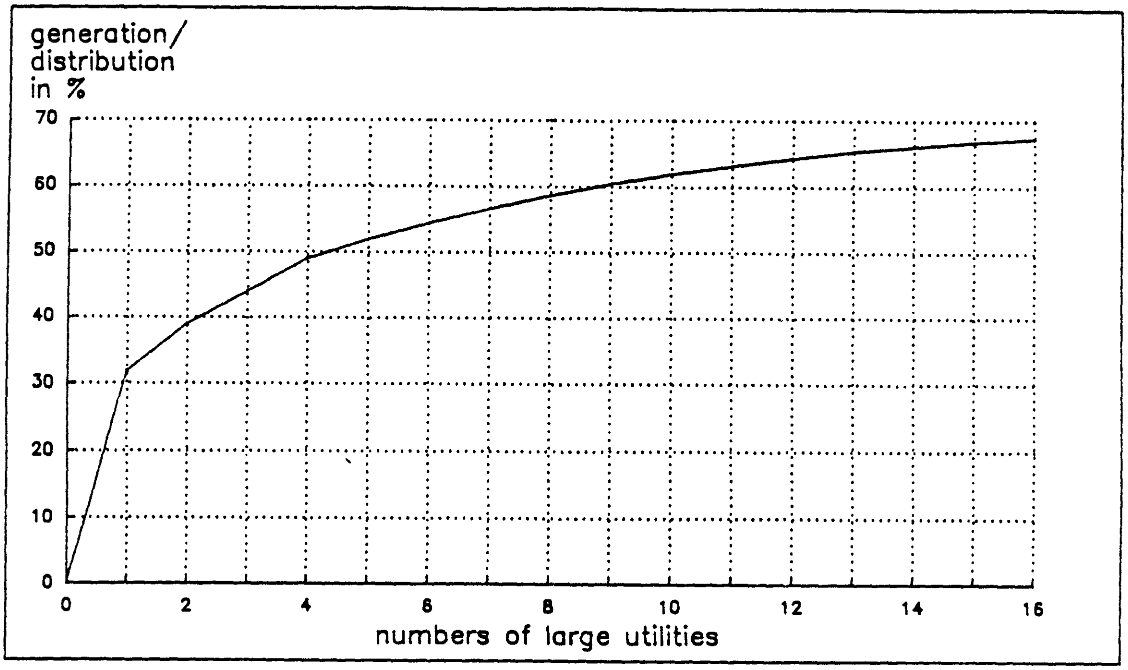


Figure 2.6 Electricity generation/distribution of large utilities.

The electric utility companies are investor owned, with the majority of stock owned mostly by public authorities, such as state and/or local governments.

Only large utilities own or share ownership of nuclear power plants. Those who own or share ownership of at least 3 plants include:

Rheinisch-Westfälisches Elektrizitätswerk AG (RWE)
Preußische Elektrizitats-AG (Preußenelektra)
Bayernwerk AG
Energieversorgung Schwaben AG (EVS)
Hamburgische Elektrizitätswerke AG (HEW)
Badenwerk AG.

Altogether, 23 utilities are involved in nuclear power. In general, they share ownership of nuclear plants. Only three utilities own nuclear plants outright.

2.2 STRUCTURE OF THE SUPPLY INDUSTRY

Over time, there have been four vendors of LWR Nuclear Steam Supply Systems (NSSS) in the Federal Republic of Germany. In the early years of the nuclear industry, Siemens and AEG competed for orders, with Siemens offering a PWR design and AEG offering a BWR. In 1969, they began to merge their nuclear operations into a new company named Kraftwerk Union AG (KWU); the last stages of the merger were completed in 1973. The pace of the merger was dictated by licensing agreements that the parent firms held with Westinghouse and General Electric. The fourth vendor is Brown-Boveri, which has designed only one plant in the Federal Republic of Germany. Thus, all the operating LWR plants were manufactured by either KWU or its parents. Since AEG and Siemens no longer manufacture nuclear power plants, only two vendors presently are operating.

As KWU owns very little of the actual equipment to manufacture the NSSS, they subcontract for the manufacture of almost all parts of the NSSS.

The design and construction of nuclear power plants in the Federal Republic of Germany has been handled almost exclusively by one company, KWU. Prior to KWU's formation, the job was done by its parents--AEG or Siemens--or begun by them and completed by KWU.

Fig. 2.7 shows the principle of the turnkey project approach in the F.R. of Germany. The customer places the responsibility in the hands of the general contractor who overtakes the engineering tasks of the project. The general contractor is partner of the subsuppliers, coordinates them, controls the time schedule and bears the technical and economic risk also for components from subsuppliers. KWU developed its own quality assurance, and quality control systems. KWU manufactures little of the equipment and components themselves but relies on a variety of subsuppliers.

The turnkey approaches vary with regard to the involvement of the utilities during the planning and construction period. Some utilities such as RWE and Preussenelektra/NWK, with large engineering staffs participate more than other utilities.

Through such participation technology transfer and knowledge about the engineering design can be shared. Major advantages of the turnkey approaches are seen in

- The optimized design of the entire nuclear power plant,
- the sole responsibility of the general contractor KWU,
- the standardized construction process procedure,
- the comprehensive project management,
- the coordination of subsuppliers, and
- the guarantees for the project.

In turnkey projects the utilities did not accept ownership of a plant until it had been operating uninterrupted at full power for one month.

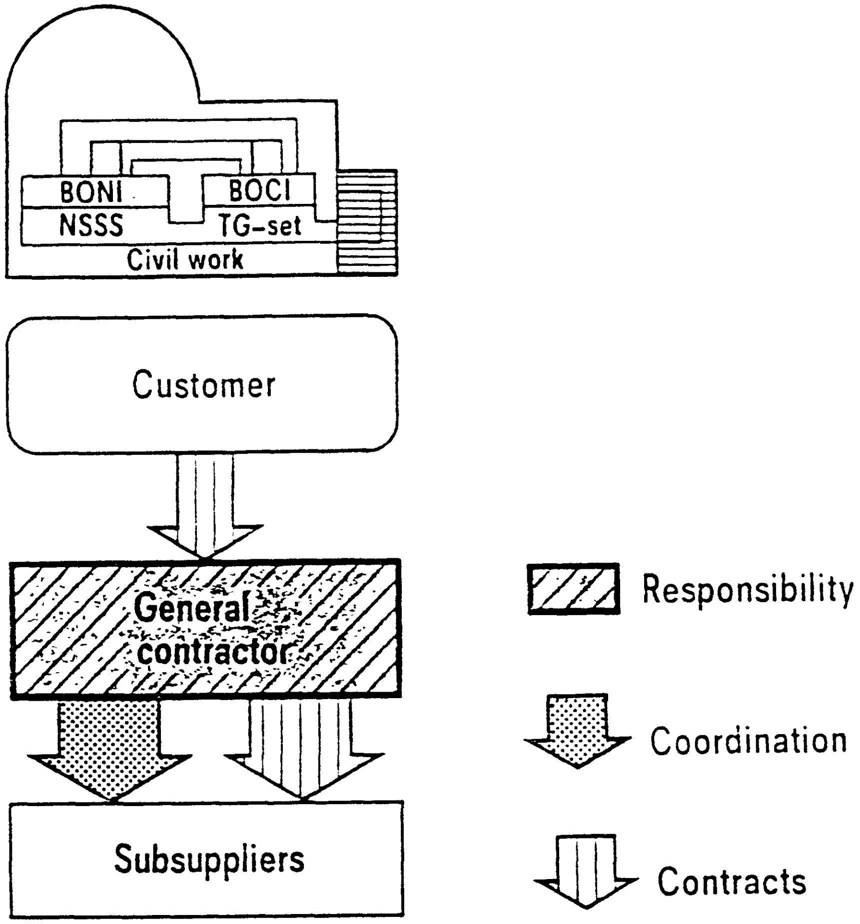


Figure 2.7 Turnkey approach.

The costs are fixed, with an agreement that the contract could be renegotiated in the event of customer changes and of forseeable regulatory changes. In most contracts it is ruled that additional cost because of unforseeable regulatory changes are shared between customers and KWU. KWU contracts have included performance guarantees for the first two years of operation; barring operator errors, KWU would pay penalties for a plant with low availability. The agreement signed for the recently completed Krummel plant guarantees 70 percent energy availability in the first year and 75 percent in the second year.

In general, there has been little involvement or oversight by utilities in KWU's design and construction of plants, although the results of operating experience were transferred to KWU, which then changed the design and construction of certain equipment, if necessary.

The size of on-site utility staffs during construction rarely has exceeded 20. Only near the end of the project do utility personnel become more involved, having now received training in plant operations.

2.3 UTILITY INTERNAL ORGANIZATION AND CAPABILITIES

The nuclear power plants are operated by "Betreibergesellschaften" (Operation Companies) which are owned by one or as in most cases by several utilities. Formally they are independent firms but actually they can be considered as part of their parents.

The organizational structure of utilities involved in nuclear power varies widely, although two structures are typical (see Figures 2.8 and 2.9). In Figure 2.8, the Executive Board of the utility oversees the Construction, Operations, Distribution, Financial, and other major divisions. Within both the Construction and Operation divisions there are nuclear departments, along with departments for thermal and other power generation sources. In Figure 2.9, the utility is divided by major

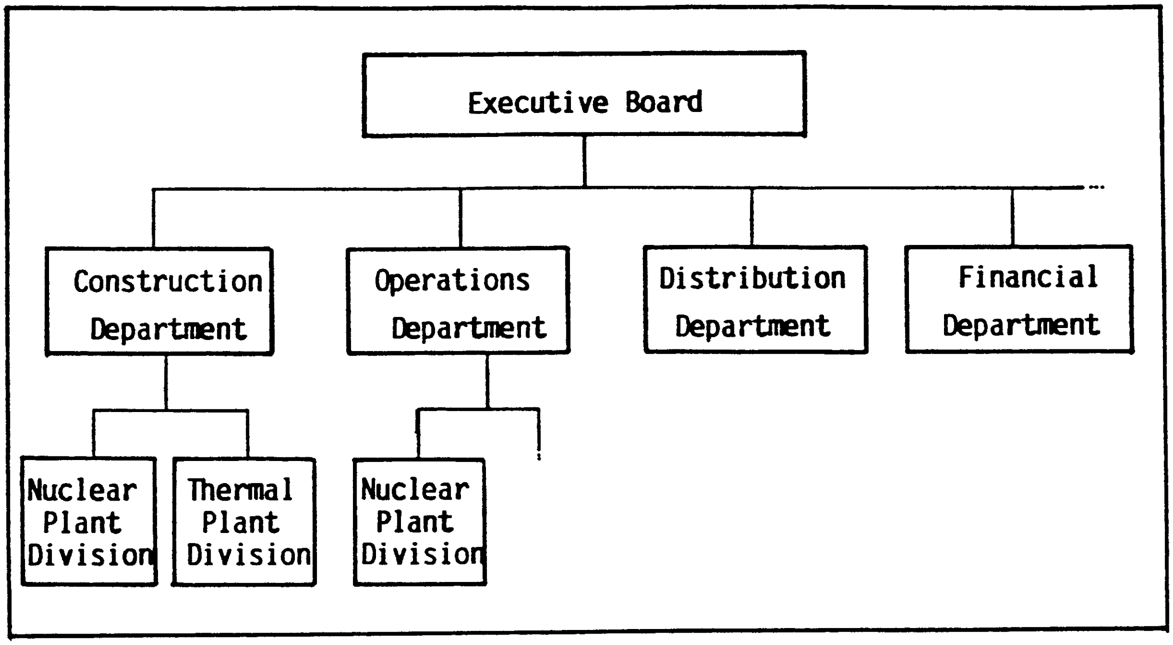


Figure 2.8 Internal Organization by Functions.

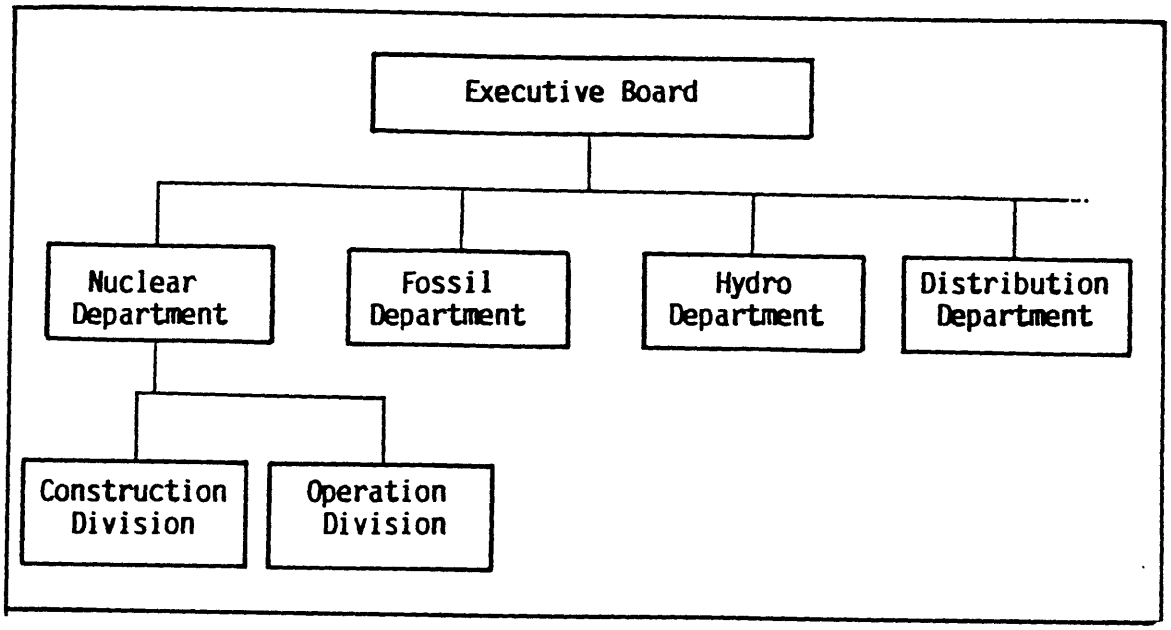


Figure 2.9 Internal Organization by Energy Sources.

power sources, with Nuclear, Fossil, Hydro, and other sources constituting major divisions along with Distribution, Financial, and other services. In this structure, Nuclear Construction and Nuclear Operations constitute the major departments within the Nuclear Division.

Regardless of utility organization, the management of nuclear plants appears to be remarkably consistent throughout the industry. In most cases the site manager has overall responsibility for the operation of the plant, and there is little oversight from utility headquarters. The site manager oversees a staff of approximately 250, divided into four major departments: Operations, Reactor Physics and Chemistry, Engineering, and Inspection and Repair. There are approximately 90 operators, and the remainder of the staff is divided among technicians, engineers, and maintenance personnel. Approximately 80 members of the site staff are engineers, who are spread throughout the site divisions.

The Engineering Division solves problems detected by the Operations and Reactor Physics and Chemistry Divisions and directs the Repair staff in performing the work (see Figure 2.10).

Engineering personnel are divided into two educational levels, those holding technical college degrees and those holding university degrees. The technical college degree qualifies an engineer to perform practical applications; the university degree is more scientific. Plant operators receive KWU training. All staff involved in operations participate in a three-to-five-year training program, which includes practice on simulators operated by KWU, the utilities, and/or by the VGB (Verband der Grosskraftswerksbetreiber, or Association of Large Power Producers). The non-engineer operations staff start as technicians and advance in the plant as a part of this three-to five-year training program. The technical college-degreed engineers either come directly from college or

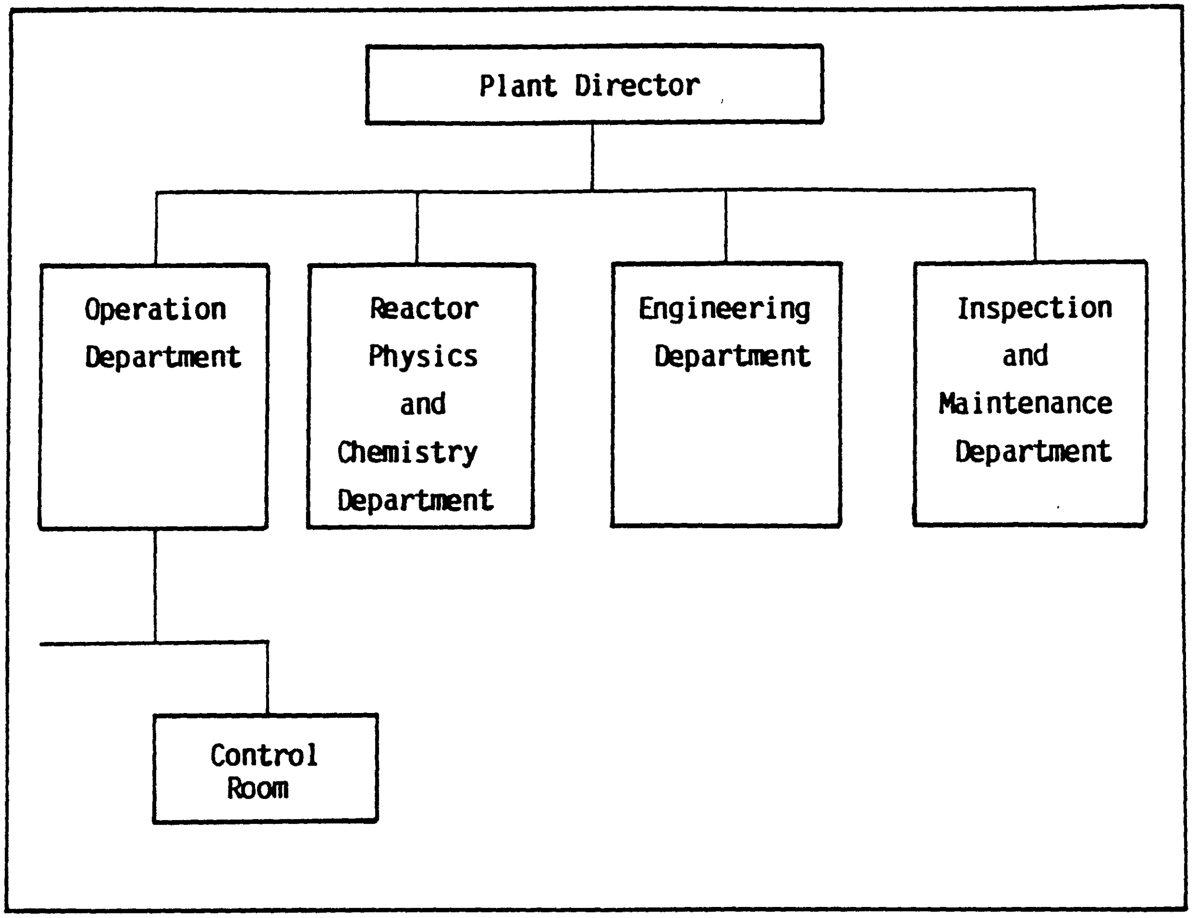


Figure 2.10 Nuclear Power Plant Management.

from fossil plants, while the university-degreed engineers are trained in nuclear engineering and come directly from the university. Operating staff turnover is small, amounting to only 5 percent annually, and the remainder of the staff has an even lower turnover rate--most of them stay with a utility throughout the duration of their professional lives.

There is no fixed model for the level of technical skills required by the utilities. In several cases, large staffs are involved directly with KWU in plant design, but there also are examples of projects that devote fewer than a dozen engineers to oversight during design and the early construction phases. At all projects, as the plant nears completion, the Utility Operations department becomes involved in construction .

In most cases, plant maintenance and outage planning is strictly the responsibility of the site manager and his staff. All engineering work for normal maintenance and refueling is performed at the plant but with KWU and its former subcontractors. Large-scale outages, such as the replacement of pipes in BWRs, are planned and engineered outside the plant, usually by KWU or some other large contractor. Outages are planned up to one year in advance. Total personnel on site during an outage can reach 1300; these personnel are supplied by KWU and various subcontractors with whom the utilities maintain service contracts. Although the site has responsibility for the plant, the engineering staffs at utility headquarters keep abreast of industry-wide generic issues and often will propose solutions to problems to plant staff.

Preventive maintenance programs play an important role for all utilities and KWU. Approximately 2% of the initial investment cost is used for the initial spare part system.

The VGB has designated commissions to ensure that information on problems encountered during operations and outages is shared between plants. For example, Nuclear power plant managers meet 10-12 times per year to exchange information. Also, KWU collects and distributes information on operations and outage problems, which is disseminated to all plant managers.

2.4 ECONOMICS OF NUCLEAR POWER

To meet base-load power needs, the principal alternative to nuclear-generated electricity is coal-fired generation (primarily lignite in plants near the mines), which is the least expensive energy source. While cost data for specific plants are not available, the industry average cost for generation by bituminous coal-fired plants ranges from a low of 0.038 US$/kWh to a high of 0.055 US$/kWh. The comparable figure for nuclear power is around 0.028 US$/kWh. Figure 2.11 shows electricity generation cost versus operating time for LWR and both bituminous-and lignite-fired power plants.

The electric utility industry in the Federal Republic of Germany is obligated to purchase a certain amount of bituminous coal from the German industry. A small amount of coal is allowed to be imported. The domestic coal is expensive and drives up the cost of electricity. Due to the relatively high cost of coal-based electricity, even an expensive nuclear power plant can appear to be economically attractive.

In recent years, the investment cost for nuclear power plants has increased, thus diminishing their cost advantage over coal-fired plants. Therefore, KWU, in conjunction with major utilities, developed and designed the so-called "convoy plant," a standardized design applied at three different sites, which will be constructed with considerably lower investment costs.

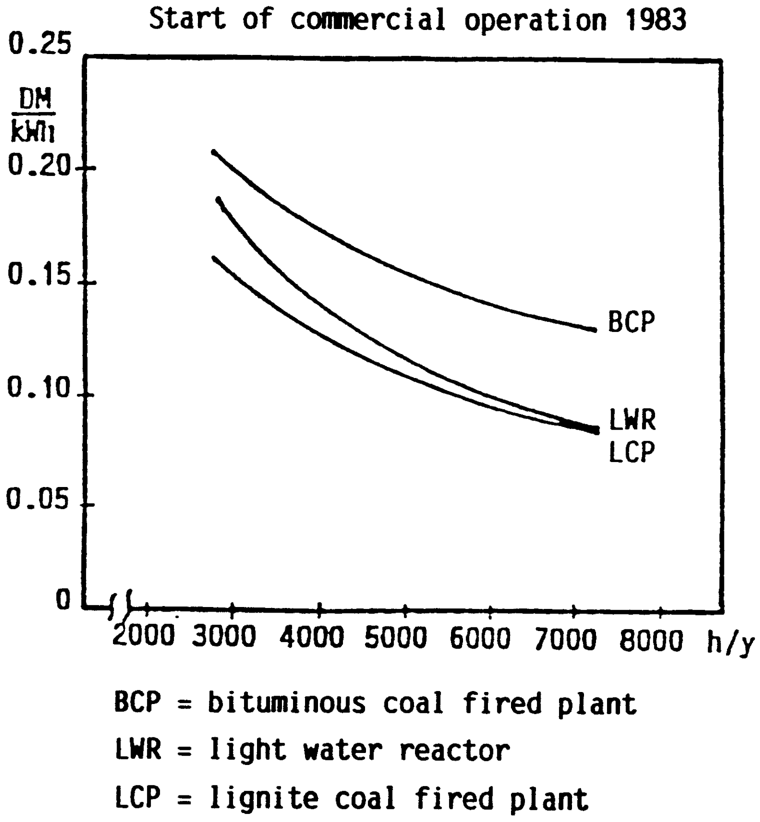


Figure 2.11 Electricity generation cost versus operating time for different plant types.

2.5 ECONOMIC REGULATION

Economic regulation of the electric utility industry is handled by state authorities, normally represented by the Ministry for Trade and Commerce. The state authorities review the costs of supplying electricity to evaluate whether the utilities have set a fair price to cover their costs and provide a fair rate of return on capital investment. This economic regulation only applies to residential and small commercial customers, as utilities are able to negotiate private contracts with large industrial customers, contracts not subject to review by the Ministry's price commission.

When the state price commissions review all expenditures, they are more interested in ensuring that a utility's long-term costs are covered than in determining whether short-term costs are the lowest attainable. The price commissions do not review sole investment undertakings, but they do assess whether a utility's electricity prices are in accord with other utilities operating under similar conditions. The utilities do not have to submit a cost analysis of power plant investments for regulatory approval.

Nuclear power plants in the Federal Republic of Germany are constructed in roughly 7 to 8 years. The utilities may pay for the plants with accumulated revenues, loans, and, if they choose, current electricity revenues. They may incorporate part of the interest on the loans in current electric rates (in the United States, usually referred to as CWIP). Both interest and inflation rates in the Federal Republic of Germany have been lower than in the United States over the past years.

2.6 SAFETY REGULATION

After World War II, the Western Allies prohibited the Federal Republic of Germany from developing nuclear power until 1955. The

Federal Republic of Germany's Atomic Energy Act was issued in 1959. At the same time, the German Constitution was amended to stipulate that, with the approval of the Federal Council, the states had responsibility for enforcing laws governing nuclear power designed by the Atomic Energy Act. Thus, each state is responsible for overseeing the safety of operating plants.

Within the Federal government, until 1986 the Federal Minister of the Interior (Bundesminister des Innern) was responsible for regulations promulgated under the Atomic Energy Act. (Today the responsibilities rest with the Federal Minister for the Environment, Nature Conservation and Nuclear Safety.) The Federal and state governments then rely upon several private organizations to draft regulations and oversee their implementation (see Figure 2.12).

While the BMI waits for the KTA to agree upon regulations, it relies upon the Reactor Safety Commission (Reaktorsicherheitskommission, or RSK) to present guidelines for the design, construction, and operation of nuclear power plants. The RSK has 20 members, all of whom are appointed by the Federal Minister of the Interior. The members are chosen from the following fields: reactor operations, civil engineering, materials, construction, instrumentation and controls, reactor physics, electrical engineering, reactor chemistry, radiation protection, environmental protection, radiation biology, and nuclear medicine. Members are expected to represent only their own expert opinions and not the interests of their home organizations, many of whom are independent university professors. The RSK guidelines do not enjoy the full weight of law but rather are used for reference by the BMI and by the states while the KTA develops its regulations.

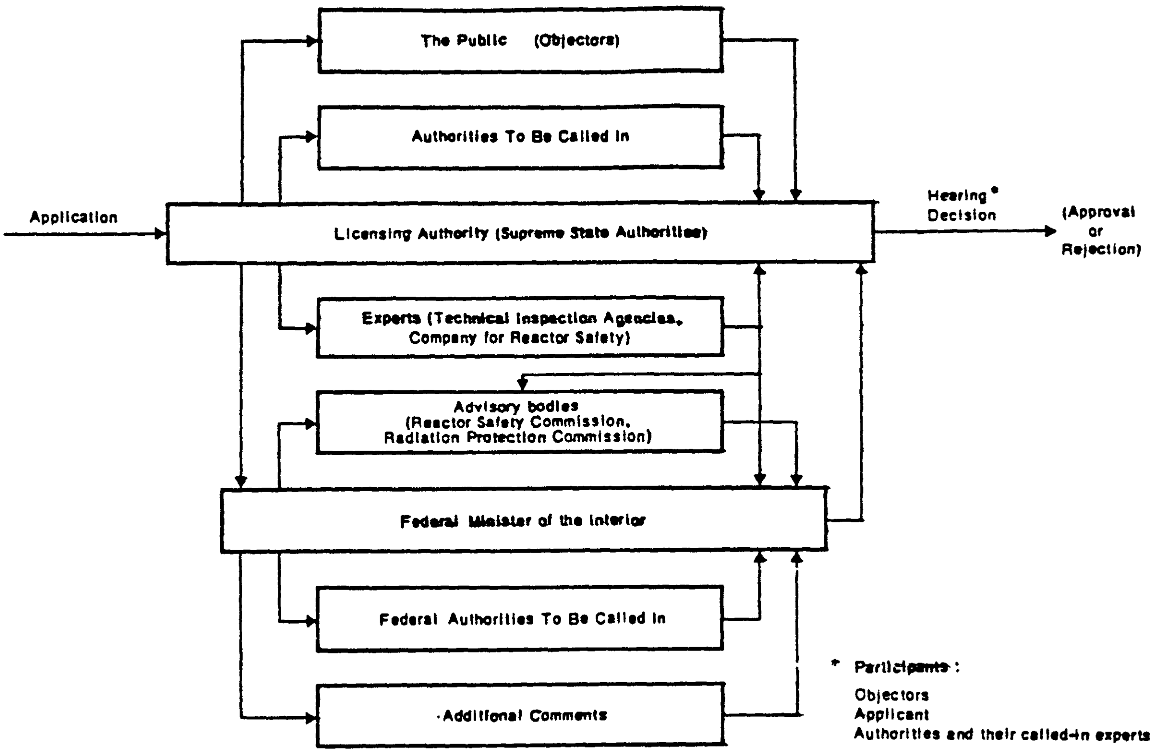


Figure 2.12 Nuclear Licensing Procedure.

The Reactor Safety Company - GRS

The Reactor Safety Company (Gesellschaft für Reaktorsicherheit, or GRS) is one of the independent experts used by the BMI and the states to perform technical studies of the safety of nuclear facilities and radiation protection. It also participates in formulating guidelines and regulations by the RSK and the KTA. Upon request by government agencies, the GRS undertakes analysis of specific safety issues. The GRS is responsible for the management of the LWR safety research program.

The Technical Inspection Agencies - TÜVs

There are 11 Technical Inspection Agencies (Technische Uberwachungsvereine, or TÜV), each of which is a private, independent company. The TÜVs have existed for over a century, serving as independent inspectors to industry. (They are similar in nature to Underwriters Laboratories in the United States but much broader in scope, performing inspections of equipment ranging from pressure vessels to motor vehicles.) Several of the 11 TÜVs perform inspections and tests of plants, as well as engineering reviews, both operating and plants under construction.

The Nuclear Safety Standards Commission - KTA

In 1972, the Federal Minister of the Interior established the Nuclear Safety Standards Commisson (Kerntechnischer Ausschuss, or KTA) to bring together participants in the nuclear industry to develop safety standards. Five groups of ten members each are represented on the KTA: manufacturers and constructors, owners and operators, independent experts, and Federal authorities; the final ten members are drawn from organizations having special technical knowledge. The KTA meets in task groups, which draft safety regulations. The drafts are reviewed by KTA subcommittees, then issued for three months of public comment. After the regulation has been finalized, it then must be approved by a 5/6 majority of the KTA. Thus, if only one of the five member groups is opposed to the regulation, it will not pass. Although a regulation does not become law, failure to comply with its provisions might imperil a plant's operating license.

The above-described structure governing the development of safety regulations shows a system of direct and regular contact between the industry and its regulators. A great deal of regulatory work is accomplished behind closed doors, with only the final results being discussed publicly. Due to such policies as the 5/6 plurality required to pass a KTA rule, once the parties have reached agreement, there is rapid implementation. However, it should not be inferred that the relationship between regulators and industry is always harmonious. On several occasions the industry has acted "voluntarily" in the face of significant regulatory pressure, the case of large-scale replacement of piping in BWRs being the most prominent example. The industry is unwilling to antagonize its regulators and will take action when a ruling appears emminent.

2.7 PUBLIC ATTITUDE AND INFLUENCE

In the 1960s, public attitude toward nuclear power was favorable. However, there was a gradual erosion of confidence in the mid 1970s, as the public became concerned with the safety of nuclear plants, fearing that they would need the protection of a police state to keep them safe from terrorist actions. At the same time, there was a growing environmental movement in Germany, with one of the main points being a concern for the potential health and environmental damages of nuclear power.

In the late 1970s, this opposition was manifested in numerous protests against nuclear power plant construction, which caused some extensive delays. These protests concentrated on proposed plants or those already under construction; little attention was paid to those already operating.

In the 1980s, public attitudes against nuclear power moderated. The ruling Christian Democratic Party favors continued development of nuclear power. The major opposition Social Democratic Party regards nuclear power as a bridge technology, and opposes any extensive development. The Green Party, one of the major environmental parties, also presently hold seats in the Federal Parliament. Their program against nuclear power has eased since their beginnings, although they are still firmly opposed to the further development of nuclear power.

There is opposition to plants under construction, in particular against the Fast Breeder Reactor at Kalkar. Public opposition seems likely to continue and probably will increase in the next several years. Major print media publications oppose nuclear power.

2.8 NUCLEAR PLANT PERFORMANCE

In this section the performance losses for the German nuclear power plants are presented and briefly examined. Energy availability was the performance index used to describe the German losses.

2.8.1 Aggregated Data

Performance losses for the German PWR's are tabulated by calendar year and by reactor age in Table 2.3 and Table 2.4 respectively. BWR energy availability losses are given by calendar year in Table 2.5 and by reactor age in Table 2.6. Finally, the mean and the standard deviation of the energy availability factors are tabulated by year and by age in Table 2.7.

2.8.2 Capacity Factor Distribution

The German PWR energy availability factor distribution is plotted over time in Figure 2.13. The figure displays a dip in the performance between 1975 and 1984 with the bottom occurring in 1979. The cause of this drop was an increase in refueling losses during this period. The average energy availability factor for the 10 years was 78.2%. The average magnitude of the standard deviations is smaller than that of the French PWR's with no trend over time visible. They do, however, show the same general correlation between performance and the magnitude of the standard deviation.

The energy availability as a function of age for the German PWR's is given in Figure 2.14. A slight increase in performance with age is observable amid the fluctuations shown. This trend is probably not significant since the number of plants at each age is not large and because the magnitude of the trend is small. The standard deviations display a trend of decreasing magnitudes with age. This was caused by the decreases in the number of plants making up the data at each age.

The energy availability over time is plotted in Figure 2.15 for the German BWR's. The performance for these plants shows a very large drop in performance, from 88.7% in 1975 to 30.1% in 1979. From 1980 the

Table 2.3
German PWR Energy Availability Losses By Year

ENERGY AVAIL. LOSSES
1975 - 1979

GERMANY
ALL PWR'S

04/15/86

			DATA:(3)	(4)	(5)	(5)	(6)
			1975	1976	1977	1978	1979
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.002	0.006	0.005	0.002	0.001
		SG	0.000	0.000	0.000	0.001	0.000
		REFUEL	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.021	0.001	0.000
			0.002	0.006	0.027	0.004	0.001
	BOP	TURBINE	0.001	0.000	0.013	0.000	0.001
		GEN	0.000	0.000	0.021	0.005	0.000
		COND	0.001	0.000	0.005	0.002	0.000
		CW/SW/CCW	0.005	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.022	0.000	0.000
			0.008	0.000	0.060	0.007	0.001
	ECONOMIC		0.000	0.000	0.008	0.000	0.000
	HUMAN						
	OTHER		0.000	0.002	0.004	0.000	0.000
	TOTAL		0.011	0.008	0.099	0.012	0.002
SCHEDULED	NSSS	FUEL	0.000	0.000	0.001	0.000	0.006
		RCS	0.015	0.002	0.000	0.023	0.016
		SG	0.000	0.004	0.007	0.001	0.000
		REFUEL	0.084	0.145	0.123	0.162	0.194
		OTHER	0.000	0.027	0.001	0.001	0.006
			0.099	0.177	0.132	0.187	0.222
	BOP	TURBINE	0.003	0.007	0.001	0.000	0.001
		GEN	0.000	0.001	0.007	0.001	0.001
		COND	0.014	0.000	0.001	0.000	0.001
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.018	0.008	0.009	0.002	0.002
	ECONOMIC		0.007	0.000	0.002	0.006	0.090
	HUMAN						
	OTHER		0.000	0.000	0.000	0.001	0.002
	TOTAL		0.123	0.185	0.144	0.195	0.317
REGULATORY			0.001	0.026	0.002	0.000	0.000
UNKNOWN			0.006	0.002	0.001	0.002	0.000
** TOTAL ENERGY AVAIL. LOSS **			0.141	0.222	0.246	0.208	0.319
** ENERGY AVAIL. FACTOR **			0.859	0.778	0.754	0.792	0.681

Table 2.3 (Continued)

ENERGY AVAIL. LOSSES
1980 - 1984

GERMANY
ALL PWR'S

04/15/86

			1980	1981	1982	1983	1984
		DATA:	(6)	(6)	(7)	(7)	(7)
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.001	0.000	0.000	0.001	0.000
		SG	0.000	0.002	0.000	0.012	0.015
		REFUEL	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.002	0.000	0.001
			0.001	0.003	0.002	0.013	0.016
	BOP	TURBINE	0.000	0.006	0.000	0.001	0.000
		GEN	0.000	0.000	0.000	0.045	0.001
		COND	0.000	0.002	0.000	0.001	0.000
		CW/SW/CCW	0.000	0.000	0.001	0.000	0.000
		OTHER	0.000	0.001	0.000	0.000	0.000
			0.000	0.009	0.001	0.046	0.001
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN						
	OTHER		0.000	0.000	0.000	0.001	0.000
	TOTAL		0.002	0.012	0.003	0.059	0.017
SCHEDULED	NSSS	FUEL	0.003	0.000	0.000	0.000	0.000
		RCS	0.004	0.005	0.002	0.003	0.000
		SG	0.000	0.003	0.000	0.000	0.000
		REFUEL	0.276	0.152	0.117	0.139	0.103
		OTHER	0.004	0.004	0.000	0.002	0.000
			0.286	0.164	0.120	0.144	0.103
	BOP	TURBINE	0.000	0.000	0.001	0.001	0.000
		GEN	0.001	0.011	0.000	0.000	0.000
		COND	0.001	0.001	0.001	0.000	0.001
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.001
			0.001	0.012	0.002	0.001	0.002
	ECONOMIC		0.005	0.005	0.000	0.015	0.015
	HUMAN						
	OTHER		0.004	0.001	0.000	0.002	0.002
	TOTAL		0.296	0.183	0.122	0.161	0.123
REGULATORY			0.007	0.006	0.007	0.004	0.028
UNKNOWN			0.000	0.000	0.000	0.001	0.001
** TOTAL ENERGY AVAIL. LOSS **			0.305	0.200	0.132	0.226	0.169
** ENERGY AVAIL. FACTOR **			0 695	0.800	0.868	0.774	0.831

Table 2.3 (Continued)

```
ENERGY AVAIL. LOSSES                                              GERMANY
1975 - 1984                                                     ALL PWR'S

04/15/86                    DATA: 7 PLANTS                 56 PLANT-YEARS
:-----------------------------------------------------------------------:
:                                   AVERAGE OVER ALL YEARS              :
:-----------------------------------------------------------------------:
: FORCED       : NSSS : FUEL                 0.000                      :
:              :      : RCS                  0.002                      :
:              :      : SG                   0.004                      :
:              :      : REFUEL               0.000                      :
:              :      : OTHER                0.002                      :
:              :      :                     ------                      :
:              :      :                      0.008                      :
:              :--------------------------------------------------------:
:              : BOP  : TURBINE              0.002                      :
:              :      : GEN                  0.008                      :
:              :      : COND                 0.001                      :
:              :      : CW/SW/CCW            0.000                      :
:              :      : OTHER                0.002                      :
:              :      :                     ------                      :
:              :      :                      0.014                      :
:              :--------------------------------------------------------:
:              : ECONOMIC                    0.001                      :
:              :--------------------------------------------------------:
:              : HUMAN                                                  :
:              :--------------------------------------------------------:
:              : OTHER                       0.001                      :
:              :--------------------------------------------------------:
:                TOTAL                       0.023                      :
:-----------------------------------------------------------------------:
: SCHEDULED    : NSSS : FUEL                 0.001                      :
:              :      : RCS                  0.006                      :
:              :      : SG                   0.001                      :
:              :      : REFUEL               0.152                      :
:              :      : OTHER                0.004                      :
:              :      :                     ------                      :
:              :      :                      0.164                      :
:              :--------------------------------------------------------:
:              : BOP  : TURBINE              0.001                      :
:              :      : GEN                  0.002                      :
:              :      : COND                 0.001                      :
:              :      : CW/SW/CCW            0.000                      :
:              :      : OTHER                0.000                      :
:      -       :      :                     ------                      :
:              :      :                      0.005                      :
:              :--------------------------------------------------------:
:              : ECONOMIC                    0.015                      :
:              :--------------------------------------------------------:
:              : HUMAN                                                  :
:              :--------------------------------------------------------:
:              : OTHER                       0.001                      :
:              :--------------------------------------------------------:
:                TOTAL                       0.185                      :
:-----------------------------------------------------------------------:
: REGULATORY :                               0.009                      :
:-----------------------------------------------------------------------:
: UNKNOWN    :                               0.001                      :
:-----------------------------------------------------------------------

** TOTAL ENERGY AVAIL. LOSS **               0.218

** ENERGY AVAIL. FACTOR **                   0.782
```

Table 2.4

German PWR Energy Availability Losses
By Reactor Age

```
ENERGY AVAIL. LOSSES BY REACTOR AGE                                  GERMANY
1975 - 1984                                                        ALL PWR'S

04/15/86                    DATA:( 5)    ( 5)    ( 5)    ( 5)    ( 5)
:------------------------------------------------------------------------:
:                        AGE:        1       2       3       4       5   :
:------------------------------------------------------------------------:
: FORCED      : NSSS : FUEL      0.000   0.000   0.000   0.000   0.000   .
:             :      : RCS       0.002   0.004   0.005   0.000   0.000   :
:             :      : SG        0.000   0.000   0.000   0.000   0.000   :
:             :      : REFUEL    0.000   0.000   0.000   0.000   0.000   :
:             :      : OTHER     0.024   0.001   0.001   0.001   0.000   :
:             :      :           ------  ------  ------  ------  ------  :
:             :      :           0.026   0.005   0.006   0.001   0.000   :
:             :----------------------------------------------------------:
:             : BOP  : TURBINE   0.001   0.006   0.012   0.002   0.001   :
:             :      : GEN       0.001   0.000   0.000   0.015   0.000   :
:             :      : COND      0.006   0.003   0.000   0.001   0.002   :
:             :      : CW/SW/CCW 0.003   0.000   0.000   0.000   0.000   :
:             :      : OTHER     0.023   0.000   0.001   0.000   0.000   :
:             :      :           ------  ------  ------  ------  ------  :
:             :      :           0.034   0.009   0.013   0.018   0.003   :
:             :----------------------------------------------------------:
:             : ECONOMIC         0.000   0.000   0.008   0.000   0.000   :
:             :----------------------------------------------------------.
:             : HUMAN                                                    :
:             :----------------------------------------------------------:
:             : OTHER            0.004   0.002   0.000   0.000   0.001   :
:             ------------------------------------------------------------:
:               TOTAL            0.066   0.017   0.027   0.019   0.004   :
:------------------------------------------------------------------------:
: SCHEDULED   : NSSS : FUEL      0.000   0.000   0.007   0.004   0.000   :
:             :      : RCS       0.010   0.023   0.000   0.000   0.017   :
:             :      : SG        0.000   0.000   0.000   0.000   0.000   .
:             :      : REFUEL    0.083   0.191   0.210   0.198   0.109   :
:             :      : OTHER     0.001   0.000   0.001   0.000   0.003   .
:             :      :           ------  ------  ------  ------  ------  :
:             :      :           0.094   0.214   0.218   0.202   0.129   .
:             :----------------------------------------------------------:
:             : BOP  : TURBINE   0.001   0.001   0.002   0.002   0.001   :
:             :      : GEN       0.006   0.002   0.003   0.001   0.000   :
:             :      : COND      0.007   0.001   0.001   0.003   0.000   :
:             :      : CW/SW/CCW 0.000   0.000   0.000   0.000   0.000   :
:      -      :      : OTHER     0.000   0.000   0.000   0.000   0.000   .
:             :      :           ------  ------  ------  ------  ------
:             :      :           0.014   0.004   0.006   0.006   0.001   .
:             :----------------------------------------------------------.
:             : ECONOMIC         0.000   0.002   0.052   0.016   0.042   :
:             :----------------------------------------------------------
:             : HUMAN                                                    .
:             :----------------------------------------------------------:
:             : OTHER            0.004   0.002   0.000   0.001   0.002   :
:             ------------------------------------------------------------:
:               TOTAL            0.111   0.222   0.276   0.225   0.175   :
:------------------------------------------------------------------------:
: REGULATORY :                   0.005   0.017   0.010   0.006   0.002   :
:------------------------------------------------------------------------:
: UNKNOWN    :                   0.001   0.002   0.000   0.004   0.001   :
:------------------------------------------------------------------------:

** TOTAL ENERGY AVAIL. LOSS **   0 182   0.258   0.313   0.254   0.182

** ENERGY AVAIL. FACTOR **       0.818   0.742   0.687   0.746   0.818
```

Table 2.4 (Continued)

ENERGY AVAIL. LOSSES BY REACTOR AGE
1975 - 1984

GERMANY
ALL PWR'S

04/15/86

			DATA: (4)	(5)	(5)	(3)	(3)
		AGE:	6	7	8	9	10
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.001	0.001	0.003	0.000	0.000
		SG	0.000	0.001	0.000	0.027	0.041
		REFUEL	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.001	0.000	0.000
			0.001	0.002	0.004	0.027	0.041
	BOP	TURBINE	0.000	0.000	0.000	0.000	0.000
		GEN	0.000	0.053	0.000	0.032	0.001
		COND	0.000	0.001	0.000	0.000	0.000
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.001	0.000	0.000	0.000
			0.000	0.055	0.000	0.032	0.001
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN						
	OTHER		0.000	0.000	0.000	0.000	0.000
	TOTAL		0.001	0.056	0.006	0.059	0.043
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.003	0.003	0.002	0.000	0.003
		SG	0.000	0.004	0.003	0.012	0.001
		REFUEL	0.218	0.104	0.121	0.157	0.177
		OTHER	0.002	0.000	0.000	0.002	0.001
			0.223	0.111	0.126	0.171	0.182
	BOP	TURBINE	0.000	0.000	0.003	0.000	0.000
		GEN	0.000	0.013	0.000	0.000	0.000
		COND	0.002	0.000	0.002	0.000	0.001
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.001	0.000	0.000
			0.002	0.013	0.006	0.000	0.001
	ECONOMIC		0.000	0.011	0.011	0.009	0.009
	HUMAN						
	OTHER		0.002	0.000	0.000	0.000	0.000
	TOTAL		0.227	0.136	0.143	0.180	0.192
REGULATORY			0.008	0.004	0.044	0.000	0.000
UNKNOWN			0.000	0.001	0.000	0.001	0.000
** TOTAL ENERGY AVAIL. LOSS **			0.236	0.197	0.192	0.240	0.235
** ENERGY AVAIL. FACTOR **			0.764	0.803	0.808	0.760	0.765

Table 2.4 (Continued)

ENERGY AVAIL. LOSSES BY REACTOR AGE
1975 - 1984

GERMANY
ALL PWR'S

04/15/86

		DATA:	(2)	(2)	(2)	(1)	(1)
		AGE:	11	12	13	14	15
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.000	0.000	0.000	0.000	0.000
		SG	0.000	0.000	0.000	0.000	0.000
		REFUEL	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.010	0.000
			0.000	0.000	0.000	0.010	0.000
	BOP	TURBINE	0.001	0.000	0.002	0.000	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND	0.000	0.000	0.000	0.000	0.000
		CW/SW/CCW	0.000	0.000	0.000	0.007	0.000
		OTHER	0.000	0.001	0.000	0.000	0.000
			0.001	0.001	0.002	0.007	0.000
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN						
	OTHER		0.000	0.000	0.000	0.000	0.000
	TOTAL		0.001	0.001	0.002	0.018	0.000
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.008	0.004	0.003	0.000	0.018
		SG	0.000	0.000	0.000	0.000	0.000
		REFUEL	0.130	0.173	0.118	0.149	0.298
		OTHER	0.000	0.009	0.009	0.000	0.004
			0.138	0.188	0.130	0.149	0.320
	BOP	TURBINE	0.000	0.000	0.000	0.000	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND	0.000	0.000	0.003	0.000	0.000
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.000	0.000	0.003	0.000	0.000
	ECONOMIC		0.011	0.008	0.010	0.000	0.001
	HUMAN						
	OTHER		0.003	0.005	0.001	0.000	0.000
	TOTAL		0.150	0.198	0.143	0.149	0.321
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL ENERGY AVAIL. LOSS **			0.151	0.199	0.145	0.167	0.321
** ENERGY AVAIL. FACTOR **			0.849	0.801	0.855	0.833	0.679

Table 2.4 (Continued)

```
ENERGY AVAIL. LOSSES BY REACTOR AGE                                  GERMANY
1975 - 1984                                                        ALL PWR'S

04/15/86                      DATA:( 1)    ( 0)    ( 0)    ( 0)    ( 0)
:----------------------------------------------------------------------.
:                         AGE:        16      17
:----------------------------------------------------------------------
: FORCED        : NSSS : FUEL        0.000                              .
:               :      : RCS         0.000                              .
:               :      : SG          0.000                              .
:               :      : REFUEL      0.000                              :
:               :      : OTHER       0.000                              :
:               :      :            ------ ------ ------ ------ ------  :
:               :      :             0.000                              :
:               :------------------------------------------------------:
:               : BOP  : TURBINE     0.000                              :
:               :      : GEN         0.000                              :
:               :      : COND        0.000                              :
:               :      : CW/SW/CCW   0.002                              :
:               :      : OTHER       0.000                              :
:               :      :            ------ ------ ------ ------ ------  :
:               :      :             0.002                              :
:               :------------------------------------------------------.
:               : ECONOMIC           0.000                              .
:               :------------------------------------------------------.
:               : HUMAN                                                 .
:               :------------------------------------------------------:
:               : OTHER              0.000                              :
:               -------------------------------------------------------:
:                 TOTAL              0.002                              :
:----------------------------------------------------------------------:
: SCHEDULED     : NSSS : FUEL        0.000                              .
:               :      : RCS         0.000                              .
:               :      : SG          0.000                              .
:               :      : REFUEL      0.108                              
:               :      : OTHER       0.000                              .
:               :      :            ------ ------ ------ ------ ------  :
:               :      :             0.108                              :
:               :------------------------------------------------------:
:               : BOP  : TURBINE     0.000                              :
:               :      : GEN         0.000                              :
:               :      : COND        0.000                              :
:               :      : CW/SW/CCW   0.000                              :
:               :      : OTHER       0.000                              
:               :      :            ------ ------ ------ ------ ------  .
:               :      :             0.000                              :
:               :------------------------------------------------------.
:               : ECONOMIC           0.026                              .
:               :------------------------------------------------------.
:               : HUMAN                                                 :
:               :------------------------------------------------------:
:               : OTHER              0.012                              :
:               -------------------------------------------------------:
:                 TOTAL              0.146                              :
:----------------------------------------------------------------------:
: REGULATORY :                       0.000                              :
:----------------------------------------------------------------------:
: UNKNOWN    :                       0.000                              :
:----------------------------------------------------------------------:

** TOTAL ENERGY AVAIL. LOSS **       0 148

** ENERGY AVAIL. FACTOR **           0 852
```

Table 2.5
German BWR Energy Availability Losses By Year

ENERGY AVAIL. LOSSES
1975 - 1979

GERMANY
ALL BWR'S

04/15/86

			1975	1976	1977	1978	1979
		DATA:	(1)	(1)	(2)	(2)	(3)
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.000	0.003	0.184	0.020	0.006
		SG					
		REFUEL	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.011	0.000	0.275	0.008
			0.000	0.014	0.184	0.295	0.015
	BOP	TURBINE	0.000	0.000	0.000	0.062	0.004
		GEN	0.000	0.000	0.001	0.003	0.000
		COND	0.000	0.000	0.002	0.005	0.001
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.008
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.000	0.000	0.004	0.070	0.013
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN						
	OTHER		0.000	0.000	0.000	0.010	0.000
	TOTAL		0.000	0.014	0.188	0.375	0.028
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.000	0.000	0.000	0.000	0.000
		SG					
		REFUEL	0.000	0.099	0.113	0.098	0.201
		OTHER	0.113	0.010	0.004	0.006	0.001
			0.113	0.108	0.118	0.104	0.201
	BOP	TURBINE	0.000	0.020	0.000	0.000	0.009
		GEN	0.000	0.004	0.000	0.000	0.001
		COND	0.000	0.000	0.000	0.000	0.008
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.001
		OTHER	0.000	0.000	0.001	0.000	0.000
			0.000	0.024	0.001	0.000	0.019
	ECONOMIC		0.000	0.000	0.000	0.000	0.001
	HUMAN						
	OTHER		0.000	0.000	0.001	0.002	0.001
	TOTAL		0.113	0.132	0.119	0.106	0.222
REGULATORY			0.000	0.200	0.104	0.100	0.432
UNKNOWN			0.000	0.000	0.015	0.002	0.017
** TOTAL ENERGY AVAIL. LOSS **			0.113	0.346	0.427	0.583	0.699
** ENERGY AVAIL. FACTOR **			0 887	0.654	0.573	0.417	0.301

Table 2.5 (Continued)

```
ENERGY AVAIL. LOSSES                                              GERMANY
1980 - 1984                                                     ALL BWR'S

04/15/86                     DATA:( 4)    ( 4)    ( 4)    ( 4)    ( 4)
:--------------------------------------------------------------------
:                                1980    1981    1982    1983    1984
:--------------------------------------------------------------------
: FORCED      : NSSS : FUEL      0.000   0.000   0.000   0.000   0.000
:             :      : RCS       0.000   0.002   0.005   0.001   0.000
:             :      : SG
:             :      : REFUEL    0.000   0.000   0.000   0.000   0.000
:             :      : OTHER     0.006   0.007   0.008   0.000   0.001
:             :      :           ------  ------  ------  ------  ------
:             :      :           0.006   0.008   0.013   0.001   0.001
:             :-------------------------------------------------------:
:             : BOP  : TURBINE   0.001   0.003   0.002   0.002   0.016
:             :      : GEN       0.000   0.001   0.000   0.001   0.000
:             :      : COND      0.008   0.033   0.005   0.001   0.002
:             :      : CW/SW/CCW 0.010   0.000   0.000   0.000   0.000
:             :      : OTHER     0.012   0.003   0.000   0.009   0.000
:             :      :           ------  ------  ------  ------  ------
:             :      :           0.032   0.040   0.008   0.013   0.017
:             :-------------------------------------------------------
:             : ECONOMIC         0.000   0.000   0.000   0.000   0.007
:             :-------------------------------------------------------
:             : HUMAN
:             :-------------------------------------------------------
:             : OTHER            0.002   0.001   0.001   0.002   0.000
:             :-------------------------------------------------------
:               TOTAL            0.039   0.050   0.021   0.015   0.026
:---------------------------------------------------------------------
: SCHEDULED   : NSSS : FUEL      0.000   0.000   0.000   0.000   0.000
:             :      : RCS       0.165   0.206   0.432   0.302   0.000
:             :      : SG
:             :      : REFUEL    0.085   0.148   0.072   0.095   0.152
:             :      : OTHER     0.013   0.002   0.001   0.004   0.004
:             :      :           ------  ------  ------  ------  ------
:             :      :           0.263   0.356   0.505   0.401   0.156
:             :-------------------------------------------------------:
:             : BOP  : TURBINE   0.000   0.000   0.000   0.000   0.010
:             :      : GEN       0.000   0.000   0.000   0.000   0.000
:             :      : COND      0.002   0.000   0.001   0.000   0.000
:             :      : CW/SW/CCW 0.000   0.001   0.002   0.000   0.000
:             :      : OTHER     0.000   0.000   0.000   0.000   0.000
:             :      :           ------  ------  ------  ------  ------
:             :      :           0.002   0.001   0.002   0.000   0.010
:             :-------------------------------------------------------
:             : ECONOMIC         0.026   0.017   0.030   0.009   0.020
:             :-------------------------------------------------------
:             : HUMAN
:             :-------------------------------------------------------
:             : OTHER            0.001   0.022   0.005   0.003   0.001
:             :-------------------------------------------------------
:               TOTAL            0.293   0.396   0.543   0.414   0.186
:---------------------------------------------------------------------:
: REGULATORY  :                  0.268   0.054   0.014   0.002   0.000
:---------------------------------------------------------------------
: UNKNOWN     :                  0.008   0.000   0.004   0.005   0.000
:---------------------------------------------------------------------:

** TOTAL ENERGY AVAIL. LOSS **   0 608   0.500   0.581   0.436   0.212

** ENERGY AVAIL. FACTOR **       0 392   0.500   0.419   0.564   0.788
```

Table 2.5 (Continued)

```
ENERGY AVAIL. LOSSES                                                GERMANY
1975 - 1984                                                       ALL BWR'S

04/15/86                      DATA: 4 PLANTS              29 PLANT-YEARS
:------------------------------------------------------------------------.
:                                  AVERAGE OVER ALL YEARS                :
:------------------------------------------------------------------------:
: FORCED       : NSSS : FUEL                   0.000                     :
:              :      : RCS                    0.016                     :
:              :      : SG                                               :
:              :      : REFUEL                 0.000                     :
:              :      : OTHER                  0.024                     :
:              :      :                        ------                    :
:              :      :                        0.040                     :
:              :---------------------------------------------------------:
:              : BOP  : TURBINE                0.008                     :
:              :      : GEN                    0.001                     :
:              :      : COND                   0.008                     :
:              :      : CW/SW/CCW              0.002                     :
:              :      : OTHER                  0.003                     :
:              :      :                        ------                    :
:              :      :                        0.022                     :
:              :---------------------------------------------------------:
:              : ECONOMIC                      0.001                     :
:              :---------------------------------------------------------:
:              : HUMAN                                                   :
:              :---------------------------------------------------------:
:              : OTHER                         0.002                     :
:              ----------------------------------------------------------:
:                TOTAL                         0.065                     :
:------------------------------------------------------------------------:
: SCHEDULED    : NSSS : FUEL                   0.000                     :
:              :      : RCS                    0.159                     :
:              :      : SG                                               :
:              :      : REFUEL                 0.118                     :
:              :      : OTHER                  0.005                     :
:              :      :                        ------                    :
:              :      :                        0.282                     :
:              :---------------------------------------------------------:
:              : BOP  : TURBINE                0.003                     :
:              :      : GEN                    0.000                     :
:              :      : COND                   0.001                     :
:              :      : CW/SW/CCW              0.001                     :
:              :      : OTHER                  0.000                     :
:       -      :      :                        ------                    :
:              :      :                        0.005                     :
:              :---------------------------------------------------------:
:              : ECONOMIC                      0.015                     :
:              :---------------------------------------------------------:
:              : HUMAN                                                   :
:              :---------------------------------------------------------:
:              : OTHER                         0.005                     :
:              ----------------------------------------------------------:
:                TOTAL                         0.307                     :
:------------------------------------------------------------------------:
: REGULATORY :                                 0.113                     :
:------------------------------------------------------------------------:
: UNKNOWN    :                                 0.005                     :
:------------------------------------------------------------------------:

** TOTAL ENERGY AVAIL. LOSS **                 0.489

** ENERGY AVAIL. FACTOR **                     0.511
```

Table 2.6

German BWR Energy Availability Losses
By Reactor Age

ENERGY AVAIL. LOSSES BY REACTOR AGE — GERMANY
1975 - 1984 — ALL BWR'S

04/15/86

			DATA: (4)	(4)	(4)	(4)	(4)
		AGE:	1	2	3	4	5
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.098	0.011	0.005	0.004	0.000
		SG					
		REFUEL	0.000	0.000	0.000	0.000	0.000
		OTHER	0.008	0.137	0.011	0.003	0.004
			0.106	0.148	0.016	0.007	0.004
	BOP	TURBINE	0.004	0.007	0.025	0.001	0.004
		GEN	0.000	0.002	0.001	0.001	0.000
		COND	0.004	0.013	0.029	0.006	0.001
		CW/SW/CCW	0.006	0.009	0.000	0.000	0.000
		OTHER	0.013	0.000	0.000	0.009	0.002
			0.027	0.031	0.055	0.017	0.007
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN						
	OTHER		0.000	0.007	0.000	0.001	0.000
	TOTAL		0.133	0.187	0.071	0.025	0.011
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.175	0.206	0.000	0.189	0.000
		SG					
		REFUEL	0.071	0.118	0.195	0.181	0.078
		OTHER	0.003	0.004	0.003	0.000	0.014
			0.249	0.328	0.198	0.370	0.092
	BOP	TURBINE	0.011	0.000	0.000	0.001	0.000
		GEN	0.002	0.000	0.000	0.000	0.000
		COND	0.006	0.002	0.000	0.000	0.000
		CW/SW/CCW	0.000	0.000	0.000	0.001	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.019	0.002	0.000	0.002	0.000
	ECONOMIC		0.000	0.009	0.000	0.002	0.043
	HUMAN						
	OTHER		0.002	0.001	0.002	0.005	0.021
	TOTAL		0.270	0.341	0.201	0.380	0.157
REGULATORY			0.057	0.049	0.300	0.259	0.053
UNKNOWN			0.022	0.000	0.004	0.008	0.002
** TOTAL ENERGY AVAIL. LOSS **			0.482	0.577	0.576	0.672	0.223
** ENERGY AVAIL. FACTOR **			0.518	0.423	0.424	0.328	0.777

Table 2.6 (Continued)

ENERGY AVAIL. LOSSES BY REACTOR AGE
1975 - 1984

GERMANY
ALL BWR'S

04/15/86

				DATA: (3)	(2)	(2)	(1)	(0)
		AGE:		6	7	8	9	10
FORCED	NSSS	FUEL		0.000	0.000	0.000	0.000	
		RCS		0.001	0.001	0.000	0.000	
		SG						
		REFUEL		0.000	0.000	0.000	0.000	
		OTHER		0.006	0.001	0.002	0.000	
				0.007	0.002	0.002	0.000	
	BOP	TURBINE		0.022	0.000	0.001	0.000	
		GEN		0.000	0.001	0.000	0.000	
		COND		0.002	0.000	0.000	0.000	
		CW/SW/CCW		0.000	0.000	0.000	0.000	
		OTHER		0.001	0.000	0.000	0.000	
				0.025	0.001	0.001	0.000	
	ECONOMIC			0.000	0.000	0.013	0.000	
	HUMAN							
	OTHER			0.000	0.002	0.004	0.000	
	TOTAL			0.033	0.006	0.021	0.000	
SCHEDULED	NSSS	FUEL		0.000	0.000	0.000	0.000	
		RCS		0.139	0.533	0.357	0.000	
		SG						
		REFUEL		0.084	0.083	0.071	0.162	
		OTHER		0.002	0.001	0.001	0.012	
				0.225	0.617	0.429	0.174	
	BOP	TURBINE		0.000	0.000	0.006	0.027	
		GEN		0.000	0.000	0.000	0.000	
		COND		0.001	0.000	0.000	0.000	
		CW/SW/CCW		0.002	0.003	0.000	0.000	
		OTHER		0.000	0.000	0.000	0.000	
				0.003	0.003	0.006	0.027	
	ECONOMIC			0.021	0.050	0.013	0.002	
	HUMAN							
	OTHER			0.001	0.001	0.004	0.000	
	TOTAL			0.251	0.672	0.452	0.203	
REGULATORY				0.071	0.027	0.000	0.000	
UNKNOWN				0.001	0.001	0.006	0.000	
** TOTAL ENERGY AVAIL. LOSS **				0.356	0.705	0.479	0.203	
** ENERGY AVAIL. FACTOR **				0.644	0.295	0.521	0.797	

Table 2.7 German Capacity Factor Distributions

By	PWR			BWR		
Year	Mean	σ	# Data	Mean	σ	# Data
75	0.859	0.033	3	0.887	0.000	1
76	0.778	0.164	4	0.654	0.000	1
77	0.754	0.104	5	0.573	0.078	2
78	0.792	0.082	5	0.417	0.070	2
79	0.681	0.131	6	0.301	0.287	3
80	0.695	0.137	6	0.392	0.236	4
81	0.800	0.052	6	0.500	0.210	4
82	0.868	0.046	7	0.419	0.194	4
83	0.774	0.094	7	0.564	0.280	4
84	0.831	0.068	7	0.788	0.036	4

By	PWR			BWR		
Age	Mean	σ	# Data	Mean	σ	# Data
1	0.818	0.093	5	0.519	0.194	4
2	0.742	0.126	5	0.423	0.193	4
3	0.687	0.153	5	0.424	0.253	4
4	0.746	0.069	5	0.328	0.235	4
5	0.818	0.098	5	0.778	0.115	4
6	0.764	0.195	4	0.643	0.074	3
7	0.803	0.129	5	0.295	0.047	2
8	0.808	0.052	5	0.520	0.269	2
9	0.760	0.014	3	0.797	0.000	1
10	0.766	0.058	3			
11	0.849	0.024	2			
12	0.801	0.063	2			
13	0.854	0.038	2			
14	0.833	0.000	1			
15	0.679	0.000	1			
16	0.852	0.000	1			
17						

FIGURE 2.13

German PWR Capacity Factor Distribution By Year

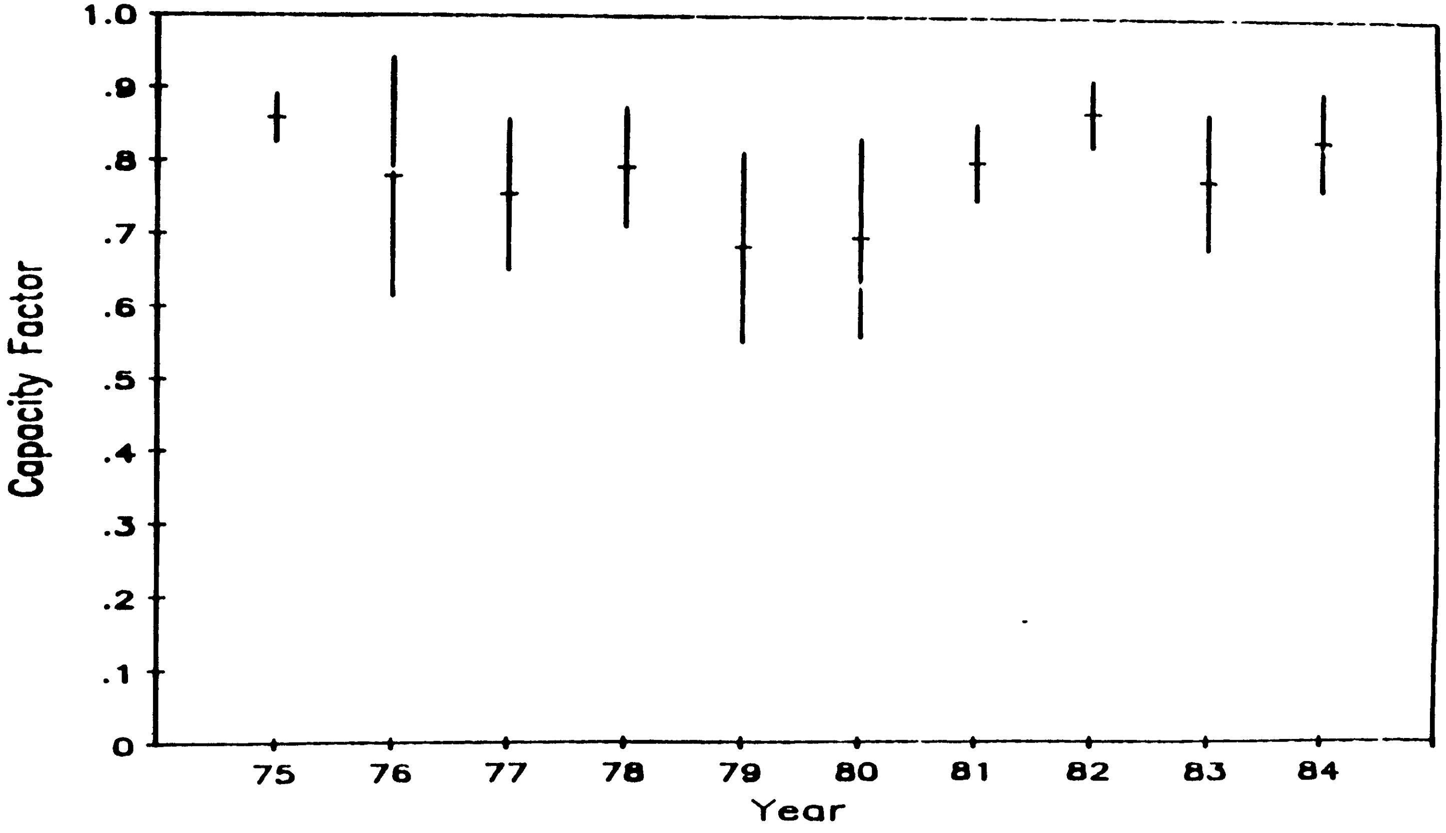


FIGURE 2.14

German PWR Capacity Factor Distribution By Reactor Age

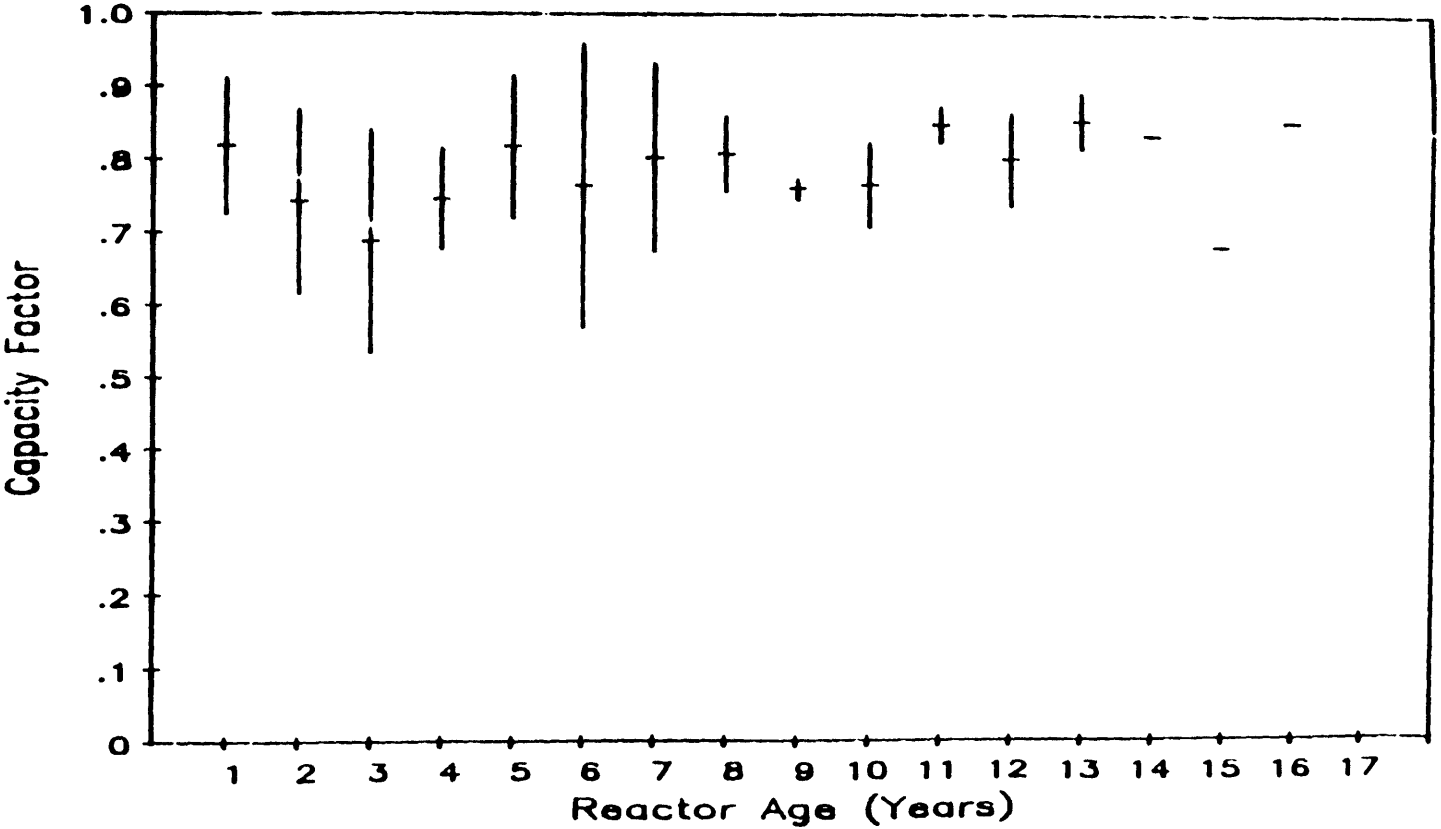
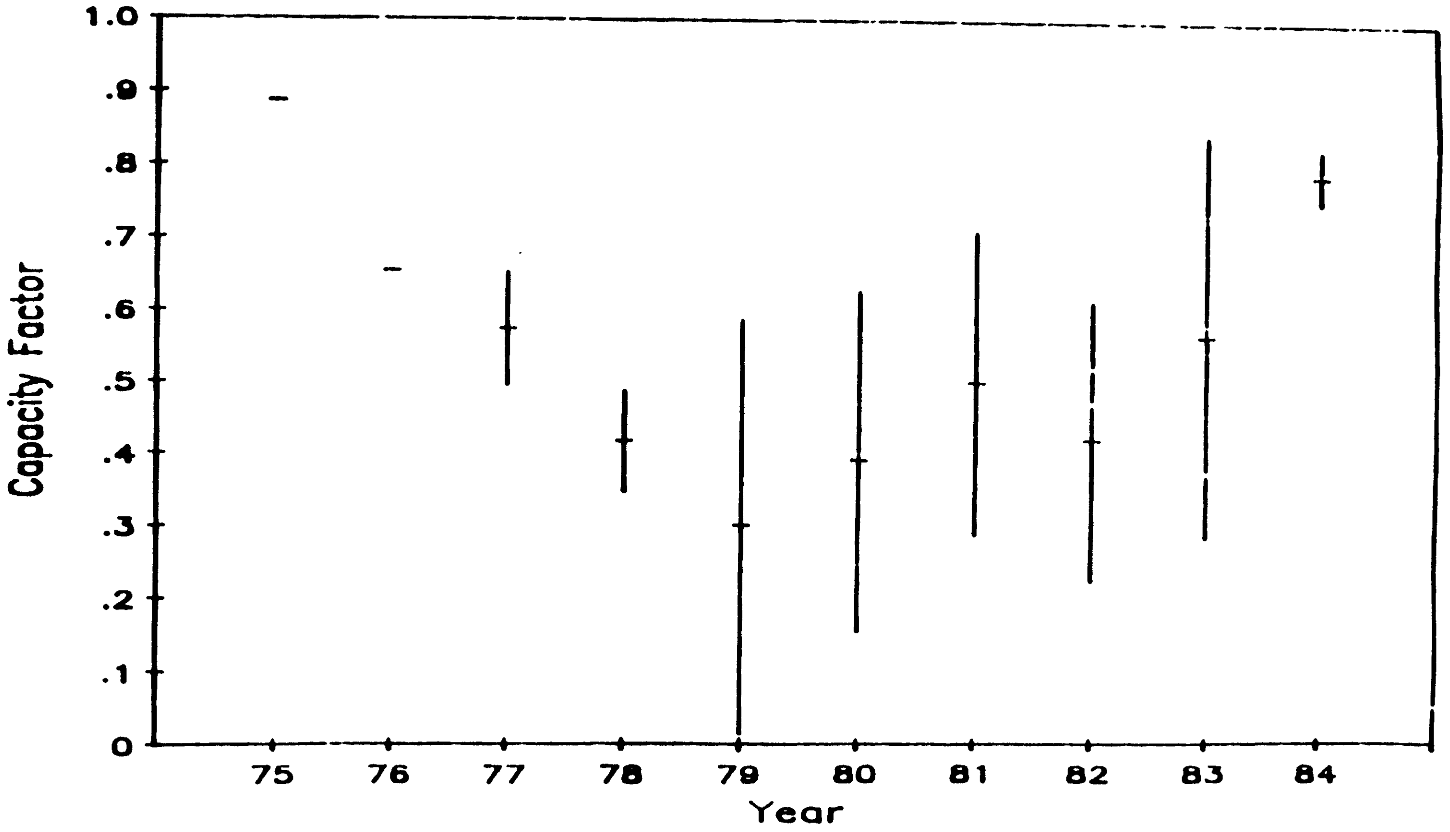


FIGURE 2.15

German BWR Capacity Factor Distribution By Year



performance began to climb back to its previous level. The causes of these tremendous losses were large outages for pipe replacements. In addition, several large regulatory losses also contributed at a couple of plants. The standard deviations shown indicate that between 1979 and 1983, large variations in performance occurred between plants in a given year.

The same BWR energy availability data are shown as a function of age in Figure 2.16. The data points showing relatively low performance with or without large standard deviations, represent the ages where the pipe replacements occurred. Thus, no age dependency is observable.

2.8.3 Losses by Outage Type

In this subsection, forced, scheduled, and regulatory losses for the German nuclear plants are displayed and examined as functions of time and age.

Forced, scheduled, and regulatory losses for German PWR's are plotted versus time in Figure 2.17. Forced losses averaged 2.3% over the 10 years, representing 10.6% of the total losses. Forced outages generally were not a problem in the German PWR's with the exception of 1977 and 1983. In 1977 the forced losses were larger as a result of outages at three plants that averaged 10% each, including a 9.7% generator loss at one particular plant. The scheduled losses, averaging 19.5% over the entire period, represent 84.9% of the average total loss of 21.8%. There is a wide peak in the scheduled losses spanning 1978 to 1981. This peak was a result of increased refueling losses in those years. The cause for the increased refueling outages is not known. Regulatory losses have been low, averaging less than 1.0%, or 4.1% of the total losses. There are no time dependent trends visible in this figure.

FIGURE 2.16

German BWR Capacity Factor Distribution By Reactor Age

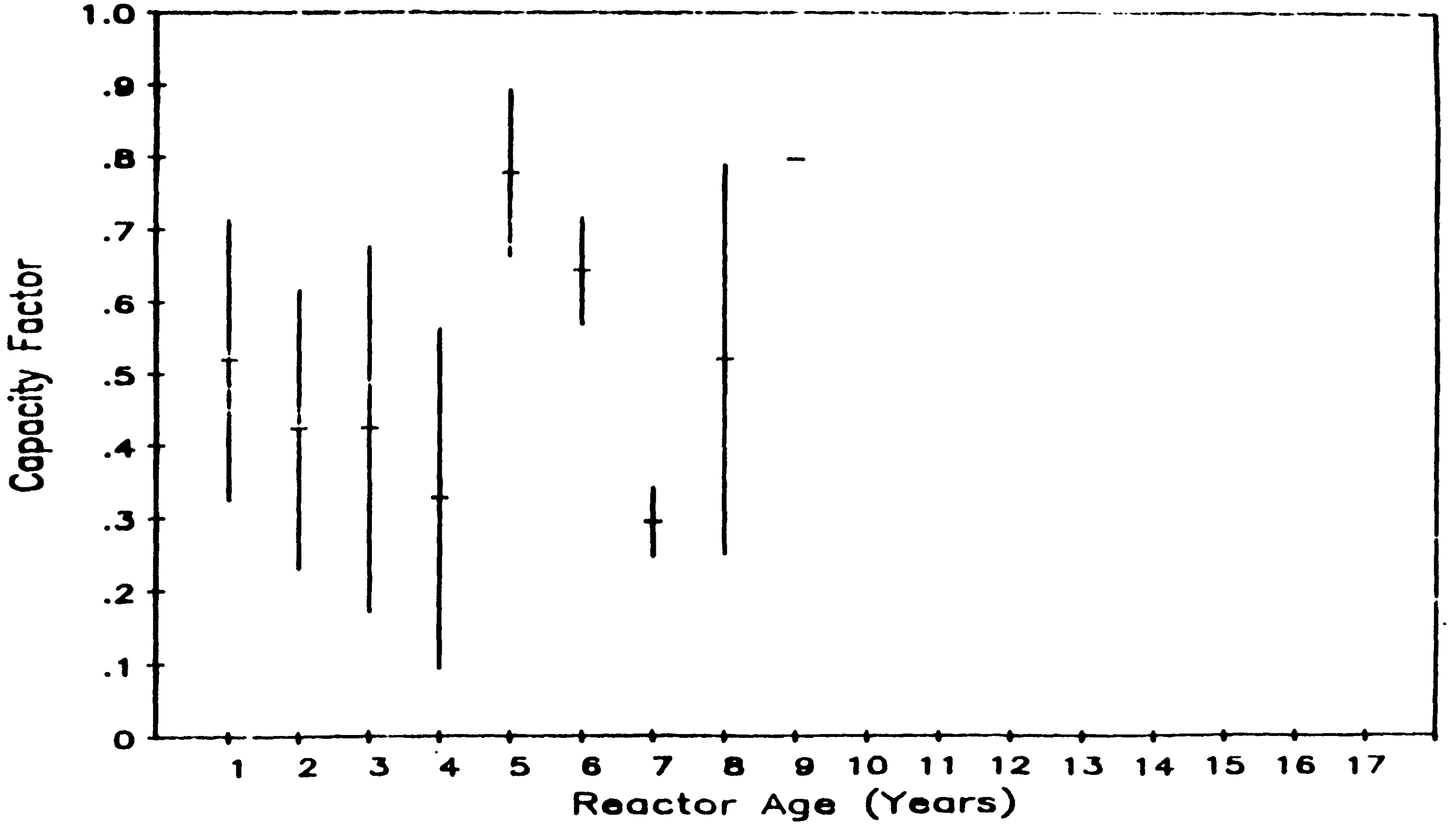
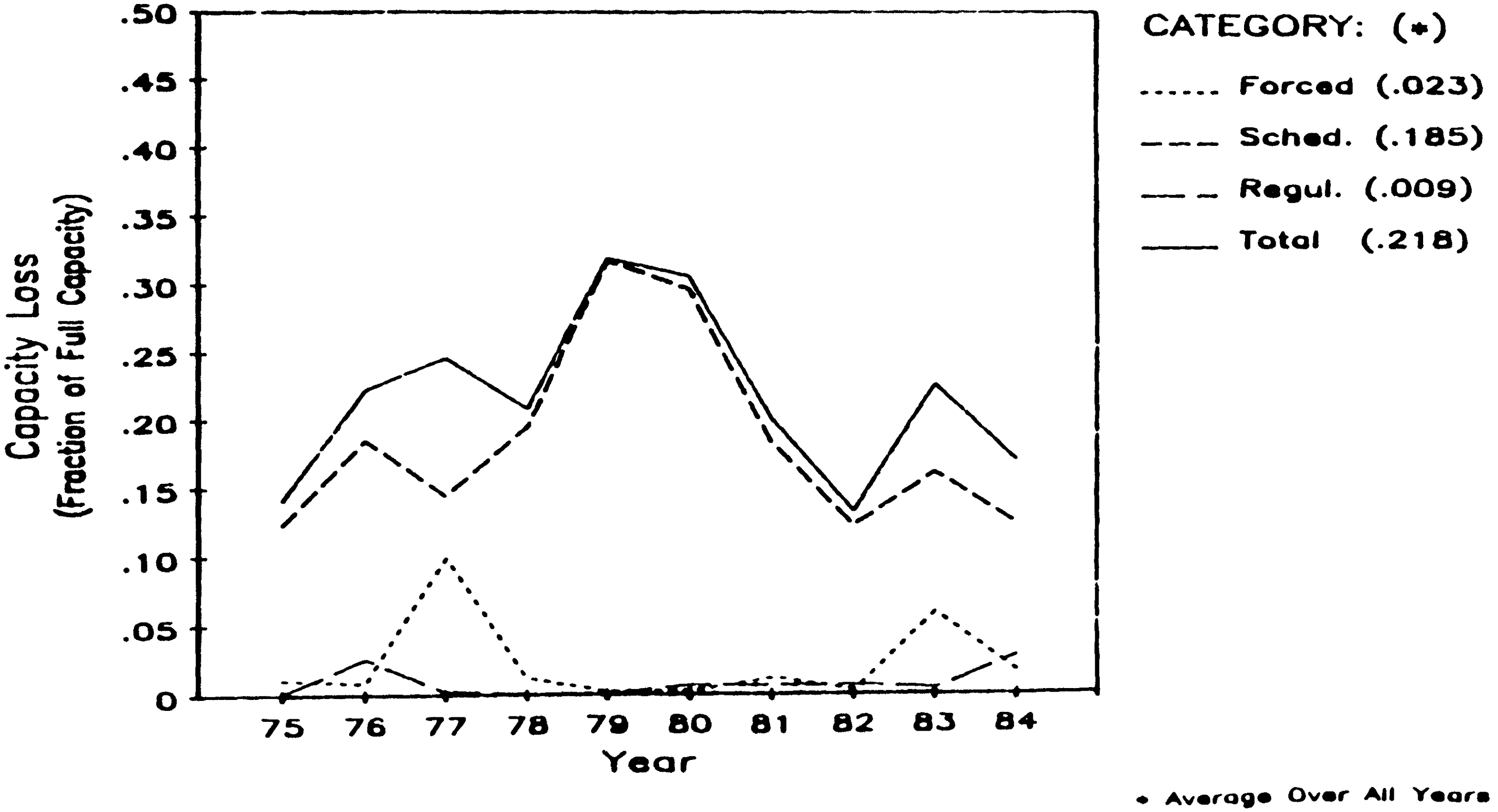


FIGURE 2.17

German PWR Capacity Losses By Year
Forced, Scheduled, and Regulatory



The same PWR losses are plotted by reactor age in Figure 2.18. Overall, the German losses exhibit a slight improvement over age with approximately 5% variation occurring between ages. The scheduled outages represent an average 85% of the total losses and therefore show the same trend as the total losses. This trend, however, is probably insignificant due to its small magnitude and the amount of fluctuation present. The regulatory losses have only affected PWR's through age 8, even though some plants are up to 16 years old.

Forced, scheduled, and regulatory losses by year for German BWR's are shown graphically in Figure 2.19. Overall, the total losses have been large, with an average total loss over the 10 year period of 48.9%. The large total losses have had contributions from all three of the categories shown with none of them showing a signficiant trend. Scheduled losses have been the largest contributor, averaging 62.8% of the total. The figure shows that scheduled losses were generally constant at 11.5% from 1975 to 1978 but then began to increase steeply to 54.3% iln 1982. The cause of this increase was large outages for pipe replacement. Forced outages contributed to the large total loss in 1977 and 1978 as a result of a large reactor cooling system outage in 1977 at one plant and a large NSSS OTHER loss in 1978 at another. Regulatory losses have also played a role in the overall losses with large losses at several plants in 1979 and 1980.

Figure 2.20 displays the German BWR losses as a function of age. A large amount of fluctuation is visible in the scheduled outages as a result of the pipe replacements which were time and not age dependent. The forced outages show an age dependence with losses decreasing with plant age. This can be attributed to reductions in losses in several NSSS categories. The regulatory losses fluctuate with age and do not exhibit any age dependency.

FIGURE 2.13

German PWR Capacity Losses By Rx Age
Forced, Scheduled, and Regulatory

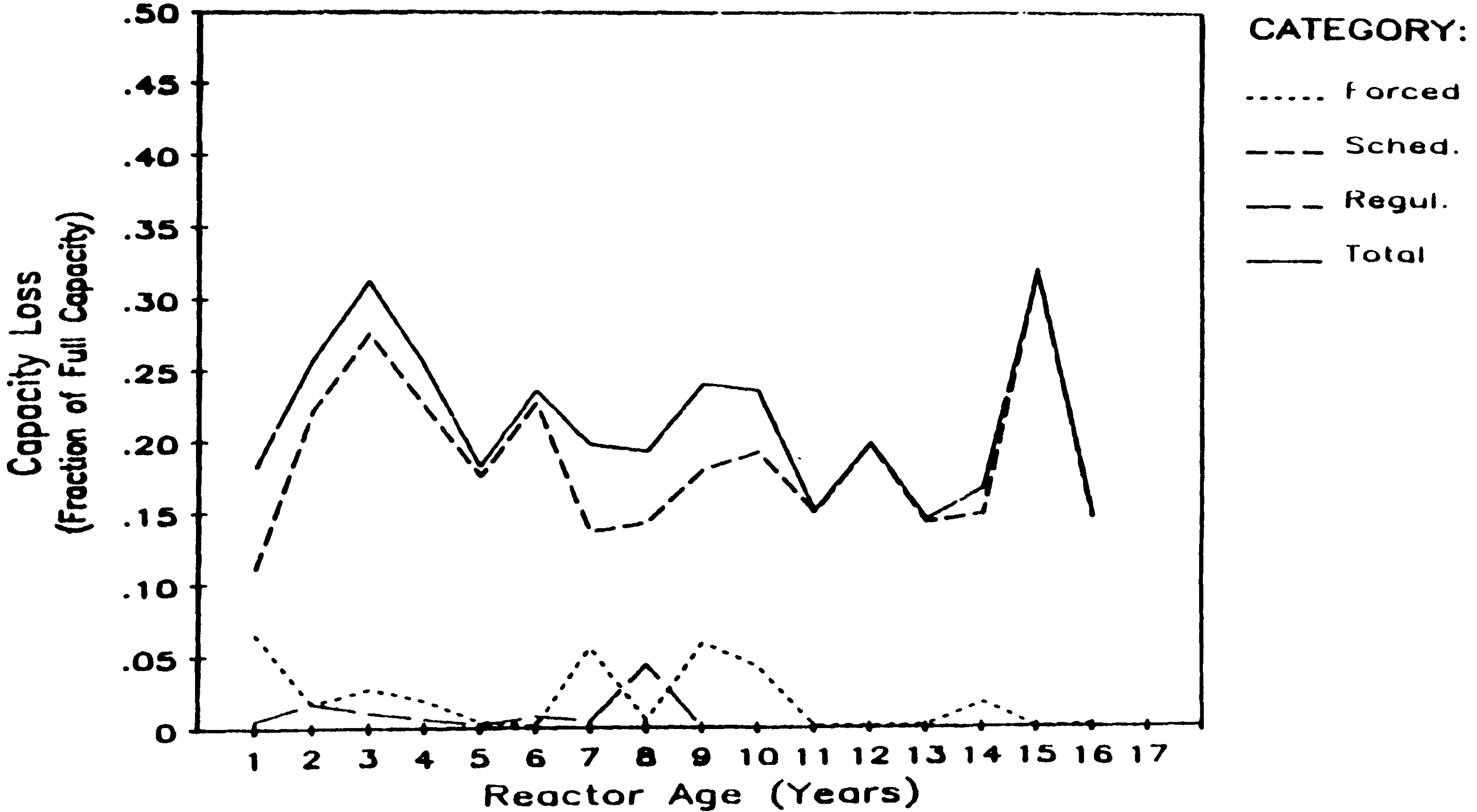


FIGURE 2.19

German BWR Capacity Losses By Year
Forced, Scheduled, and Regulatory

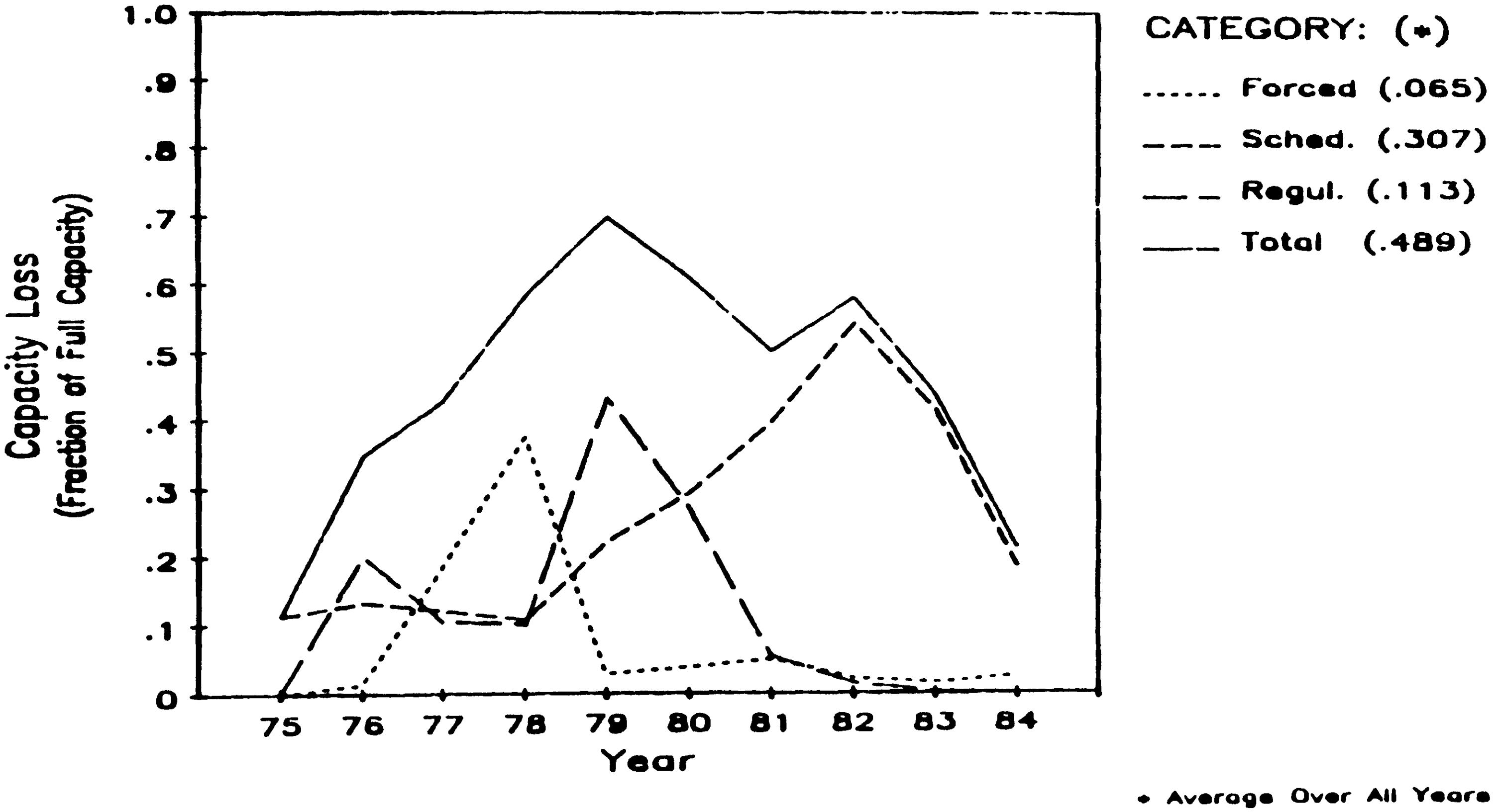
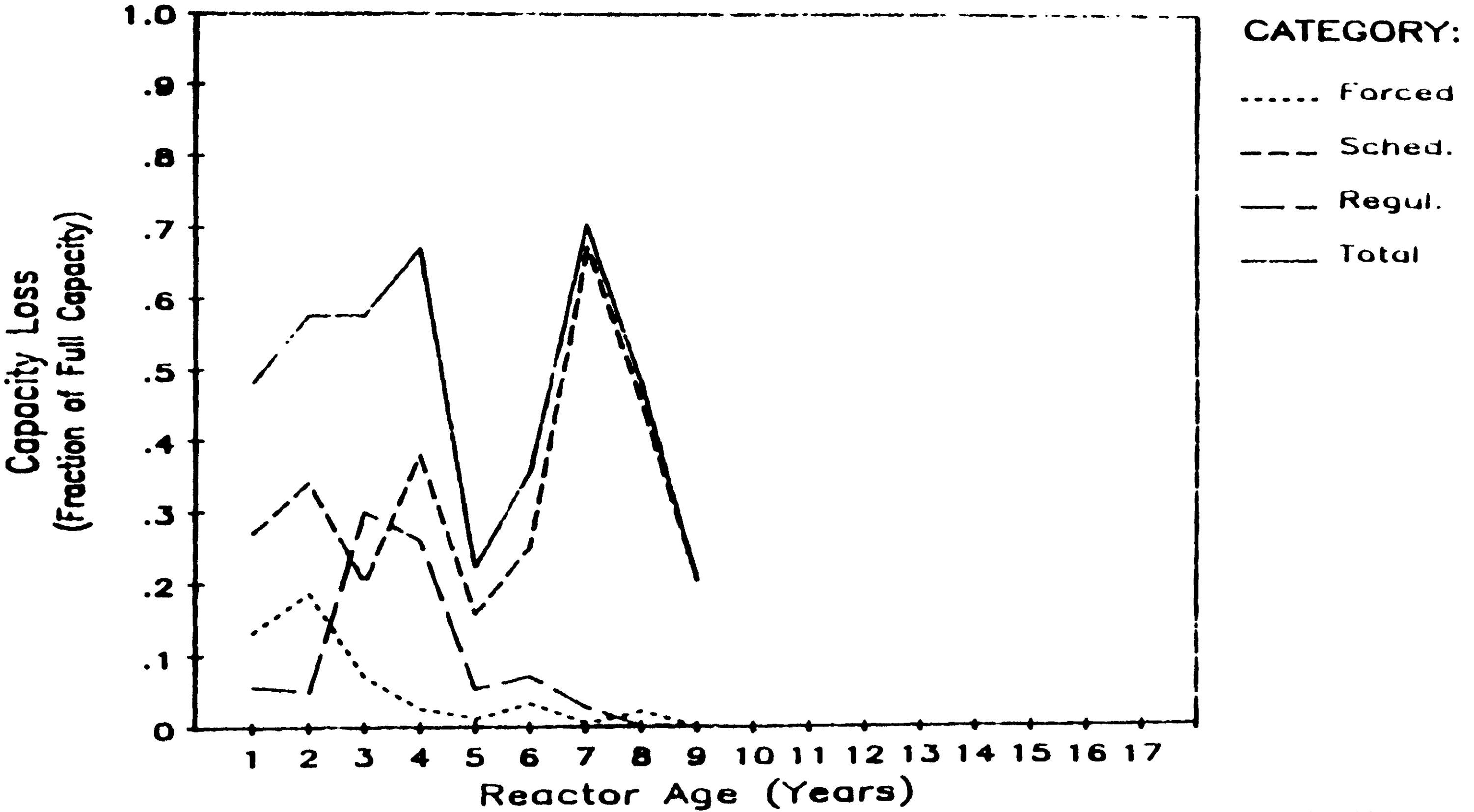


FIGURE 2.20

German BWR Capacity Losses By Rx Age
Forced, Scheduled, and Regulatory



2.9 OBSERVATIONS

The operating performance of German Nuclear Power Plants has significantly improved since the end of the 1970's. The main problems of German BWR's between 1975 and 1979 regarding the pipe replacements were resolved at that time.

The German utility industry consists of more than 1100 different companies, although only a few of them are involved in nuclear power. In spite of the large number of companies, their range of sizes and diversity, there exists a close professional relationship between German utilities.

All investigated LWRs have been built by KWU or its parents. They were all turnkey projects in which the respected utilities participated in various degrees. Although the internal organizations of nuclear power utilities are not consistent the management appears to be remarkably capable and strong. Most of them have been involved in the construction process and apply these experiences during operation. Close relations remain between most utilities and KWU after the plans are handed over. Utilities provide information about operating experiences which may lead to design and construction changes to the supplier KWU for further improvements. Also KWU continuously provides information about new developments to the utilities.

The economics of nuclear power and economic regulation have imposed no impact on decisions regarding nuclear power plant operation. Between safety regulation authorities, utility management and suppliers exists a professional atmosphere which is open to all problems of safety and performance improvement.

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CHAPTER 3

FRANCE

3.1 STRUCTURE OF THE ELECTRIC INDUSTRY

About 90 percent of electricity in France is generated by the government-owned national public utility, Electricite de France (EDF). The remainder is generated by some industries for their own use (mines, steel, manufacturers).

French nuclear power policy is determined by the government of the Republic and implemented by Electricite de France. A program of pressurized water reactor plant construction was undertaken in 1969, and intensified in 1973. Its purposes are to replace oil and coal in the electric sector and to supply the French economy with an ever-increasing fraction of energy in the form of electricity.

To date, the goals of this program are being accomplished with great success, as illustrated by Figures 3.1, 3.2, and 3.3. By 1984, installed capacity was 55,000 MWe, of which 33,000 MWe was nuclear. By 1985, these amounts were 58,000 MWe and 37,000, respectively.

Tables 3.1 and 3.2 list installed capacity and energy fractions for 1984, including hydroelectricity. In 1984, 59 percent of all electricity in France was generated by nuclear power plants. By 1985, this has risen to 65 percent (or, equivalently, 88 percent of the non-hydro energy generated by EDF).

Nuclear power plants are located variously throughout France (see Figure 3.4). By the end of 1985, the following nuclear plants were connected to the grid: 32 units at 900 MWe, 5 units at 1300 MWe, and one unit at 300 MWe. The 900 MWe units were of two standard types, and all

Table 3.1

Installed Capacity
End of 1984
(total 85 GWe)

Type of plant		Percent
Nuclear		39
Hydro		26
Coal		19
Oil		14
Other		2
	Total	100

Table 3.2

Output In 1984
(total 310 TWh)

Type of plant		Percent
Nuclear		59
Hydro		22
Coal		14
Oil		3
Other		2
	Total	100

Figure 3.1

Capacity by Energy Source
(GW)

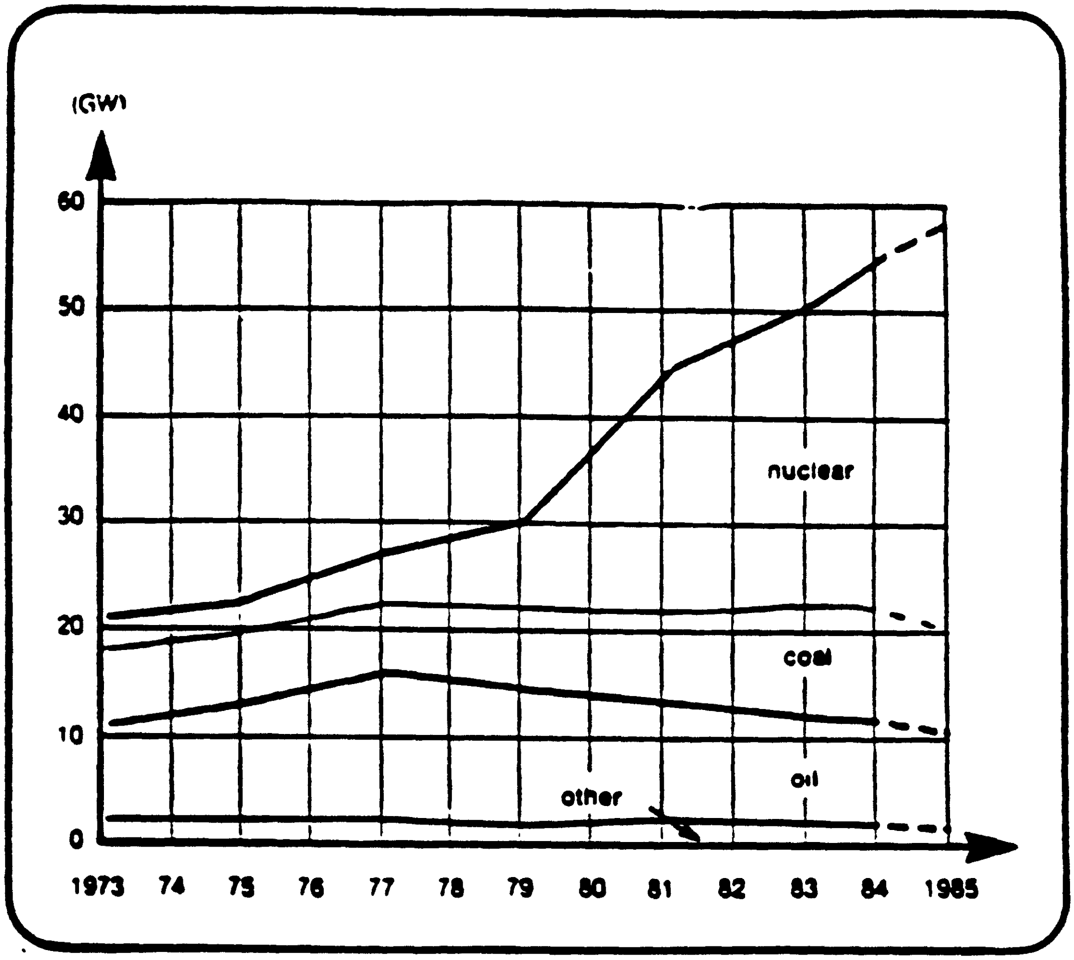


Figure 3.2

Net Output by Energy Source
(TWh)

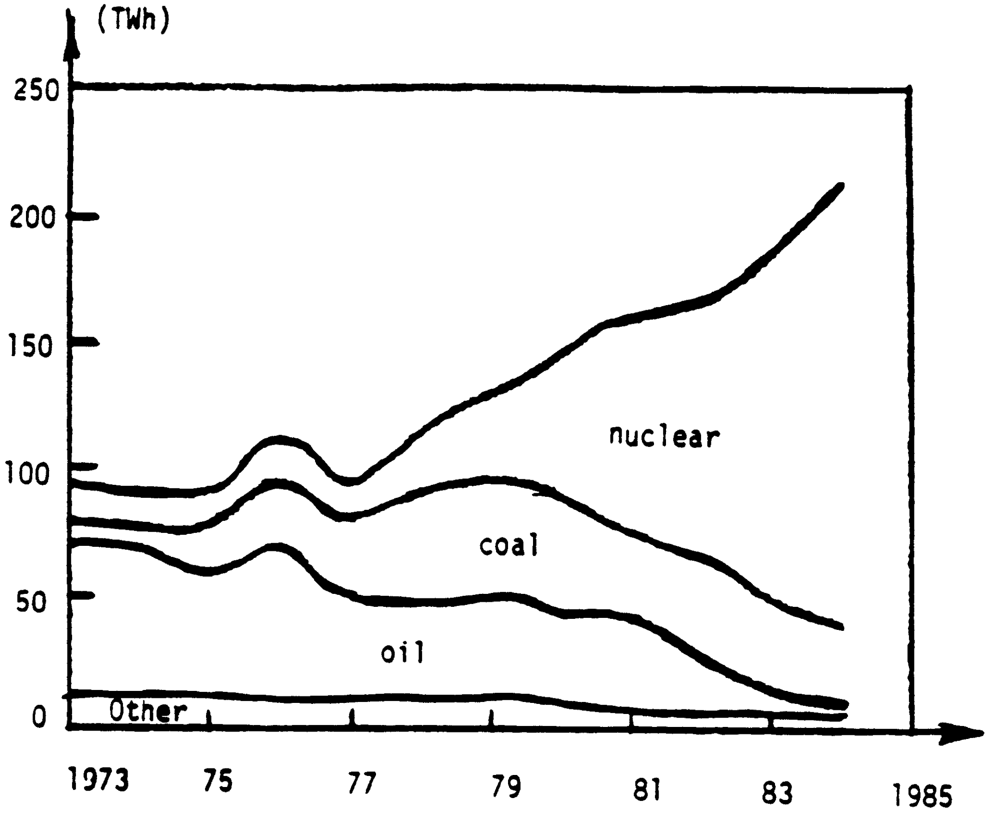


Figure 3.3

Capacity by Energy Source
(%)

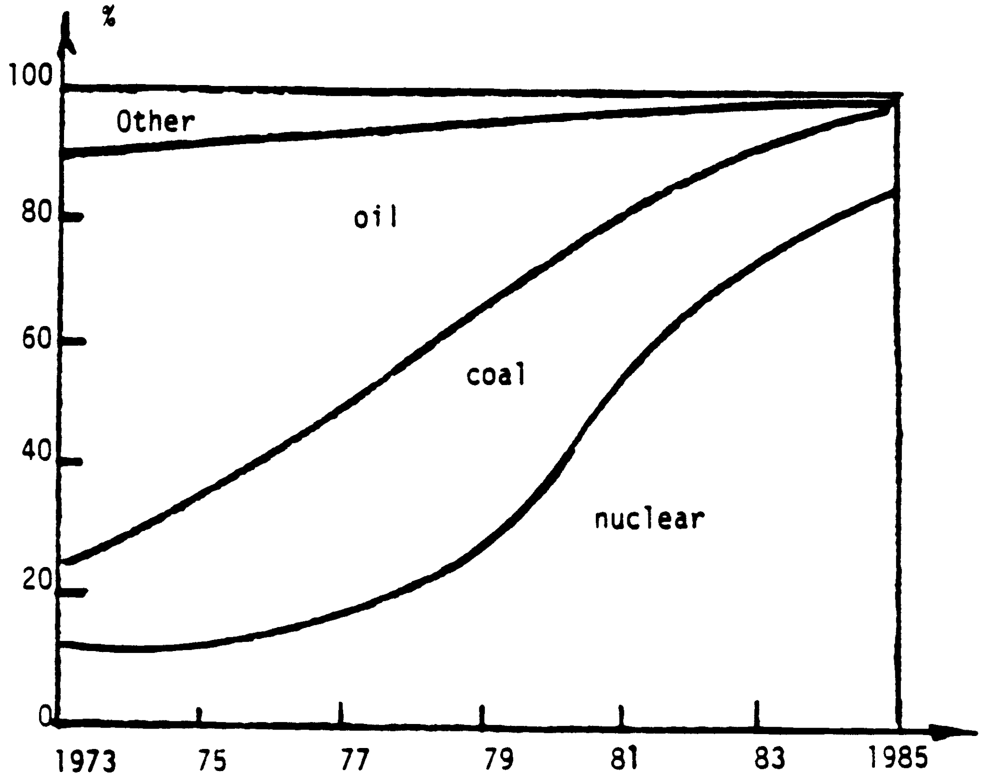
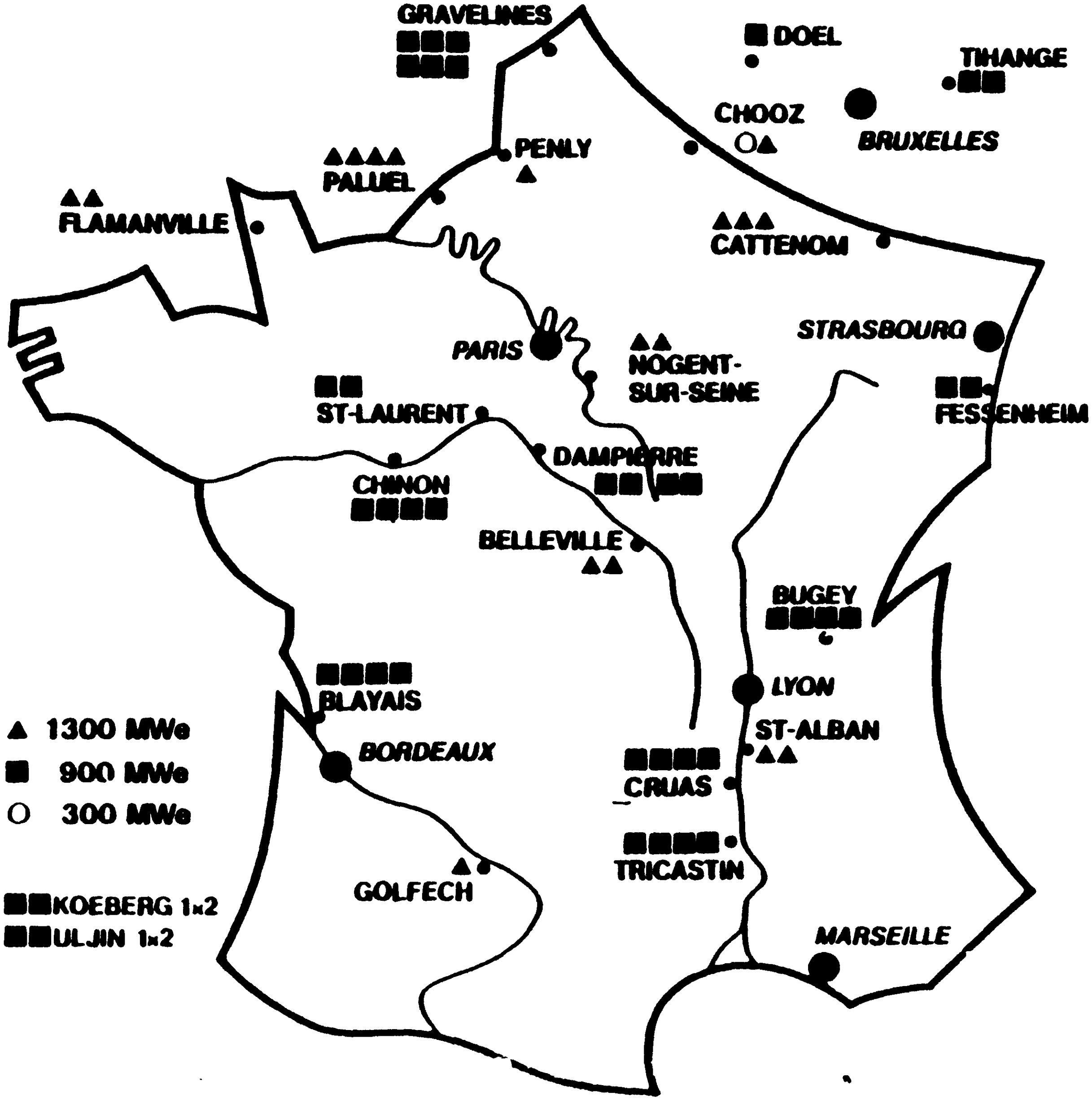


Figure 3.4

FRAMATOME PWR NSSS's OR NUCLEAR ISLANDS



the 1300 MWe units were of the same standard type. Clearly, standardization over a relatively large number of units that are sequentially installed at the same or different sites is a distinct and distinguishing feature of the French nuclear program.

The French grid is interconnected with those of surrounding countries. Only recently has France become a net exporter of electricity. In 1984, 25 TWh were exported (about 8 percent of total generation) and in 1985, 23.5 TWh (about 7 percent).

Another interesting feature of the French system is that as the non-nuclear fraction of electricity is reduced, more and more nuclear units are being used in a load-following rather than in a base-load mode. This is because economics favor the load-following mode of nuclear units over alternatives.

3.2 STRUCTURE OF THE SUPPLY INDUSTRY

There is only one supplier of nuclear steam supply systems (NSSS) in France: FRAMATOME. FRAMATOME presently is owned by the CGE (Compagnie Generale d'Electricite) (40 percent) the CEA (35 percent), EDF (10 percent), DUMEX, a civil contractor (12 percent), and the staff (3 percent, which will be offered for sale to the personnel in the near future).

FRAMATOME was created in 1958 to design and manufacture PWRs and related components. It began its activities with a license from Westinghouse on PWR technology on the first plant at Chooz, in the Ardennes. In early 1981, a new relationship was established with Westinghouse on the basis of cooperation on an equal footing, an acknowledgment of the maturity of French PWR technology.

FRAMATOME designs, manufactures, and sells 600, 900 to 1000, and 1300 MWe electric nuclear steam supply systems, as well as nuclear islands. FRAMATOME has sold two 1450 MWe units (designated N-4).

FRAMATOME's activities cover seven main areas: (1) basic design; (2) design of key nuclear components; (3) manufacture of key nuclear components (reactor vessel, steam generators, pressurizers, and in-core instrumentation); (4) supply of enriched uranium fuel assemblies (first cores and initial reloads); (5) procurement, transportation, erection, testing, and startup; (6) maintenance and in-service inspection of commissioned units; and (7) supply of various other products and services. FRAGEMA, a subsidiary of FRAMATOME and COGEMA, supplies further reloads, fuel management, and irradiated fuel examination services.

Depending on the customer's preference, FRAMATOME can supply any of the following:

- NSSS
- Installation and start-up of NSSS
- Nuclear islands
- Complete nuclear power plants, in conjunction with industrial partners and civil engineering contractors
- Nuclear fuel

Figure 3.5 lists orders received by FRAMATOME from EDF and from utilities around the world, as of December 1985. Other industries cooperate with FRAMATOME in the supply of components (see Table 3.3).

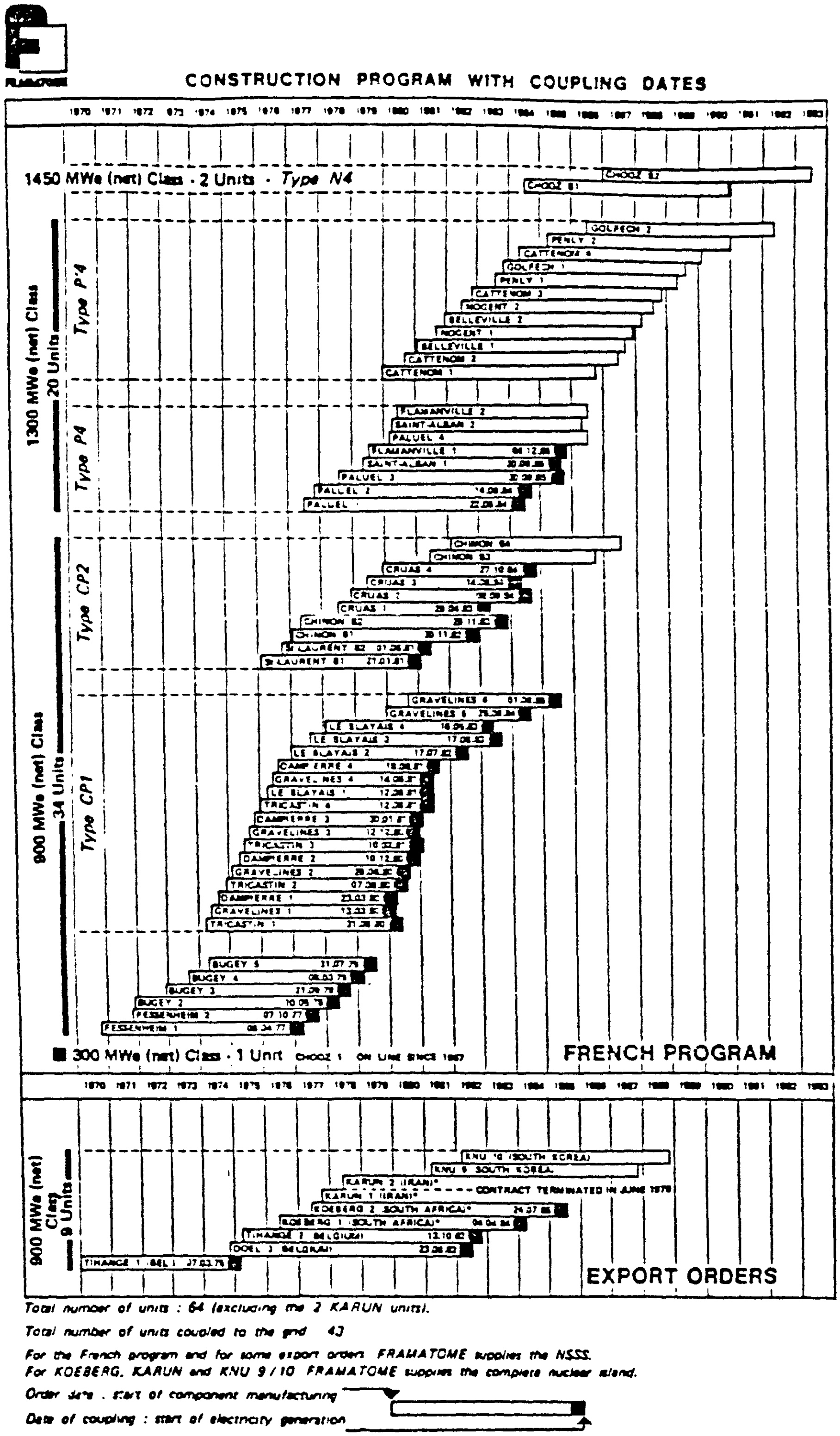
Extended NSSS are contracted by EDF to FRAMATOME. Each contract specifies the scope and some management issues of the project. The scope covers the design of the PWR core and associated systems, primary and auxiliary components and pipings, and related electric systems, as well as procurement of parts and the manufacture, transport, erection, testing, and commissioning of each plant.

Table 3.3

CAPABILITIES of FRAMATOME and AFFILIATES for PWR NSSS component and fuel fabrication

NAME OF FIRM Location of facility	COMPONENTS OR EQUIPMENT	PRODUCTION CAPACITY
FRAMATOME Le Creusot, Chalon, and Courbevoie	Reactor vessels Reactor internals Steam generators Pressurizers In-core instrumentation systems	6 to 8 units/year 6 to 8 sets/year 18 to 24 units/year 8 units/year 8 systems/year
JEUMONT SCHNEIDER Jeumont	Reactor coolant pumps Control rod drive mechanisms	24 units/year 8 sets of 60 units/year
SPIE BATIGNOLLES Ferrière	Sets of prefabricated reactor coolant loops	6 to 8 sets/year
MERLIN GERIN Grenoble	Ex-core nuclear instrumentation CRDM sequencers & position indicators	6 to 8 sets/year 6 to 8 sets/year
FRAGEMA with F.B.F.C. Dessel, Romans and Pierrelatte	Fuel assemblies and associated components	1250 metric tons/year

Note: The capacity of the above mentioned facilities is adequate to produce 6 to 8 NSSSs per year together with their first cores and subsequent reloads.



Total number of units : 64 (excluding the 2 KARUN units).

Total number of units coupled to the grid 43

For the French program and for some export orders FRAMATOME supplies the NSSS.
For KOEBERG, KARUN and KNU 9/10 FRAMATOME supplies the complete nuclear island.

Order date : start of component manufacturing

Date of coupling : start of electricity generation

Figure 3.5 Nuclear Power Plants Equipped with FRAMOTOME PWRs.

There is close cooperation between EDF and FRAMATOME throughout the design, construction, and commissioning stages of each plant. EDF retains responsibility for licensing and overall plant design. FRAMATOME is responsible for compliance of the primary circuit with a 1974 law on nuclear pressure vessels and piping. In effect, EDF gives FRAMATOME a turnkey contract for the scope of NSSS equipment, including fuel-handling equipment, auxiliary systems, and controls. The interrelations between EDF and FRAMATOME are illustrated by the organization charts given in Figures 3.6 and 3.7, and Figure 3.8 shows the standard technical organization of FRAMATOME at each site. FRAMATOME has responsibility under EDF supervision for installing, testing, and commissioning the NSSS equipment.

The various EDF and FRAMATOME organizational levels shown in Figure 3.6 interact to facilitate the management and progress of each project and to expedite communication among all parties. There is also a committee (not shown in the figures) that meets bi-monthly to coordinate activities and to resolve problems that may have arisen at the interface between the NSSS and the balance-of-plant. In addition, the President of EDF and the President of FRAMATOME meet regularly to establish policy and to coordinate leadership.

Main points related to the project management are:

1. Design of nuclear plants at the 900, 1300 or 1450 MWe level;
2. Standard documentation;
3. Procurement from FRAMATOME factories and other approved suppliers;
4. Establishment of standard construction methods;
5. Procedures for handling modifications in design, procurement, and site layout;

Figure 3.6

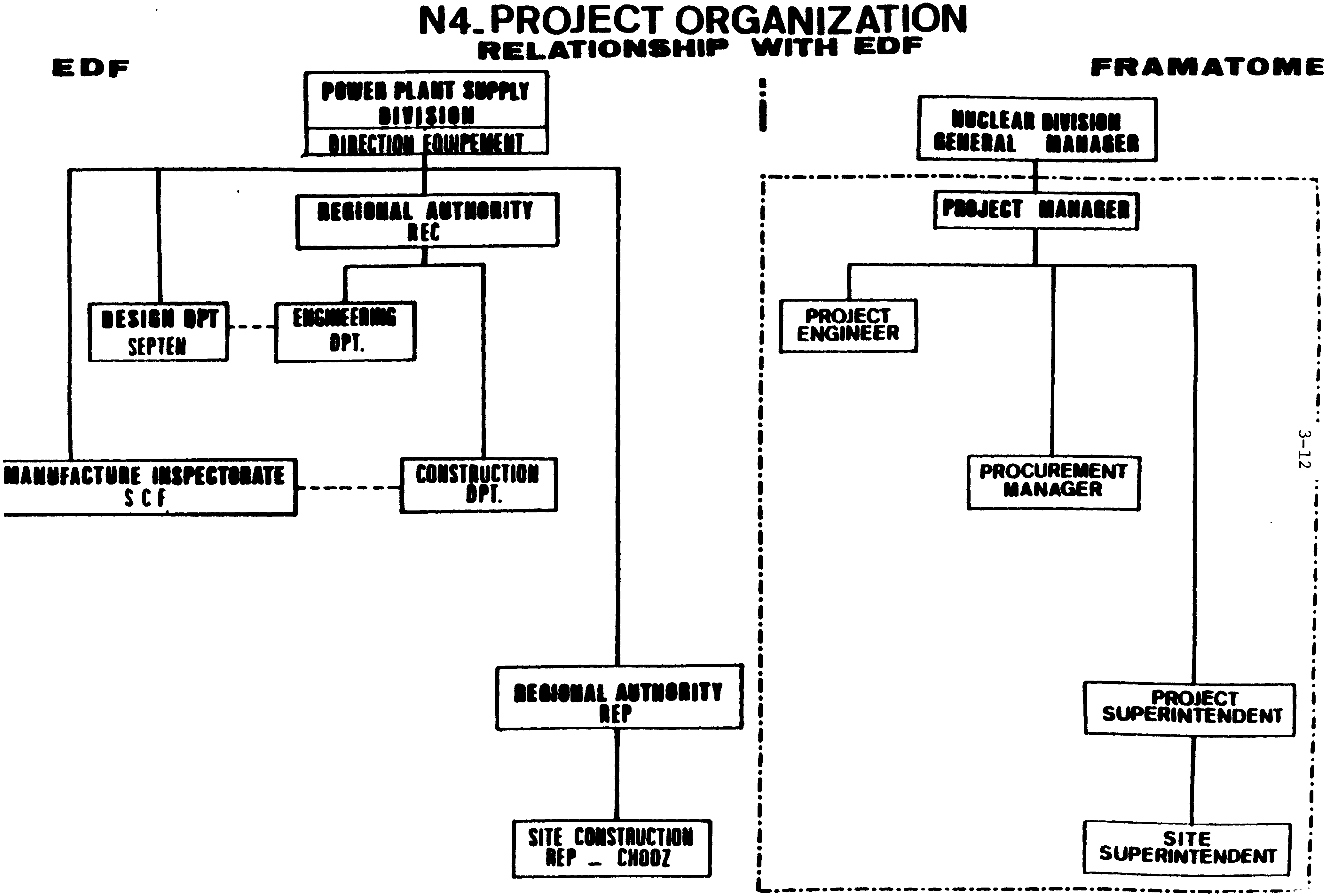

N4_PROJECT ORGANIZATION
RELATIONSHIP WITH EDF
EDF
FRAMATOME
POWER PLANT SUPPLY DIVISION
DIRECTION EQUIPEMENT
REGIONAL AUTHORITY REC
DESIGN DPT SEPTEN
ENGINEERING DPT.
MANUFACTURE INSPECTORATE SCF
CONSTRUCTION DPT.
REGIONAL AUTHORITY REP
SITE CONSTRUCTION REP _ CHOOZ
NUCLEAR DIVISION GENERAL MANAGER
PROJECT MANAGER
PROJECT ENGINEER
PROCUREMENT MANAGER
PROJECT SUPERINTENDENT
SITE SUPERINTENDENT

Figure 3.7

N4.PROJECT TEAM ORGANIZATION

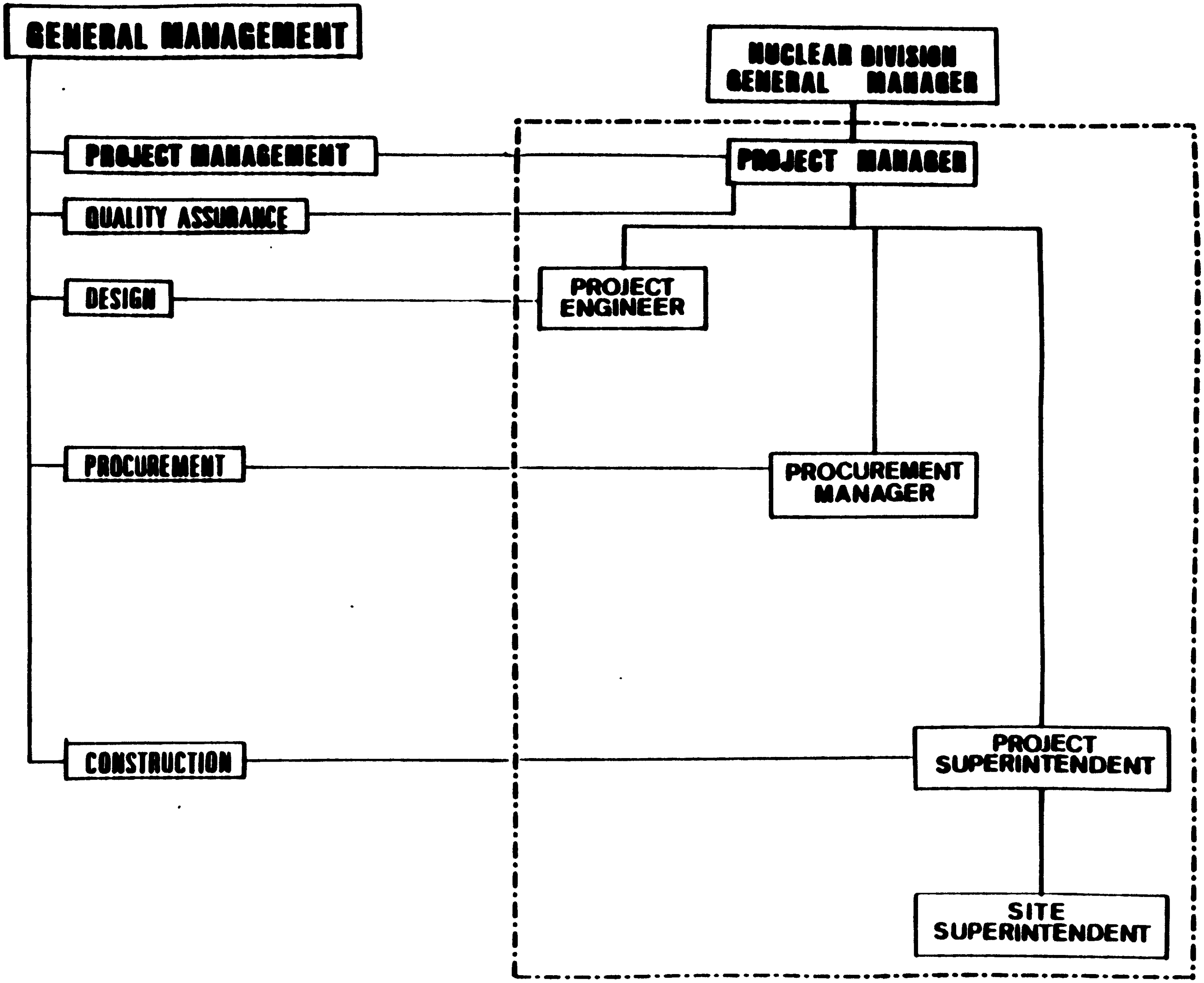
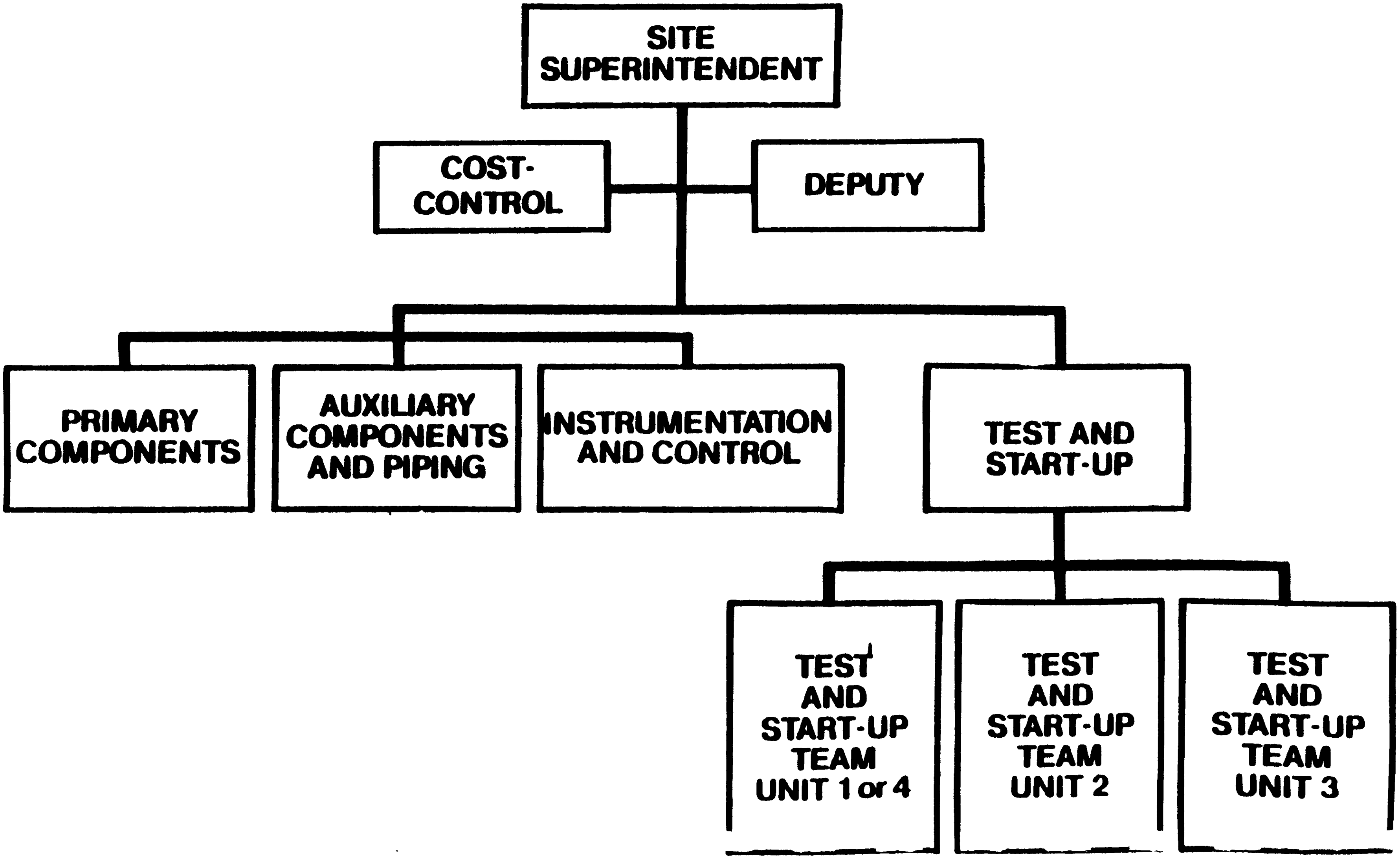


Figure 3.8

FRAMATOME STANDARD TECHNICAL ORGANIZATION (FRENCH SITES)



6. Development and improvement of features to be included in future plants;
7. Feedback concerning design, manufacturing, erection, and start-up to aid in component and procedure improvements; this is handled by a liaison between EDF and FRAMATOME and includes reporting of abnormal events;
8. Coordinating time schedules, because several plants are installed each year;
9. Manufacturing capacity and possibility of replacing defective parts of components if necessary;
10. Reduction of manufacturing and construction times; and
11. In general, a productive spirit of cooperation exists between EDF and FRAMATOME because they share the same objectives and strive to achieve the best performance.

In general, the relationship between EDF and FRAMATOME is like that between a customer and a supplier who have had a long-standing collaboration on solving problems at interfaces. Both EDF and FRAMATOME attempt to achieve the best results so as to facilitate the acceptance of nuclear power in France, and to establish high credentials for competition in the international market.

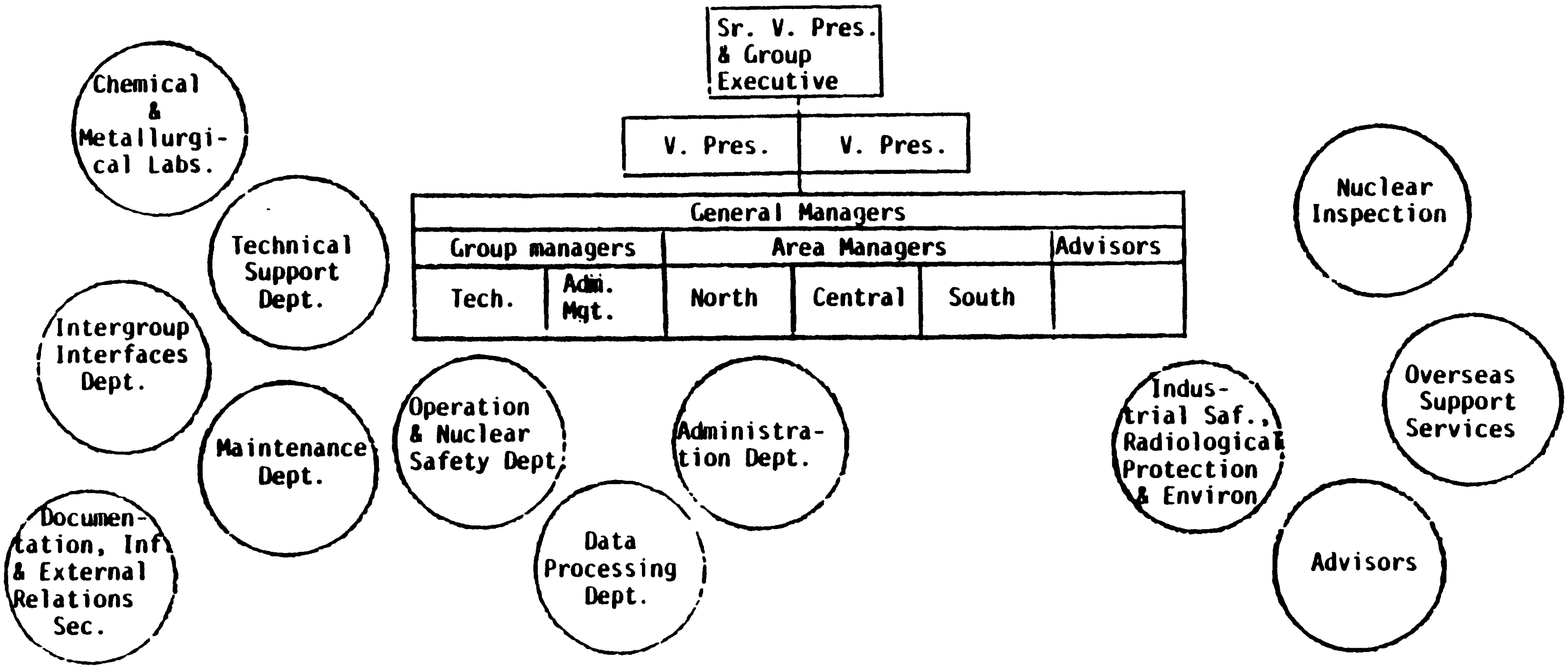
3.3 UTILITY INTERNAL ORGANIZATION AND CAPABILITIES

Nuclear-and fossil fuel-generated electricity in France is under the direction of a Senior Vice President and Group Executive of EDF. Immediately under him are two Vice Presidents, one responsible for nuclear and the other for fossil fired stations. The remaining top management is shown in Figure 3.9.

For EDF purposes, France is divided into three areas, each under the jurisdiction of an area manager. Each area consists of two or more operating regions (GRPT) headed by a regional manager. There are eight operating regions. In each area there are both fossil- and nuclear-fired production centers (CPN). There are ten nuclear production centers, each

Figure 3.9

Utility Internal Organization



having one or more nuclear power plants. Each CPN is headed by a site manager. Most sites have four nuclear plants, but several have less and two have more (see Figure 3.4 above).

Top management consults with four staff teams: nuclear inspection; industrial safety, radiological protection and environment; overseas support services; and advisors. The technology group manager has six departments that provide technical and staff support: chemical and metallurgical laboratories; technical support; intergroup interface; maintenance; operation and nuclear safety; and documentation, information, and external relations. Finally, the administration manager heads two departments: administration and data processing.

Each four-unit site has an organizational chart, as shown in Figure 3.10. A typical site has about 900 staff. The total number of EDF employees directly related to the generation of electricity by fossil and nuclear-fired plants has grown over time, doubling over the past ten years (see Figure 3.11).

EDF runs its own special educational and training programs for managers of nuclear installations and shift operating personnel, and is solely responsible for recruitment and training of personnel. There are five training schools for operators, with one or two plant simulators available at each. EDF licenses its own nuclear reactor operators without interference from or supervision by regulatory authorities. This reflects the fact that EDF's technical and managerial competence is held in high regard.

Training continues on the job. There are six shifts per unit, one of which is in retraining a few months each year. In addition, computer-aided training is available during regular work hours. There is a computer console near each control room, and any member of the operator

Figure 3.10

Organizational Chart of Four-Unit Sites

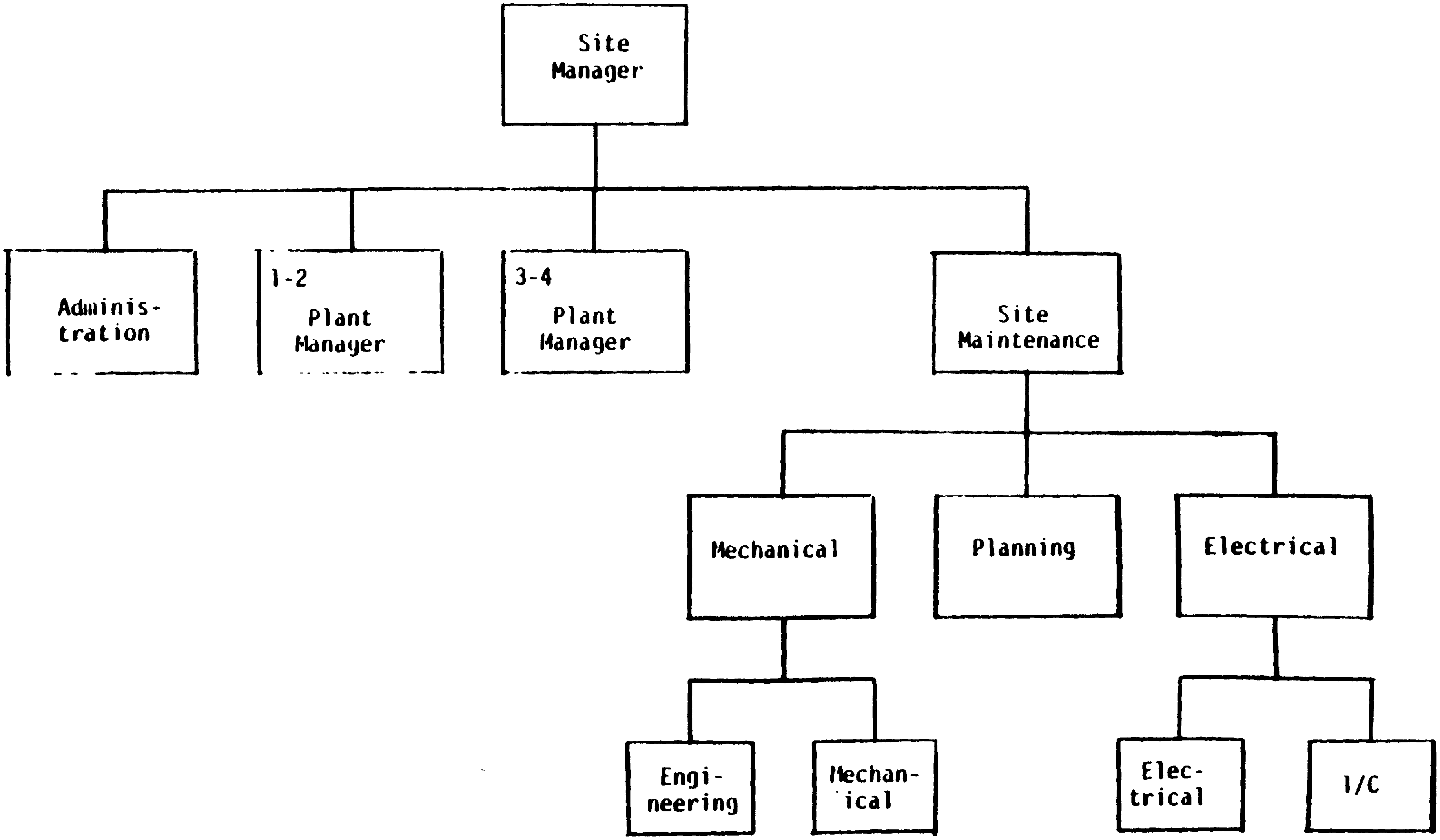
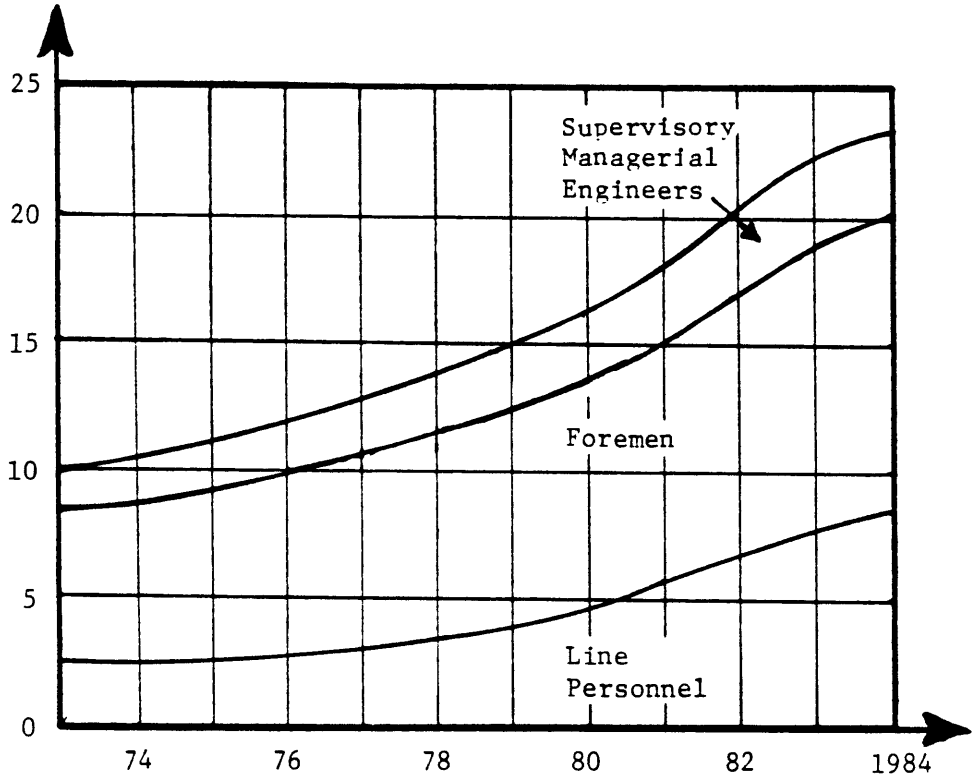


Figure 3.11

Size of SPT's staff



teams can use it whenever they have free time during their regular working schedule.

One characteristic of operator training programs is the crew concept, as opposed to the one-person, one-duty approach.

Turnover of operating personnel is relatively low. However, operating procedures are largely uniform throughout all nuclear units, so personnel can be transferred from site to site without much difficulty.

Initially, some personnel were being hired away from coal-fired plants. However, this did not prove to be very effective, because these personnel had difficulty adapting to the requirements of nuclear installations. So the policy changed, and EDF now hires graduates from technical high schools and provides training both before and on the job. At present, personnel from coal-fired plants are not available.

The training of maintenance personnel follows similar patterns. Graduates from mechanical, electrical, and instrumentation and control schools are hired and given short courses in health physics, reactor characteristics, etc. The EDF maintenance philosophy is to do the work fast, but not too fast, if the route is known. If the route is unknown, then the work is done more slowly.

The training course for maintenance managers lasts 33 weeks and emphasizes practical aspects. This is to be contrasted to university training, where the emphasis is on theories such as statistics, reliability, etc.

EDF has a Construction Division in Lyon, France, which is in charge of the basic design of the plants. The Construction Division is an organization of 5500 people, in charge of constructing of power plants, with an annual budget of FF 20 billion (about $3 billion). Its responsibilities include site selection, design, procurement and purchasing, contracts, testing, and commissioning. The division of scope of the Construction Division and of the Construction Division subcontracts is as follows:

Construction Division

- Balance of plant of the nuclear island;
- Balance of plant of the conventional island;
- Civil works (except for some architect engineering tasks which are subcontracted; and
- Coordination of subcontractors.

Subcontracts

- Main contracts for NSSS, including associated equipment, steam generators, and installation and erection;
- Contracts for the turbine-generator; and
- Part of the Architect/Engineer scope.

The Construction Division has five regional units. Each is responsible for site selection and preparation in its respective region, and for designing certain elements particular to each site (such as site layout, the circulating water system and condenser, and the demineralized water system). Each regional unit also has responsibility for parts of the detailed design applicable to all sites, as assigned by Headquarters. Specific examples are:

Marseille region:	Responsible for NSSS construction
Tours region:	Turbine hall
Paris:	Electrical design and control room

The detailed design performed by the regional unit is in accordance with the basic design of the nuclear power block layout performed by SEPTEN (see below). The Construction Division also is responsible for discussions with the safety authorities for which it uses FRAMATOME in a relationship analogous to that between a utility owner and a reactor manufacturer in the United States.

Service d'Etudes et Projects Thermique et Nucleaire (SEPTEN) is the design and projects group within the Construction Division. Its staff numbers 400. SEPTEN exercises control over a project in several ways. It performs the basic design of the nuclear power block layout; FRAMATOME does the detailed design and all calculations. It writes the specifications for the plant (general, performance, and warranty). Finally, it identifies all codes and standards to be applied. These are French codes; no ASME codes have been used since the first unit.

The specifications given to FRAMATOME are for high plant performance, flexibility of plant maintenance, and some special codes and standards. The layout is specified by EDF, but EDF does not perform this detailed engineering of the Architect/Engineering scope. It receives the plant upon commissioning even though it is in close contact and cooperation with FRAMATOME throughout all earlier phases of work.

Maintenance and outage planning receive special attention. The maintenance department in Paris employs some 700 personnel, who plan maintenance and outages for the entire EDF. They are in contact with maintenance groups at each nuclear site, as well as with FRAMATOME and its suppliers. Cost-benefit analyses are used to evaluate the effects of maintenance and other programs. The maintenance programs are carried out in cooperation with maintenance teams at each site.

Maintenance problems--specifically what kind and how much to do--are viewed by EDF as an economic issue. Maintenance carries a cost that may be offset by the savings that result from generating more kilowatt hours from existing plants, which in turn requires higher availability. If components are not well maintained they break down, and money is lost.

Therefore, preventative maintenance is essential--but not to an extent that the plant does not produce adsequate power. This is the first principle used by EDF in its approach to maintenance.

The second principle is to reduce both forced and planned outages. Under the EDF plan, the cost of planned outages is the cost of nuclear power, because outages are planned only when an alternate nuclear plant is available. The cost of a forced outage may or may not be nuclear, depending on its availability at the time. Consequently, on average, a forced outage is more costly than a planned outage of equal duration. EDF maintenance policy can be stated as follows:

(1) achieve the minimum economic amount of preventative maintenance;

(2) perform it fast and well, by means of planning, procedures, availability of needed spare parts, specialized tools, and robotics;

(3) know the components;

(4) foresee and prepare for the next failure;

(5) use operational experience: ask for vendor advice; do not necessarily believe it at the beginning; think of your own solution; and

(6) set up an independently developed preventative maintenance program; do not open or replace a component except when there is incipient trouble; and remember that too much maintenance is as bad as too little.

EDF has developed its own data base on components to determine failure rates, probability of incipient failures, etc. EDF believes that similar data bases can be developed through cooperation among smaller utilities (outside of France) or owner groups.

EDF has developed its maintenance policies and procedures through a dedicated maintenance staff of 700 people of whom 500 are engineers, assigned as follows:

	Number of Personnel
Headquarters maintenance department	80 (50 engineers)
Technical support group	320
Laboratories	300

Outage planning is done both at EDF Headquarters and at each plant site. Headquarters develops and publishes a control program in a standard outage planning document. This document conforms with the EDF national plan for KW production requirements (how much and when electricity is needed during the year). Detailed outage planning also is done at each plant site by the technical support unit in conjunction with the maintenance staff. The site manager can depart from the national plan if necessary.

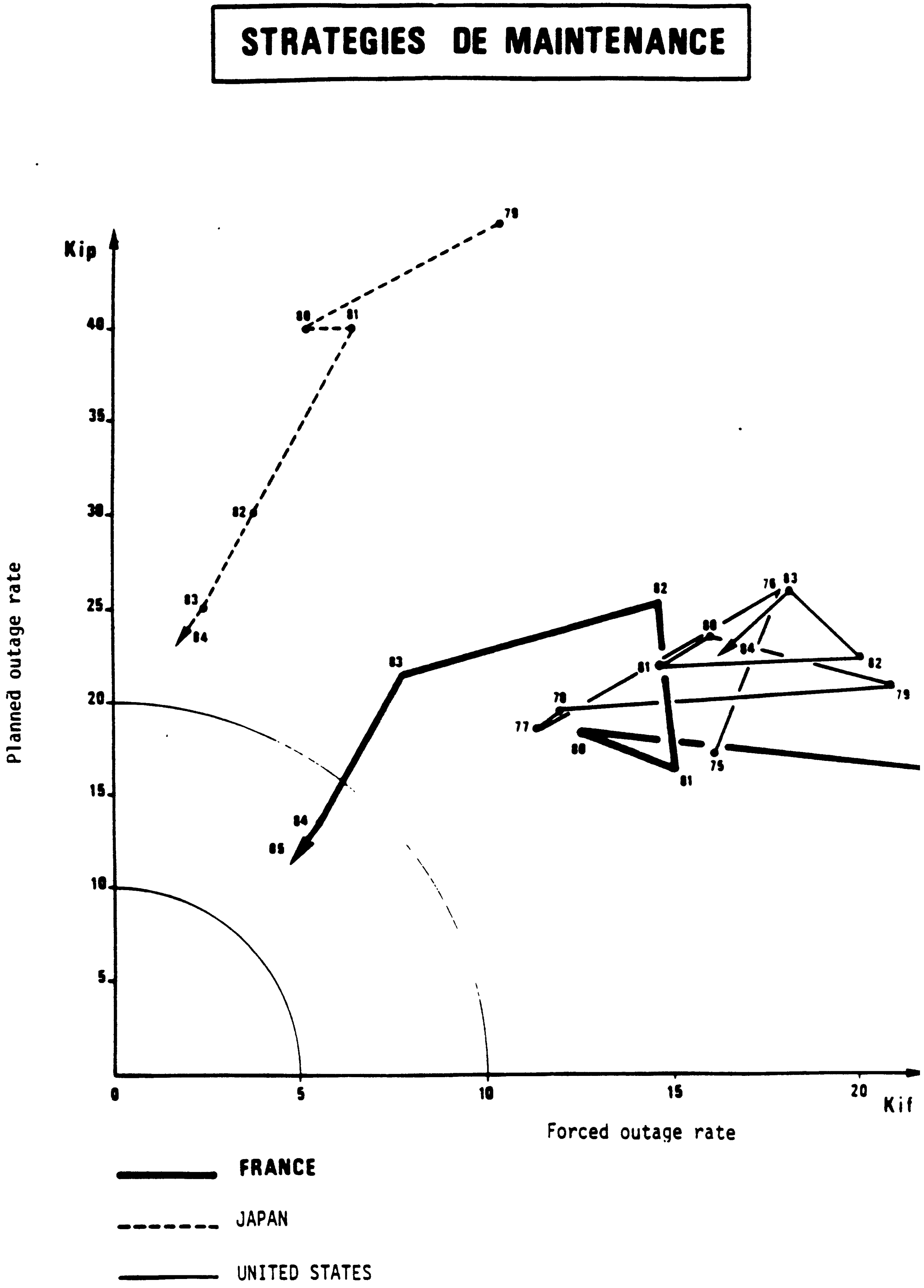
The cost of maintaining 30 units in 1985 was about FF 3 billion (or about $500 million U.S.), which is approximately 1 percent of capital cost or 4 percent of capital equipment cost. Comparative shares of annual maintenance costs for other equipment are as follows:

aircraft	10-15 percent
electronics	15 percent
personal car	5 percent

Note that the EDF nuclear plant figures apply to a rapidly growing fleet of reactors in their early years of operation. Current maintenance costs could include some new equipment modification or start-up fixing costs, both of which might be expected to decrease with time. Nevertheless, it is reasonable to expect that maintenance costs will increase with time, due to equipment aging.

EDF has compared the results of its maintenance program with data from Japan and the United States (see Figure 3.12). Clearly, maintenance policies have resulted in improvements in availability since 1979 in Japan, and since 1982 in France.

Figure 3.12



STRATEGIES DE MAINTENANCE

3.4 ECONOMICS OF NUCLEAR POWER

We do not have adequate information on some aspects of the economics of nuclear power in France. The economics of nuclear plants require knowledge and consideration of many factors such as nominal costs, inflation rates, interest rates, methods of charging construction work in progress, and construction times.

Several general observations can be tendered from anecdotal information. For example, nuclear-generated electricity is cheaper than that generated from both coal-and oil-fired power stations, as shown by the relative cost figures in Figure 3.13.

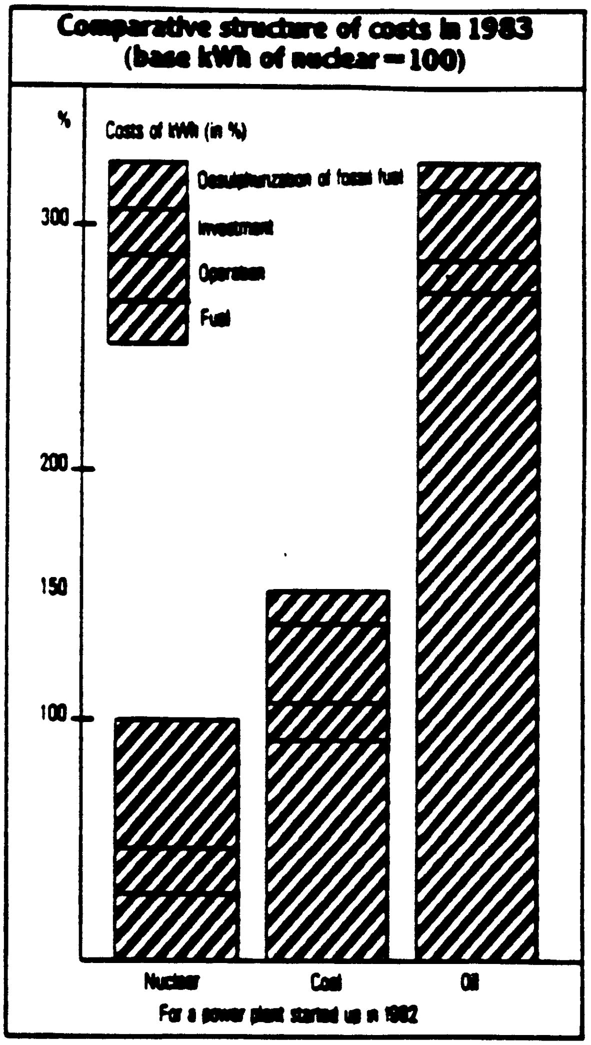
Nuclear power plants are built in six years or slightly more. This reasonable construction period must contribute to a lower capital cost relative to that of some U.S. nuclear plants, which take two to three times as long to complete.

Recent nuclear plants have been commissioned at a nominal cost of about $1000/kWe. This figure is the sum of all financial outlays and does not include any interest charges prior to commissioning.

3.5 ECONOMIC REGULATION

The average cost of electricity is about 3¢/kWhr in France, in contrast to about 7¢/kWhr in the United States. Electricity rates are set or, better, approved by the government on the basis of recommendations by EDF. EDF is not financed directly by the government. It raises 70 percent of its capital from the market and finances the remaining 30 percent through retained earnings.

Figure 3.13



Comparative structure of costs in 1983
(base kWh of nuclear = 100)

For a power plant started up in 1982

3.6 SAFETY REGULATION

Safety regulation is the responsibility of the Ministry of Industry and International Trade. The authorities and technical support involved in safety regulation are illustrated in Figure 3.14.

The High Council for Nuclear Safety was created in 1973; in 1981 its authority was extended and its composition enlarged. It advises the Minister on matters of nuclear safety and consists of individuals of high scientific, technical, economic, and social abilities, and representatives from trade unions, environmental protection associations, and top civil servants.

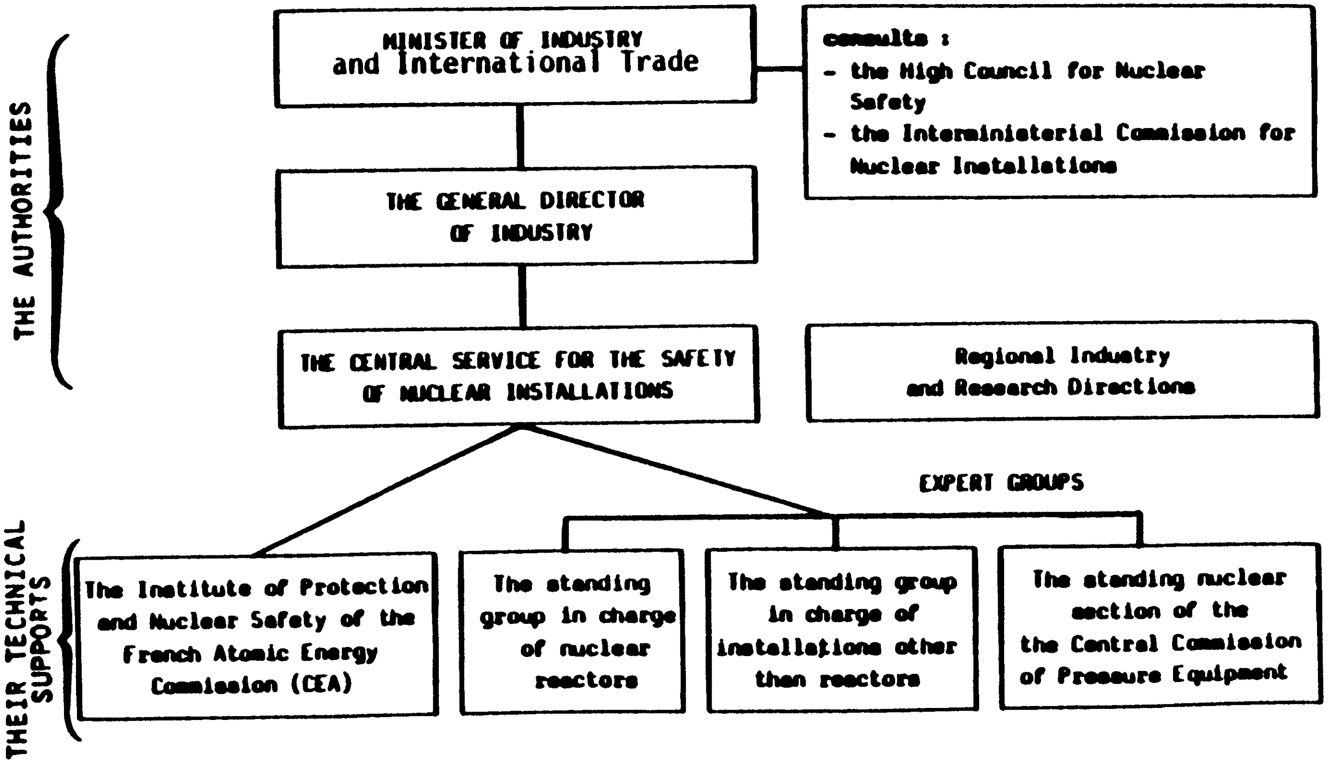
The Central Service for Safety of Nuclear Installations (again, see Figure 3.14) was created in 1973 to define the state's role as a promoter of nuclear energy, and the role of the authorities as guardians of both public security and the environment.

Regional Industry and Research Directors have responsibility for overseeing nuclear installations in various regions of the country through special nuclear divisions in each region. There are eight, located in eight different cities. The one in Dijon, for example, is responsible for ensuring that pressure vessel regulations are satisfied in NSSS construction. There are about 80 inspectors.

The Bureau de Controle de la Construction Nucleaire (BCCN), a part of the SCSIN, supervises the design and construction of primary pressure components from the standpoint of safety. It is manned by high-level engineers and plays a major part in ensuring technical progress, soundness of primary circuit components, and respect for quality assurance procedures.

Figure 3.14

Organization of the Central Service for Safety of Nuclear Installations



The Institute of Protection and Nuclear Safety has existed since 1981. It carries out civil protection and nuclear safety studies. It has a staff of 1300 people, half of whom are engineers. Its responsibilities include:

- human and environmental protection;
- safety of nuclear installations, particularly under accident conditions;
- safety of radioactive waste storage;
- decommissioning of nuclear plants; and
- security and control of nuclear materials.

The Central Service for Safety of Nuclear Installations is supported by three expert groups, as shown in Figure 3.14. These groups are charged with studying technical safety problems that arise during construction, commissioning, operation, and decommissioning of nuclear installations and their auxiliary facilities.

It is noteworthy that French authorities believe that, from a practical viewpoint, the builders and operators of nuclear installations are the only entities in a position to make the technical provisions required for safety during construction and operation. In accordance with nuclear regulations, only the plant operator can be granted authorization to construct the plant and moreover, once built, the operator has ultimate responsibility for its safe operation.

The Central Service for the Safety of Nuclear Installations has five Divisions and a General Secretariat.

- A division in charge of nuclear installations other than reactors, such as fuel reprocessing plants;
- A division in charge of PWRs of the 900 MWe standard design and of the Creys-Manville fast breeder reactor power plant;

- A division in charge of PWRs of the 1300 and 1450 MWe standard design;
- A division in charge of questions concerning nuclear boiler-making, inspection, effluent releases, technical regulations and emergency plans; and
- A General Secretariat in charge of legal, financial, and administrative matters.

After inspection, the inspectors report their findings to the Central Service in Paris. The Central Service sends a letter to EDF elucidating its findings and asks EDF to respond. About 90 percent of the issues are readily resolved. Depending on whether the problem is local or general, the report may be sent to the Site Manager or to Headquarters. The resolution of a hard issue may require some meetings and further discussions but always is resolved in a cooperative manner between the Central Service and EDF.

In some past instances there has been interference by third parties. These were created primarily by the surfacing of internal documents prior to their being fully discussed by EDF and regulators. Even then, the questions were answered by both EDF and the Ministry and no problems ensued.

In general, a high spirit of cooperation and professional pride prevails in all interactions between EDF and the regulators.

3.7 PUBLIC ATTITUDE AND INFLUENCE

The public attitude vis-a-vis nuclear power is excellent. Illustrative of this is the fact that various towns compete for the privilege of having a nuclear installation in their county or township so they can enjoy the economic benefits during construction and the tax privileges during operation.

3.8 NUCLEAR PLANT PERFORMANCE IN FRANCE

This section briefly discusses the various causes of the loss of energy availability of PWRs operated and maintained by EDF.

Energy Availability Factor

The average availability factor of French PWRs over time is graphed in Figure 3.15. From 1982 to 1984 this average increased from 63.1 to 81.6 percent. In addition, its yearly standard deviation has been steadily decreasing, indicating that all the plants were operating at a level close to the average.

Figure 3.16 presents the average energy availability factor and its uncertainty (standard deviation) versus reactor age. It is clear from this graph that no inference can be made about the effects of age on reactor performance.

Losses by Outage Type

This section subdivides the loss in performance into its components and reviews the dependence of each of these components on time and age.

Forced, scheduled, and regulatory losses versus time are graphed in Figure 3.17. Note that both forced and scheduled loss components decrease over time as the total loss decreases. In particular, the improvement in forced outage, which in 1982 accounted for 32.0 percent of the total loss, was almost entirely due to the decrease in total losses from 1982 to 1983. The specific category responsible for the reduction generally was attributable to the NSSS. The improvement in scheduled outages, which accounted for 66.2 percent of the total average loss, was the cause of the reduction of total losses from 1983 to 1984. The specific category responsible for the reduction in losses was not

Figure 3.15

French PWR Capacity Factor Distribution by Year

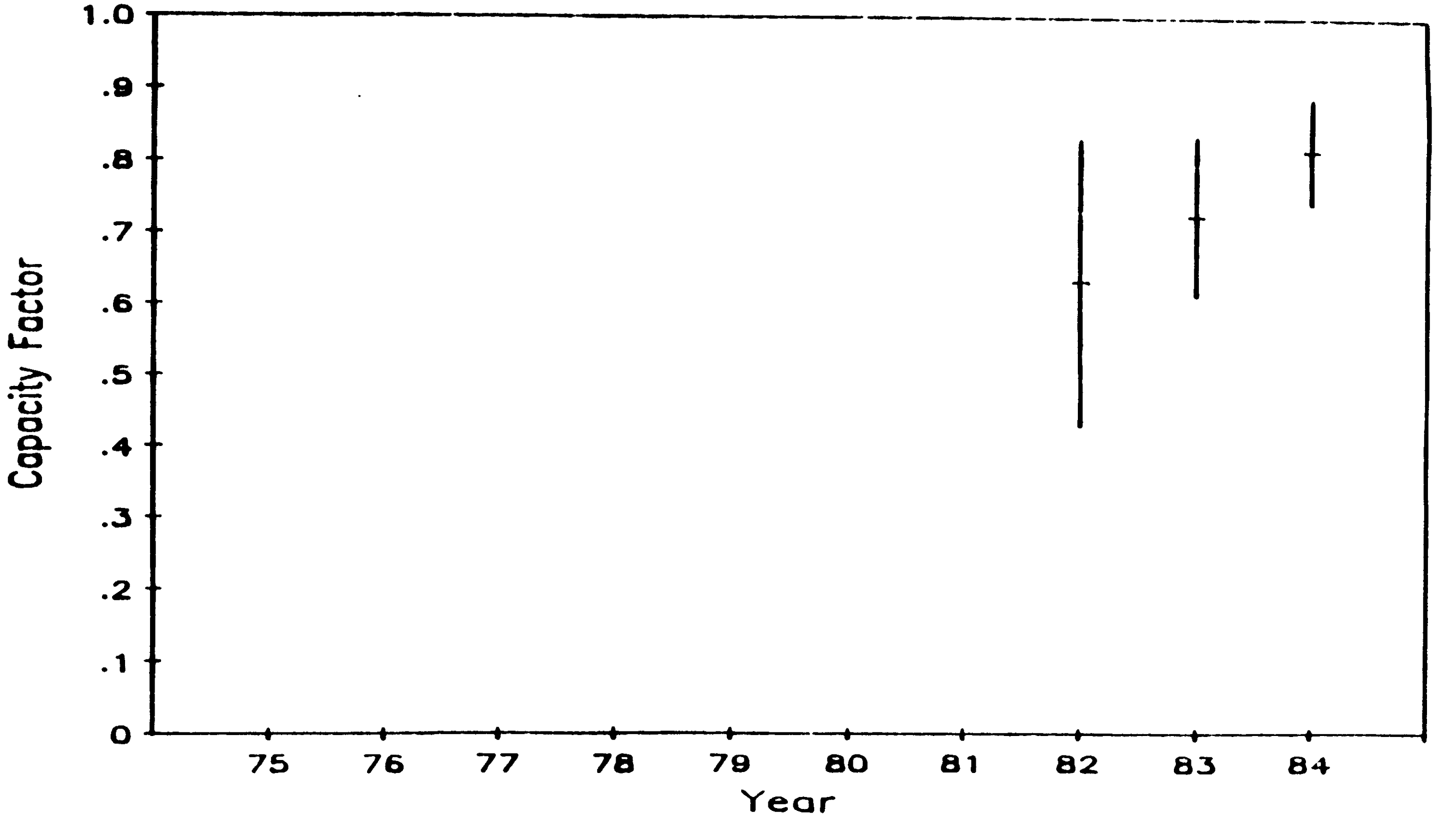


Figure 3.16

French PWR Capacity Factor Distribution by Reactor Age

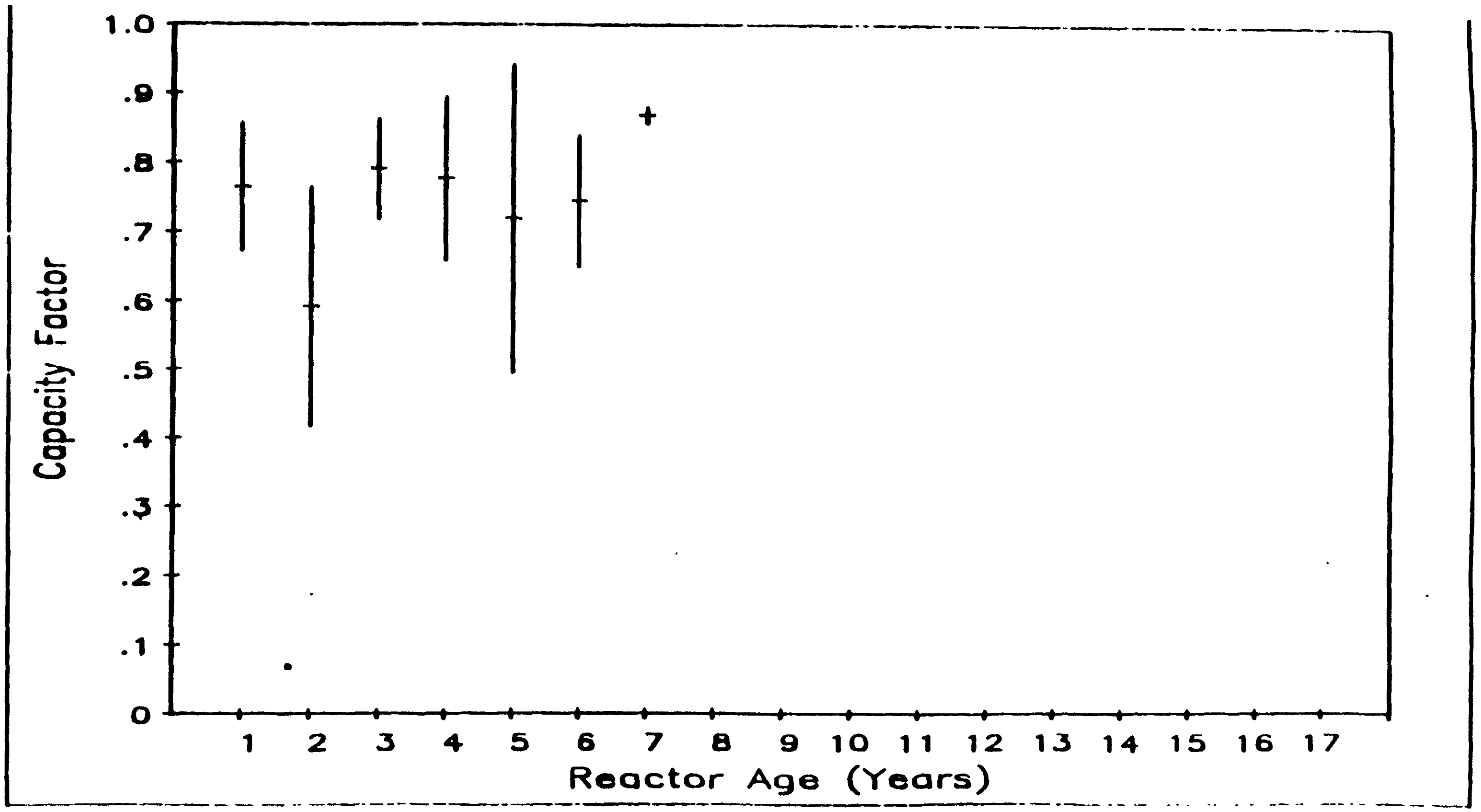
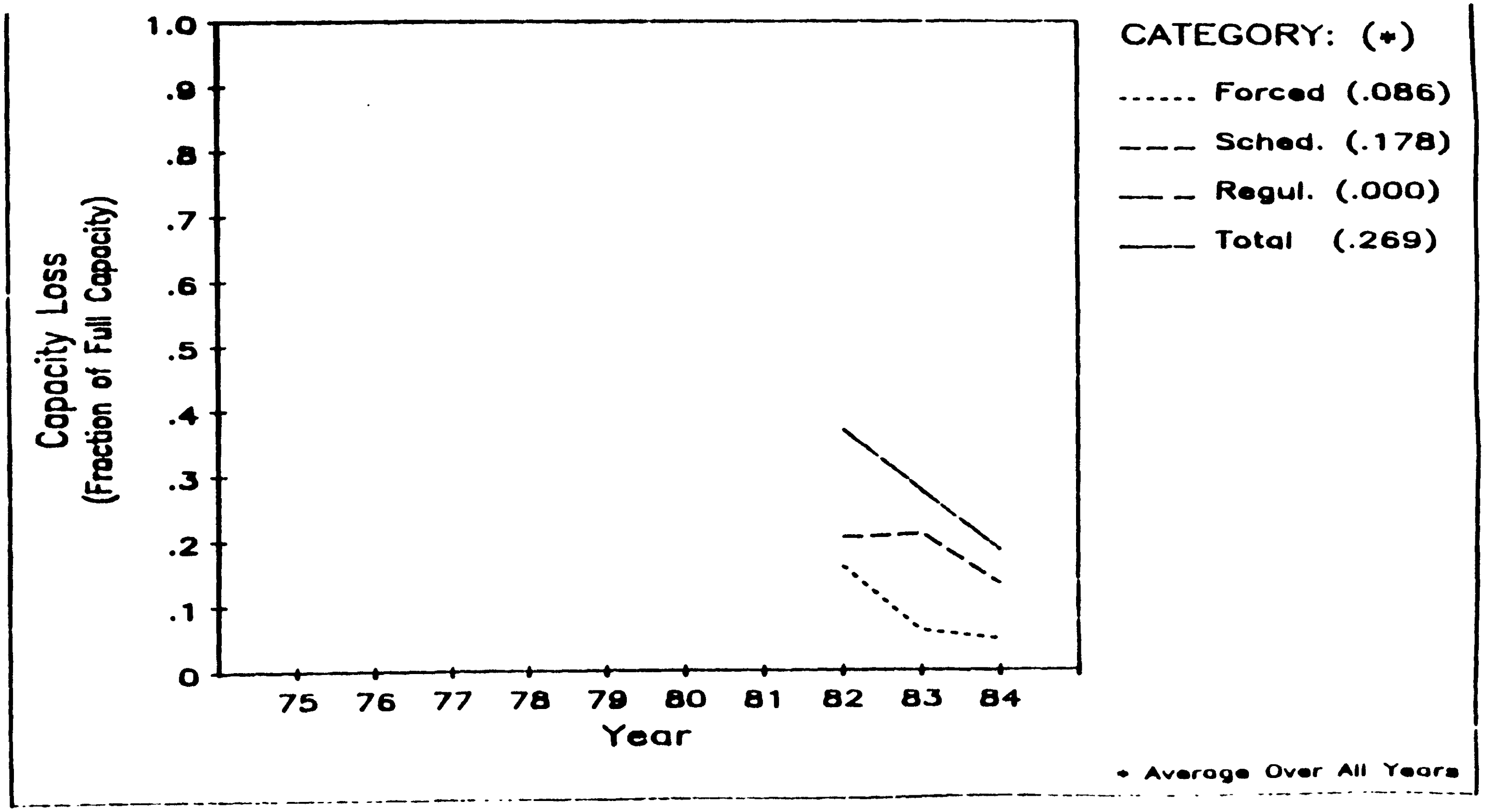


Figure 3.17

French PWR Capacity Losses by Year: Forced, Scheduled, and Regulatory



available. It is noteworthy that there have been no reported regulatory losses.

The preceding loss categories, as a function of age, are graphed in Figure 3.18. The forced, scheduled, and total losses fluctuate so widely that no definite conclusions can be reached about their dependence on age.

NSSS and BOP Losses

The losses in the NSSS and the balance of plant (BOP) cannot be determined because sufficiently disaggerated data were not available.

Table 3.4 presents performance factors--capacity factor and energy availability--for all PWR plants operated by EDF for the years 1982 to 1985. For each year, the table lists the number of reactors in commercial operation for one full year or more, the average capacity factor and its standard deviation, and the average energy availability factor and its standard deviation. The statistics are evaluated over all reactors in commercial operation during the corresponding year. In addition, the table includes the average capacity factor and average energy availability factor, the corresponding standard deviations, and the regressions of these two factors.

It is clear from these data that each factor has increased by about 18 percentage points (by about 30 percent), while its standard deviation has narrowed significantly.

For 1986 the goal is for the performance factors to increase even a little more. For example, for the first three units at CRUAS, the goal for average energy availability factor is 83 percent. For unit number 4, which is the newest at the site, the goal for 1986 is only 73 percent.

Figure 3.18

French PWR Factor Capacity Losses: Forced, Scheduled, and Regulatory

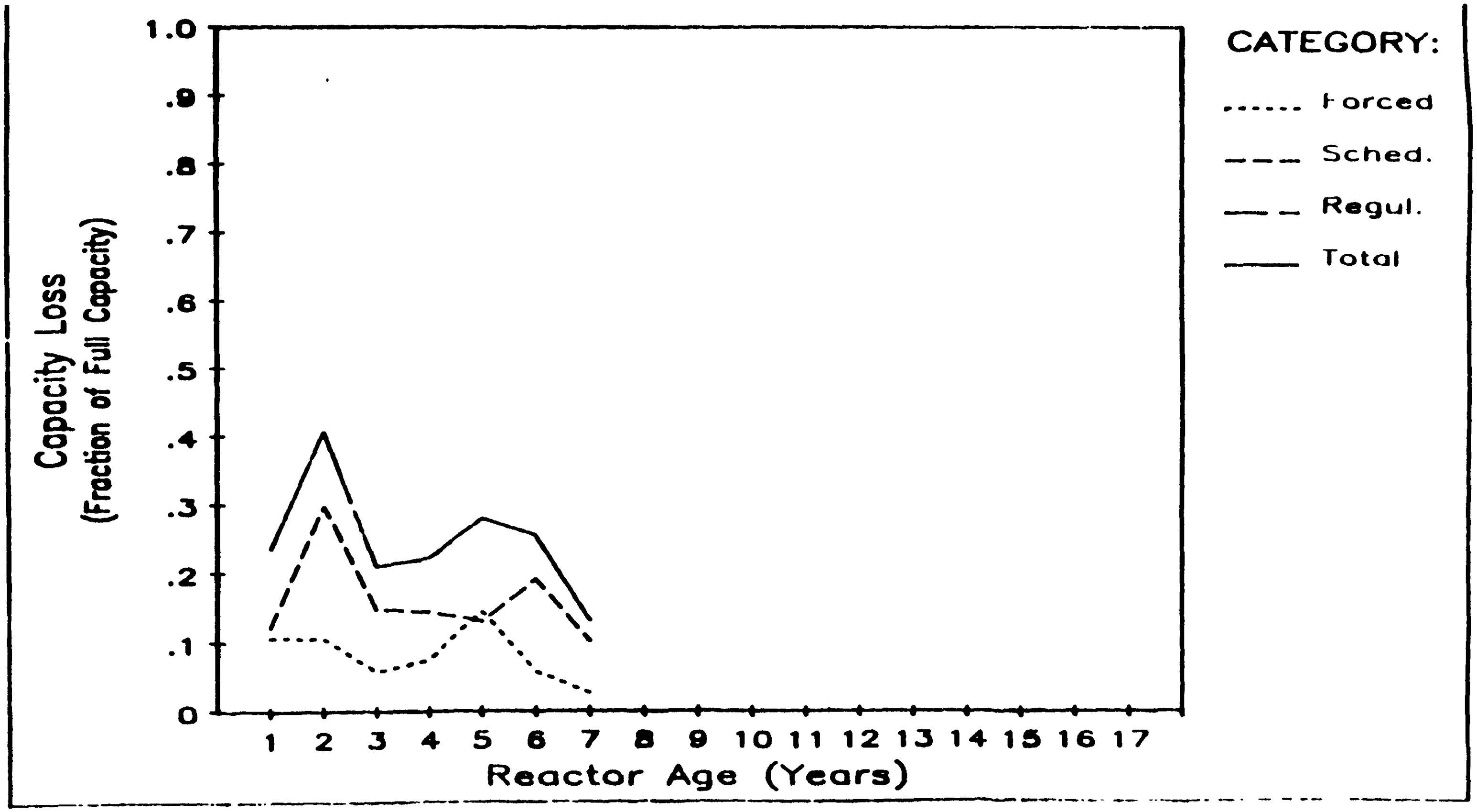


Table 3.4

Performance Factors of PWRs Operated by EDF

		Capacity Factor		Energy Availability Factor	
Year	Number of Units	Average	Standard Deviation	Average	Standard Deviation
1982	19	0.582	0.169	0.637	0.302
1983	19	0.688	0.108	0.729	0.111
1984	24	0.763	0.065	0.820	0.074
1985	28	0.762	0.065	0.821	0.071
4-year results for all units		0.709	0.105	0.762	0.158

Regressions

Capacity factor = 0.607 + 0.0615 Y ; r = 0.930
Energy availability factor = 0.655 + 0.0643 Y ; r = 0.945

3.9 OBSERVATIONS

The French nuclear power program is unique in many respects:

- It is managed in its entirety by the only electric public utility in the nation, Electricite de France.
- It consists exclusively of pressurized water reactors, standardized in 3 types, 600, 900 to 1000, and 1300 MWe; units of 1450 MWe have been recently added.
- It has only one supplier of nuclear steam supply systems, FRAMATOME.
- It is regulated by the Ministry of Industry and International Trade but the technical leadership and competence for assuring the safety of each plant during construction and operation lies primarily with Electricite de France and to a lesser degree with FRAMATOME.
- It is characterized by a well organized and well executed outage and maintenance program.
- It enjoys a high spirit of cooperation among all that work in the program, and elicits the professional pride of scientific, engineering, and technical personnel.
- It has the confidence and support of the vast majority of French people.

It will be extremely interesting to follow how events after 1985 -- Chernobyl accident, economic affairs, and political developments -- will affect the French nuclear program in the foreseeable future.

CHAPTER 4

JAPAN

4.1 STRUCTURE OF THE ELECTRIC POWER INDUSTRY

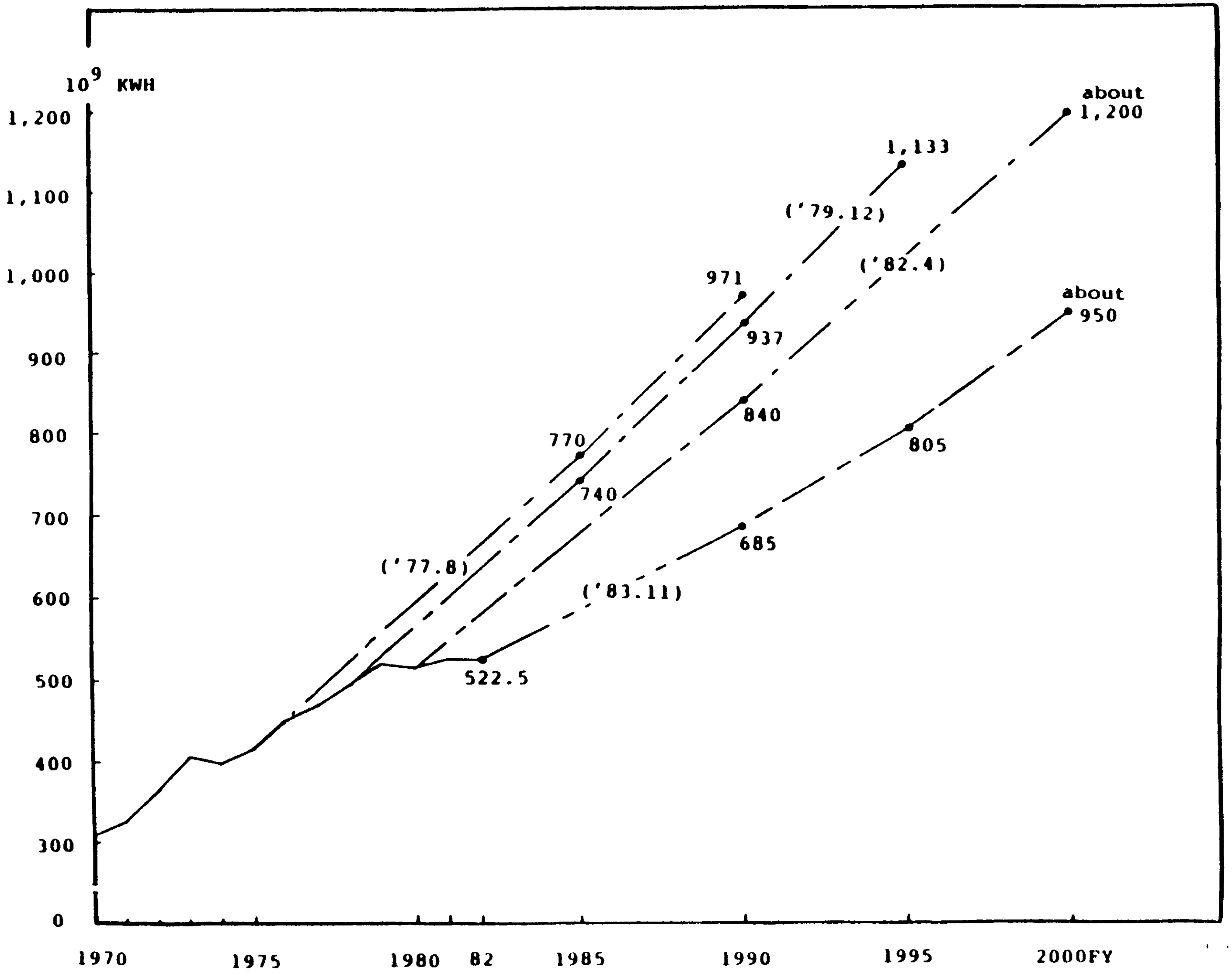
Introduction

As of 1984, the Japanese electric power system had an installed capacity of approximately 155,000 MW (IEE 1984), ranking it third after the United States and the Soviet Union. About one half as much electric power is produced per capita as in the United States. In 1983, 19.8 percent of total Japanese energy end-use demand was consumed in the form of electricity, and the electric power sector consumed about 38 percent of Japan's primary energy supplies (IEA 1985). Since the early 1970s, electricity demand has grown somewhat more rapidly in Japan than in other advanced industrialized countries (4.6 percent on annual average for 1970-83 (IEE 84), although, as elsewhere, growth has been consistently slower than expected (see Figure 4.1). In late 1983, the Electric Utility Industry Council, an advisory body to Japan's Ministry of International Trade and Industry (MITI), projected an annual growth rate of approximately 3 percent through the end of the century (IEE 84).

Historically, the industrial sector in Japan has been the primary consumer of electricity, and as recently as 1983 it accounted for 60 percent of total electricity consumption--well above corresponding levels in other advanced industrial nations. However, in recent years residential and commercial demand has been growing more rapidly than industrial demand, and this is projected to continue (at approximately 4 percent annually through 2000, compared with about 2.3 percent for industrial demand (Sakisaka 83).

Figure 4.1

Outlook for Electric Power Generation in Japan



Source: Sakisaka 33.

Power Generation by Fuel Source

Figures 4.2 and 4.3 show installed capacity and electricity generation trends through 1983. Oil is still the dominant fuel, but in the decade following 1973 its share of generation fell by a factor of two. During this period absolute oil consumption in the electric sector also fell by almost a third, despite the fact that total electricity output increased by 36 percent. The displacement of oil has been achieved primarily through the increased use of nuclear power, LNG, and, to a lesser extent, coal. These trends will continue at least through the 1990s. New nuclear plants are projected to provide 41 percent of new and replacement capacity over the next decade, while LNG and coal plants will provide 31 and 20 percent respectively (IEE 84). The current distribution of installed capacity and electricity generation by fuel type is shown below:

	INSTALLED CAPACITY(GWE)	GENERATION(10^9 kWh)
Nuclear	20.5 (13.9%)	133.9 (22.9%)
Coal	9.6 (6.5%)	51.3 (8.8%)
LNG	27.1 (18.3%)	123.2 (21.2%)
Petroleum + LPG	57.8 (39.0%)	202.7 (34.8%)
Geothermal	0.2 (0.1%)	1.1 (0.2%)
Hydro	32.8 (22.1%)	70.7 (12.1%)

(Source: IEA 85)

Ownership Patterns

Japan's electric power system is divided into 9 service areas, which are primarily served by 9 privately owned, vertically integrated power

Figure 4.2

Installed Electricity Generating Capacity Trends by Source
(Total electric utility industry)
(1955 - 1983)

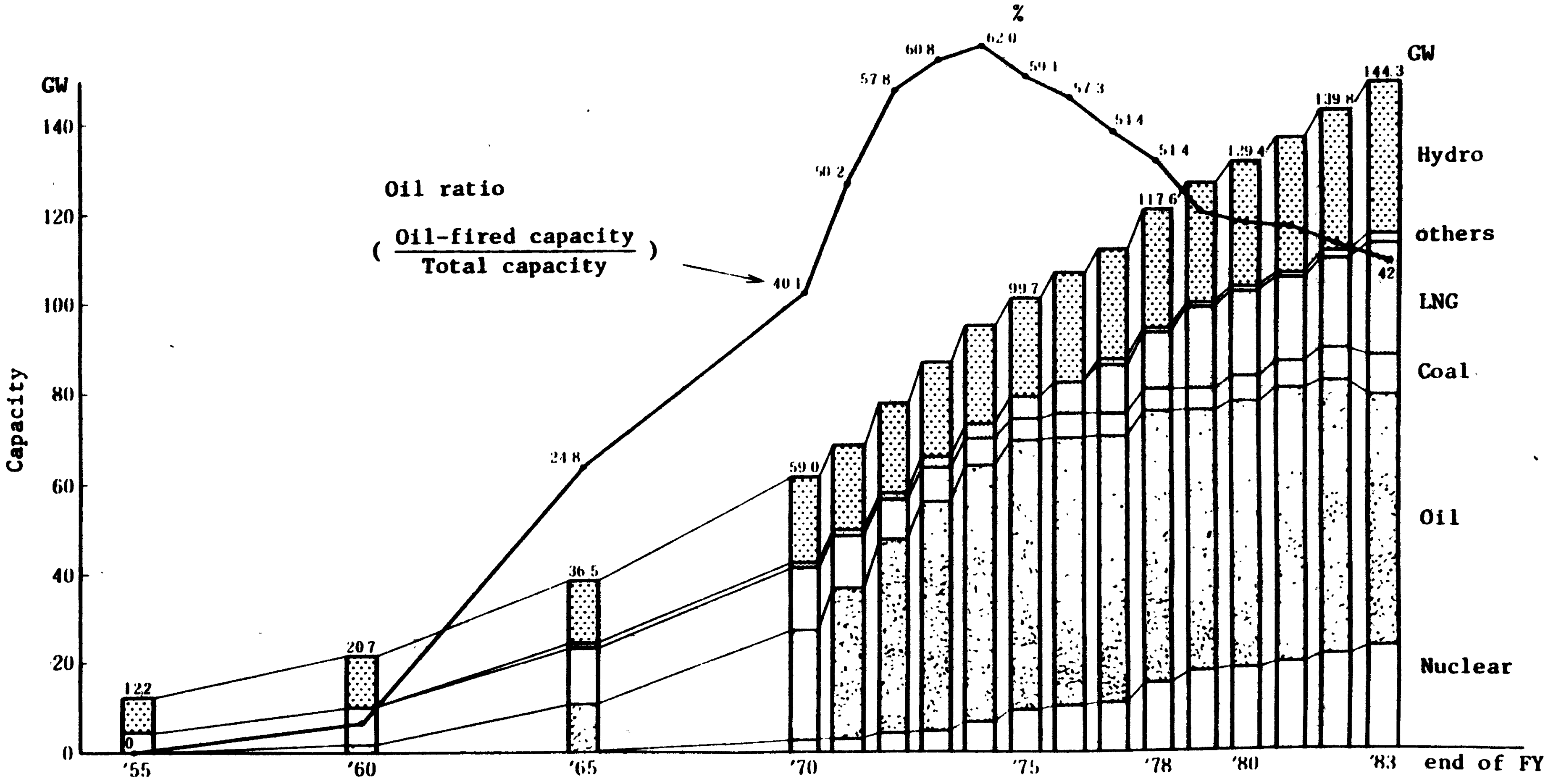
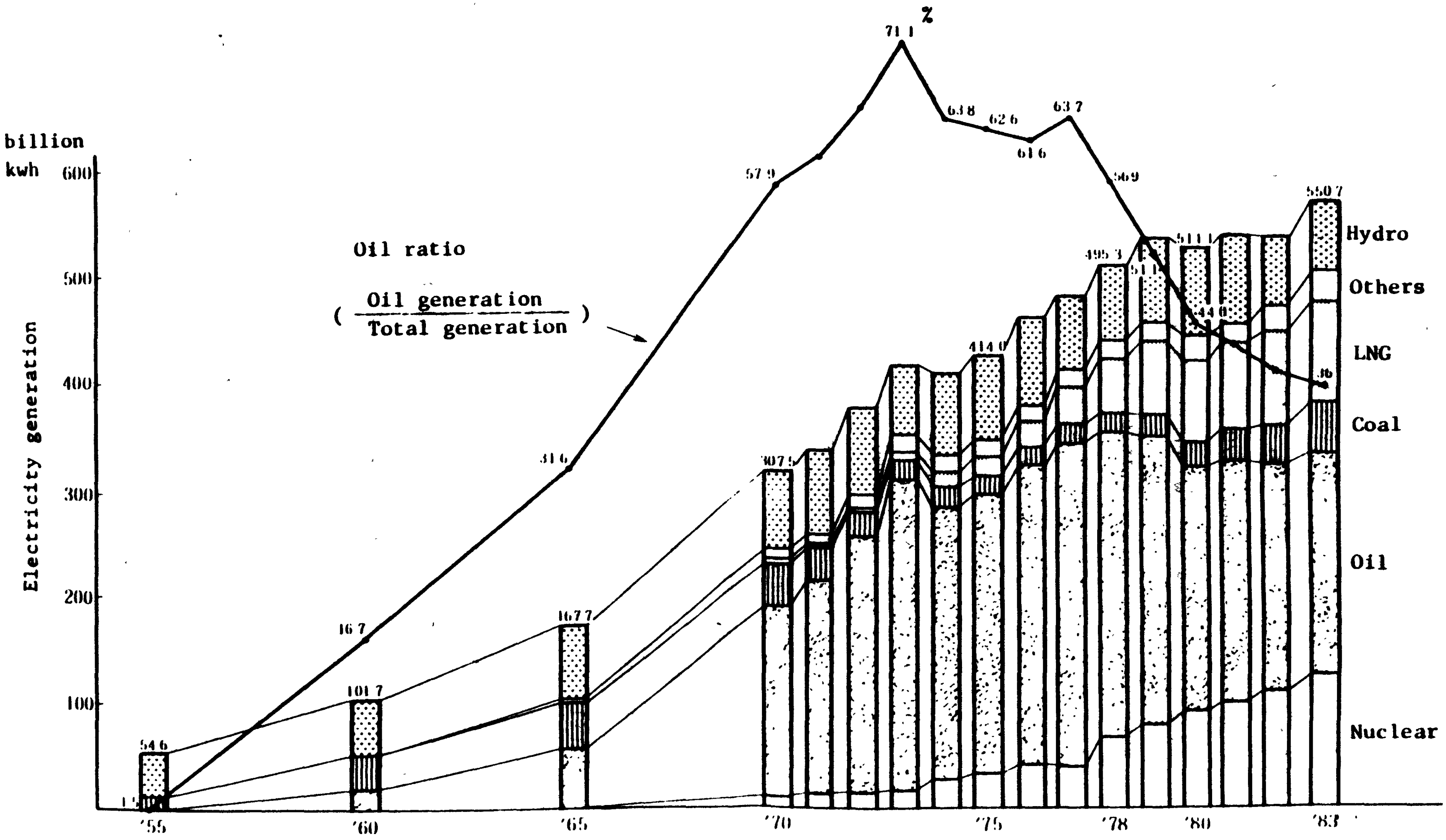


Figure 4.3

Electricity Generation Trends by Source
(Total electric utility industry)
(1955 - 1983)



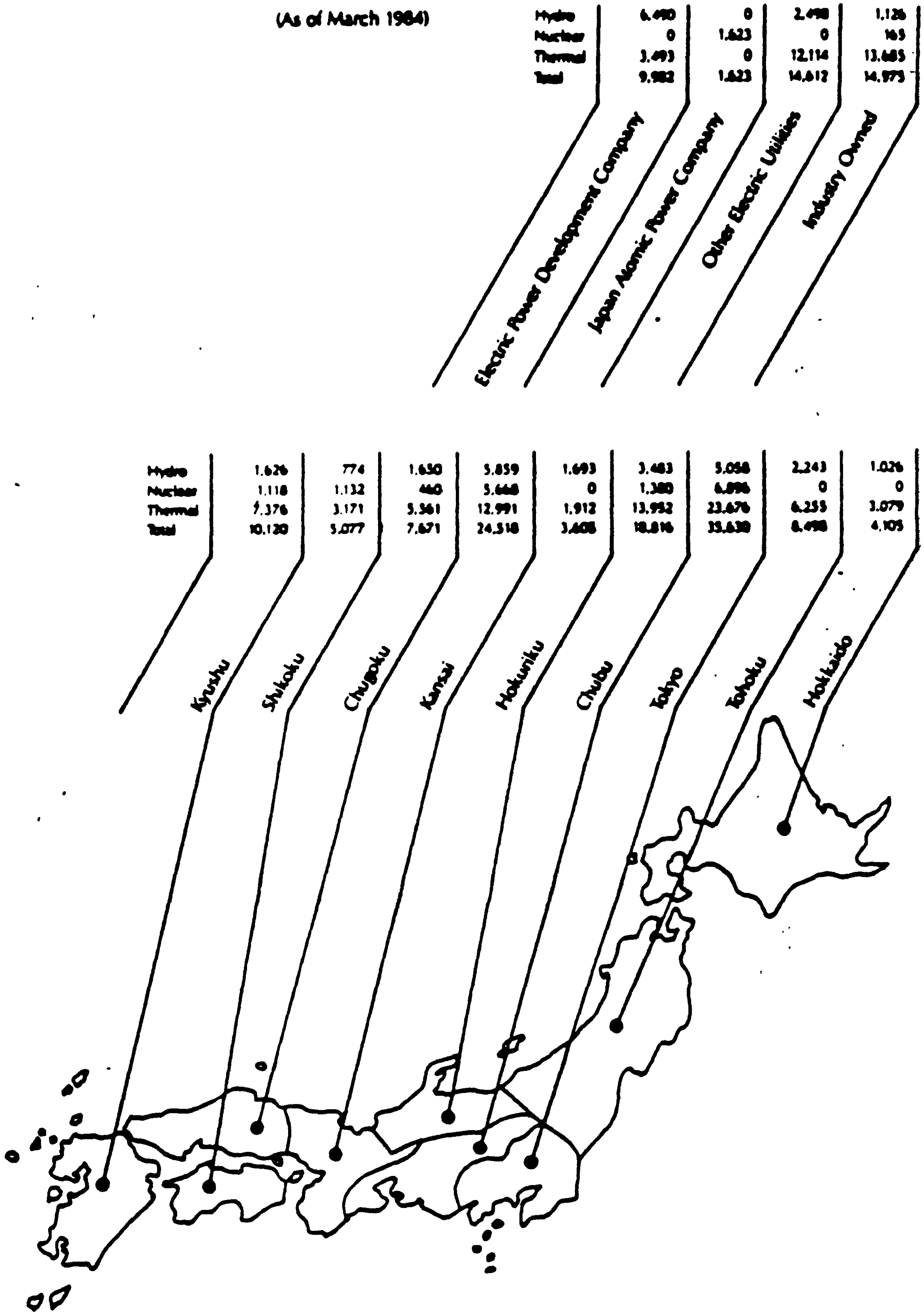
companies. The two largest are the Tokyo Electric Power Company (TEPCO) and the Kansai Electric Power Company (KEPCO). The other seven, in decreasing order of size (by installed capacity) are Chubu, Kyushu, Tohoku, Chugoku, Shikoku, Hokkaido, and Hokuriku. Together these nine companies generate over 70 percent of Japan's electric power. In addition, there are two companies that are jointly owned by the government and private interests. The Electric Power Development Company (EPDC), owned 70 percent by the government and the rest by utilities, owns and operates mostly hydroelectric and coal-fired plants, and also operates transmission lines connecting most of the distribution territories of the private companies. The Japan Atomic Power Company (JAPCO), which was formed in 1957 to pioneer the introduction of nuclear technology into Japan, owns and operates three nuclear power plants. Both these companies wholesale the power they produce to the nine regional generating companies. The remainder of the power (approximately 24 percent) is generated by 33 small prefectural companies (mostly from small hydroelectric plants); 19 joint venture companies established by utilities and large industrial users; the Okinawa Electric Power Company; and a few other minor generating companies. The current distribution of generating capacity in the utility industry is shown in Figure 4.4 and the degree of concentration is given in Table 4.1, with corresponding data for the United States shown for purposes of comparison.

Ownership of Nuclear Plants

As of January 1986 there were 31 nuclear units in commercial operation in Japan (24,731 MWe): 16 BWRs, 14 PWRs, and 1 GCR. (The first Japanese nuclear power plant was a gas-cooled reactor of the Magnox

Figure 4.4

Service Areas of Nine EPCs and Generating Capacity Units: 10^3 kW)



(As of March 1984)

	Electric Power Development Company	Japan Atomic Power Company	Other Electric Utilities	Industry Owned
Hydro	6.490	0	2.498	1.126
Nuclear	0	1.623	0	165
Thermal	3.493	0	12.114	13.685
Total	9.982	1.623	14.612	14.975

	Kyushu	Shikoku	Chugoku	Kansai	Hokuriku	Chubu	Tokyo	Tohoku	Hokkaido
Hydro	1.626	774	1.650	5.859	1.693	3.483	5.058	2.243	1.026
Nuclear	1.118	1.132	460	5.668	0	1.380	6.896	0	0
Thermal	7.376	3.171	5.561	12.991	1.912	13.952	23.676	6.255	3.079
Total	10.120	5.077	7.671	24.518	3.605	18.816	35.630	8.498	4.105

Source: INPO 85.

Table 4.1

Concentration of Generating Capacity--United States/Japan

(CUMULATIVE GENERATING CAPACITY)

	USA		JAPAN	
	MWe	Per Cent	MWe	Per Cent
Largest 5 Utilities	79,938	16.4	94,452	70.1
10	137,370	28.5	124,662	90.1
15	182,307	37.8	130,586	94.9
20	219,109	45.4	134,240	97.5
25	249,310	51.7	136,911	99.5
30	276,630	57.3	137,649	100.0
35	299,388	62.0	137,660	100.0
40	319,077	66.1		
45	338,181	70.0		
50	355,609	73.7		
55	385,727	79.9		
60	410,487	85.1		
70	429,550	89.0		
80	444,110	92.0		
90	455,702	94.4		
100	473,223	98.1		
120	481,004	99.7		
140	482,431	100.0		
180	482,610	100.0		
199	482,610	100.0		
	199 UTILITIES		31 UTILITIES	

Source: Poole 86.

type, supplied by the British.) An additional 11 units (10,788 MWe) are under construction, of which 6 are PWRs and 5 BWRs. Six others (3 PWRs and 3 BWRs, 6275 MWe) are in the planning stage.

The two largest utilities also have the largest nuclear programs: TEPCO has 10 units in operation and another 5 planned or under construction, while KEPCO has 9 in operation and another 2 planned. Between them, these two utilities account for about 60 percent of the operating and committed capacity (24,000 MWe out of 40,000 MWe total). However, 7 of the 9 regional companies have at least one nuclear plant in operation, and the other two (Hokuriku and Hokkaido) have units planned or under construction. Table 4.2 summarizes the distribution of plants by owner. As the table indicates, the Japanese utilities have adhered to the practice of building only PWRs or BWRs, with the single exception of JAPCO, which has one unit of each type in service (as well as the original gas-cooled reactor).

4.2 STRUCTURE OF THE SUPPLY INDUSTRY

Compared to the United States and the major nuclear nations of Western Europe, Japan's nuclear program got off to a rather late start. Since the mid-1960s, however, the Japanese have moved purposefully and with some speed to establish an indigenous LWR industry, which today has become among the most advanced in the world. At its heart lie three primary nuclear plant manufacturers owned by three large, integrated industrial groups: For PWRs, the Mitsubishi Group; for BWRs, the Tokyo Atomic Industrial Consortium (led by Hitachi) and the Nippon Atomic Industry Group (led by the Toshiba Corporation).

LWR technology was introduced into Japan through licensing agreements with the American vendors Westinghouse and General Electric. The first

Table 4.2

Nuclear Power Stations in Japan

(As of June 28, 1985)

	Company Name	Power Station Name (Unit number)	Location	Reactor Type
Operating	Japan Atomic Power Co.	Tokai	Ibaraki Prefecture	GCR
	•	Tokai Daini	•	BWR
	•	Tsuruga (No. 1)	Fukui Prefecture	•
	Tohoku E.P. Co.	Onagawa (No. 1)	Miyagi Prefecture	•
	Tokyo E.P. Co.	Fukushima Daiichi (No. 1)	Fukushima Prefecture	•
	•	• (No. 2)	•	•
	•	• (No. 3)	•	•
	•	• (No. 4)	•	•
	•	• (No. 5)	•	•
	•	• (No. 6)	•	•
	•	Fukushima Daini (No. 1)	•	•
	•	• (No. 2)	•	•
	•	• (No. 3)	•	•
	Chubu E.P. Co.	Hamaoka (No. 1)	Shizuoka Prefecture	•
	•	• (No. 2)	•	•
	Kansai E.P. Co.	Mihama (No. 1)	Fukui Prefecture	PWR
	•	• (No. 2)	•	•
	•	• (No. 3)	•	•
	•	Takahama (No. 1)	•	•
	•	• (No. 2)	•	•
	•	• (No. 3)	•	•
	•	• (No. 4)	•	•
	•	Ohi (No. 1)	Fukui Prefecture	•
	•	• (No. 2)	•	•
	Chugoku E.P. Co.	Shimane (No. 1)	Shimane Prefecture	BWR
	Shikoku E.P. Co.	Ikata (No. 1)	Ehime Prefecture	PWR
	•	• (No. 2)	•	•
	Kyushu E.P. Co.	Genkai (No. 1)	Saga Prefecture	•
	•	• (No. 2)	•	•
	•	Sendai (No. 1)	Kagoshima Prefecture	•
		Total		(30 units)
Under Construction	Japan Atomic Power Co.	Tsuruga (No. 2)	Fukui Prefecture	PWR
	Hokkaido E.P. Co.	Tomari (No. 1)	Hokkaido Prefecture	•
	Tokyo E.P. Co.	Fukushima Daini (No. 4)	Fukushima Prefecture	BWR
	•	Kashiwazaki-Kariwa (No. 1)	Niigata Prefecture	•
	•	• (No. 2)	•	•
	•	• (No. 5)	•	•
	Chubu E.P. Co.	Hamaoka (No. 3)	Shizuoka Prefecture	•
	Chugoku E.P. Co.	Shimane (No. 2)	Shimane Prefecture	BWR
	Kyushu E.P. Co.	Genkai (No. 3)	Saga Prefecture	PWR
	•	• (No. 4)	•	•
	•	Sendai (No. 2)	Kagoshima Prefecture	•
		Total		(11 units)
Under Planning	Tohoku E.P. Co.	Maki (No. 1)	Niigata Prefecture	BWR
	Tokyo E.P. Co.	Kashiwazaki-Kariwa (No. 3)	•	•
	•	• (No. 4)	•	•
	Kansai E.P. Co.	Ohi (No. 3)	Fukui Prefecture	PWR
	•	• (No. 4)	•	•
	Shikoku E.P. Co.	Ikata (No. 3)	Ehime Prefecture	•
		Total		(6 units)
		GRAND TOTAL		(48 units)
R & D	PNC	ATR Fugen	Fukui Prefecture	ATR
	•	FBR Monju	•	FBR

NOTE: "Under planning" refers to the power plant whose construction was decided by the Electric Power Development Coordination Council but has not been granted a construction permit yet.

Source: INPO 85.

PWR units were supplied by Westinghouse on a turnkey basis. Later units of the same design were built—with progressively increasing participation--by Mitsubishi. The first plant of each new design vintage was built by the American vendor. Similarly, General Electric supplied the first BWR of each new design, with either Toshiba or Hitachi assuming responsibility for increasing fractions of subsequent units under license to General Electric. Today plant design and the supply of virtually the full range of systems and components are carried out domestically.

Unlike their U.S. counterparts, Japanese nuclear suppliers now act as Architect/Engineers (A/E) for the entire plant, rather than just the nuclear steam supply systems. (For the earlier plants, the Japanese suppliers did not have a full (A/E) capability, and the utilities enlisted the help of both American vendor and (A/E) firms.) Also, it normally is the case in Japan that all major systems and components for a given plant, both nuclear and conventional, are manufactured by members, affiliates, or associates of the supplier group. Thus, for example, in the Mitsubishi group, Mitsubishi Heavy Industries is engaged in the manufacture of main components, including nuclear steam supply systems; Mitsubishi Electric Corporation in the supply of instrumentation and control systems; and Mitsubishi Atomic Power Industries in design. Mitsubishi Nuclear Fuel supplies fuel and Mitsubishi Metal Corporation manufactures cladding tubes for the fuel. Figure 4.5 describes the organization of the Toshiba group.*

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*In addition to the three LWR industry groups, in the early years of the Japanese nuclear program, two other groups were formed. The First Atomic Power Industry Group, led by Fuji Electric, participated as a subcontractor to GEC of Britain in the construction of the Magnox plant, and is now involved in advanced reactor development. The Sumitomo Atomic Energy Group does not have a reactor vendor, but is actively engaged in the nuclear fuel cycle industry.

Generally, the utilities contract separately for the civil works. To date, five large civil engineering firms have been involved in nuclear power plant construction: Kajima Corporation, Taisei Corporation, Obayashi-Gumi, Shimizu Construction, and Takenaka Komuten.

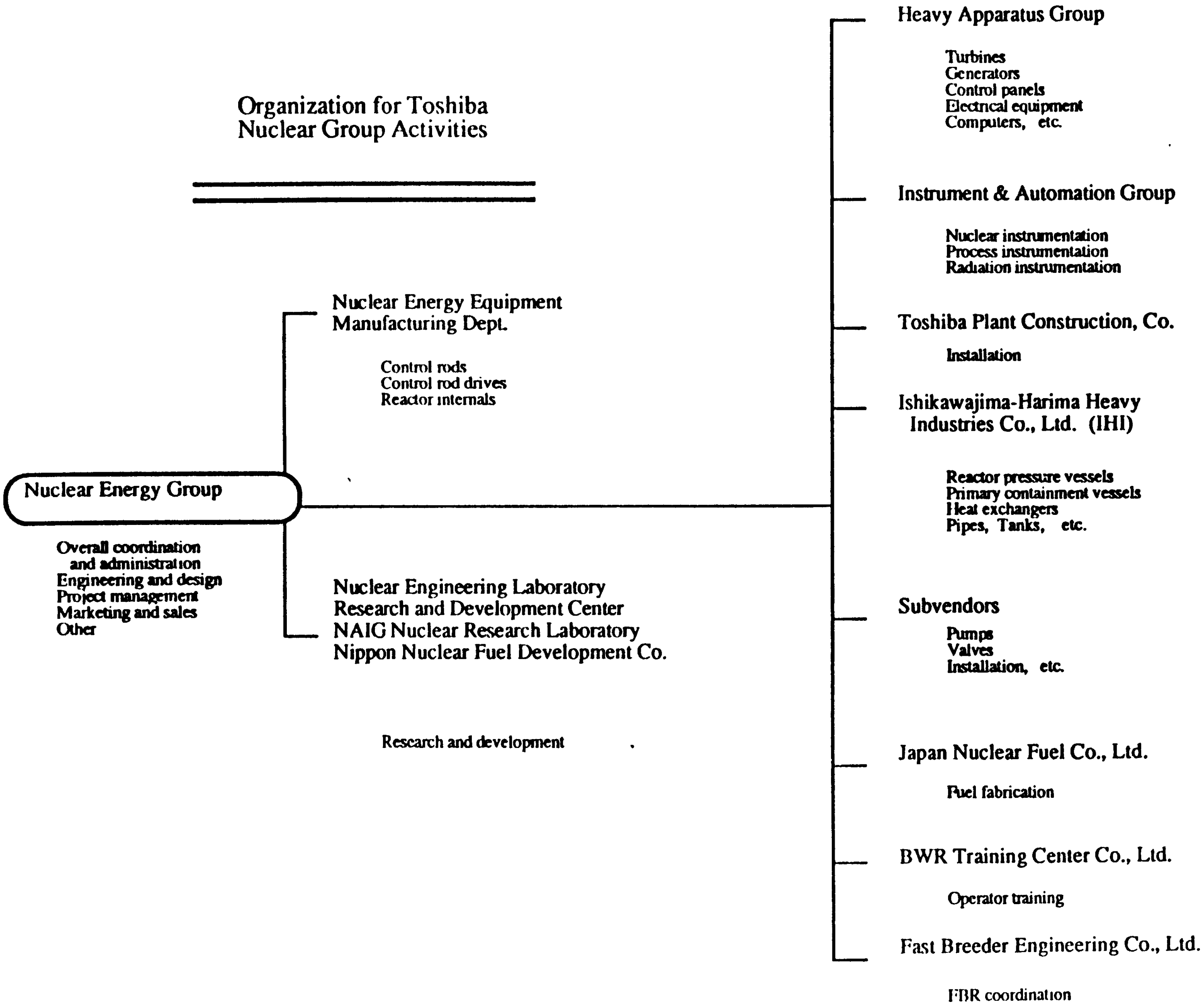
With three private NSSS manufacturers, there obviously is competition in the Japanese nuclear supply industry, but for several reasons it is probably somewhat less vigorous than an initial look might suggest. For example, the policy of building units of only one type has reduced the supply options of the utilities (in the case of the "PWR" utilities, to a single firm). Moreover, some evidence suggest that the ordering patterns of the BWR utilities partly have been influenced by a perceived need to ensure adequate business for both of their BWR suppliers. In addition, the supplier practice of tendering for the entire plant has inhibited utilities from fostering competition among secondary suppliers.

Interactions among the utility, the reactor manufacturer, and its subcontractors have been described in a recent report prepared by a visiting team of U.S. experts sponsored by the Institute of Nuclear Power Plant Operations (INPO). According to the INPO team, these relationships generally are close and cooperative, and continue throughout the plant life:

> Japanese plant manufacturers continue to provide extensive support and retain significant responsibility to the utility for the life of the plant . . . . The manufacturer is frequently the primary contractor for annual inspection (outage) work. . . . Plant manufacturer personnel are in residence at many plants, and manufacturer specialists are available to any plant requiring assistance. Others have contracts with particular utilities
>
> to have on-site engineers. One manufacturer has one or two engineers at each operational station.
>
> . . . A similar set of long-term relationships exists between the plant manufacturers and their subcontractors and between the utilities and their contractors/subcontractors. Hence, the benefits of these relationships apply to most equipment and services provided to Japanese nuclear power plants.

Figure 4.5

Organization of the Nuclear Supply Industry in Japan



In some plants, vendors are responsible for as much as 70 percent of periodic maintenance activities, as well as for plant modifications (Battelle, 85, pp. 5-19).

4.3 UTILITY INTERNAL ORGANIZATION AND CAPABILITIES

The following discussion pertains almost entirely to nuclear plant operations and maintenance functions.*

Operations

The operations department consists of 4 or sometimes 5 rotating shifts and a supporting day-staff organization. For a 2-unit site the operations department typically includes 80 to 95 personnel. A MITI-certified Supervisory Operator (usually the Shift Supervisor) must be on duty on each shift. There is no requirement for Supervisory Operators to hold university degrees. Personnel with three other specific technical licenses also must be present at each plant site: a Chief Nuclear Engineer, a Chief Electrical Engineer, and a Chief Boiler and Turbine Engineer. The requirements for certification as a Chief Nuclear Engineer are such that those achieving this qualification are normally university graduates, although this is not mandatory.

Maintenance

The utility maintenance organization is responsible for managing the plant maintenance program, but utilities do not normally maintain a

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*In the absence of direct interview data gathered during the course of this project, the author relied primarily on two recent reports prepared by teams of visiting U.S. experts (INPO 85, and Battelle 85), together with interview data assembled by the author during several previous trips.

substantial in-house workforce of maintenance technicians. The nuclear power plant vendors, general maintenance contractors, and subcontractors provide the bulk of hands-on labor and supervision. It is not uncommon for vendor or contractor personnel who were involved in plant construction also to participate in maintenance activities. The utility's relationships with its maintenance contractors typically are close and durable. In some cases the utility has a controlling interest in the firm. Also, the management levels of these firms often are staffed by retired or "on-loan" utility employees.

Throughout the industry there is a strong commitment to preventive maintenance. Maintenance programs are based on a statutory requirement for annual inspections at every nuclear power plant. The bulk of preventive maintenance is conducted during the annual inspection outage. In the past these annual outages have lasted four months or more, although their duration gradually is being reduced. Maintenance is performed on both safety-related and balance-of-plant (BOP) equipment, and frequently extends beyond visual inspection to include component disassembly and measurement of wear. Some of the inspections are required by statute and are conducted by MITI officials or MITI-designated inspectors, while others are undertaken at the utility's initiative. Annual outages are meticulously planned by the utility's maintenance system experts in conjunction with the general maintenance contractor and plant manufacturer. Implementation of the maintenance schedule is closely monitored and controlled by the utility maintenance staff. Most Japanese utilities use a 10-year maintenance plan or a 5-year rolling plan. Detailed planning for the next annual outage is a continuous process, beginning immediately after the most recent outage, or in some cases even earlier. Last-minute modifications are rare.

During normal operation some 100 to 200 personnel are assigned to perform routine maintenance work. At some plants the general maintenance contractor keeps a limited number of personnel permanently on site. During the annual outage an additional 500 to 1300 maintenance/inspection staff are present, most of whom are contractor or subcontractor employees.

The contract craftsman and his supervisor are directly responsible for the quality of the maintenance work they undertake. The utility maintenance staff relies heavily on its contractors to specify and implement proper quality assurance procedures, but also performs checks on the work while it is being performed. A distinctive feature of the effort to ensure quality at Japanese nuclear power plants is that there generally is not a separate, independent quality assurance or quality control organization; rather, emphasis is placed on integrating quality considerations into the efforts of those with line responsibilities, both within the utility organization and among the contractors.

Training

The approach taken by Japanese nuclear utilities to the training of operator and maintenance personnel reflects certain basic practices and attitudes found throughout Japanese industry. These include the group orientation of Japanese culture and management and the life-time employment system. One consequence of the latter is that it is rare that an experienced individual is hired into a utility organization. Rather, new employees generally are recent high school or college graduates who have little or no practical experience. Extensive on-the-job training is therefore required. The expectation of low employee turnover encourages utilities to invest heavily in training and education programs. The training process for each individual can last for many years; it typically takes 7 to 8 years to become a reactor operator, and 12 to 14 years to reach the rank of chief operator.

A characteristic feature of both operations and maintenance training programs is the intentional avoidance of specialization. Job positions are defined broadly, and on-the-job training is provided in several fields. Similarly, the utilities generally practice a system of spiral job rotation, which aids in the creation of generalists. One argument frequently invoked by Japanese experts against employee specialization is that it tends to inhibit the development of a consensus based on a common understanding of any given technical problem. Generalists are likely to perceive more clearly the larger context of their current activity and to identify more strongly with the objectives of the enterprise as a whole.

In addition to the formal training programs and examinations required for promotion, continuing training for operators is conducted both on-shift and at nuclear training centers. There are two such centers in Japan, one for BWR operators (established by the BWR utilities), and the other for PWR operators (established by the PWR utilities). Each is equipped for classroom and simulator training. Operators receive approximately one week of simulator training each year. Part of this training is provided collectively to entire shifts (the "family training" concept). On-shift training usually is led by the shift supervisor. Each utility is responsible for its own operator training program, but is required to present its program to MITI for review.

Utility maintenance staff also receive extensive training over a long period. At some utilities maintenance training programs range up to 20 years in length. Several of the major utilities have established their own training centers for maintenance workers. These centers include full-scale mock-ups of major equipment and components, as well as the capability to simulate the physical environment of nuclear power plants. As with operator training, MITI reviews the utilities' maintenance training programs, although there are no government-administered qualifications for maintenance workers.

4.4 ECONOMICS OF NUCLEAR POWER

The Agency of Natural Resources and Energy (ANRE) of MITI periodically releases comparative estimates of the cost of power generation by fuel source. Over the years nuclear power consistently has been the lowest-cost source of electricity, although its advantage with respect to the next most economic source--coal-fired thermal plants--has been declining in recent years. This is primarily due to rapid increases in nuclear power plant construction costs and a concomitant stabilization of world coal prices. According to the latest MITI estimates, issued in October 1985, nuclear power maintains a small cost advantage over coal.

MITI traditionally has based its cost comparisons on estimates of first-year generating costs, an approach that tends to favor low capital cost, high fuel cost sources relative to capital intensive alternatives. In 1985, for the first time, MITI presented comparisons based on lifetime levelized cost estimates. Both sets of results are reproduced in Table 4.3. The cost of waste management and disposal and reactor decommissioning are not included in the nuclear cost estimates. According to MITI, even if these components were included, nuclear power would retain its cost advantage or at least break even with coal. However, the declining margin of superiority has created new incentives for government and industry to improve the economic efficiency of nuclear generation. For existing plants the focus is on reducing the length of the annual inspection outage, extending the intervals between inspections, and improving plant reliability. In the longer run, the emphasis is on developing advanced LWR designs that have reduced capital and fuel costs and enhanced availability.

4.5 ECONOMIC REGULATION

Electric utility rates are controlled by the MITI. Rates are set based on the principle of full cost recovery, including a fair rate of return on investment.

The ratio of internal to external funds for capital investment raised by the nine major utilities has fluctuated widely over the last two decades. During the 1970s the share of internal funds fell sharply. There were several reasons for this, including the adverse impact of inflation on the real value of the depreciation accounts, stagnant electricity demand, and unexpectedly low nuclear plant capacity factors. By 1979 the internal funds ratio had fallen below 20 percent. In the following year it began to rise again, in large part because of a 43 percent increase in electricity rates; data recently obtained for one utility indicate that internal funds now account for well over 50 percent of capital investment. New stock issues have played a limited role throughout this period, largely because of the relatively high cost of capital from this source. (Due to the custom of giving preferential treatment to existing shareholders, new stock issues usually are allotted to the shareholders at par value, and less frequently through public subscription at market prices.)

External funds primarily originate from bond issues and loans from a variety of institutions. The power companies rank as the most important clients of the leading banks, and receive preferential treatment with respect to interest rates and terms (and did so even during the late

Table 4.3

Comparative Busbar Generating Costs[1,2,3]

	First-Year Cost (¥/kwh)	Lifetime Levelized Cost (¥/kwh)	
		1%/yr[5]	3%/yr[5]
Hydro	~ 21	~ 13	~ 13
Oil	~ 17	~ 17	~ 19
Coal	~ 14	~ 12	~ 13
LNG	~ 17	~ 16	~ 18
Nuclear	~ 13	~ 10	~ 11

Notes

1. Estimated for plants beginning operation in 1985.

2. Capacity factor assumed to be 70 percent (45 percent for hydro).

3. Estimates made for the following model plants:

General Hydro	10-40 MW class
Oil	4 x 600 MW
Coal	4 x 600 MW burning imported coal
LNG	4 x 600 MW
Nuclear	4 x 1100 MW

4. Power plant lifetimes used for calculating levelized costs: nuclear (16 yrs); fossil (15 yrs); hydro (40 yrs).

5. Assumed rate of increase in real fuel prices (i.e., net of inflation.

Source: Atoms in Japan, April 1986.

1970s, when poor earnings were the norm). Utility financings also receive most favored status regarding interest rates and terms in the bond market. This preferential treatment is at least partly the result of government promotional policies. A substantial portion of loans to utilities originate from the Japan Development Bank, a semi-governmental organization authorized to lend at below-market rates. The government also has granted several special privileges to utility borrowings and bond financings. Table 4.4 summarizes data on the fund-raising behavior of Japanese utilities.

In general, although financial constraints have had an impact on the structure of utility fund raising, there is no discernible evidence that rate regulation or any other factor has been a significant cause of capital shortages. The Japanese utilities appear to have maintained a sound financial position throughout the post-1973 decade, and it seems highly unlikely that financial considerations have affected utility investment decisions in ways that subsequently might have threatened the operating performance of nuclear plants.

4.6 SAFETY REGULATION

Authority over licensing and safety regulation of nuclear power reactors rests almost exclusively with the central government. MITI is the licensing authority, and is responsible for the administration of the safety regulatory program. Figure 4.5 illustrates the licensing procedure for commercial nuclear power plants in Japan. The first step in the process is a review by MITI of the environmental impact of the proposed site. As part of this review, a public hearing is held, and MITI also consults an environmental advisory committee. The plan for the proposed project then is submitted to the Electric Power Resources

Table 4.4

Japanese Utility Financial Structure

	(Nine Power Companies)			(Typical Utility)	
Investment in Plant and Equipment	1964-73[1]	1974-78[1]	1979[2]	1984[3]	1985[3]
Internal Funds:	52.0	43.7	18.0	62.6	67.5
Depreciation	33.9	23.7		46.2	53.5
Reserves, retained earnings, etc.	10.5	14.3		15.9	16.9
Capital increase	7.6	5.7		0.5	-2.9
External Funds:	48.0	56.3	82.0	37.4	32.5
Loans	21.7	30.2	49.1	23.5	20.2
Bonds	26.3	26.1	32.9	13.9	12.5

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1. Source: Tajima (1979)
2. Source: Suetsuna (1951)
3. Source: Toichi (1985)

Development Coordination Council (EPRDCC), which is chaired by the Prime Minister and on which the Minister of International Trade and Industry, the Minister of Economic Planning, and other senior officials also serve. Before issuing a decision on the project, EPRDCC consults with the Prefectural Governor.

Following EPRDCC approval, the utility submits to MITI an application for a reactor installation (establishment) permit. At this stage MITI is required both to conduct the first safety examination of the project and to consult the Atomic Energy Commission (AEC) on developmental aspects and the Nuclear Safety Commission (NSC) on safety aspects.*

The NSC conducts a second, independent safety examination, during which a second public hearing is held. After receiving reports from the AEC and the NSC, MITI, with the consent of the Prime Minister, then may issue the reactor installation permit. The utility then is required to submit to MITI a construction permit application containing detailed information on design and construction procedures. MITI issues the construction permit in several installments, with manufacturing and construction work proceeding only to the extent authorized. When the authorized work is completed, MITI conducts inspections to ensure that the construction plan has been followed and that quality is being maintained, observes on-site tests, then issues an operating permit for the relevant section of the plant. This process continues through initial criticality, low power testing, and full power operational

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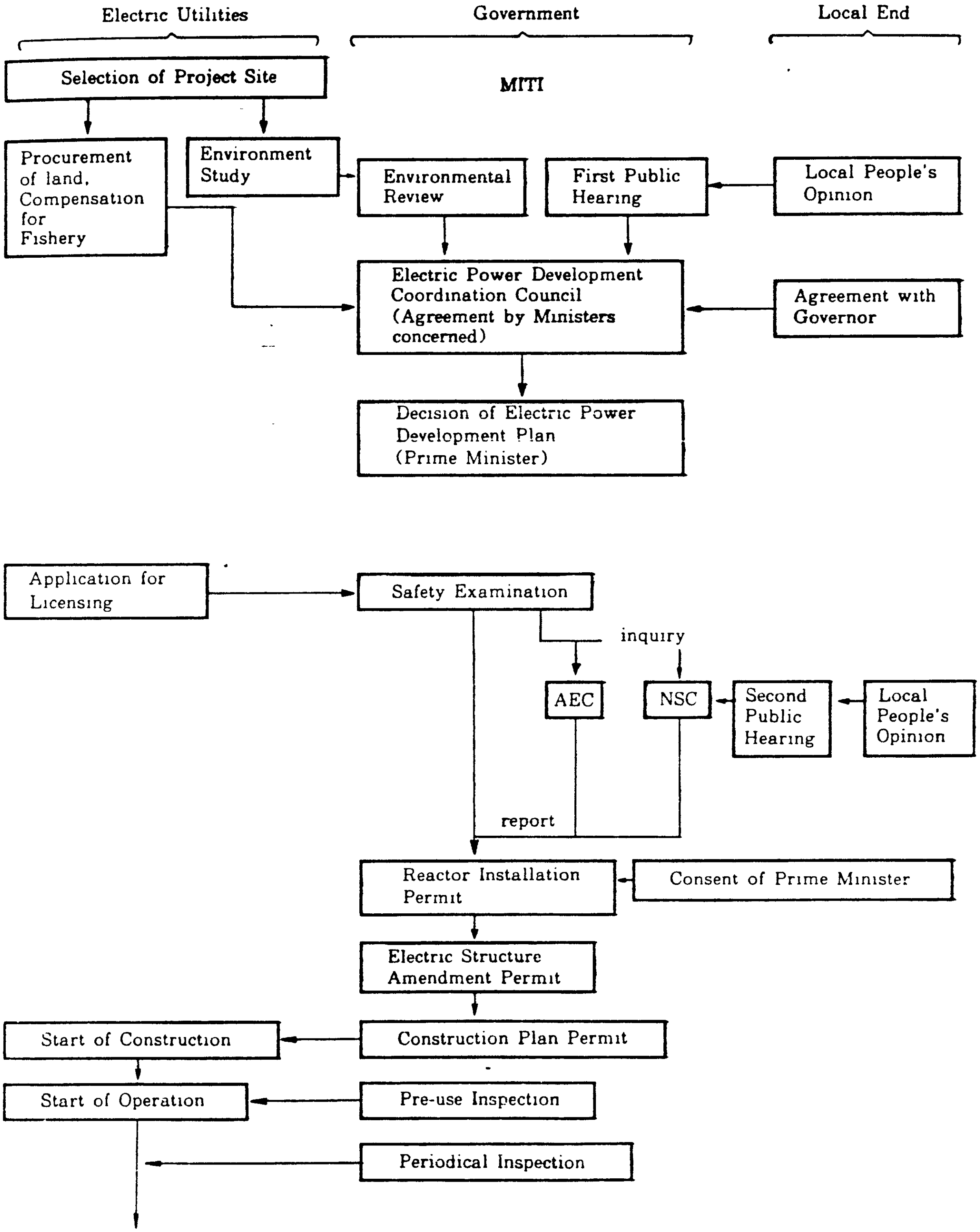
*The AEC and NSC, both advisory organizations to the Prime Minister and organizationally located within the Prime Minister's office, were created in 1978, following a reorganization of the old Atomic Energy Commission into a commission with primary responsibility for the promotion of nuclear power (the AEC) and one with primary responsibility for nuclear safety (the NSC).

Figure 5

Licensing Procedure for Commerical Nuclear Power Plants



testing. Following the final tests, MITI grants an operating license and the plant goes into commercial operation.

The two public hearings are mandatory, but local opponents of a new plant are not legally empowered to interrupt the licensing process. Typically, negotiations between the utility and local citizens begin well before the formal license applications are submitted. These negotiations often are complex and in some cases have been very protracted. They generally are concluded before construction begins, however, and delays due to local opposition during construction are rare.

During operation, MITI is required by law to conduct a detailed, annual safety inspection. In addition, MITI assigns a "resident expert" to each plant to monitor compliance with operating and maintenance procedures and equipment standards. Finally, the utilities submit periodic reports to MITI on routine activities, and they and the resident experts also are required to submit oral and written reports on certain off-normal conditions and events.

The government regulatory bureaucracy is quite small. According to one recent estimate, when all the relevant agencies are considered, there are only about 500 government officials engaged in overseeing both the promotion and regulation of nuclear power in Japan (INPO, 85, p.11). The centralization of functions within MITI also is notable. The Ministry is responsible not only for administering the safety regulatory process, but also, *inter alia*, for promoting a technically strong and financially healthy electric utility and nuclear supply industry, for ensuring the reliability and adequacy of electricity supplies, for setting electricity rates, and for conducting certain types of research and development to lead to greater economic efficiency in nuclear power plant construction and operation. The strong government support in Japan for nuclear power and the combined promotional and regulatory roles of MITI almost certainly are responsible, at least in part, for the generally cooperative attitude that characterizes interactions between utilities and regulators. The utilities perceive the regulatory organization not as an inherently adversarial body, but rather as one that shares their objective of attaining efficient nuclear power generation. In turn, the utilities themselves generally have evinced a strong commitment to safety, frequently taking action to resolve technical problems without waiting for directives from the regulatory authorities. Another indication of the extent of cooperation is provided by the frequency of joint research and development programs and safety analyses between the industry and its regulating agencies.

Of course, the utility-regulator relationship has not always been free from tension. One prominent example is the widely-reported incident in March 1981 at the Tsuruga nuclear power plant, a 357 MW BWR owned and operated by the Japan Atomic Power Company (JAPCO). A substantial leak of radioactive water into a general waterway and subsequently into the sea went unreported by the utility, and only indirectly came to the attention of the authorities. Subsequent investigations revealed that there previously had been several other problems and incidents at the plant, which also had gone unreported. MITI, finding evidence of serious management shortcomings on the utility's part, ordered a six-month suspension of operations.

One interesting aspect of the Tsuruga incident was the strong reaction it engendered from the nine private electric power companies--the majority shareholders in JAPCO. In the immediate aftermath of the incident, the presidents of all nine comapnies publicly called for a management "cleanup" of JAPCO. The two senior executives at the company subsequently resigned. Although the government investigation concluded that the Tsuruga leak would have no adverse effects on public health, both government and industry officials expressed serious concern over possible damage to public confidence in the safety and integrity of the industry. One practical consequence of the incident was increased demand for participation by local governments in the safety regulatory process.

4.7 PUBLIC OPINION TOWARD NUCLEAR POWER

As in several other countries, public opinion in Japan toward nuclear power exhibits somewhat contradictory tendencies. On the one hand, the majority of the public, prompted by strong government statements of support, generally appears persuaded of the importance of nuclear power to Japanese economic health and national security. On the other hand, there appears to be fairly widespread uneasiness toward the idea of having a nuclear power plant sited locally. The latter has considerably complicated the siting process--a task already made difficult by the high population density, seismic activity, and the shortage of inland cooling water supplies that characterizes the Japanese islands. The government (primarily under the auspices of MITI) has taken a number of measures to promote the acquisition of sites, including the establishment of a special electricity consumption tax (recently raised to 0.6 yen/kWh), from which income is used to subsidize both the construction and maintenance of public facilities and the development of industries in regions surrounding nuclear plants. An electric rate discount system also has been introduced for residential and commercial customers near plants, and additional grants are provided to prefectures where power generation exceeds local power consumption by more than a factor of 1.5.

The government also allocates substantial sums each year to public education efforts.

Despite these measures, siting constraints continue to be one of the most difficult problems facing the Japanese nuclear program. By and large, however, through a combination of promotional measures and tightly circumscribed opportunities for public intervention, residual public opposition has had little impact on the implementation of nuclear projects once construction has begun. In the operating phase, the impact of public opinion on plant performance, to the extent that it is felt at all, probably is a positive influence, in the sense that achievement of higher plant productivities has been elevated by the government to the level of a national policy goal.

4.8 NUCLEAR POWER PLANT PERFORMANCE IN JAPAN

In this section the performance losses for the Japanese nuclear power plants are briefly described. The performance index used to describe the Japanese losses was [1-Capacity Factor (%)/100].

4.8.1 Aggregated Data

The Japanese PWR capacity losses as a function of calendar year and reactor age are tabulated in Table 4.5 and Table 4.6. The BWR capacity losses are tabulated by year in Table 4.7 and as a function of reactor age in Table 4.8. The mean and the standard deviations of the capacity factors are tabulated by year and by reactor age in Table 4.9.

4.8.2 Capacity Factor Distribution

Japanese PWR capacity factors are plotted against time in Figure 4.6. The Japanese plants have had an average capacity factor of 63.3%

over the ten year period. Performance from 1975 to 1979 fluctuated from year to year with several years having large standard deviations. The large standard deviation in 1975 was the result of a 92.4% loss attributed to the annual refueling and inspection outage at a single plant. A different plant with an 89.6% refueling loss accounts for the large standard deviation in 1977. The low performance in 1979 is the result of long refueling outages at many of the plants which may have resulted from the accident at Three Mile Island in that year. Since then the performance has increased as a result of reductions in the duration of refueling outages. The standard deviation over these years has remained relatively constant.

The PWR capacity factors are displayed as a function of age in Figure 4.7 and exhibit no age dependence. The standard deviations have been relatively constant with an average of 0.158.

Capacity factors for the Japanese BWR's are plotted over time in Figure 4.8. Performance has averaged 61.0% during the 10 year period shown. Lengthy refueling outages at 2 out of 3 BWR's contributed to the 28.1% capacity factor in 1975. In 1977 large refueling losses at 3 out of 5 plants resulted in an average capacity factor of 25.8%. The cause of these long outages is unknown. The large standard deviations for these two years were because the remainder of the plants in those years did not perform as poorly. From 1979 on, BWR performance has improved as a result of reductions in refueling and inspection outages.

The BWR capacity factors are shown by age in Figure 4.9. The capacity factors and standard deviations fluctuate with age but neither exhibits any age dependency.

4.8.3 Losses by Outage Type

In this subsection, forced, scheduled, and regulatory losses for the Japanese nuclear plants are displayed and examined as functions of time and age.

In Figure 4.10, the forced, scheduled and regulatory losses are displayed over time for the Japanese PWR's. Japanese losses have generally been large, averaging 36.7% over the 10 years studied. From 1979 to 1984, the performance of the Japanese PWR's steadily improved.

The scheduled losses comprised the largest fraction of the total losses, with a 10 year average of 34.0%. This represents 92.3% of the total. Scheduled losses have been high as a result of mandatory shutdowns for inspection and maintenance which are usually performed during the refueling outages. Reductions in the length of these outages since 1979 account for the increase in performance exhibited. The other scheduled losses are small as a result of the large amount of maintenance performed. Forced outages have been small, averaging 2.6% over the 10 year period. In addition, the forced losses show a time dependent decrease. The cause of this trend cannot be assigned to any one category; it arises from a general reduction in forced outage losses in several categories. No regulatory losses are reported for any of the PWR's.

The PWR losses are shown as a function of reactor age in Figure 4.11. None of the outage categories studied shows an age dependent trend in this figure. The large peaks in both forced and scheduled losses at age 11 were caused by a steam generator repair and a large refueling at one plant.

BWR outage categories are plotted over time in Figure 4.12. As the figure illustrates, the total and scheduled losses fluctuated prior to

1979 and then began to decrease from year to year. The scheduled outages represented 96.4% of the total losses and followed the total loss curve closely. The reason for this was once again the large mandatory outages for inspection and maintenance each year. Forced outages have been relatively constant with a 10-year average of 1.4%. As with the PWR's, there were no regulatory losses reported.

Finally, in Figure 4.13, the BWR outage categories are plotted in reactor age. The figure shows fluctuation in the total losses with an increasing tendency with age. This trend is probably insignificant due to its small magnitude and fluctuation that is present from year to year. Forced outages are small and exhibit a slight decrease with age. This trend is also probably insignificant. The small peak in the forced outages at ages 12 and 13 was attributable to turbine losses at one plant.

Table 4.5

Japanese PWR Capacity Losses By Year

```
CAPACITY LOSSES                                                       JAPAN
1975 - 1979                                                       ALL PWR'S

03/25/86                       DATA:( 4)    ( 5)    ( 6)    ( 6)    ( 8)
:-------------------------------------------------------------------------:
:                                    1975    1976    1977    1978    1979  :
:-------------------------------------------------------------------------:
: FORCED      : NSSS : FUEL        0.000   0.000   0.000   0.000   0.000  :
:             :      : RCS         0.000   0.000   0.000   0.013   0.000  :
:             :      : SG          0.006   0.054   0.007   0.009   0.027  :
:             :      : REFUEL                                              :
:             :      : OTHER       0.001   0.002   0.000   0.000   0.020  :
:             :      :            ------  ------  ------  ------  ------  :
:             :      :             0.006   0.056   0.007   0.022   0.048  :
:             :-----------------------------------------------------------:
:             : BOP  : TURBINE     0.024   0.001   0.000   0.000   0.000  :
:             :      : GEN         0.000   0.000   0.000   0.000   0.000  :
:             :      : COND                                                :
:             :      : CW/SW/CCW   0.025   0.005   0.004   0.001   0.000  :
:             :      : OTHER       0.000   0.000   0.000   0.000   0.000  :
:             :      :            ------  ------  ------  ------  ------  :
:             :      :             0.049   0.006   0.004   0.001   0.001  :
:             :-----------------------------------------------------------:
:             : ECONOMIC                                                   :
:             :-----------------------------------------------------------:
:             : HUMAN              0.000   0.000   0.000   0.000   0.000  :
:             :-----------------------------------------------------------:
:             : OTHER              0.025   0.009   0.000   0.003   0.002  :
:              -----------------------------------------------------------:
:               TOTAL              0.080   0.072   0.012   0.026   0.050  :
:-------------------------------------------------------------------------:
: SCHEDULED   : NSSS : FUEL        0.000   0.004   0.000   0.000   0.000  :
:             :      : RCS         0.000   0.000   0.000   0.000   0.000  :
:             :      : SG          0.000   0.000   0.000   0.000   0.000  :
:             :      : REFUEL      0.433   0.209   0.413   0.354   0.572  :
:             :      : OTHER       0.000   0.000   0.001   0.000   0.000  :
:             :      :            ------  ------  ------  ------  ------  :
:             :      :             0.433   0.212   0.413   0.354   0.572  :
:             :-----------------------------------------------------------:
:             : BOP  : TURBINE     0.001   0.003   0.006   0.009   0.002  :
:             :      : GEN         0.000   0.000   0.000   0.000   0.000  :
:             :      : COND                                                :
:             :      : CW/SW/CCW   0.000   0.000   0.000   0.000   0.000  :
:             :      : OTHER       0.000   0.000   0.000   0.000   0.000  :
:             :      :            ------  ------  ------  ------  ------  :
:             :      :             0.001   0.003   0.006   0.009   0.002  :
:             :-----------------------------------------------------------:
:             : ECONOMIC           0.000   0.009   0.000   0.001   0.000  :
:             :-----------------------------------------------------------:
:             : HUMAN                                                      :
:             :-----------------------------------------------------------:
:             : OTHER              0.004   0.057   0.020   0.004   0.030  :
:              -----------------------------------------------------------:
:               TOTAL              0.438   0.281   0.439   0.367   0.604  :
:-------------------------------------------------------------------------:
: REGULATORY  :                    0.000   0.000   0.000   0.000   0.000  :
:-------------------------------------------------------------------------:
: UNKNOWN     :                    0.008   0.026   0.000   0.000   0.000  :
:-------------------------------------------------------------------------:

** TOTAL CAPACITY LOSS **          0.525   0.379   0.451   0.393   0.655

** CAPACITY FACTOR **              0.475   0.621   0.549   0.607   0.345
```

Table 4.5 - (Continued)

```
CAPACITY LOSSES                                                 JAPAN
1980 - 1984                                                 ALL PWR'S

03/25/86                     DATA:( 8)   ( 9)   (10)   (10)   (11)
:------------------------------------------------------------------:
:                                  1980   1981   1982   1983   1984 :
:------------------------------------------------------------------:
: FORCED      : NSSS : FUEL        0.000  0.000  0.000  0.000  0.000 :
:             :      : RCS         0.006  0.000  0.000  0.000  0.002 :
:             :      : SG          0.013  0.032  0.005  0.018  0.000 :
:             :      : REFUEL                                       :
:             :      : OTHER       0.004  0.000  0.000  0.001  0.000 :
:             :      :             ------ ------ ------ ------ ------ :
:             :      :             0.023  0.033  0.005  0.019  0.002 :
:             :-----------------------------------------------------:
:             : BOP  : TURBINE     0.000  0.000  0.000  0.001  0.000 :
:             :      : GEN         0.000  0.000  0.000  0.000  0.000 :
:             :      : COND                                         :
:             :      : CW/SW/CCW   0.002  0.000  0.001  0.000  0.000 :
:             :      : OTHER       0.000  0.000  0.000  0.000  0.000 :
:             :      :             ------ ------ ------ ------ ------ :
:             :      :             0.002  0.000  0.001  0.001  0.000 :
:             :-----------------------------------------------------:
:             : ECONOMIC                                            :
:             :-----------------------------------------------------:
:             : HUMAN              0.000  0.000  0.000  0.000  0.000 :
:             :-----------------------------------------------------:
:             : OTHER              0.000  0.001  0.000  0.002  0.000 :
:              -----------------------------------------------------:
:               TOTAL              0.025  0.034  0.006  0.022  0.002 :
:------------------------------------------------------------------:
: SCHEDULED   : NSSS : FUEL        0.000  0.000  0.000  0.000  0.000 :
:             :      : RCS         0.000  0.000  0.000  0.000  0.000 :
:             :      : SG          0.000  0.000  0.000  0.000  0.000 :
:             :      : REFUEL      0.348  0.311  0.260  0.232  0.269 :
:             :      : OTHER       0.000  0.000  0.000  0.000  0.000 :
:             :      :             ------ ------ ------ ------ ------ :
:             :      :             0.348  0.311  0.260  0.232  0.269 :
:             :-----------------------------------------------------:
:             : BOP  : TURBINE     0.002  0.001  0.000  0.000  0.000 :
:             :      : GEN         0.000  0.000  0.000  0.000  0.000 :
:             :      : COND                                         :
:             :      : CW/SW/CCW   0.000  0.000  0.000  0.000  0.000 :
:             :      : OTHER       0.000  0.000  0.000  0.000  0.000 :
:             :      :             ------ ------ ------ ------ ------ :
:             :      :             0.002  0.001  0.000  0.000  0.000 :
:             :-----------------------------------------------------:
:             : ECONOMIC           0.000  0.000  0.000  0.000  0.000 :
:             :-----------------------------------------------------:
:             : HUMAN                                               :
:             :-----------------------------------------------------:
:             : OTHER              0.000  0.011  0.006  0.009  0.000 :
:              -----------------------------------------------------:
:               TOTAL              0.351  0.323  0.266  0.241  0.269 :
:------------------------------------------------------------------:
: REGULATORY :                     0.000  0.000  0.000  0.000  0.000 :
:------------------------------------------------------------------:
: UNKNOWN    :                     0.000  0.000  0.000  0.000  0.000 :
:------------------------------------------------------------------:

** TOTAL CAPACITY LOSS **          0.376  0.357  0.272  0.264  0.271

** CAPACITY FACTOR **              0.624  0.643  0.728  0.736  0.729
```

Table 4.5 - (Continued)

```
CAPACITY LOSSES                                                      JAPAN
1975 - 1984                                                     ALL PWR'S

03/25/86                    DATA:11 PLANTS               77 PLANT-YEARS
:------------------------------------------------------------------------:
:                                 AVERAGE OVER ALL YEARS                  :
:------------------------------------------------------------------------:
: FORCED       : NSSS : FUEL                  0.000                       :
:              :      : RCS                   0.002                       :
:              :      : SG                    0.016                       :
:              :      : REFUEL                                            :
:              :      : OTHER                 0.003                       :
:              :      :                       ------                      :
:              :      :                       0.021                       :
:              :--------------------------------------------------------- :
:              : BOP  : TURBINE               0.001                       :
:              :      : GEN                   0.000                       :
:              :      : COND                                              :
:              :      : CW/SW/CCW             0.002                       :
:              :      : OTHER                 0.000                       :
:              :      :                       ------                      :
:              :      :                       0.003                       :
:              :----------------------------------------------------------:
:              : ECONOMIC                                                 :
:              :----------------------------------------------------------:
:              : HUMAN                        0.000                       :
:              :----------------------------------------------------------:
:              : OTHER                        0.002                       :
:               ----------------------------------------------------------:
:                TOTAL                        0.026                       :
:------------------------------------------------------------------------:
: SCHEDULED    : NSSS : FUEL                  0.000                       :
:              :      : RCS                   0.000                       :
:              :      : SG                    0.000                       :
:              :      : REFUEL                0.325                       :
:              :      : OTHER                 0.000                       :
:              :      :                       ------                      :
:              :      :                       0.325                       :
:              :----------------------------------------------------------:
:              : BOP  : TURBINE               0.002                       :
:              :      : GEN                   0.000                       :
:              :      : COND                                              :
:              :      : CW/SW/CCW             0.000                       :
:              :      : OTHER                 0.000                       :
:              :      :                       ------                      :
:              :      :                       0.002                       :
:              :----------------------------------------------------------:
:              : ECONOMIC                     0.001                       :
:              :----------------------------------------------------------:
:              : HUMAN                                                    :
:              :----------------------------------------------------------:
:              : OTHER                        0.011                       :
:               ----------------------------------------------------------:
:                TOTAL                        0.340                       :
:------------------------------------------------------------------------:
: REGULATORY :                                0.000                       :
:------------------------------------------------------------------------:
: UNKNOWN    :                                0.002                       :
:------------------------------------------------------------------------:

** TOTAL CAPACITY LOSS **                     0.367

** CAPACITY FACTOR **                         0.633
```

Table 4.6

Japanese PWR Capacity Losses By Reactor Age

CAPACITY LOSSES BY REACTOR AGE
1975 - 1984

JAPAN
ALL PWR'S

03/23/86

		DATA:	(9)	(9)	(10)	(9)	(8)
		AGE:	1	2	3	4	5
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.009	0.005	0.000	0.000	0.003
		SG	0.000	0.000	0.037	0.031	0.000
		REFUEL					
		OTHER	0.001	0.004	0.000	0.015	0.001
			0.010	0.009	0.037	0.046	0.004
	BOP	TURBINE	0.007	0.001	0.000	0.001	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.010	0.001	0.001	0.001	0.001
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.017	0.002	0.001	0.002	0.001
	ECONOMIC						
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.013	0.000	0.002	0.001	0.000
	TOTAL		0.039	0.011	0.040	0.049	0.006
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.002	0.000
		RCS	0.000	0.000	0.000	0.000	0.000
		SG	0.000	0.000	0.000	0.000	0.000
		REFUEL	0.207	0.347	0.440	0.331	0.338
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.207	0.347	0.440	0.333	0.338
	BOP	TURBINE	0.002	0.004	0.003	0.002	0.001
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.002	0.004	0.003	0.002	0.001
	ECONOMIC		0.001	0.000	0.000	0.003	0.000
	HUMAN						
	OTHER		0.033	0.019	0.003	0.018	0.000
	TOTAL		0.243	0.370	0.446	0.357	0.340
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.015	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.297	0.381	0.486	0.406	0.346
** CAPACITY FACTOR **			0.703	0.619	0.514	0.594	0.655

Table 4.6 - (Continued)

CAPACITY LOSSES BY REACTOR AGE — JAPAN
1976 - 1984 — ALL PWR'S

03/23/86

			DATA:	(7)	(6)	(5)	(4)	(2)
			AGE:	6	7	8	9	10
FORCED	NSSS	FUEL		0.000	0.000	0.000	0.000	0.000
		RCS		0.000	0.000	0.000	0.000	0.000
		SG		0.000	0.031	0.022	0.000	0.000
		REFUEL						
		OTHER		0.000	0.001	0.000	0.001	0.000
				0.000	0.032	0.022	0.001	0.000
	BOP	TURBINE		0.000	0.000	0.001	0.000	0.000
		GEN		0.000	0.000	0.000	0.000	0.000
		COND						
		CW/SW/CCW		0.000	0.000	0.000	0.000	0.000
		OTHER		0.000	0.000	0.000	0.000	0.000
				0.000	0.000	0.001	0.000	0.000
	ECONOMIC							
	HUMAN			0.000	0.000	0.000	0.000	0.000
	OTHER			0.000	0.000	0.004	0.000	0.000
	TOTAL			0.001	0.032	0.027	0.002	0.000
SCHEDULED	NSSS	FUEL		0.000	0.000	0.000	0.000	0.000
		RCS		0.000	0.000	0.000	0.000	0.000
		SG		0.000	0.000	0.000	0.000	0.000
		REFUEL		0.312	0.358	0.282	0.293	0.469
		OTHER		0.000	0.000	0.000	0.000	0.000
				0.312	0.358	0.282	0.293	0.469
	BOP	TURBINE		0.002	0.001	0.002	0.000	0.000
		GEN		0.000	0.000	0.000	0.000	0.000
		COND						
		CW/SW/CCW		0.000	0.000	0.000	0.000	0.000
		OTHER		0.000	0.000	0.000	0.000	0.000
				0.002	0.001	0.002	0.000	0.000
	ECONOMIC			0.000	0.000	0.000	0.000	0.000
	HUMAN							
	OTHER			0.003	0.008	0.000	0.000	0.007
	TOTAL			0.317	0.367	0.284	0.294	0.477
REGULATORY				0.000	0.000	0.000	0.000	0.000
UNKNOWN				0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **				0.318	0.399	0.311	0.296	0.477
** CAPACITY FACTOR **				0.682	0.601	0.689	0.704	0.523

Table 4.6 - (Continued)

CAPACITY LOSSES BY REACTOR AGE JAPAN
1975 - 1984 ALL PWR'S

03/23/86 DATA:(1) (1) (0) (0) (0)

		AGE:	11	12	13	14	15
FORCED	NSSS	FUEL	0.000	0.000			
		RCS	0.000	0.000			
		SG	0.180	0.000			
		REFUEL					
		OTHER	0.000	0.000			
			0.180	0.000			
	BOP	TURBINE	0.000	0.000			
		GEN	0.000	0.000			
		COND					
		CW/SW/CCW	0.000	0.000			
		OTHER	0.000	0.000			
			0.000	0.000			
	ECONOMIC						
	HUMAN		0.000	0.000			
	OTHER		0.000	0.000			
	TOTAL		0.180	0.000			
SCHEDULED	NSSS	FUEL	0.000	0.000			
		RCS	0.000	0.000			
		SG	0.000	0.000			
		REFUEL	0.398	0.050			
		OTHER	0.000	0.000			
			0.398	0.050			
	BOP	TURBINE	0.000	0.001			
		GEN	0.000	0.000			
		COND					
		CW/SW/CCW	0.000	0.000			
		OTHER	0.000	0.000			
			0.000	0.001			
	ECONOMIC		0.000	0.000			
	HUMAN						
	OTHER		0.077	0.000			
	TOTAL		0.475	0.051			
REGULATORY			0.000	0.000			
UNKNOWN			0.000	0.000			

** TOTAL CAPACITY LOSS ** 0.655 0.051

** CAPACITY FACTOR ** 0.345 0.949

Table 4.7

Japanese BWR Capacity Losses By Year

CAPACITY LOSSES 1975 - 1979

JAPAN ALL BWR'S

03/27/86

			1975	1976	1977	1978	1979
DATA:			(3)	(5)	(5)	(9)	(10)
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.010	0.025	0.001	0.000	0.004
		SG					
		REFUEL					
		OTHER	0.020	0.001	0.000	0.000	0.001
			0.030	0.025	0.001	0.000	0.005
	BOP	TURBINE	0.000	0.008	0.000	0.000	0.004
		GEN	0.000	0.003	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.002	0.000	0.000	0.004
		OTHER	0.001	0.000	0.000	0.000	0.001
			0.001	0.012	0.000	0.000	0.009
	ECONOMIC						
	HUMAN		0.000	0.000	0.001	0.001	0.000
	OTHER		0.018	0.005	0.000	0.004	0.001
	TOTAL		0.049	0.042	0.002	0.005	0.015
SCHEDULED	NSSS	FUEL	0.005	0.012	0.003	0.032	0.023
		RCS	0.000	0.000	0.000	0.000	0.000
		SG					
		REFUEL	0.652	0.204	0.696	0.423	0.286
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.657	0.216	0.699	0.454	0.309
	BOP	TURBINE	0.000	0.000	0.000	0.000	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.000	0.000	0.000	0.000	0.000
	ECONOMIC		0.000	0.003	0.006	0.009	0.000
	HUMAN						
	OTHER		0.014	0.119	0.035	0.036	0.051
	TOTAL		0.670	0.339	0.740	0.498	0.360
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.719	0.381	0.742	0.503	0.375
** CAPACITY FACTOR **			0.281	0.619	0.258	0.497	0.625

Table 4.7 - (Continued)

CAPACITY LOSSES
1980 - 1984

JAPAN
ALL BWR'S

03/27/86

		DATA:	(10)	(10)	(11)	(11)	(13)
			1980	1981	1982	1983	1984
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.000	0.000	0.004	0.003	0.000
		SG					
		REFUEL					
		OTHER	0.003	0.001	0.000	0.001	0.000
			0.003	0.002	0.004	0.004	0.000
	BOP	TURBINE	0.005	0.003	0.003	0.002	0.000
		GEN	0.001	0.000	0.000	0.005	0.001
		COND					
		CW/SW/CCW	0.003	0.005	0.001	0.000	0.001
		OTHER	0.001	0.000	0.000	0.000	0.000
			0.011	0.008	0.004	0.007	0.002
	ECONOMIC						
	HUMAN		0.000	0.002	0.000	0.000	0.000
	OTHER		0.004	0.004	0.003	0.004	0.000
	TOTAL		0.018	0.015	0.011	0.015	0.002
SCHEDULED	NSSS	FUEL	0.015	0.014	0.010	0.009	0.004
		RCS	0.000	0.000	0.000	0.000	0.000
		SG					
		REFUEL	0.314	0.329	0.255	0.280	0.267
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.329	0.343	0.265	0.289	0.272
	BOP	TURBINE	0.000	0.000	0.000	0.000	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.002	0.000	0.000	0.000	0.000
			0.002	0.000	0.000	0.000	0.000
	ECONOMIC		0.001	0.002	0.001	0.002	0.001
	HUMAN						
	OTHER		0.034	0.026	0.021	0.012	0.004
	TOTAL		0.366	0.371	0.288	0.303	0.277
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.383	0.386	0.298	0.318	0.279
** CAPACITY FACTOR **			0.617	0.614	0.702	0.682	0.721

Table 4.7 - (Continued)

```
CAPACITY LOSSES                                                      JAPAN
1975 - 1984                                                      ALL BWR'S

03/27/86                    DATA:13 PLANTS                 87 PLANT-YEARS
:-------------------------------------------------------------------------:
:                                     AVERAGE OVER ALL YEARS               :
:-------------------------------------------------------------------------:
: FORCED      : NSSS : FUEL                   0.000                        :
:             :      : RCS                    0.003                        :
:             :      : SG                                                  :
:             :      : REFUEL                                              :
:             :      : OTHER                  0.002                        :
:             :      :                        ------                       :
:             :      :                        0.005                        :
:             :-----------------------------------------------------------:
:             : BOP  : TURBINE                0.002                        :
:             :      : GEN                    0.001                        :
:             :      : COND                                                :
:             :      : CW/SW/CCW              0.002                        :
:             :      : OTHER                  0.000                        :
:             :      :                        ------                       :
:             :      :                        0.006                        :
:             :-----------------------------------------------------------:
:             : ECONOMIC                                                   :
:             :-----------------------------------------------------------:
:             : HUMAN                         0.000                        :
:             :-----------------------------------------------------------:
:             : OTHER                         0.003                        :
:             ------------------------------------------------------------:
:               TOTAL                         0.014                        :
:-------------------------------------------------------------------------:
: SCHEDULED   : NSSS : FUEL                   0.013                        :
:             :      : RCS                    0.000                        :
:             :      : SG                                                  :
:             :      : REFUEL                 0.331                        :
:             :      : OTHER                  0.000                        :
:             :      :                        ------                       :
:             :      :                        0.344                        :
:             :-----------------------------------------------------------:
:             : BOP  : TURBINE                0.000                        :
:             :      : GEN                    0.000                        :
:             :      : COND                                                :
:             :      : CW/SW/CCW              0.000                        :
:             :      : OTHER                  0.000                        :
:             :      :                        ------                       :
:             :      :                        0.000                        :
:             :-----------------------------------------------------------:
:             : ECONOMIC                      0.002                        :
:             :-----------------------------------------------------------:
:             : HUMAN                                                      :
:             :-----------------------------------------------------------:
:             : OTHER                         0.030                        :
:             ------------------------------------------------------------:
:               TOTAL                         0.376                        :
:-------------------------------------------------------------------------:
: REGULATORY  :                               0.000                        :
:-------------------------------------------------------------------------:
: UNKNOWN     :                               0.000                        :
:-------------------------------------------------------------------------:

** TOTAL CAPACITY LOSS **                     0.390

** CAPACITY FACTOR **                         0.610
```

Table 4.8
Japanese BWR Capacity Losses By Reactor Age

CAPACITY LOSSES BY REACTOR AGE
1975 - 1984

JAPAN
ALL BWR'S

03/23/86

			1	2	3	4	5
		DATA:	(11)	(10)	(10)	(9)	(10)
		AGE:	1	2	3	4	5
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.010	0.005	0.003	0.001	0.001
		SG					
		REFUEL					
		OTHER	0.007	0.003	0.001	0.000	0.000
			0.017	0.008	0.004	0.001	0.001
	BOP	TURBINE	0.003	0.002	0.005	0.001	0.001
		GEN	0.000	0.001	0.001	0.002	0.003
		COND					
		CW/SW/CCW	0.000	0.002	0.003	0.002	0.005
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.003	0.005	0.009	0.005	0.009
	ECONOMIC						
	HUMAN		0.000	0.000	0.001	0.001	0.000
	OTHER		0.006	0.004	0.000	0.003	0.003
	TOTAL		0.026	0.019	0.014	0.009	0.015
SCHEDULED	NSSS	FUEL	0.018	0.012	0.012	0.018	0.010
		RCS	0.000	0.000	0.000	0.000	0.000
		SG					
		REFUEL	0.259	0.266	0.423	0.261	0.349
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.277	0.278	0.435	0.279	0.359
	BOP	TURBINE	0.000	0.000	0.000	0.000	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.002	0.000	0.000	0.000
			0.000	0.002	0.000	0.000	0.000
	ECONOMIC		0.000	0.005	0.001	0.002	0.002
	HUMAN						
	OTHER		0.044	0.060	0.017	0.038	0.021
	TOTAL		0.321	0.345	0.453	0.320	0.382
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.347	0.364	0.467	0.329	0.397
** CAPACITY FACTOR **			0.653	0.636	0.533	0.671	0.603

Table 4.8 - (Continued)

CAPACITY LOSSES BY REACTOR AGE
1975 - 1984

JAPAN
ALL BWR'S

03/23/86

		DATA:	(9)	(5)	(5)	(5)	(3)
		AGE:	6	7	8	9	10
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.006	0.000	0.000	0.003	0.000
		SG					
		REFUEL					
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.006	0.000	0.000	0.003	0.000
	BOP	TURBINE	0.000	0.000	0.000	0.003	0.007
		GEN	0.001	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.001	0.000	0.002	0.000	0.000
		OTHER	0.002	0.000	0.000	0.002	0.000
			0.004	0.000	0.002	0.005	0.007
	ECONOMIC						
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.002	0.007	0.004	0.000	0.000
	TOTAL		0.012	0.008	0.006	0.009	0.007
SCHEDULED	NSSS	FUEL	0.008	0.011	0.008	0.008	0.008
		RCS	0.000	0.000	0.000	0.000	0.000
		SG					
		REFUEL	0.340	0.478	0.329	0.365	0.441
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.348	0.489	0.337	0.373	0.449
	BOP	TURBINE	0.000	0.000	0.000	0.000	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.000	0.000	0.000	0.000	0.000
	ECONOMIC		0.000	0.001	0.007	0.001	0.000
	HUMAN						
	OTHER		0.021	0.021	0.031	0.018	0.015
	TOTAL		0.369	0.511	0.376	0.392	0.463
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.381	0.519	0.381	0.401	0.470
** CAPACITY FACTOR **			0.619	0.481	0.619	0.599	0.530

Table 4.8 - (Continued)

CAPACITY LOSSES BY REACTOR AGE
1975 - 1984

JAPAN
ALL BWR'S

03/23/86

			DATA:	(2)	(1)	(1)	(1)	(0)
			AGE:	11	12	13	14	15
FORCED	NSSS	FUEL		0.000	0.001	0.000	0.000	
		RCS		0.000	0.000	0.000	0.000	
		SG						
		REFUEL						
		OTHER		0.000	0.000	0.009	0.000	
				0.000	0.001	0.009	0.000	
	BOP	TURBINE		0.000	0.016	0.018	0.000	
		GEN		0.000	0.000	0.000	0.000	
		COND						
		CW/SW/CCW		0.000	0.001	0.000	0.000	
		OTHER		0.000	0.000	0.000	0.000	
				0.000	0.017	0.018	0.000	
	ECONOMIC							
	HUMAN			0.005	0.000	0.000	0.000	
	OTHER			0.000	0.026	0.000	0.000	
	TOTAL			0.005	0.044	0.027	0.000	
SCHEDULED	NSSS	FUEL		0.009	0.009	0.004	0.002	
		RCS		0.000	0.000	0.000	0.000	
		SG						
		REFUEL		0.443	0.306	0.147	0.306	
		OTHER		0.000	0.000	0.000	0.000	
				0.452	0.315	0.151	0.308	
	BOP	TURBINE		0.000	0.000	0.000	0.000	
		GEN		0.000	0.000	0.000	0.000	
		COND						
		CW/SW/CCW		0.000	0.000	0.000	0.000	
		OTHER		0.000	0.000	0.000	0.000	
				0.000	0.000	0.000	0.000	
	ECONOMIC			0.000	0.000	0.000	0.000	
	HUMAN							
	OTHER			0.009	0.023	0.029	0.000	
	TOTAL			0.461	0.338	0.180	0.308	
REGULATORY				0.000	0.000	0.000	0.000	
UNKNOWN				0.000	0.000	0.000	0.000	
** TOTAL CAPACITY LOSS **				0.466	0.382	0.207	0.308	
** CAPACITY FACTOR **				0.534	0.618	0.793	0.692	

Table 4.9 - Japanese Capacity Factor Distributions

By	PWR			BWR		
Year	Mean	σ	# Data	Mean	σ	# Data
75	0.475	0.363	4	0.281	0.330	3
76	0.621	0.125	5	0.619	0.136	5
77	0.549	0.283	6	0.258	0.215	5
78	0.607	0.103	6	0.497	0.267	9
79	0.345	0.157	8	0.625	0.096	10
80	0.624	0.154	8	0.617	0.123	10
81	0.643	0.179	9	0.614	0.136	10
82	0.728	0.132	10	0.702	0.145	11
83	0.736	0.173	10	0.682	0.081	11
84	0.729	0.129	11	0.721	0.138	13

By	PWR			BWR		
Age	Mean	σ	# Data	Mean	σ	# Data
1	0.703	0.166	9	0.653	0.249	11
2	0.619	0.145	9	0.636	0.134	10
3	0.514	0.299	10	0.533	0.275	10
4	0.593	0.187	9	0.671	0.127	9
5	0.655	0.212	8	0.603	0.219	10
6	0.682	0.168	7	0.620	0.149	9
7	0.601	0.189	6	0.481	0.258	5
8	0.689	0.127	5	0.618	0.133	5
9	0.705	0.071	4	0.599	0.064	5
10	0.524	0.013	2	0.529	0.155	3
11	0.345	0.000	1	0.533	0.244	2
12	0.949	0.000	1	0.618	0.000	1
13				0.793	0.000	1
14				0.692	0.000	1
15						
16						
17						

Figure 4.6

Japanese PWR Capacity Factor Distribution By Year

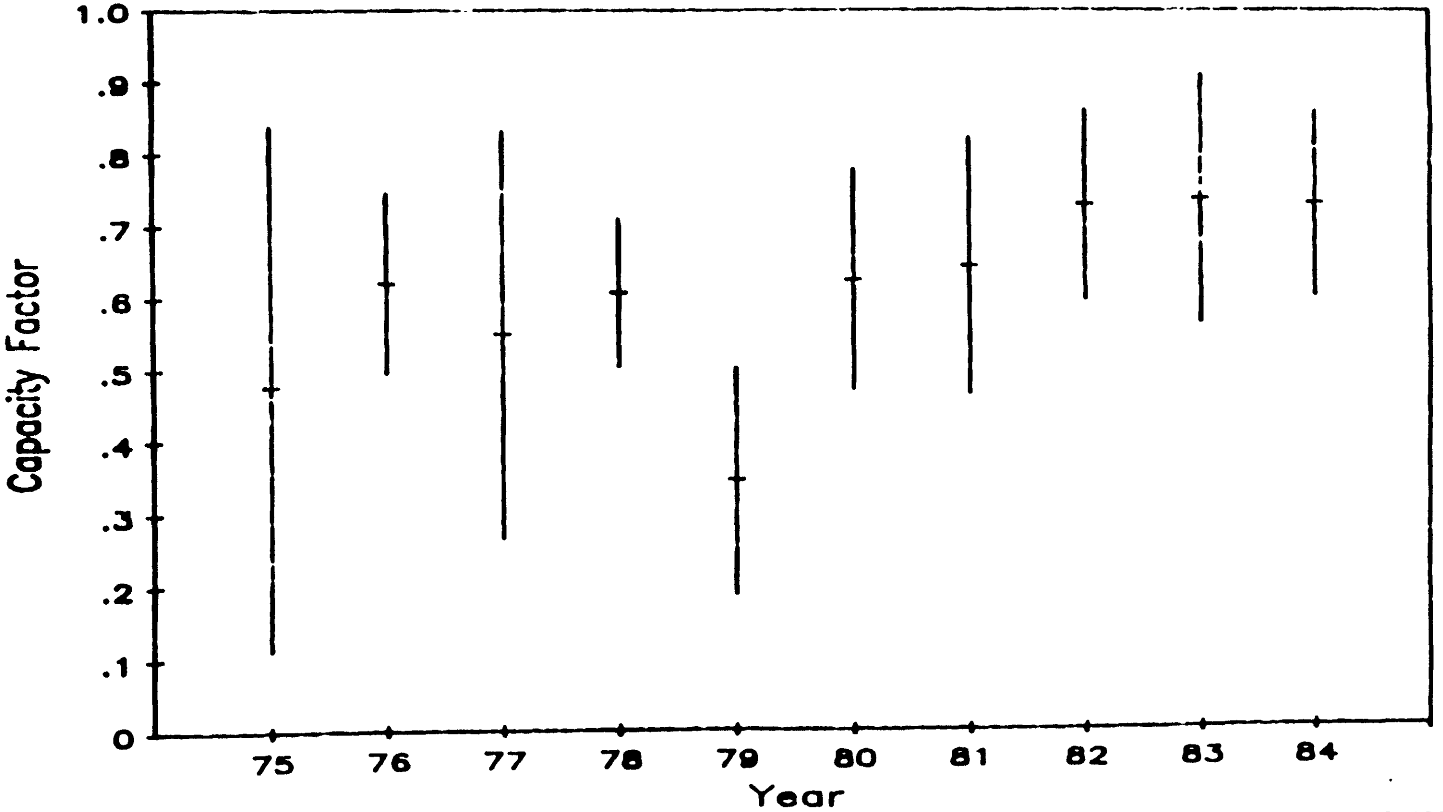


Figure 4.7

Japanese PWR Capacity Factor Distribution By Reactor Age

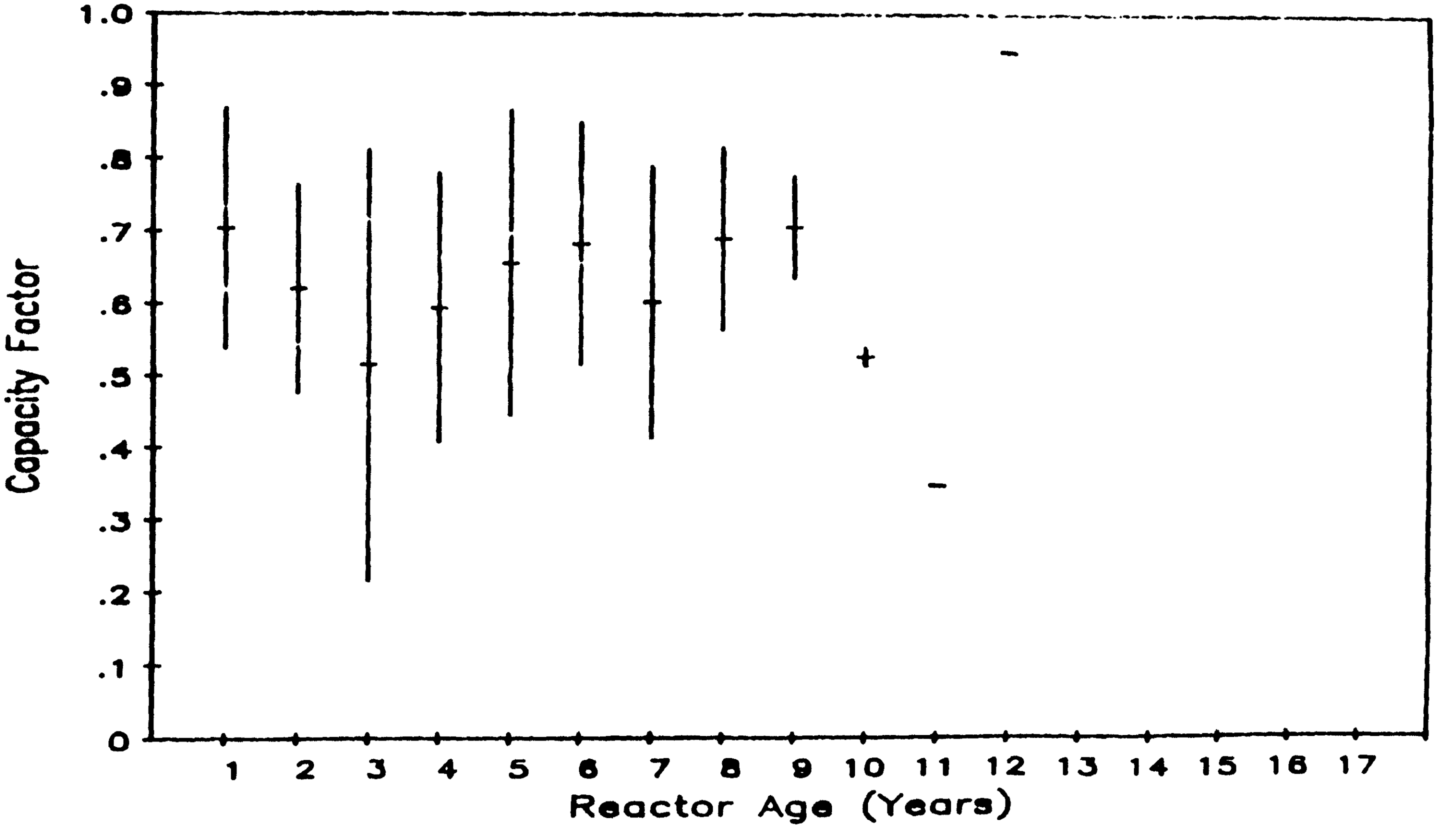
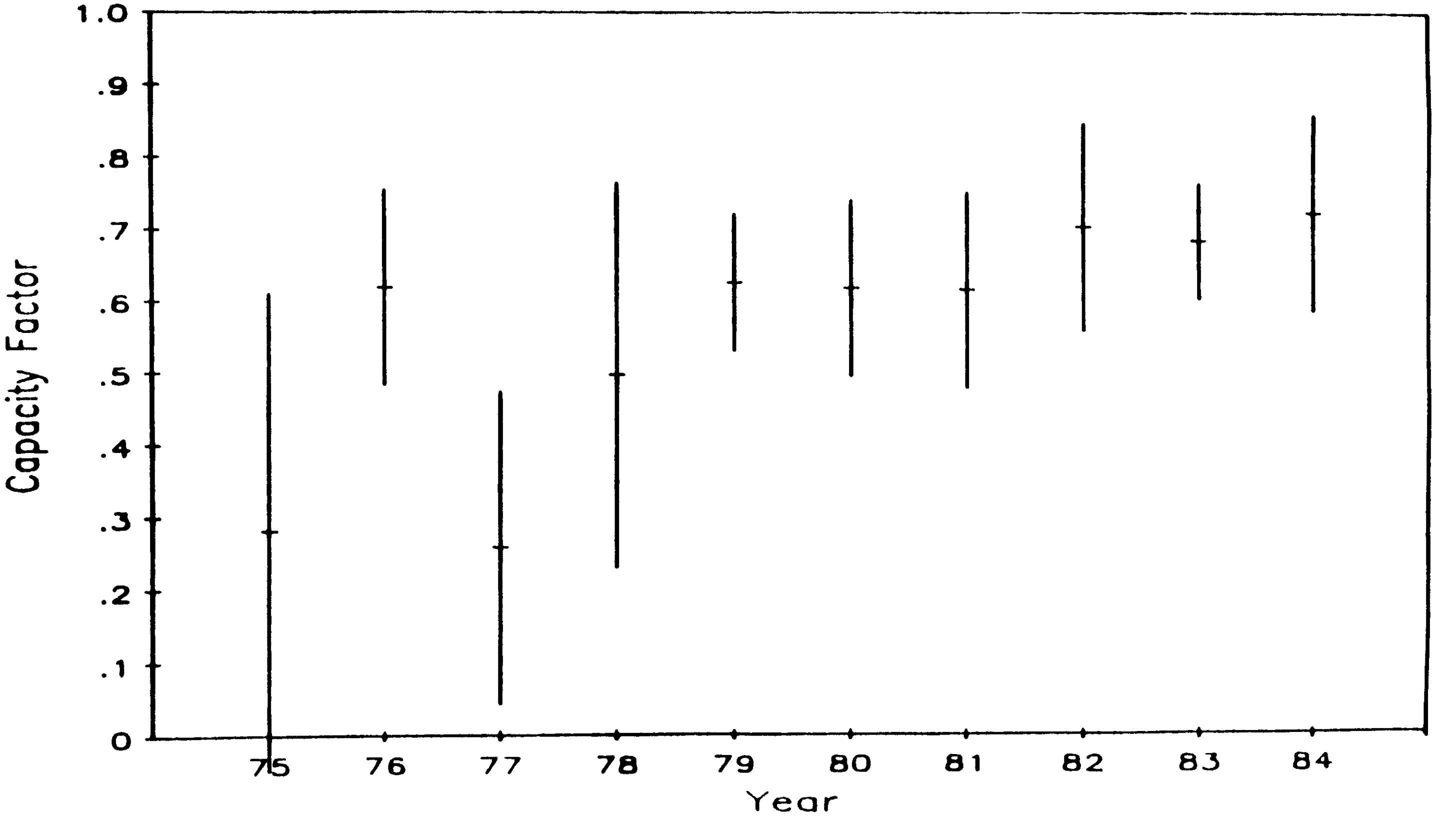


Figure 4.8



Japanese BWR Capacity Factor Distribution By Year

Figure 4.9

Japanese BWR Capacity Factor Distribution By Reactor Age

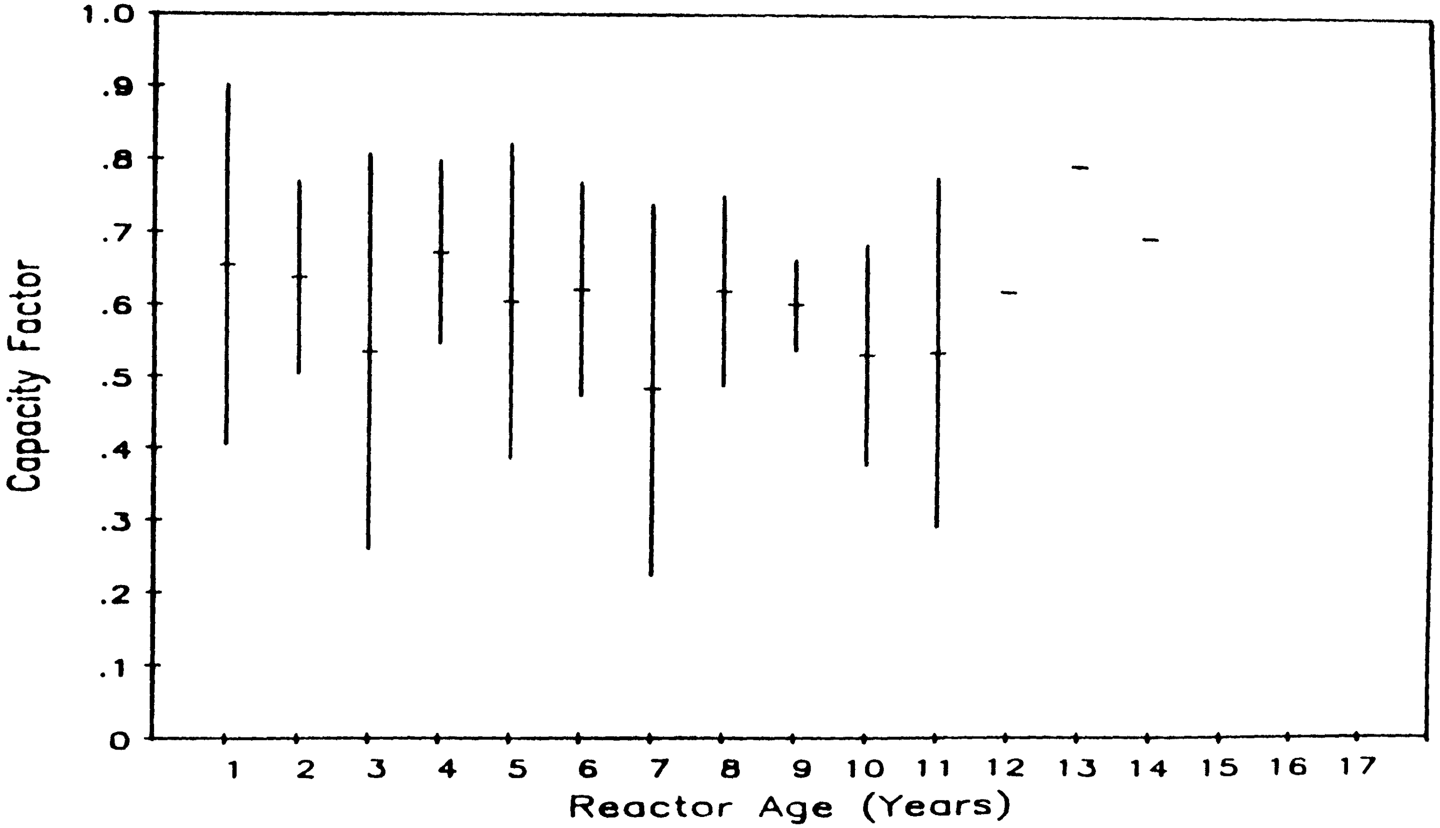


Figure 4.10

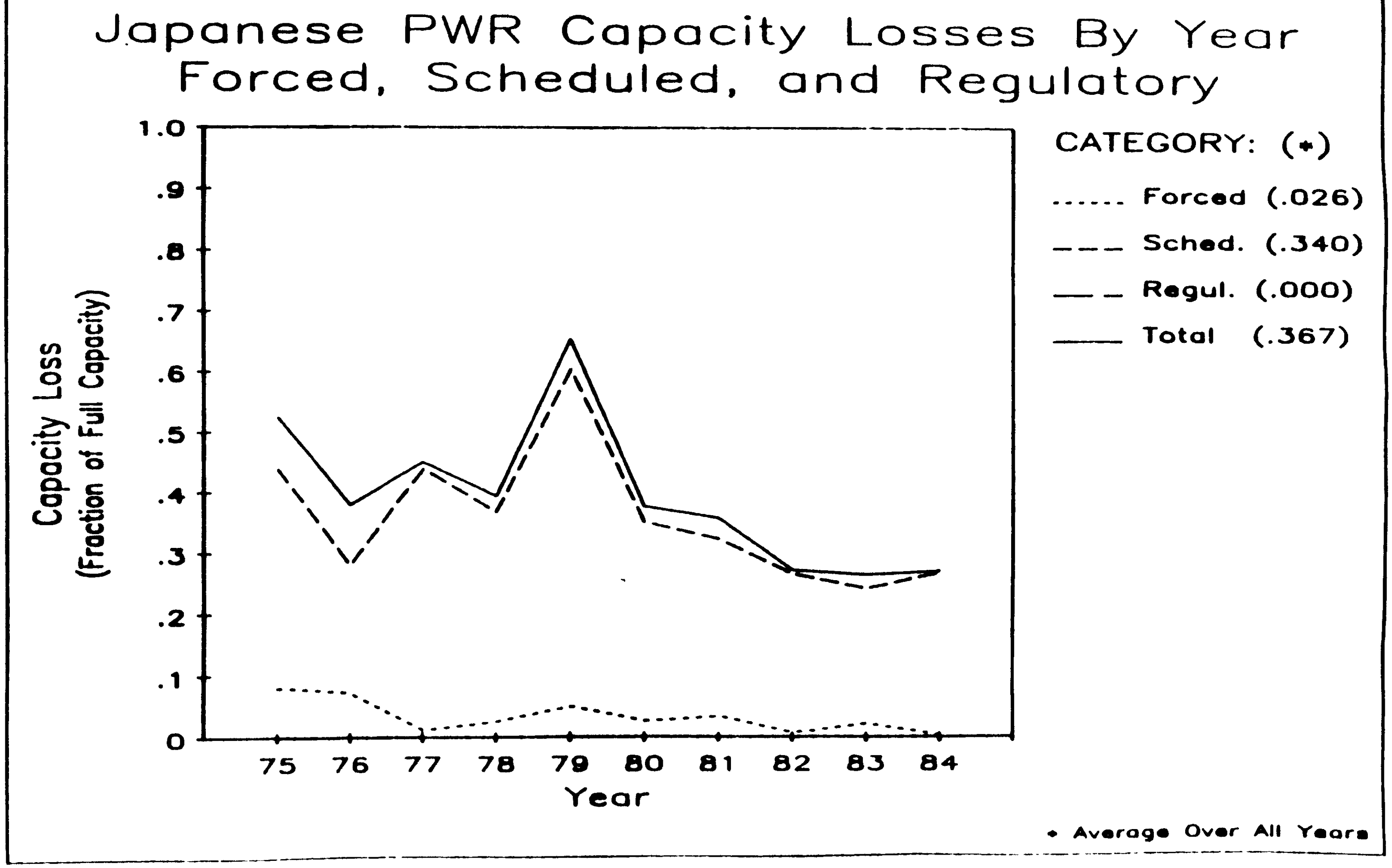

Japanese PWR Capacity Losses By Year
Forced, Scheduled, and Regulatory
Capacity Loss
(Fraction of Full Capacity)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
75
76
77
78
79
80
81
82
83
84
Year
CATEGORY: (*)
...... Forced (.026)
– – – Sched. (.340)
—— – Regul. (.000)
——— Total (.367)
* Average Over All Years

Figure 4.11

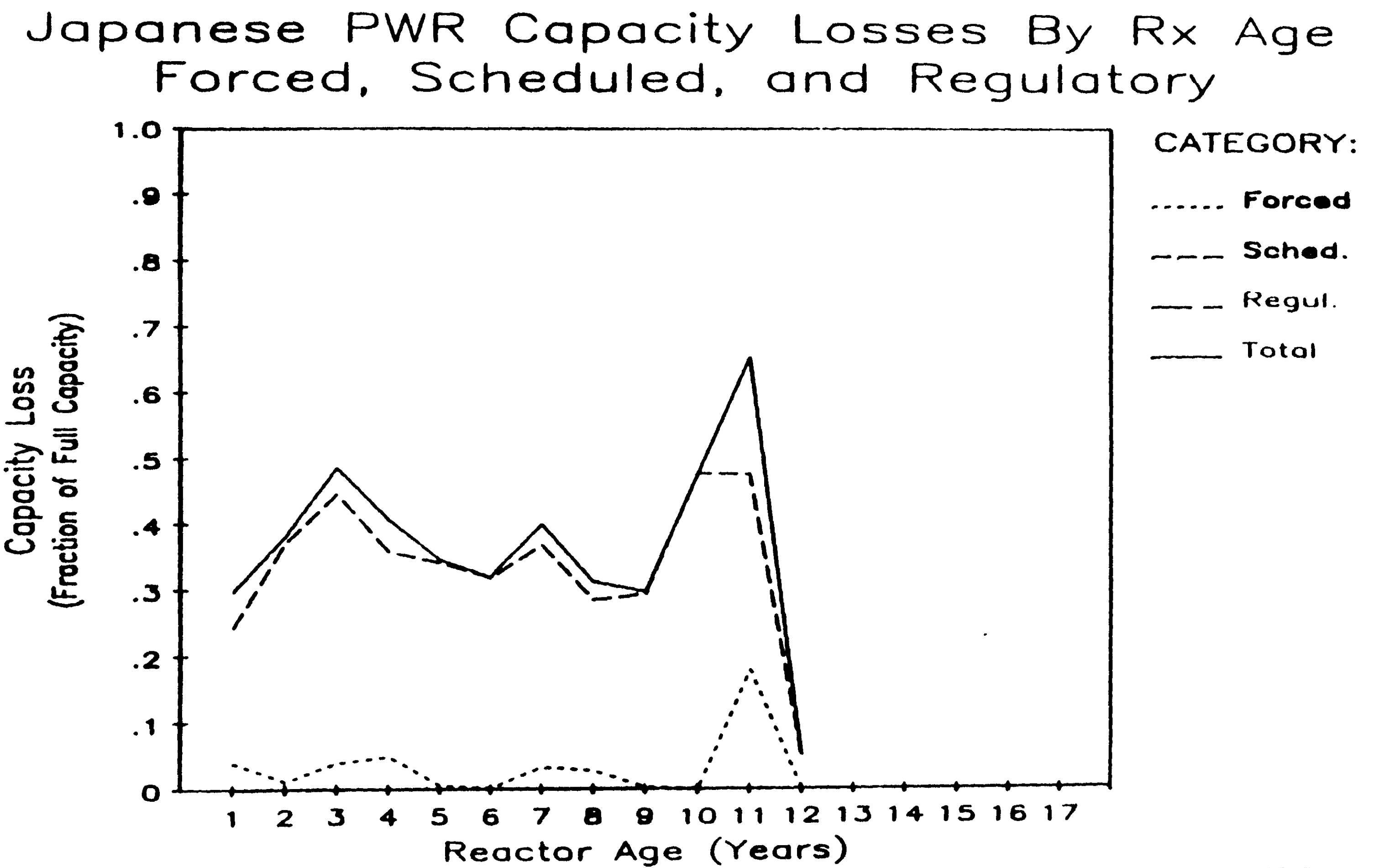

Japanese PWR Capacity Losses By Rx Age
Forced, Scheduled, and Regulatory
Capacity Loss
(Fraction of Full Capacity)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Reactor Age (Years)
CATEGORY:
Forced
Sched.
Regul.
Total

Figure 4.12

Japanese BWR Capacity Losses By Year
Forced, Scheduled, and Regulatory

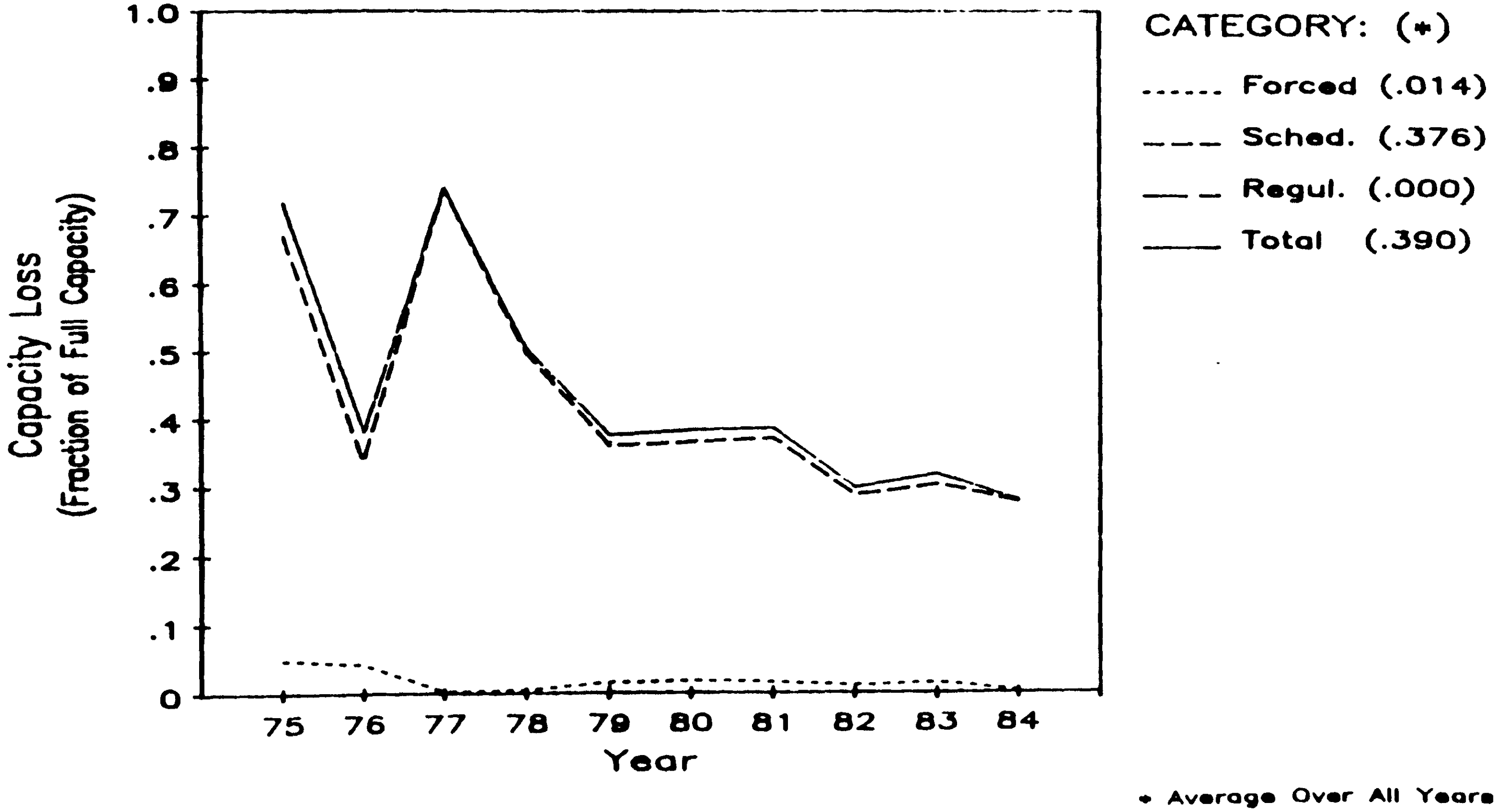
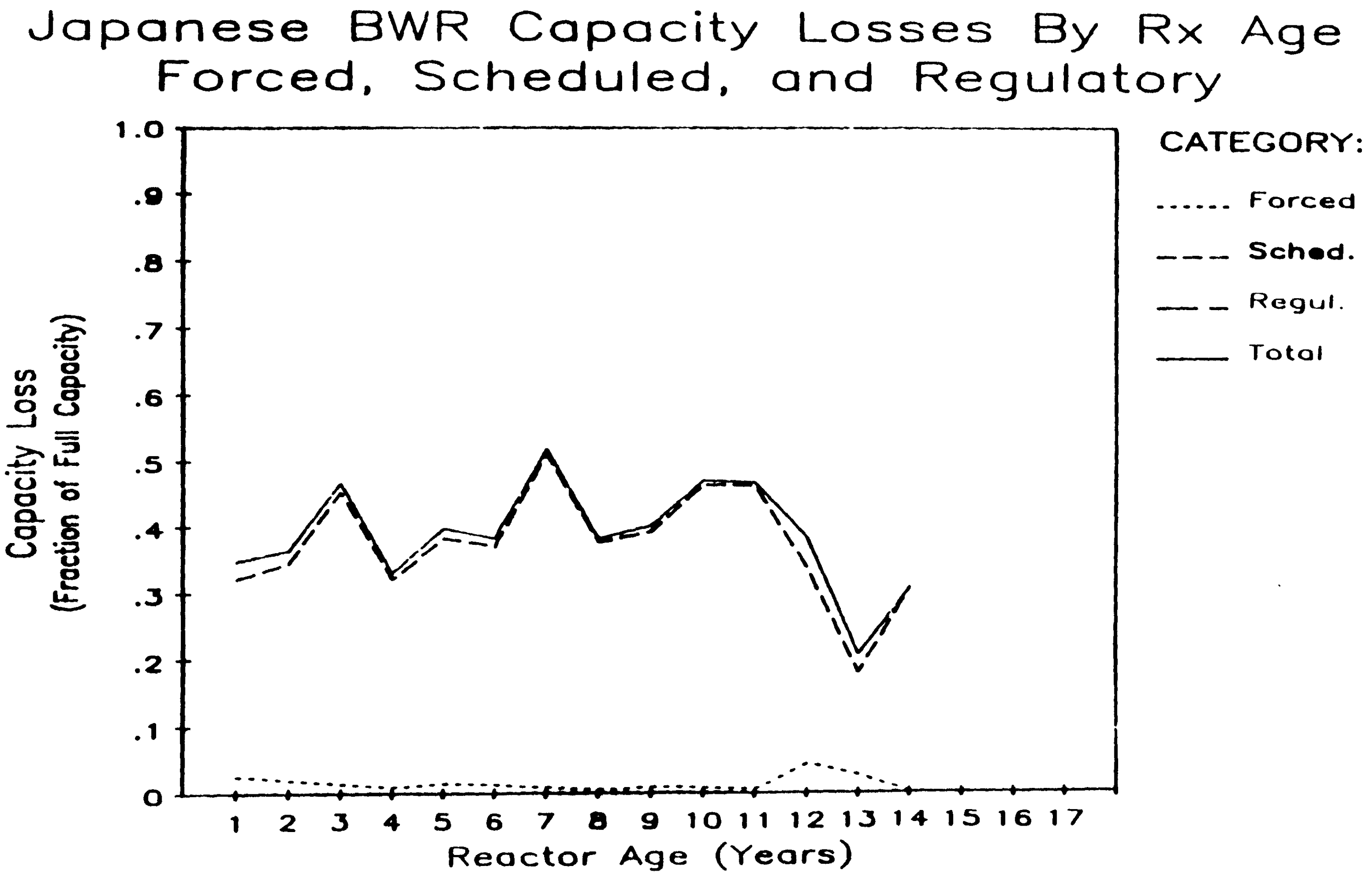


Figure 4.13


Japanese BWR Capacity Losses By Rx Age
Forced, Scheduled, and Regulatory
Capacity Loss
(Fraction of Full Capacity)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Reactor Age (Years)
CATEGORY:
Forced
Sched.
Regul.
Total

4.9 OBSERVATIONS

The operating performance of Japanese nuclear power plants has improved substantially since the mid to late 1970s, when capacity factors of 50% or less were not unusual. The main problems encountered at that time included steam generator corrosion in PWRs and stress corrosion cracking in BWRs. The response to these problems - major research and development programs with cost sharing by the utilities, plant manufacturers and government followed by prompt implementation of the findings - illustrates one of the principal strengths of the Japanese nuclear program: close, cooperative relations between the main participants. A related aspect is the continuity of the utility-manufacturer relationship throughout the operating life of the plant. Many observers attribute much of the success of Japanese efforts to improve plant operating performance to these organizational characteristics. Other factors which have almost certainly played an important role in these efforts include the attention to quality in plant design and construction, the strong emphasis on preventive maintenance and the comprehensive training programs for both operations and maintenance personnel.

To a substantial extent, each of these factors is rooted in basic Japanese technical and business practices which are not unique to the nuclear industry. Additionally, however, the goal of improving nuclear power plant reliability was quickly elevated to the status of a national policy objective when it became clear that reactor performance was well below what had originally been expected. This helped to promote collaboration among the various industrial participants and facilitated the mobilization of the necessary financial and technical resources. Moreover, public opinion has also been conditioned to view the task of upgrading plant reliability as one that will simultaneously lead to improved plant safety.

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CHAPTER 5

SWEDEN

5.1 STRUCTURE OF THE ELECTRIC INDUSTRY

The electric utility industry in Sweden is a combination of the state-owned Swedish State Power Board (SSPB) and a number of privately owned utilities, in which municipal and cooperative distribution companies are major investors. The extent of state and municipal investment in these companies is 80 percent. The electric power transmission grid is nationwide, with strong interconnections to Denmark, Finland, and Norway, and is called the Nordic Electric Power Transmission System. The total capacity as of 1984 was 33,705 MWe (see Table 5.1).[1] Two additional nuclear units of 1060 MWe went into commercial operation in 1985. Under current law, which was enacted following the 1980 Swedish Nuclear Referendum, no additional nuclear units will be constructed, and all 12 existing nuclear plants must be decommissioned by the year 2010. This decision may be reconsidered in the future, if the point stated in a 1985 report by the Swedish Royal Academy is heeded: "To phase out nuclear power in the year 2010 is technically unjustified and, moreover, undefensible from the standpoint of the national economy."[2]

Table 5.2 shows individual nuclear plant capacities,[3] and Table 5.3 shows electric production by generation type for 1984.[1]. Nuclear generation accounted for 39 percent of total electric production. In the ten years from 1974 to 1983, generation increased from 77 to 116 TWhr. During most of this period, net imports were small and both positive and negative (i.e., net exports). In the last three years of the period, the net imports by 1984 had increased to 10 TWhr, or about 9 percent of consumption (see Table 5.3, column 1). The recent addition of two large

Table 5.1

Swedish Electric Generating Capacity
(MWe)

	1984	1985
Hydroelectric	15,290	15,690
Thermal (oil & gas)	8,060	8,018
Nuclear	7,355	9,455
TOTAL	33,705	33,163

Table 5.2

Swedish Nuclear Plant Capacities
(MWe net)

Unit	1st year Commerical Operation	Capacity	Type
Barseback 1	1975	570	BWR
Barseback 2	1977	570	BWR
Forsmark 1	1980	900	BWR
Forsmark 2	1981	900	BWR
Forsmark 3	1985	1050	BWR
Ringhals 1	1976	750	BWR
Ringhals 2	1975	800	PWR
Ringhals 3	1981	915	PWR
Ringhals 4	1983	915	PWR
Oskarshamn 1	1972	440	BWR
Oskarshamn 2	1974	595	BWR
Oskarshamn 3	1986	1050	BWR

Table 5.3

Electricity Production
(TWhr)

	1984	1985
Hydroelectric	62.8	70.1
Nuclear	39.1	55.9
Oil & Gas	4.0	6.3
Production	105.9	132.3
Imports	10.4	5.1
TOTAL CONSUMPTION	116.3	137.4

units--Forsmark 3 and Oskarshamn 3--probably will reduce net imports for at least several years.

The SSPB is the largest utility in Sweden, accounting for about half of total generating capacity. The SSPB owns the four Ringhals nuclear units and is majority owner and operator of the Forsmark Kraftgrupp, which is comprised of the three Forsmark units. OKG AB owns the three Oskarshamn units. OKG was formed by its owners specifically to be a nuclear generating company. Sydkraft AB is the fourth nuclear utility and owns the two Barseback units. In addition to these utilities, there are a number of smaller companies that own hydroelectric and thermal plants, but not nuclear plants.

Cooperation among the utilities is a national goal and affects all their operations. Although power can be bought and sold among the utilities under free market conditions, the system is operated from a national point of view. For example, when reservoir water levels are high, as they were in 1985, hydroelectric plants operated at near capacity and nuclear plants operated at reduced output. Normally the nuclear plants would be base loaded.

The Reactor Safety Board (RKS) is one example of cooperation among nuclear utilities. RKS was formed in 1980 by the nuclear utilities following the accident at Three Mile Island. Its role and purpose are stated in a September 1985 presentation by RKS:

> The four owners of nuclear power plants in Sweden--the Swedish State Power Board, Forsmarks Kraftgrupp AB, Sydkraft AB and OKG AKTIEBOLAG--have formed the NUCLEAR SAFETY BOARD OF THE SWEDISH UTILITIES as a joint body for collaboration in safety matters. The Board participates in coordination of the safety work of the facilities and conducts its own safety projects, wherever this is more efficient than the utilities working independently.

> The work of the Board shall contribute to optimizing safety in the operation of the Swedish nuclear energy facilities. The most important function of the Board is to collect, process and evaluate information on operational disturbances and incidents at Swedish and foreign nuclear power plants and then use the knowledge thus gained to improve the safety of the operation of the Swedish nuclear power plants [experience feedback]. Wherever it is advantageous from the viewpoint of safety, the Board shall devise a common policy and common standards of safety and shall coordinate the resources of the reactor owners.
>
> One goal of the Board shall be that the safety work in Swedish nuclear power plants be conducted with openness and with insight from the public and politicians.

In order to obtain information on foreign plant operations, RKS has cooperative agreements with the Institute of Nuclear Power Operations (INPO) in the United States and with nuclear utilities in other countries. RKS thus is a key link in the process of nuclear plant information exchange, to promote the learning and application of experience among plants.

The Chief Executive Officers of the four Swedish Nuclear utilities are the RKS Board members, who help to assure that its tasks are carried out effectively.

The RKS also has a close relationship with the Swedish Nuclear Power Inspectorate (SKI) (described below), as evidenced by the fact the Managing Director of RKS was previously the Deputy Director of SKI. The Reliability Data Book[4] for Swedish nuclear power plants was prepared jointly by RKS and SKI. This book is a compilation of the components, failure modes, and statistics of Swedish nuclear power plants.

The RKS consists of a secretariat of 10 people and operates through a set of 4 committees, one for each of 4 activities: safety analysis and experience feedback, education and training, quality assurance, and emergency preparedness. Committee members are drawn from technical experts and managers of the nuclear utilities.

RKS is one of three organizations formed by the utilities to foster cooperation. The other two are the SKB (for fuel and waste management), and the AKU (for plant personnel training and plant simulators).

5.2. STRUCTURE OF THE SUPPLY INDUSTRY

Swedish industry is remarkable for its ability to provide the major components of nuclear steam supply systems (NSSS). A number of companies are involved, but perhaps the best known is ASEA-ATOM because of its roles both as systems designer and in NSSS export. ASEA-ATOM is an off-shoot of the ASEA company. The Swedish government purchased a controlling share in ASEA-ATOM but later sold out after the nuclear referendum. Other companies, such as ASEA-STAL and UDDCOMB, among others, also have played important roles. However, the market in Sweden is not large enough to foster internal competition, considering the capital investments that are required. Instead, resources are concentrated on developing the capability to produce the ASEA-ATOM BWR system, for which the technology was developed in Sweden.

The discipline of market competition was evidently provided by the purchase of the three Ringhals PWR units from Westinghouse. Even so, many of the components for these units were provided by Swedish industry. The fact, the decision to purchase these units outside Sweden provided a degree of diversification in reactor types and a window for observing developments in PWR technology in the United States. It seems likely that knowledge of equipment prices in the Westinghouse scope of supply helped the SSPB to hold Swedish prices down, although data on this point are not available.

The interactions between the utilities and their Swedish suppliers are close and cooperative, driven by the need to succeed in their joint venture. This is true at the management level of the projects. However, with respect to size and available resources, there are important differences among the utilities. The SSPB has broad engineering and construction capability. It took the responsibility for civil work design, construction, and coordination in its early nuclear units (i.e., Ringhals 1 and 2, and Forsmark 1 and 2). Subsequently, it moved away from performing its own designs to turnkey contracts, as at Ringhals 3 and 4 and Forsmark 3. On the other hand, OKG had a turnkey contract with ASEA-ATOM for Oskarshamn 1; for units 2 and 3, OKG played a larger role, performing systems engineering and project management. For these units, OKG had three contracts: one for the NSSS with ASEA-ATOM; one with STAL-LAVAL for the turbine generator; and one for construction. The Architect/Engineer for unit 3 was a (new) joint venture between ASEA-ATOM and STAL-LAVAL. Unit 3 was constructed in just under five years.

It is clear that the same close relationships did not obtain in the case of Westinghouse, which was not part of the Swedish nuclear industry. Relationships were formed on a much more commercial basis. On balance, several Swedish observers felt Westinghouse to be "a good supplier," noting that the Westinghouse PWRs were purchased at favorable prices.

5.3 UTILITY INTERNAL ORGANIZATION AND CAPABILITIES

As noted above, the SSPB is the largest utility in Sweden, owning about half the electric generating capacity and supplying about half the market for power. Formed in 1915, the SSPB was the principal developer of the Swedish hydroelectric system, which provided the bulk of Sweden's electricity until the mid-1960s, when significant fossil generation was introduced, and the early 1970s, when nuclear generation was introduced.

Until recently, SVF had evolved as a centralized organization, undertaking civil works design, coordination, and construction of its power plant projects. As noted above, SSPB moved from this mode of organization to turnkey contracting and decentralized operations. In 1986, a major reorganization has taken effect, the effect of which is decentralization: Engineering for the plants will be done on the site itself.

The Director General of SSPB is appointed by the government. Hydroelectric and oil-fired power production is under the purview of a Vice President, who reports to the Director General; the same is true for nuclear plants. The Vice President for Nuclear Plants is responsible for the units at Ringhals and at Forsmark, in which the SSPB has controlling interest. There are 1100 staff at the 4-unit Ringhals site, and 800 at the 3-unit Forsmark site.

SSPB uses a system of management-by-objective at its nuclear units. Goals are set for the site superintendent, who has responsibility for accomplishing them. Under this system, both availability and capacity factor have improved, as shown in Table 5.4. It is notable that the management philosophies at each site have evolved differently. At Ringhals the operation and maintenance staff operate with many detailed, written instructions to govern reactor operation, while at Forsmark there are fewer such instructions. The superintendent chooses which management system to implement, provided it is justifiable. The management at SSPB Headquarters is tolerant of these differences, although there is a preference for the Forsmark system. Occasionally Headquarters brings the two together to negotiate a companionable approach, but it does not attempt to mandate procedures; rather, it restricts its intervention to setting goals and reviewing performance and issues. This system of

Table 5.4

Nuclear Plant Performance

	BWR			PWR			BWR & PWR		
YEAR	No. Units	Capacity Factor	Standard Deviation	No. Units	Capacity Factor	Standard Deviation	No. Units	Capacity Factor	Standard Deviation
1975	2	0.648	0.048	0.667	0.452	--	2.667	0.599	0.094
1976	3.667	0.530	0.128	1	0.584	--	4.667	0.541	0.116
1977	4	0.612	0.074	1	0.573	--	5	0.604	0.068
1978	5	0.747	0.062	1	0.584	--	6	0.720	0.083
1979	5	0.660	0.126	1	0.512	--	6	0.636	0.128
1980	5	0.736	0.063	1	0.617	--	6	0.716	0.073
1981	6.5	0.750	0.063	1.333	0.498	0.149	7.833	0.707	0.126
1982	7	0.768	0.086	2	0.403	0.247	9	0.687	0.206
1983	7	0.731	0.103	2.167	0.485	0.115	9.167	0.672	0.149
1984	7	0.809	0.051	3	0.670	0.063	10	0.767	0.084
1985	7	0.774	0.054	3	0.704	0.065	10	0.753	0.066
1975-1985:		0.724	0.110		0.571	0.150		0.690	0.132
REGRESSION:									
	C.F. = 0.604 + 0.0202 Y r = 0.809				0.509 + 0.00873 Y r = 0.314			0.586 + 0.0175 Y r = 0.812	

Y ≡ Year - 1975

r = regression coefficient

NOTES: (1) Fractions in the No. of Units column indicates partial year of commercial service of new unit(s) in the first year of service.

(2) Regressions are based on one capacity factor point for each year operation.

management-by-objectives is credited with the performance improvements that have taken place.

Maintenance and outage planning receive close attention from all management levels. Planning for outages begins one year in advance. It is done in cooperation with the other nuclear utilities in Sweden and with one Finnish utility. The reasons for this include the design similarities of the ASEA-ATOM BWR systems and equipment, and the fact that the preferred shutdown window is in the summer months, when the load is low due to summer vacations. Another factor is the accumulation in late spring of reservoir water for the hydroelectric systems. The consequence of these factors is that the demand on the resources required for plant shutdown and maintenance are most available during a relatively short period from late spring through summer. What is important is both the knowledge of what to do and how to do it, and the availability of both trained people and special equipment. As noted above, the RKS plays a central role in collecting and distributing information on component and system failure. RKS has organized a system of committees that bring together maintenance supervisors from all plants, so learning experiences can be shared and applied to maintenance and outage planning.

SSPB recognizes the importance of maintenance and outage planning by assigning engineers from the design projects to the plant sites.

All four nuclear utilities use the same training program, including the AKU for simulator training at Studsvik. The training philosophy is geared to performing simulator exercises, learning detailed procedures, and developing a comprehensive understanding of plant systems, including dynamic responses in both normal and abnormal conditions. SSPB uses the Westinghouse owner's group training guidelines. Analogous guidelines are being developed for the ASEA-ATOM BWRs. Candidates for operator training are gymnasium (high school) engineers.

SSPB recently expanded the training programs for maintenance technicians in the major component areas (i.e., pumps, valves, instrumentation, and control). The program includes three types of training: general and theoretical; special training for the specific components to which the trainees are assigned; and training in the safety significance of these components.

None of the Swedish nuclear utilities favors the idea of a university degree requirement for shift supervisors.

OKG is a relatively small organization compared to SSPB. It is headed by a President, with six reporting vice presidents (production, projects, technology, administration, personnel, and fuel). A total of 870 staff are employed, of whom 40 are at the Stockholm office and the remainder at the Oskarshamn site, of whom 700 are assigned to power production.

The breakdown of these 700 staff by assignment is as follows:

operations at the 3 units, including 50 per unit maintenance people (mechanical, electrical, I & L)	430
personnel common to 3 units	200
personnel at spent fuel facility	70
TOTAL	700

OKG benefited from the Forsmark 3 design, which is similar except for civil works, which had to be modified because of soil differences. The spare parts are common with Forsmark 3.

OKGs reactor operators are hired from the Navy and from technical high school graduates. The training program is with SSPB. For personnel having no prior experience, the program lasts three years.

Each unit has a shift supervisor. Shift supervisors usually are selected from among reactor operators and do not have university engineering degrees. Selection of the shift supervisor is considered to be a key decision, and is made with great care. The oldest shift supervisors are about 40 years old. There are seven shifts for each plant, but one or more is always in training. The older shift supervisors tend to move to daytime jobs.

OKG has one shift supervisor for all three units at the Oskarshamn site. This person has a degree. There is also one person on shift at the site whose responsibility is to follow operational problems and to communicate as necessary with SKI.

OKG undertakes all planning for shutdowns and most of the outage maintenance. On average, OKG employs about 600 personnel for normal refueling and maintenance outages. The duration of such outages are 3 to 6 weeks, and they occur annually for the 5-region ASEA-ATOM BWR cores. OKG does not use an 18-month cycle, noting that a SYDKRAFT unit at Barseback tried it and found it uneconomical.

A major factor in the learning experience is the fact that the lead man for each component type (e.g., the "valve man") at Oskarshamn personally knows his counterpart at the Ringhals and Barseback sites, and also at the Finnish plants; these personnel maintain contact by telephone to find out what is going on. ASEA-ATOM continues to be involved in maintenance activities, and has assigned one man to the site, generally a component specialist.

5.4 ECONOMICS OF NUCLEAR POWER

Primarily as a result of increased capacity factors, by mid-1984 SSPB reduced the cost of nuclear generation from about 19 to 16 ORE/kWhr (27 to 23 mils/kWhr @ 7 Swedish Kronor per $1.00 US), and it has remained at that level to the present. This cost includes capital (33 percent), operation and maintenance (28 percent), fuel (26 percent), and radioactive waste handling (13 percent). The average generation cost of Oskarshamn units 1, 2, and 3 is 24 ORE/kWhr. (Oskarshamn unit 3 was completed at a cost of SEK 11 billion [$1.57 billion], including SEK 3.5 billion in interest charges [$0.5 billion]. The financing was 10 percent from equity and from 90 percent bonds.) In comparison, the average cost of electricity in Sweden, including low-cost hydro power, is 17 ORE/kWhr. Depending on the seasonal availability of stored water, nuclear provides the base load, with hydro next in line.

5.5 ECONOMIC REGULATION

To a considerable extent, the price of electricity in Sweden is determined by market forces noting SSPB's role as the major producer of both hydro and nuclear power. There is no economic regulation by a separate agency of government, which means, in effect, that electricity cannot be sold above SVF's price so long as SVF capacity is available. This can make difficulties for private investors in nuclear plants.

5.6 SAFETY REGULATION

Nuclear safety regulation in Sweden is the responsibility of the National government, which acts through a number of institutions (see Figure 5.1). Of these, the Nuclear Safety Inspectorate (SKI), which is analogous to the U.S. Nuclear Regulatory Commission, has day-to-day

Figure 5.1
Safety Regulation Organization

Prime Minister & Cabinet

Ministry of

Industry

Agriculture

Communications

Labor

- Nuclear Inspectorate (SKI)

Radiation Protection Institute (SSI)

National Board of Shipping

Spent Fuel Board

National Board of Occupational Health (Pressure Vessel) Integrity

City Councils
Local Authorities

Local Safety Authority

involvement in nuclear plant operations, as well as playing a role in decision making on licensing and policy-making on technical issues. Specifically-assigned SKI personnel are responsible for knowledge of each plant status and activities. The Radiation Protection Institute (SSI) is analogous to the U.S. National Council on Radiation Protection. The National Board of Shipping approves the shipment of all fuels and radioactive materials. The National Board of Occupational Health is responsible for pressure vessel requirements and approvals.

In addition to these formal lines of authority, there is a local safety authority or committee for each site, comprised of local officials as well as plant officials and technical experts. The local safety authority does not have the power to order plant shutdown, as does SKI.

SKI's safety approach and method of operation can be summarized as follows:

- The primary safety responsibility rests with the plant owner;
- SKI issues general guidelines and regulations, and sets safety goals;
- Plant owners propose designs and solutions to problems, which SKI then reviews;
- SKI audits design, construction, and operation and judges how well the various jobs are performed and how safe is the result; and
- SKI performs recurrent safety analyses of plants.

A notable characteristic of the Swedish nuclear community is its relatively small size: 3 utilities, 4 sites, and 2 reactor manufacturers. All key personnel on any technical issue can meet on short notice in a small conference room; and they all know each other. This, together with the fact that the system is not encumbered with all the legal and documentation requirements that obtain in the United States, makes for a less formal and more expedited process.

During the construction process, SKI reviews information provided by the applying utility and writes a summary of the findings for each of the regulatory boards indicated in Figure 5.1. A hearing on environmental impacts follows, but there is no formal hearing on radiation impacts. SKI follows the progress of construction in detail, and the owner provides a detailed design and step-by-step construction plan.

A recent example is informative. SSPB proposed to replace the steam generators at Ringhals unit 2. SKI reviewed the proposed procedure and ruled that replacement was not a safety issue: that it was in fact advantageous to do so. The conclusion of the review was that replacement was an investment and political issue, which should be decided by the Minister of Energy (who approved the replacement).

The SKI organization is shown in Figure 5.2. The government appoints both the members of the SKI Board and the Director General, who acts as the Board Chairman. There are three advisory committees, all of which report to the Director General. The members are all experts in their various fields, not employees of SKI, and all must be approved by the Board. The Reactor Safety Committee has no members from industry. The other two committees' members are drawn from government, industry, and universities.

The Director General and the department heads form the Executive Office. The Office of Regulation reviews the submission of applicants and formulates safety rules. The Office of Inspection sees that the rules are observed.

SKI has 90 staff and a budget of SEK 27 million reserved for analysis and licensing activities. The research budget is SEK 45 million; all

Figure 5.2
SKI Organization

SKI BOARD

Director General

Advisory Committees:
- Reactor Safety
- Safeguards
- Research

Information Secretariat

Administration

Office of Inspection
- Barseback
- Forsmark
- Oskarshamm
- Ringhal
- Nuclear Materials

Office of Regulation
- Division of Licensing and Safety Assessment
- Division of Nuclear Waste
- Systems and Reliability Analysis
- Division of Research

research activities are subcontracted, not performed in-house. The budget is financed by fees paid by the nuclear utilities.

SKI has strong ties internationally, with cooperative agreements on information, regulation, and research with the countries of Western Europe, the United States, Canada, and Japan. The principal organizations involved include the Nuclear Energy Agency (NEA) of the OECD, the NEA Committee on the Safety of Nuclear Installations, the International Atomic Energy Agency, and two Nordic groups: the Nordic Liason Committee for Atomic Energy and the Nordic Authority Group (for reactor safety and radiation protection).

At the working level, there are important differences between the Swedish and the U.S. systems. Although there is no fraternization between SKI and the nuclear utilities, the relationships are not adversarial, as they are in the United States. SKI, being a small organization, depends on and receives relevant data from nuclear utilites, as well as from international sources. Due to its small size and concomitant flexibility, SKI acts much quicker than can the U.S. Nuclear Regulatory Commission. For example, after Three Mile Island, changes in Sweden were made rapidly. Ringhals 2 was not permitted to start until these changes were accomplished. In the Swedish view, the main reasons why such prompt action is possible are:

- o Sweden's nuclear power industry has an uncomplicated legal framework;
- o SKI is fully empowered to make decisions;
- o the safety committees can be contacted within a few days for a quick response on problems and questions;
- o the utilities have primary responsibility for plant safety, not SKI;

- the criteria for investment protection of plants is more stringent than the criteria for public protection; for example, the core damage probability goal for blackout is 10^{-6} per reactor year. (The plants probably have not yet reached this goal, but the probability is less than 10^{-5} with the Swedish grid.)

- Swedish utilities often take the initiative on issues. As an example, Oskarshamn decided to install parallel electrical and I & C cables before the Brown's Ferry fire (although the actual installation was accomplished after).

A major concern of SKI is the possibility of ground contamination following a severe accident. SKI has in particular studied the attainment of stable conditions with a damaged core cooled and covered by water at atmospheric pressure, and the possibility of containment in a severe accident sequence, especially in the case of pressure suppression failure from hydrogen burning or from failure of weak spots during a core meltdown. In the case of the Barseback plant, as a result of this consideration (together with political opposition from nearby Copenhagen), the decision was taken to install a containment vent and filter, at a cost of $40 million. Since then further action was taken to install similar systems at other plants. At present, ASEA-ATOM is in the process of developing a less expensive system.

The Ringhals PWR steam generators also have received careful attention from SKI in connection with chemistry and crevice corrosion problems. These have caused a significant amount of availability loss of the PWRs (units 2, 3, and 4).

SKI has put considerable effort into studying questions about BWR power uprating to utilize stretch capability in the turbine-generators. With changes in the high-pressure turbine blades, five BWRs have been uprated an average of 7 percent.

SKI feels that the efforts on large problems, e.g., containment and steam generators, are almost complete. The work load, however, has not decreased: there still are many small problems. Human factors are being carefully studied, and maintenance quality assurance also continues to receive its close attention.

5.7 PUBLIC ATTITUDES

Public attitude was a major issue at the time of the 1980 referendum. Since the decision for the 2010 planned nuclear phase-out, however, concerns over current operations have fast faded, and public attitudes are not considered a significant current problem.

Sweden has a "sunshine" law, which applies to SKI. Management and staff are determined to demonstrate integrity in their activities. Judged in terms of media and public response, this policy has been successful.

In Sweden, as elsewhere, it is true that opposition to nuclear power plants is not centered at the plant locality. Tax revenues, well-paying jobs, and stable employment are a factor. In Sweden the local safety committees for each plant site have contributed much to allaying public concern. These safety committees are appointed by the government, and include local authorities as well as plant personnel. Their major task is to inform local people about ongoing activities at the plant site. The local safety committee is paid for by SKI. The utility must provide all requested information. The fact that the committee serves as an entity where local officials may become acquainted with plant personnel also is considered important. Local authorities can decide for themselves if they have confidence in the plant management.

5.8 PERFORMANCE OF SWEDISH NUCLEAR PLANTS

Table 5.4 summarizes the performance of Swedish nuclear plants. It shows the number of units in service from 1975 to 1985, the mean capacity factor of each, and the standard deviation of each. (Forsmark 3 and Oskarshamn 3 are not included, because they came on line during 1985.) The table shows data for BWRs, PWRs, and for both combined. At the bottom of the table, the mean capacity factor for the years 1975-1985, weighted by the number of units in service, is given, as is the corresponding standard deviation and the capacity factor linear regression.

BWR and PWR capacity factors are shown in Figures 5.3 and 5.4.

The BWR capacity factor exceeded the PWR capacity factor in all years except 1976. The 11-year average is 0.724 for BWRs and 0.571 for PWRs. The net effect of this lower PWR capacity factor is to reduce the mean capacity factor of all plants by 3.5 percent over BWR performance. Note that BWR performance is improving significantly, at a rate of 2 percentage points annually, as shown by the regression analysis. PWR performance also is improving, but at a lower rate of about 0.9 percentage points annually. The performance improvements in 1984 and 1985 are important in this regard: Without these increases, performance would have been level or slightly decreasing over time.

Figure 5.5 plots BWR capacity factors by reactor age. This figure shows that performance is improving with age, an improvement resulting from reductions in forced balance-of-plant losses. The magnitude of the standard deviations fluctuates with age, and shows little dependence on age. Plotted as a function of age in Figure 5.6, the performance of PWRs show a slight increasing age dependency. The large standard deviations

Figure 5.3

Swedish BWR Capacity Factor Distribution by Year

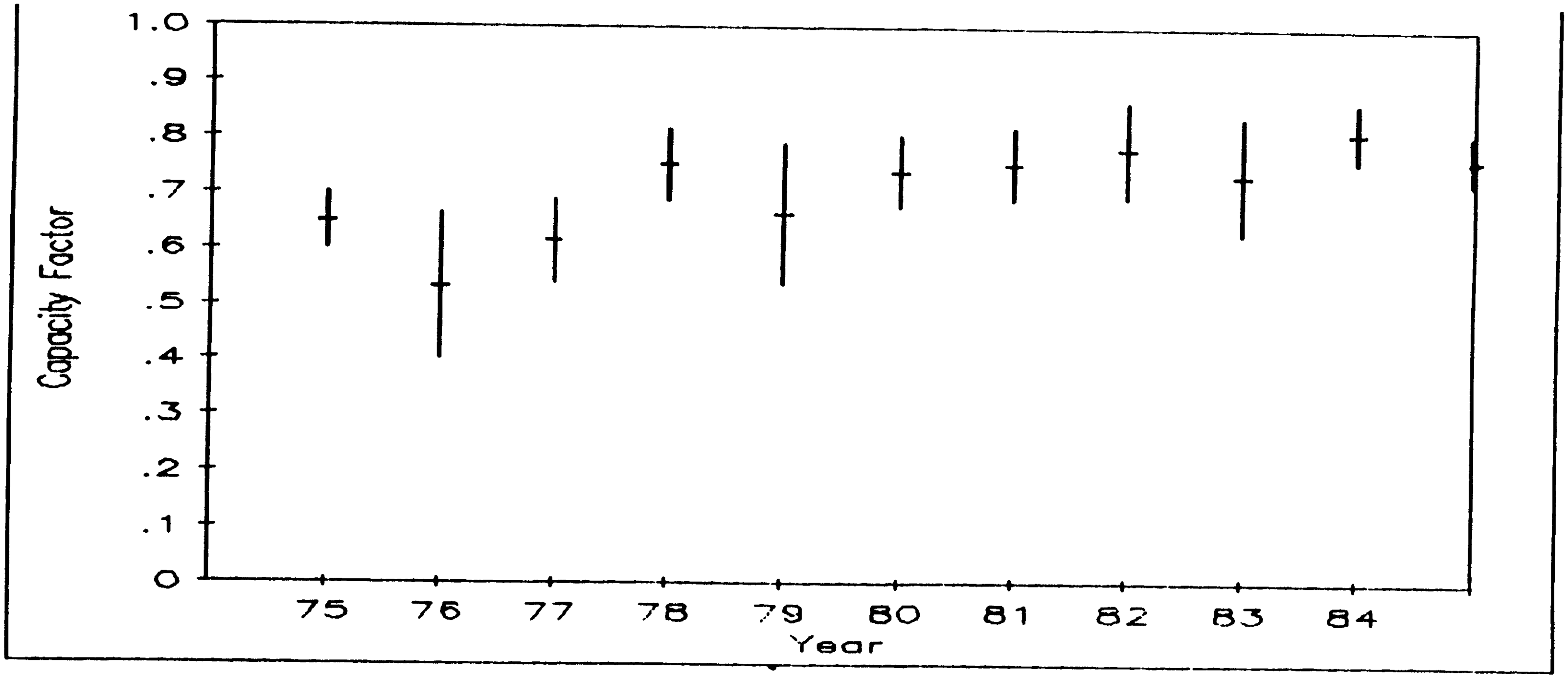


Figure 5.4

Swedish PWR Capacity Factor Distribution by Year

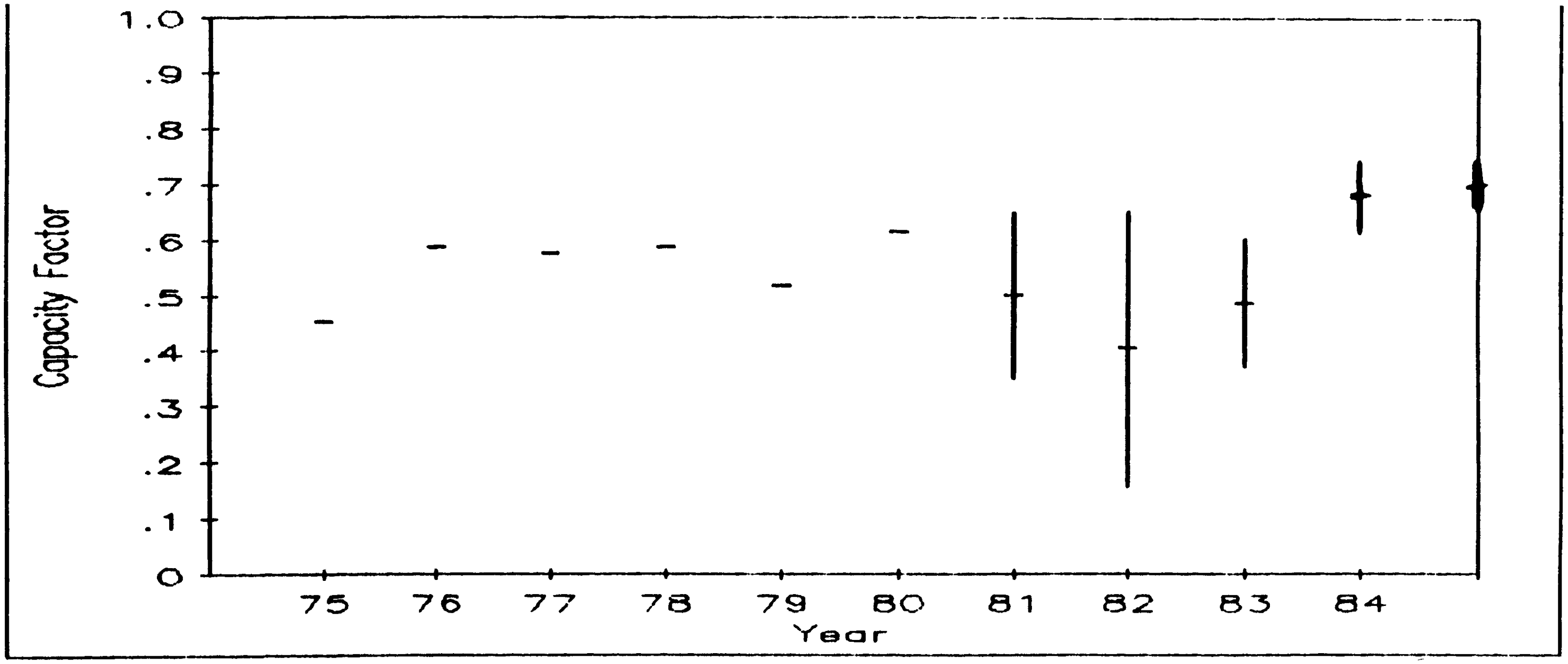


Figure 5.5

Swedish BWR Capacity Factor Distribution by Reactor Age

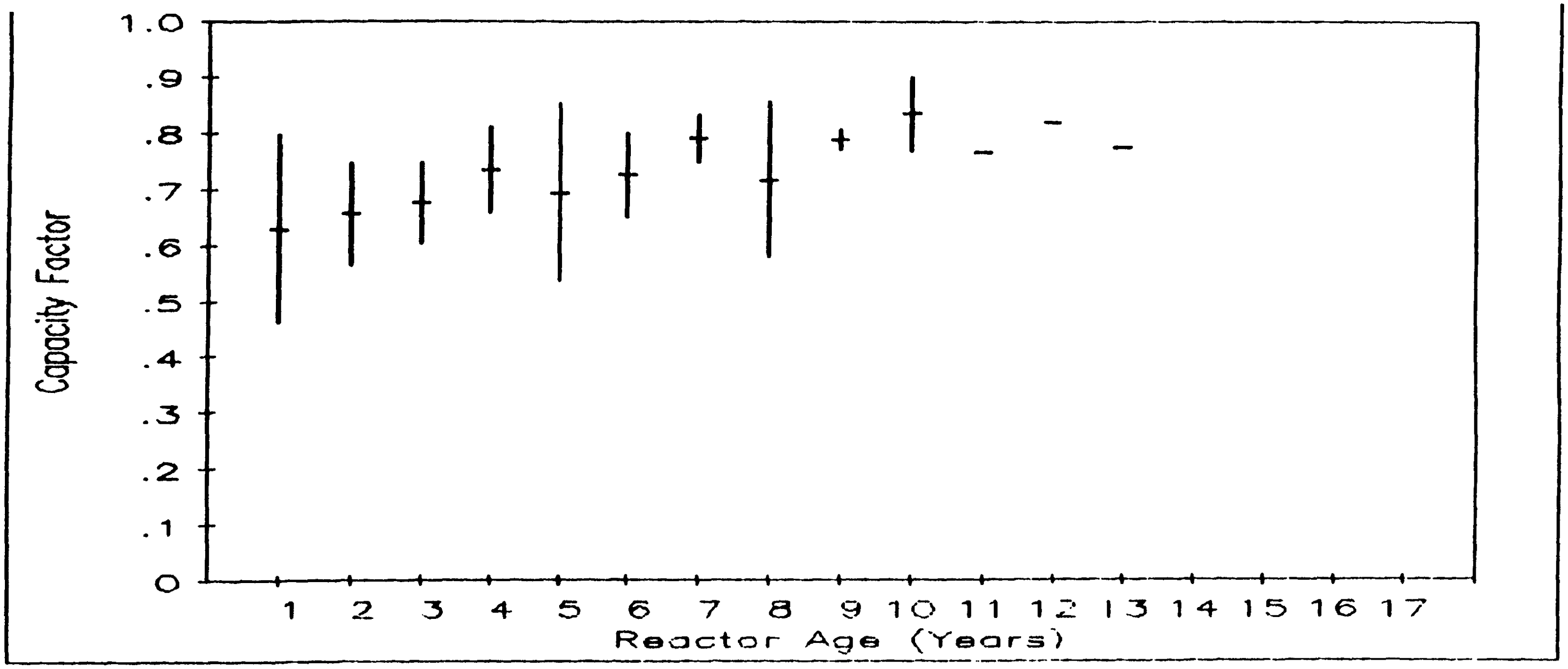
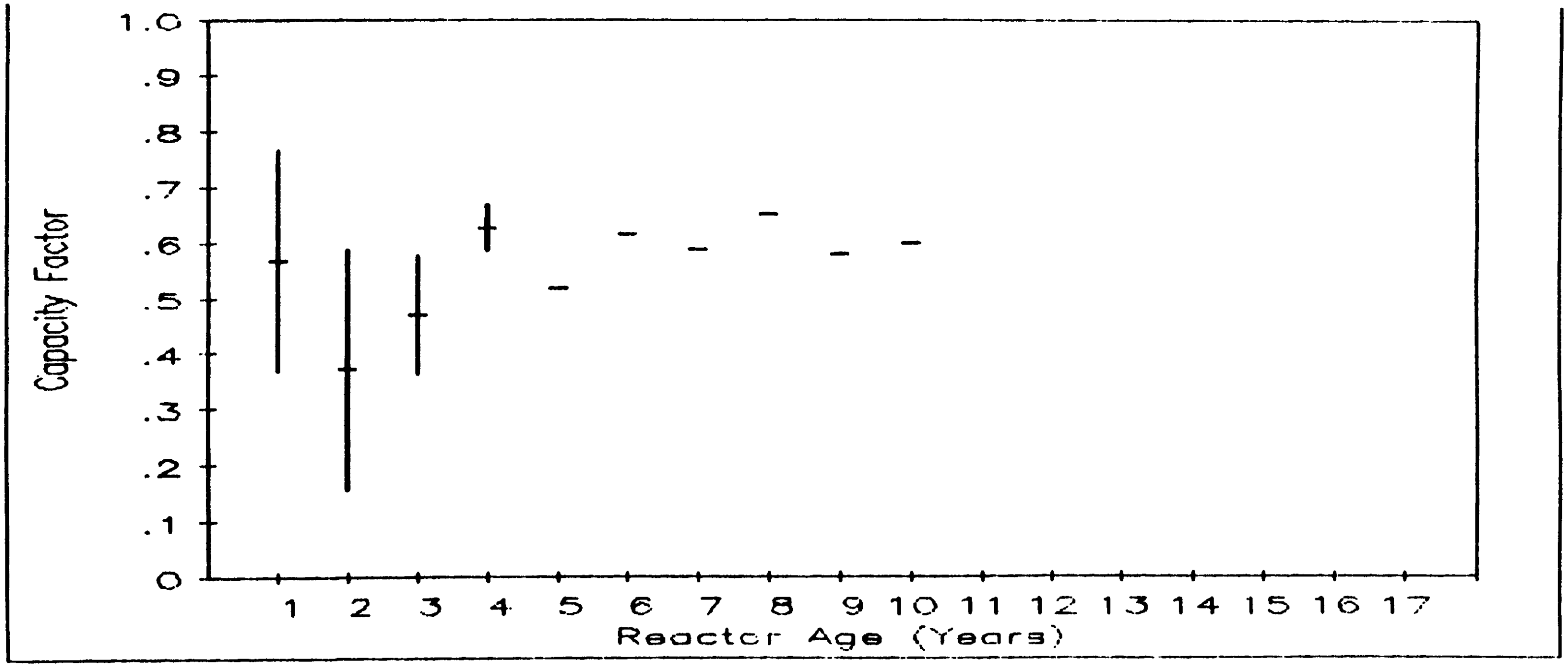


Figure 5.6

Swedish PWR Capacity Factor Distribution by Reactor Age



in the first three years of reactor operation indicate there is considerable variation in performance of the new units.

The consensus in Sweden is that the BWR/PWR differences can be explained by the additional down time required to correct problems in PWRs, especially for steam generators. An additional factor may be the difference between the utility/supplier relationships for the two reactor types. BWR data support the notion that a close utility/supplier relationship and the larger number of BWR units (especially considering the Finnish BWRs, which are not included in the data base) helped to increase the learning process and resulted in steadily improving BWR performance. In the case of PWRs, however, the learning process may have been slower, due to fewer units as well as the supplier relationships.

In any event, the performance of the BWR units in Sweden is exemplary.

This report has not examined energy availability, but it is notable that availability has exceeded capacity factor by at least 5 percent over the years. In 1985, on average, availability exceeded capacity factor by 9 percent for BWRs and 11 percent for PWRs.

In the following paragraphs the forced, scheduled, and regulatory losses for the Swedish nuclear plants are examined as functions of time and age.

Figure 5.7 plots forced, scheduled, and regulatory losses for BWRs by year. The BWRs exhibit small fluctuations in forced and scheduled losses over the period. Forced and scheduled losses contributed nearly equally to total losses each year, with regulatory losses almost negligible. Additionally, the forced, scheduled, and total losses have slowly decreased over time. In the forced outage category, the reduced losses are due to fewer losses in the balance-of-plant. Individual categories within the scheduled outage category are not distinguishable.

Figure 5.7

Swedish BWR Capacity Losses by Year: Forced, Scheduled, and Regulatory

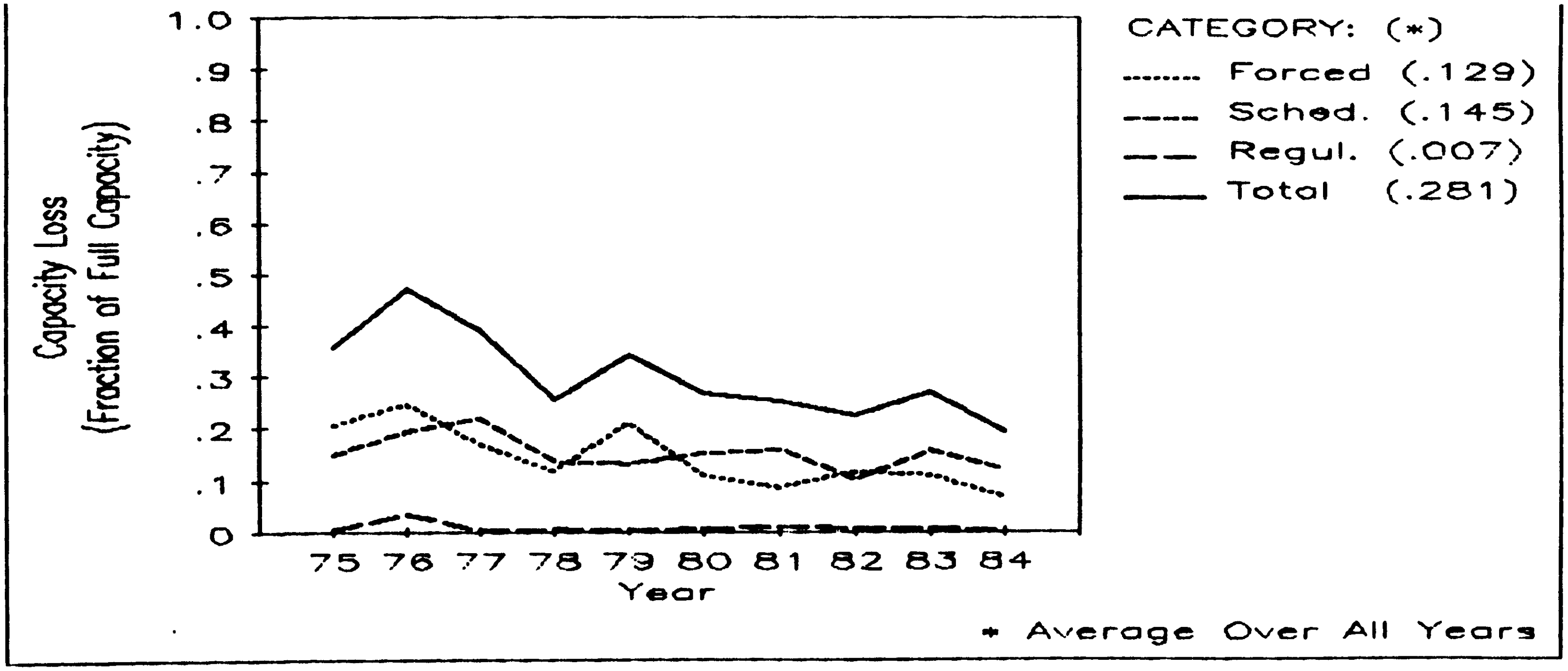


Figure 5.8 plots BWR outage category losses as a function of age. Here too, the forced and scheduled loss categories show a general correlation with plant age, both decreasing with age. The age-dependent decrease in the forced losses was due to reductions in many areas, while data on aggregate scheduled losses would not permit the identification of the responsible system(s).

Figure 5.9 plots forced, scheduled, and regulatory losses for PWRs by year. From 1975 through 1980 the data are from one PWR. A second plant came on line in 1981, and a third in 1983. The major contributor to the total losses over the ten years was forced outages, representing 52.4 percent of the total loss. A considerable amount of variation is shown from year to year from several different systems. Scheduled losses were generally less than the forced losses, with an annual average of 17.4 percent. As with forced losses, there are fluctuations in the year-to-year data that cannot be explained. The regulatory losses prior to 1982 generally were small. In 1982 and 1983 regulatory losses--associated mostly with steam generator inspections at two plants--were primarily responsible for a drop in the average performance of approximately 20 percent of full capacity. None of the outage categories shows dependence on time.

Figure 5.10 also shows the same PWR losses as a function of reactor age. The total losses exhibit a decreasing tendency with age, but due to the small number of plants in the Swedish data, this probably is not statistically significant. The forced losses also tend to follow this curve, but do not display as much age dependence. Scheduled losses fluctuate about a constant value with no trend visible. As with Figure 9, the regulatory losses were small, except over one two-year period.

Figure 5.8

Swedish BWR Capacity Losses by Rx Age: Forced, Scheduled, and Regulatory

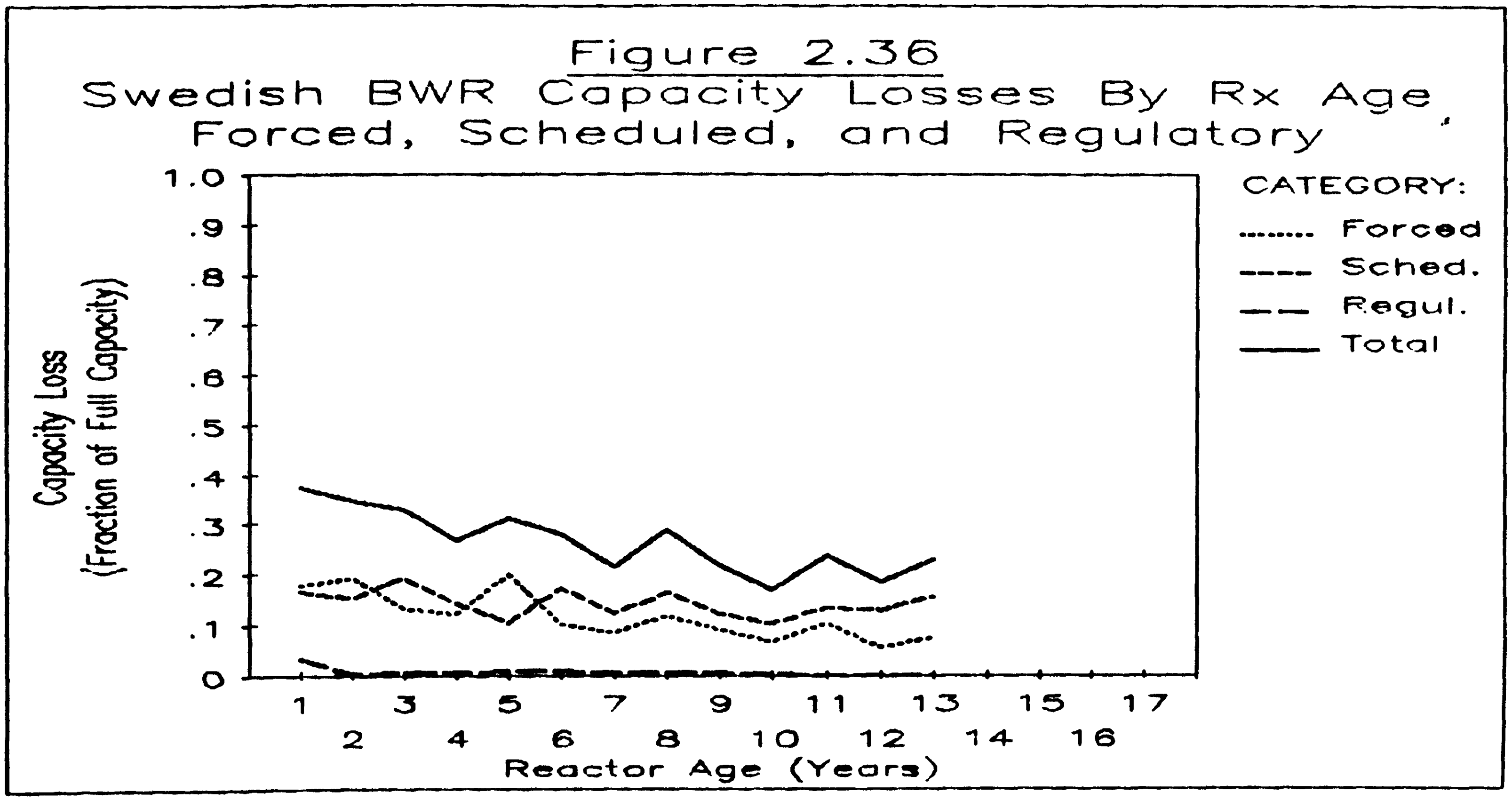


Figure 5.9

Swedish PWR Capacity Losses by Year: Forced, Scheduled, and Regulatory

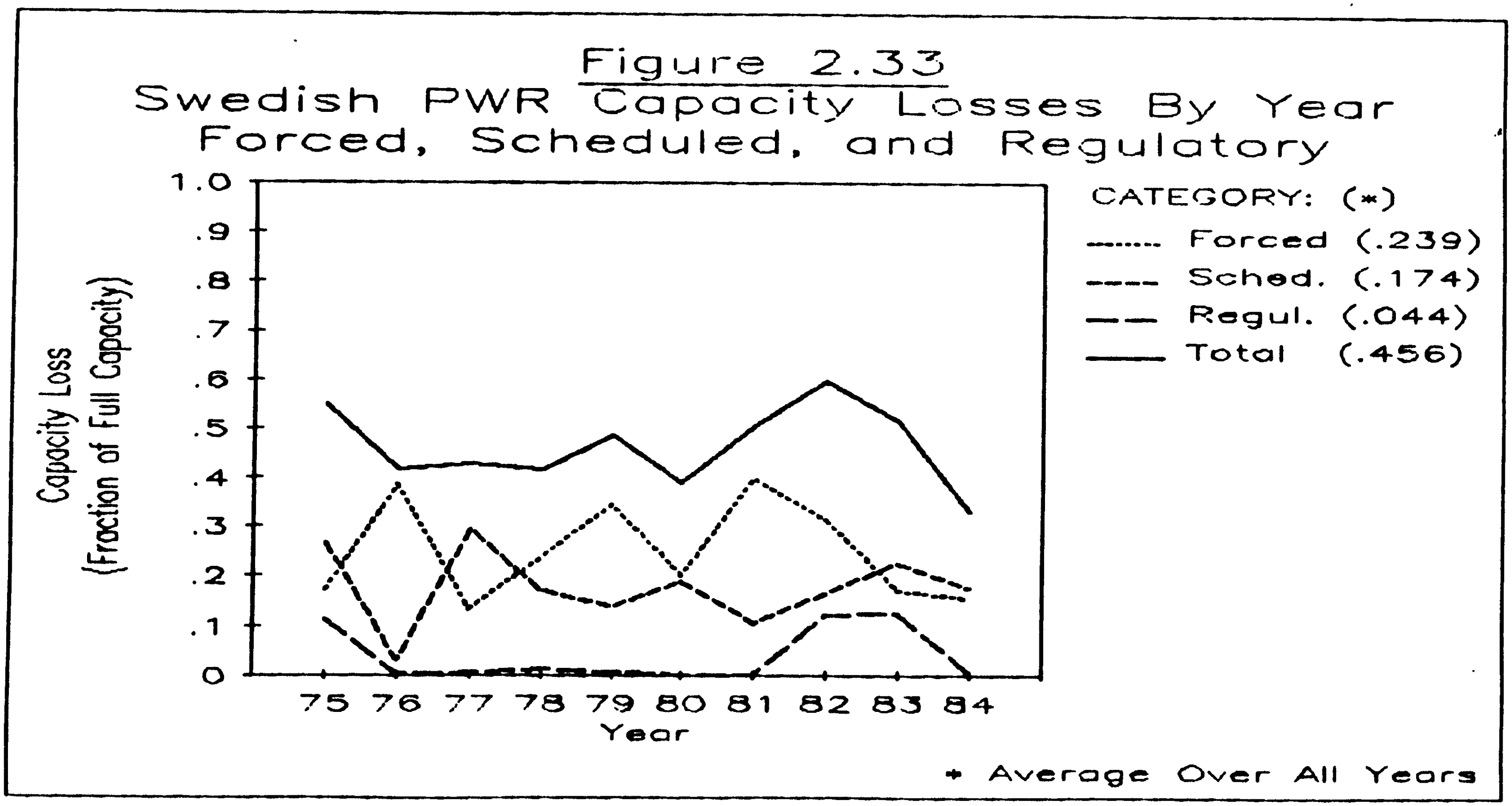
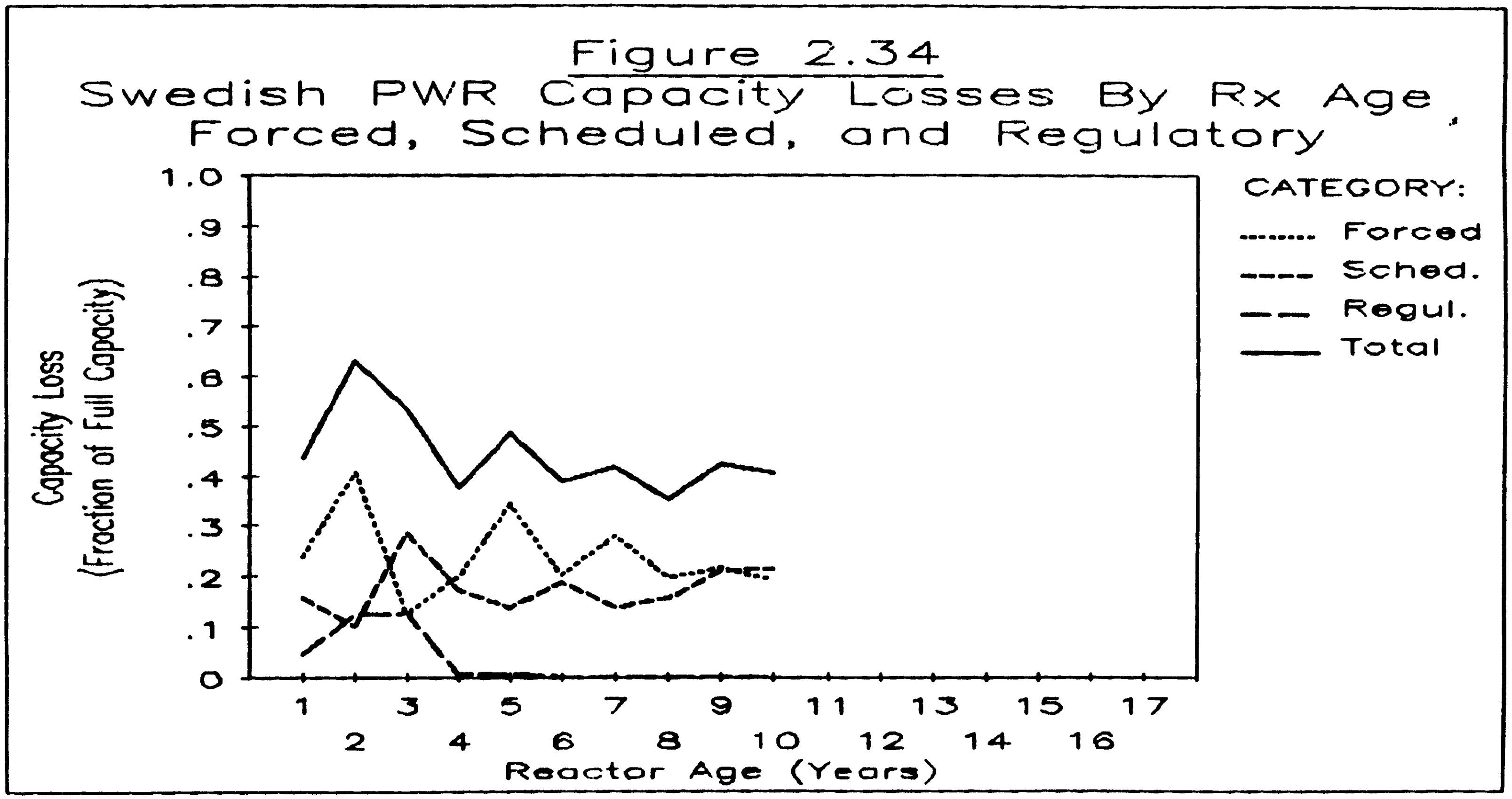


Figure 5.10

Swedish PWR Capacity Losses by Rx Age: Forced, Scheduled, and Regulatory



5.9 OBSERVATIONS

The Swedish nuclear power industry is very interesting, because it has demonstrated effective performance in a small but technologically advanced society and economy. Especially in the case of BWRs, its success is based on a strong infrastructure in all aspects of nuclear systems, components, and construction technology. It is not due to design standardization, to design or operating procedure, or to bureaucratic organization. It is a system that is tolerant of diversity in organization and operating procedures, but very exacting with respect to end results. Above all, it is a cooperative system--the organization and personnel involved are dedicated to working together to achieve first, a safe, and second, an economically efficient nuclear generation system. Specific factors that have contributed to successful performance include the following:

Government Activities

- effective organization and coordination of the necessary activities of government in the environment, public health and safety, etc., so nuclear operations are not delayed;
- no interventions in the Swedish licensing process;
- SKI has the power to make final decisions on nuclear plant operation; and
- SKI has the flexibility to be able to work formally and informally with utility organizations, such as RKS, on reliability and technical issues such as human factors analysis.

Utility Managment

- ability of state and private utilities to engage in planning and operations cooperatively; long-standing relationships have extended to nuclear plant cooperation, even to the extent of the Forsmark units, which are a joint SSPB/private utility venture;

- the flexibility to form new organizations for specific tasks as need arises, (e.g., the RKS and AKU for training);
- international connections that greatly augment the learning and experience feedback programs;
- effective implementation of experience feedback down to the level of plant maintenance technicians;
- training programs organized by the nuclear utilties for both operators and maintenance personnel;
- outage planning, scheduling, and implementation as a full-time, year-round activity;
- backfitting accomplished during normal plant outages;
- clear definition of safety roles, in which SKI develops requirements, approves utility solutions, and monitors progress; the utilities develop the solutions and are responsible for safety; and
- effective use of major suppliers (such as ASEA-ATOM) to help resolve generic problems as well as equipment malfunctions.

Assuming this performance trend continues, it appears that perhaps the major problem facing the electric utility industry over the next 5-10 years is the resolution of the future of nuclear power in Sweden. Will the referendum calling for decommissioning in the year 2010 be recalled, or will it stand?

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CHAPTER 6

SWITZERLAND

6.1 STRUCTURE OF THE ELECTRIC INDUSTRY

The Swiss Electric Power Industry has an installed capacity of approximately 15,020 MW, which generated 49.1 TWh in 1984. The capacity and generation by technology is as follows:

Hydro	11,430 MW	(76 %)	30,872 GWh	(63 %)
Nuclear	2,890 MW	(19 %)	17,396 GWh	(35 %)
Fossil	700 MW	(5 %)	884 GWh	(2 %)
	15,020 MW	(100 %)	49,152 MWh	(100 %)

Figure 6.1 is a flow diagram for electricity in Switzerland for 1984. Hydro accounted for approximately 76 percent of total installed capacity, and nuclear power plants generated approximately 35 percent of the electric energy.

The share of hydro fell from about 80 percent in 1975 to about 60 percent in 1984 (see Figure 6.2), while nuclear increased from below 20 percent to 35 percent over the same period. Fossil power plants have a very small share, which decreased from 3.8 percent to 1.6 percent. Figure 6.3 illustrates the electricity generation by energy sources.

Electricity consumption was 15,891 GWh in 1960 and 39,665 GWh in 1984, amounting to an average annual growth rate of 6.4 percent. In the future, this growth in electricity demand is expected to continue, although at a lower rate.

Per capita electricity consumption in Switzerland was 6,159 kWh in 1984. This was slightly higher than in the Federal Republic of Germany (5,848 kWh) and also higher than in Belgium (4,874 kWh), Austria (4,814 kWh), France (4,750 kWh), the United Kingdom (4,258 kWh), and the Netherlands (4,247).

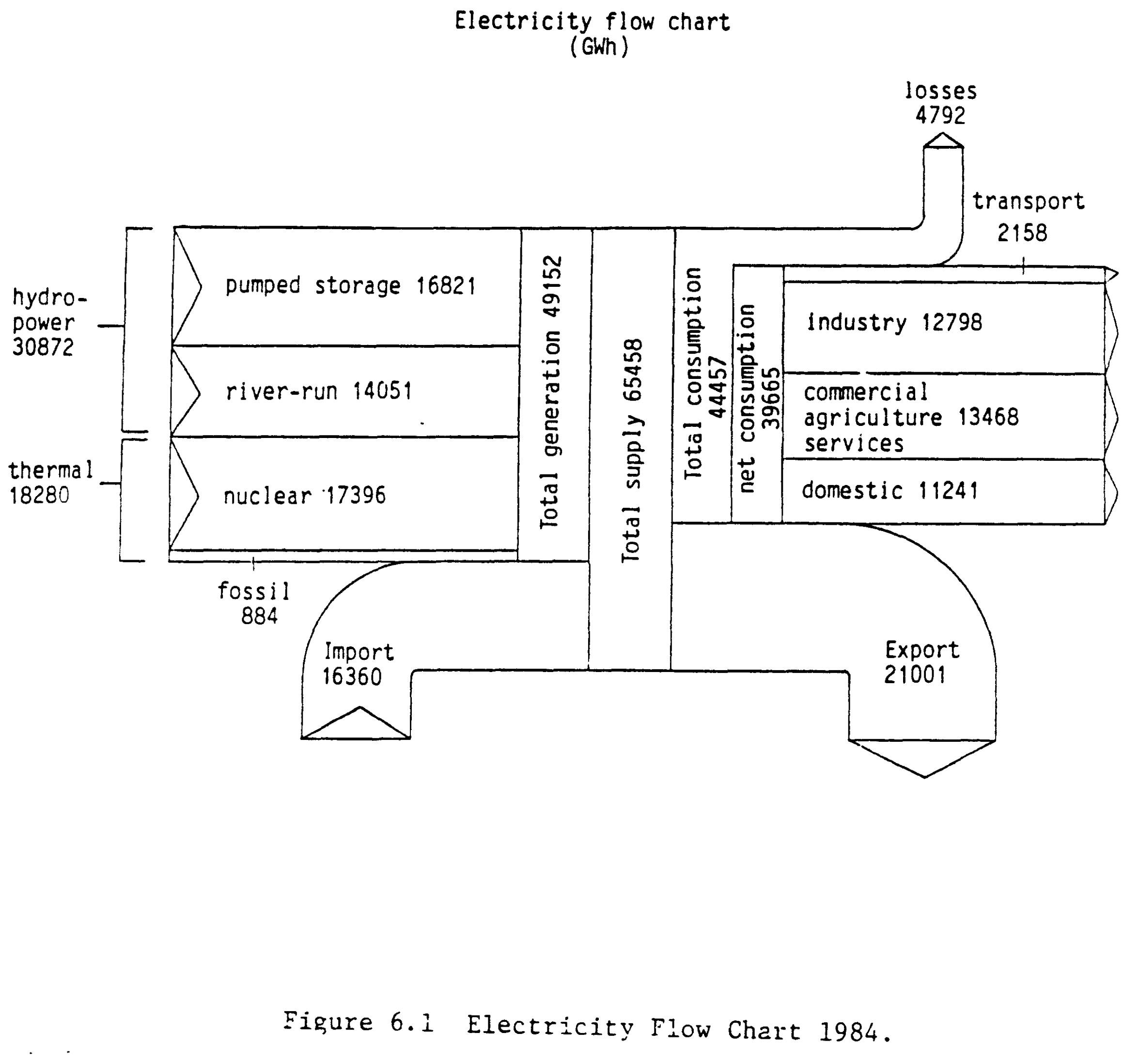


Figure 6.1 Electricity Flow Chart 1984.

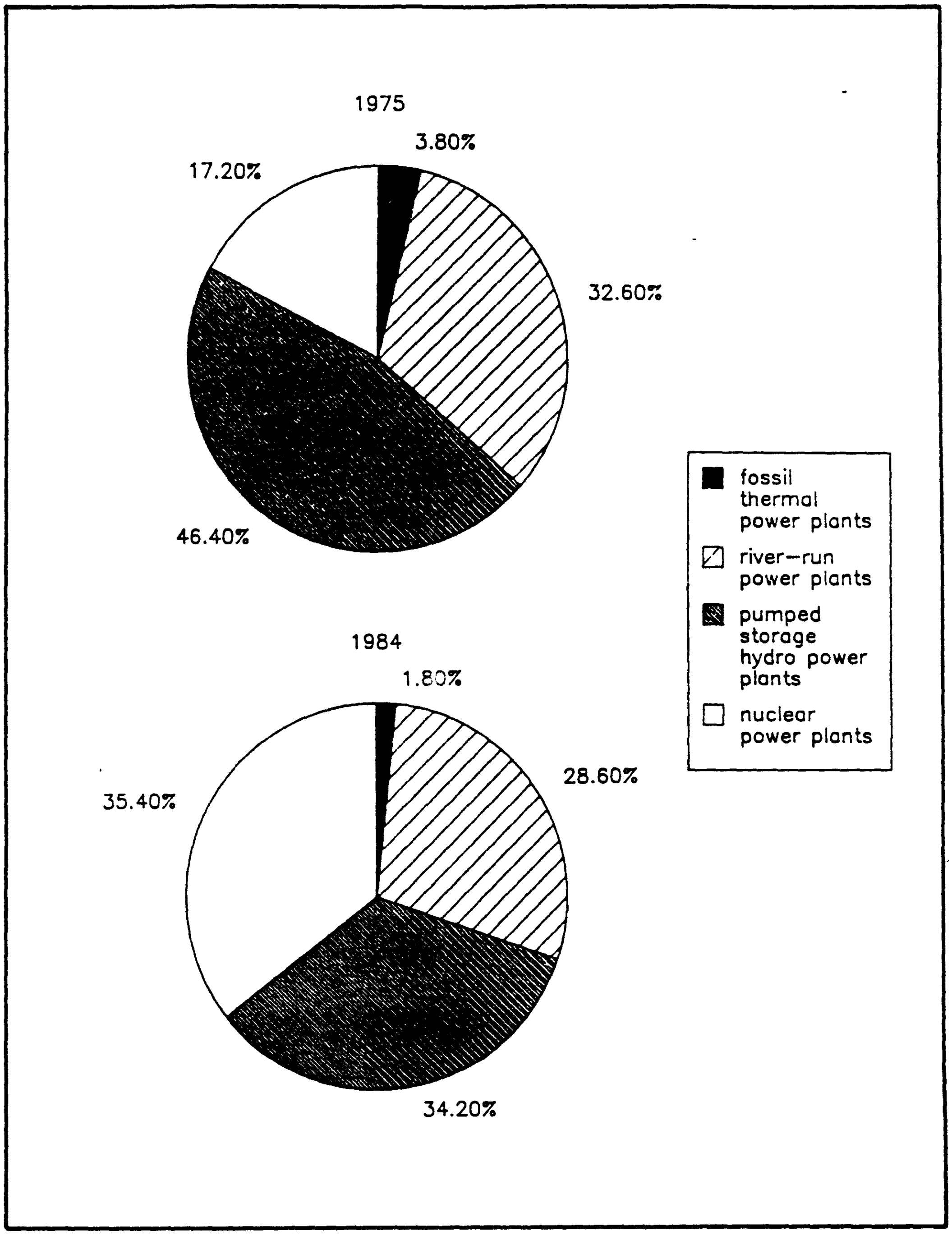


Figure 6.2 Electricity generation by plant types 1975 and 1984.

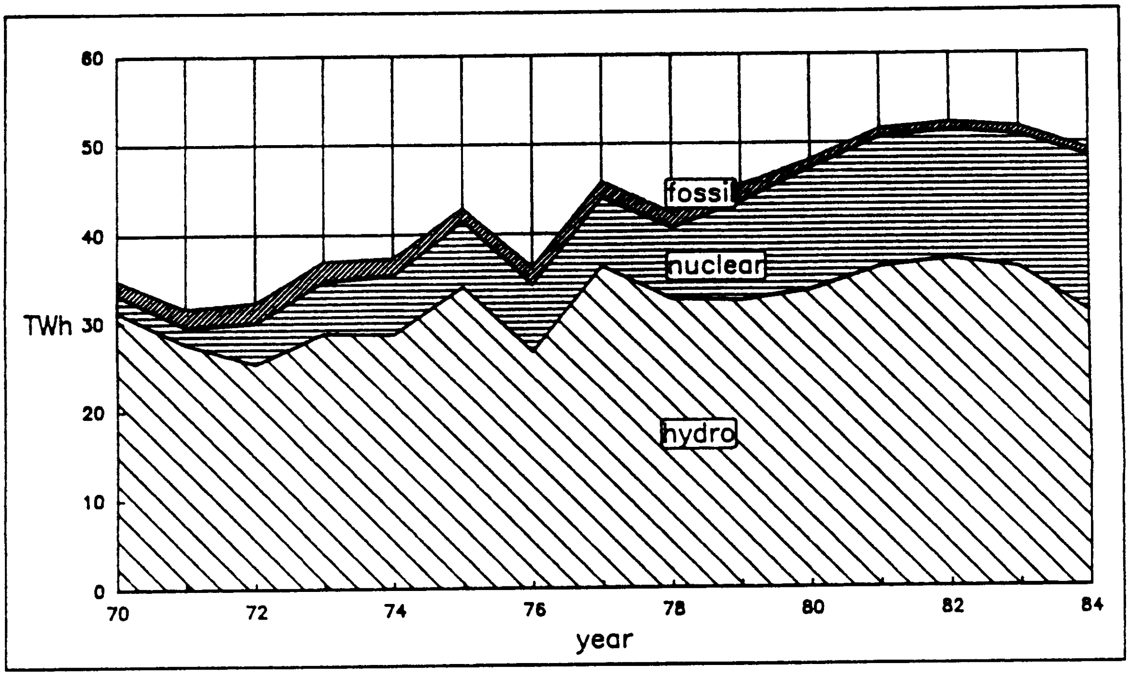


Figure 6.3 Electricity generation by energy sources.

In 1984, some 5 TWh of electricity was exported net to other countries. In the last 25 years the Swiss electric industry has exported more than it imported. However, because of poor snowfall (and the high share of hydro), domestic production was not sufficient to meet the demand in 9 of those 25 years. In those years, electricity was imported, mainly from France.

Approximately 1,200 independent electric utilities are involved in supplying 6.5 million Swiss citizens in some 3,000 communities. The size of these utilities varies greatly. The electricity supply of a utility can be 100,000 kWh for a small village cooperative and can reach 13,000 million kWh for a large supplier (Nordostschweizerische Kraftwerke AG).

A distinction must be made between public electric utilities, which supply electricity to others, and industrial enterprises and railway companies, which generate electricity for themselves (approximately 8 percent to 9 percent of total generation).

The owners of the electric utility industry are public institutions, such as states (called Cantons) and communities. They account for approximately 72 percent of ownership, while private owners account for the remainder (see Figure 6.4). Private institutions, such as banks and industrial firms, own primarily generation and transportation facilities, while public ownership is concentrated on distribution companies.

A few large utilities control the major share (70 percent) of generation, as well as the national transportation system and its interconnections with other countries. These companies supply electricity to Canton and regional distribution companies, but generate only a small amount of electricity. Some interregional

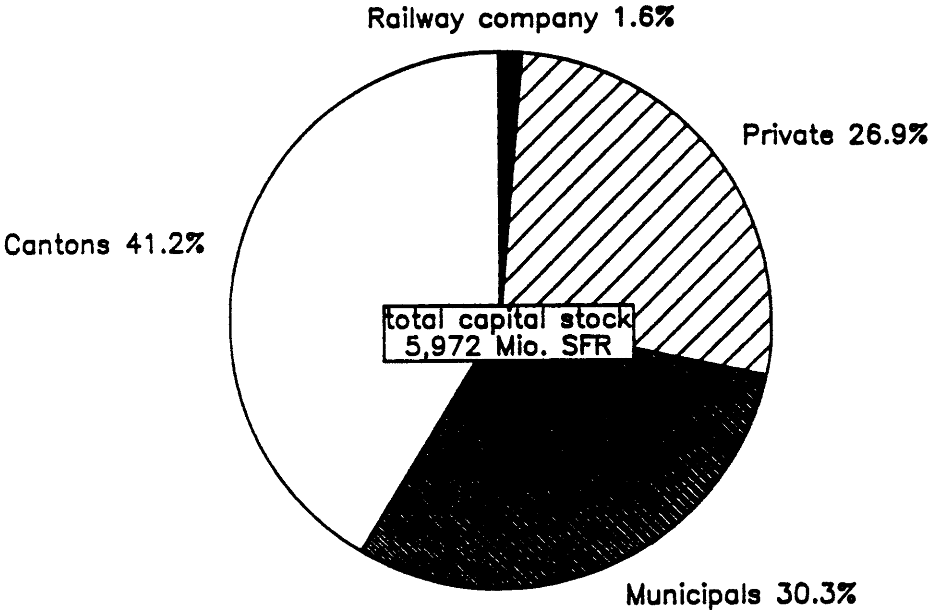


Figure 6.4 Ownership of electric utilities.

suppliers also deliver energy to end users. Figure 6.5 illustrates the structure of the Swiss electric utility industry. The large utilities are private companies.

Figure 6.6 illustrates how electricity is generated and distributed in the Swiss electric utility industry. The diagram shows the 16 largest utilities. Note that 16 utilities supply nearly 50 percent of all electricity to end users. Six major utilities also are involved in nuclear undertakings. Despite the high degree of decentralization of the Swiss electric industry, there is a highly efficient, reliable, and interconnected grid system. This system is connected to the Western European grid system, which allows electricity exchange with neighboring countries.

There are five LWRs in operation in Switzerland:

Beznau 1	350 MW	PWR	first year of operation 1969, owner NOK
Beznau 2	350 MW	PWR	first year of operation 1971, owner NOK
Muehleberg	320 MW	BWR	first year of operation 1972, owner BKW
Gosgen	920 MW	PWR	first year of operation 1979, owner KKG
Leibstadt	950 MW	BWR	first year of operation 1984, owner KKL

NOK = Nordostschweizerische Kraftwerke AG
BKW = Bernische Kraftwerke AG
KKG = Kernkraftwerk Gosgen-Daniken AG,
shareholders: Aare-Tessin AG fur Elektrizitat 35 percent, Centralschweizerische Kraftwerke 12.5 percent, Nordostschweizerische Kraftwerke AG 25 percent, City of Zurich 15 percent, Community of the city of Bern 7.5 percent, and Swiss Federal Railways 5 percent.

KKL = Kernkraftwerk Leibstadt AG,
shareholders: Aare-Tessin AG fur Elektrizitat 16.5 percent, Badenwerk AG, FRG 7.5 percent, Aargauisches Elektrizitatswerk 5 percent, Bernische Kraftwerke AG 7.5 percent, Centralschweizerische Kraftwerke 10 percent, Elektrizitats-Gesellschaft Laufenburg AG 15 percent, Elektrowatt AG 5 percent, Kraftubertragungswerke Rheinfelden, FRG, 5 percent, Kraftwerk Laufenburg 5 percent, Motor-Columbus AG 5 percent, and others.

Figure 6.7 illustrates the locations of these nuclear power plants.

Opposition to nuclear power has been growing in Switzerland. The Leibstadt plant was delayed for several years before coming on line in

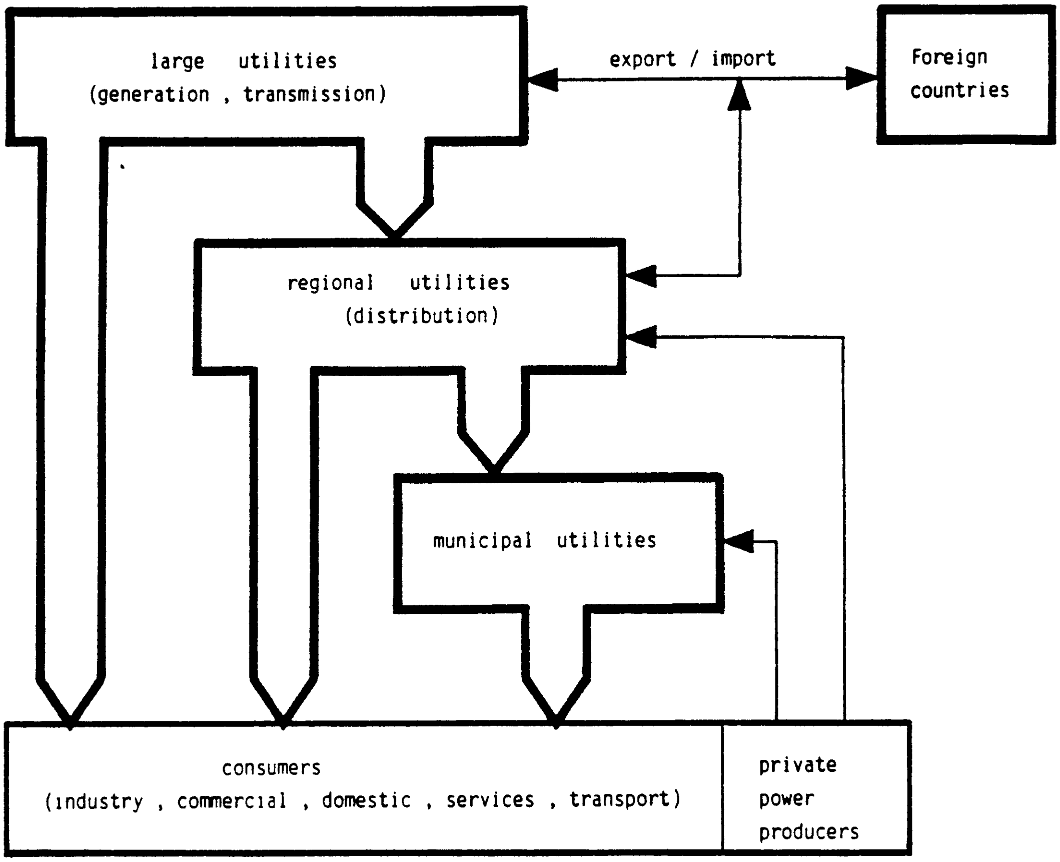


Figure 6.5 Structure of generation and distribution system.

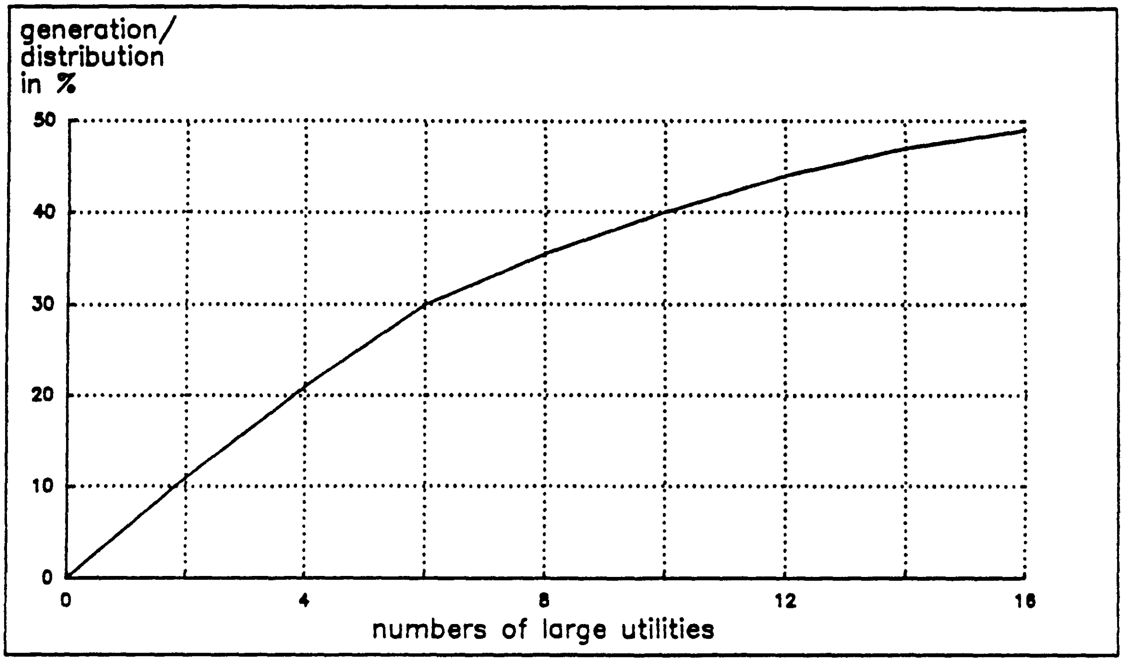


Figure 6.6 Electricity generation and distribution of large utilities.

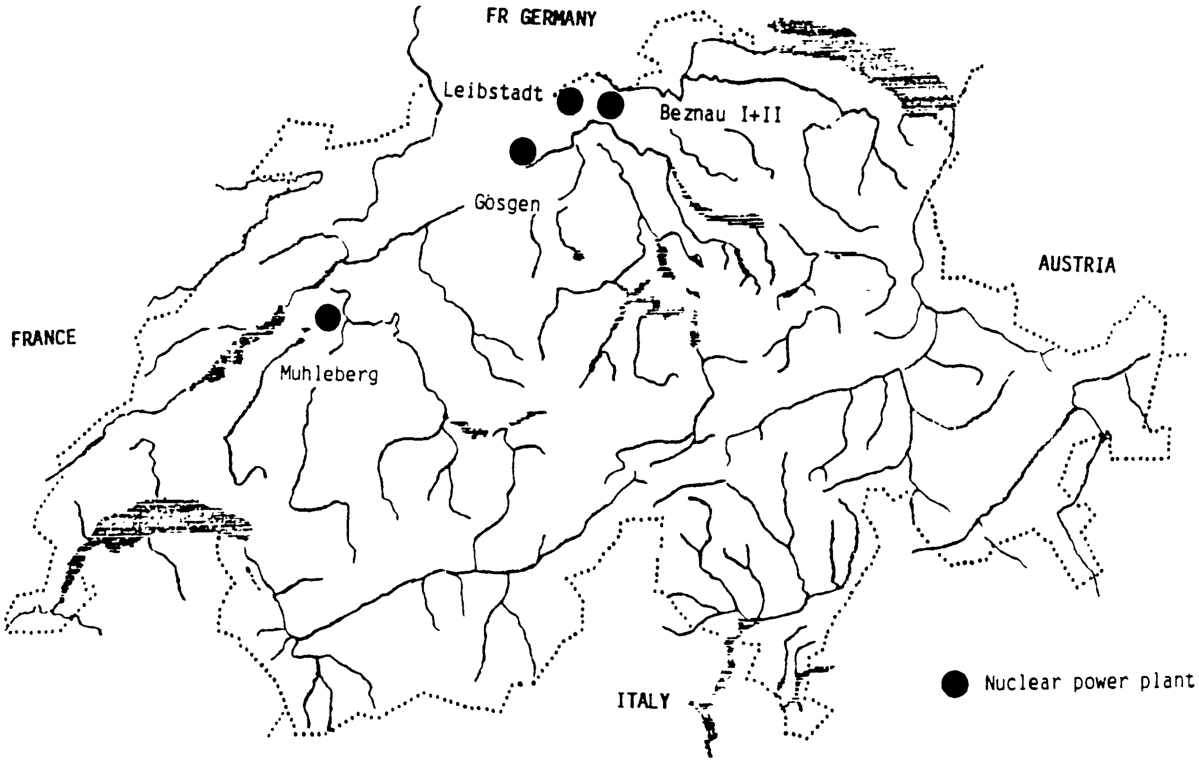


Figure 6.7 Location of Nuclear Power Plants.

1984. Three more plants are planned: Kaiseraugst, Graben, and Verbois.

Work has just begun on the 925 MW BWR Kaiseraugst. It is owned by several shareholders from Switzerland, France, and the Federal Republic of Germany, and is projected to start operating in 1994. The site and design have been licensed for the 1,140 MW BWR nuclear power plant at Graben. The Kernkraftwerk Graben AG is owned by several Swiss shareholders (Kernkraftwerk-Beteiligungsgesellschaft AG with 39 percent and Bernische Kraftwerke AG Beteiligungsgesellschaft with 45 percent). But at this writing the project has been postponed indefinitely. For the nuclear power plant at Verbois only the site has been licensed, and there is no clear indication of when further progress will be made.

6.2 STRUCTURE OF THE SUPPLY INDUSTRY

Hydro-electric power capacity peaked in the early 1960s, after which alternative technologies were considered. Due to the expected environmental disadvantages of fossil power plants, attention turned to nuclear power.

The Swiss electric generation industry's principle experience had been with hydro-electric plants, and it had had no experience with nuclear plants. Swiss utilities conducted feasibility studies for light water, heavy water, and gas-cooled nuclear plants. As a result, in 1965 Nordostschweizerische Kraftwerke AG signed a contract with Westinghouse International Atomic Power Co. and Brown, Boveri & Co. to build the 350 MW PWR Beznau 1. Two years later the same suppliers were given the order to build the second block Beznau 2, also 350 MW.

In 1967 Bernische Kraftwerke AG ordered from Brown, Boveri & Co. and General Electric Technical Services Co. a 320 MW BWR for Muehleberg. Like Beznau 1 and 2, Muehleberg is equipped with 2 Brown Boveri turbine generator sets.

The 920 MW PWR Gosgen was built by the general contractor Kraftwerk Union AG, which also provided the turbine generator.

The 950 MW BWR Leibstadt was supplied by the general contractors Brown, Boveri & Co. and General Electric Technical Services Co. BBC delivered the turbine generator.

The 925 MW BWR Kaiseraugst is planned to be built by the general contractors Brown, Boveri & Co. and General Electric Technical Services Co. BBC will supply the turbine generator. The Architect/Engineers are Motor-Columbus Consulting Engineers and Electricite de France.

From the foregoing information, it can be seen that the Swiss electric utilities used different suppliers and Architect/Engineers, taking advantage of the competition. Nineteen utilities in Switzerland are involved in nuclear power. There is an interaction between the utilities with regard to the exchange of operating experiences.

6.3 UTILITY INTERNAL ORGANIZATION AND CAPABILITIES

The ownership of nuclear power plants in Switzerland are shared by several utilities. The plant management has the full responsibility for operation, maintenance and for managing backfitting projects. Fig. 6.8 shows a plant organization.

One significant feature of the Swiss nuclear power program is the size of plant staffs. The units have at least 180 people on site (Muehleberg) and reaches up to 350 for the twin Beznau station, 10 percent of whom hold engineering degrees (10 with university degrees and 20 with technical college degrees). At the outset of the Swiss nuclear program, there were only 120 people on site, but it has gradually grown to its present size.

The site manager has complete responsibility for the plant and receives little direction from utility headquarters. This responsibility

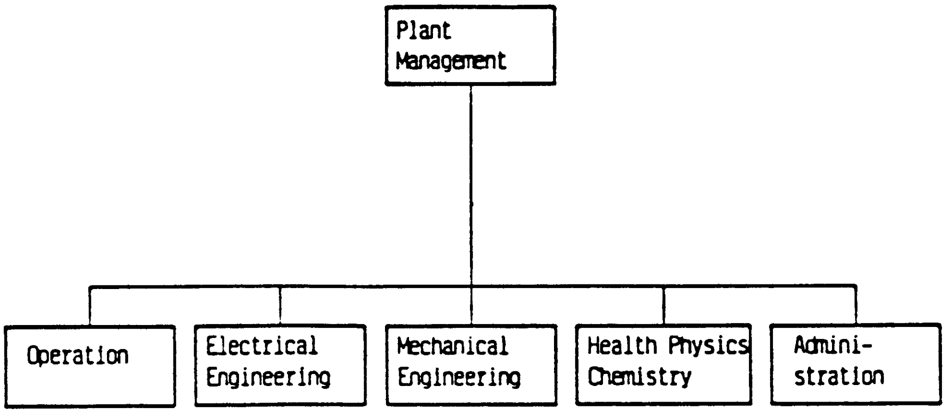


Figure 6.8 Plant organization.

extends to maintenance and outage planning, as well as to daily operations. The position of site manager is one of the most highly respected positions in the Swiss nuclear industry, very nearly the peak of the profession.

Preparation and planning for outages is begun one year in advance. Refueling is performed by several subcontractors, each responsible for the equipment they originally supplied to the plant. The site manager retains oversight responsibility throughout the outage.

Plant operators receive training on simulators in both theoretical and practical operating problems. There is very little turnover among plant operators.

The first Swiss plant (Beznau 1) was of Westinghouse design. The future operators were sent to the Westinghouse offices in Pittsburgh for training in both plant design and operations. They then returned to Switzerland to become involved in the construction of Beznau. The Westinghouse training programs were adapted directly by the Swiss utilities for their own use. Today, however, the Swiss industry is independent of American oversight.

Different Swiss nuclear plants developed a maintenance strategy which pays much attention to the planning of maintenance and to the annual shutdowns. This includes also preventive maintenance programs and corrective maintenance. A feedback control system (Figure 6.9) aims to minimize the necessary downtime on the basis of information and experience gained.

One of the Swiss plants (Gosgen) was designed by KWU, and the staff of that plant participates with German utilities in the information exchange with KWU.

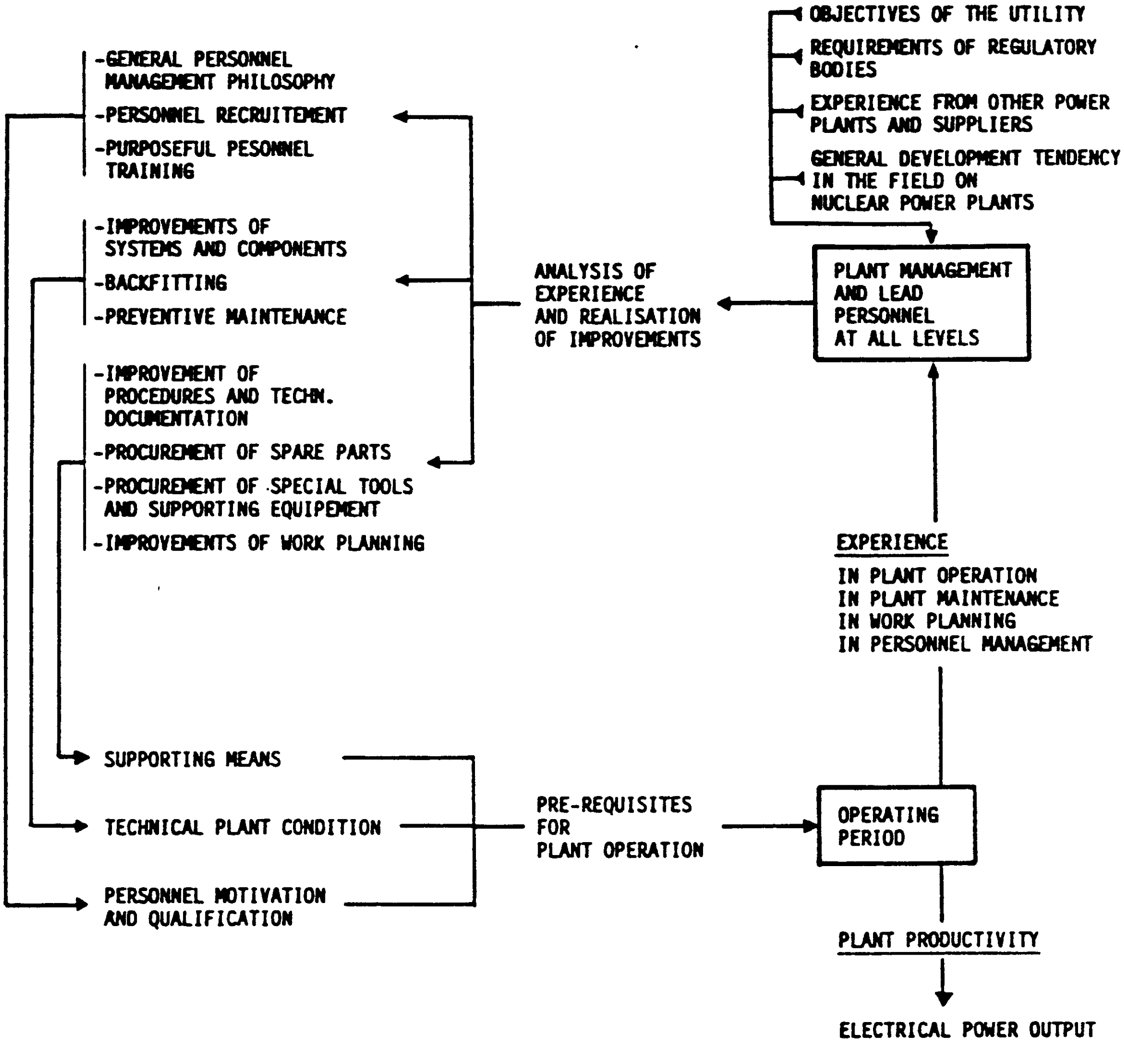


Figure 6.9 Feedback control system.

6.4 ECONOMICS OF NUCLEAR POWER

We could not obtain any information on the historical cost of electicity generation with regard to different types of generation. Figure 6.10 shows average electricity prices from 1960 to 1984 in real and nominal terms.

The decision to build nuclear rather than fossil fuel-fired plants primarily was based on political and environmental considerations. Economic criteria did not play an important role. However, economic feasibility studies show that electricity from nuclear power plants is less expensive than if coal-fired power plants had been built. The International Energy Agency calculates the cost of nuclear electricity generation as 0.0355 US$/kWh for Switzerland today.

6.5 ECONOMIC REGULATION

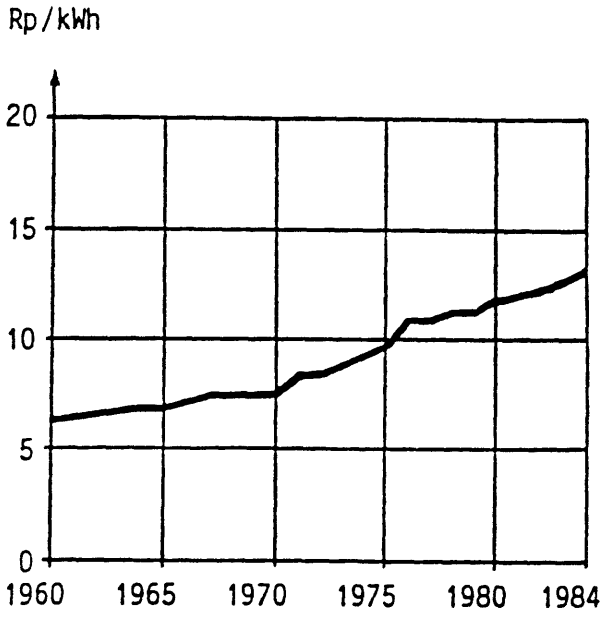
The approximately 1,200 Swiss electric utilities can set their prices and tariffs independently. They base their tariffs on the cost structure of electricity generation or on the prices they pay to the interregional electric utilities.

The large, privately-owned interregional suppliers are not economically regulated.

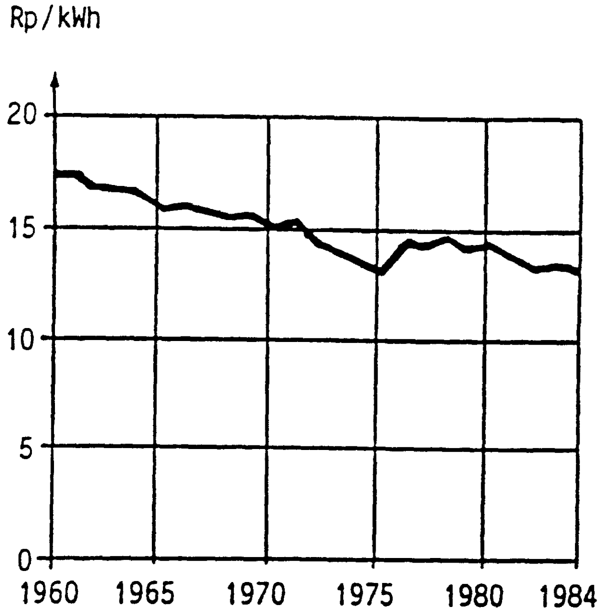
The public distribution companies, which deliver electricity to end users, need their tariffs approved by Cantonal institutions.

In general, there is no economic regulation in Switzerland comparable to that in the United States.

There are no regulations on the federal level. Regulations vary different from Canton to Canton. Some Cantons evaluate the cost structure of the utilities and their tariffs. In general, the existing economic regulatory system does not influence the decisions of electric



nominal price



real price in 1984 Rp.

Figure 6.10 Average Electricity Prices.

utilities with regard to their investments and operating procedures.

For the future, an electricity law is in preparation that may regulate the structure of tariffs.

6.6 SAFETY REGULATION

Article 24 of the Swiss Federal Constitution states that:

- atomic energy legislation is the resposibility of the Confederation, and
- The Confederation shall establish regulations concerning protection against the hazards of ionizing radiation.

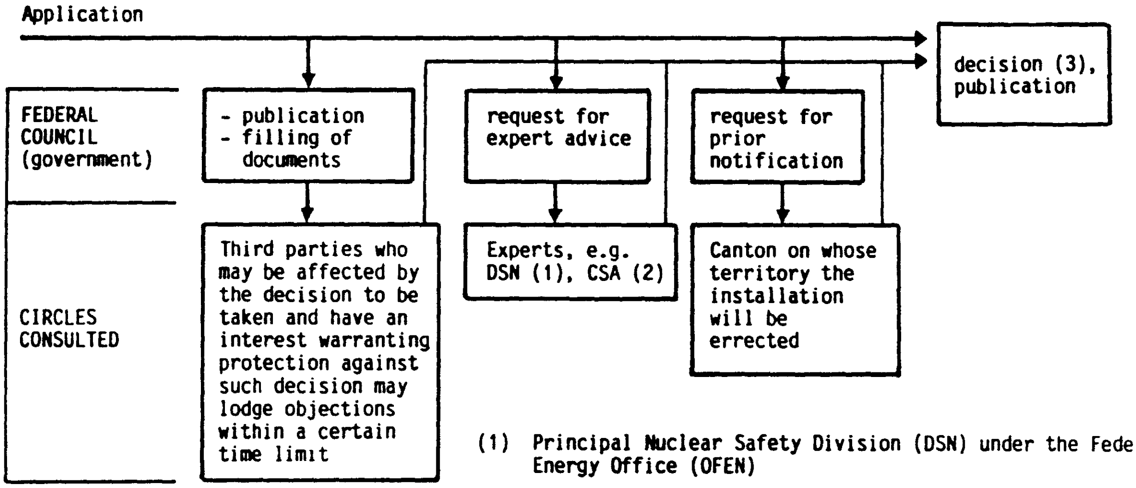
The Federal Energy Act of 1959 and the Federal Order concerning the Energy Act of 1978 regulate the construction and operation of nuclear power plants and other atomic installations.

The Federal Council decides whether to issue a general license. Where necessary the Federal Assembly (Parliament) may be called upon to approve the decision.

The Federal Department of Transport, Communications, and Energy and its Federal Energy Office are responsible for implementing legislation on the use of nuclear energy. The Federal Energy Office evaluates applications for general licenses for the construction, operation, and modification of nuclear power plants. The Federal Nuclear Safety Inspectorate in the Federal Energy Office deals with matters concerning nuclear safety and radiation protection.

Figure 6.11 illustrates Federal licensing procedures. In addition to following Federal licensing procedures, applicants are required under Cantonal law to apply for authorization with regard to land-use planning, environmental protection, landscape, workers, forestry, fire, water, and the use of river water in cooling purposes.

The responsibility for inspection of nuclear power plants resides with the Confederation. Federal Council bodies, such as the Federal



(1) Principal Nuclear Safety Division (DSN) under the Federal Energy Office (OFEN)

(2) Federal Commission for the Safety of Nuclear Installations (advisory body for OFEN and Federal Council)

(3) Decision may not be appealed

Figure 6.11 Licensing Procedure.

Nuclear Safety Inspectorate, are responsible for most technical inspections of nuclear power plants. Experts not employed by the government may assist the Federal Council bodies.

The utilities and their regulators maintain a highly professional relationship which allows to discuss openly any safety related operating problem on a technical basis. There is some opportunity for public intervention in nuclear power plant licensing procedures. Through this system public groups delayed the start of the Leibstadt plant and postponed Graben and Verbois.

6.7 PUBLIC ATTITUDES AND INFLUENCE

At the outset of the development of nuclear power in Switzerland, there was little public interest either for or against the technology. In the mid-1970s, growing opposition to nuclear power in Germany also was felt in Switzerland, at which time the first meaningful opposition developed. This opposition led in 1979 to a public referendum on nuclear power.

This 1979 referendum (and another in 1984) asked the public to vote on the future of nuclear power. In both cases, less than half the public voted; in the first vote, nuclear power survived by a vote of 51 percent to 49 percent. In the second, nuclear power received 55 percent of the vote.

Part of the recent success of nuclear power in Switzerland has been attributed to perceptions that it is a more environmentally sound technology than fossil fuel alternatives.

6.8 NUCLEAR PLANT PERFORMANCE

In this section the performance losses for the Swiss nuclear power plants are presented and briefly examined. Capacity was the performance index used to compile the Swiss nuclear plant performance data.

6.8.1 AGGREGATED DATA

Swiss PWR capacity losses are tabulated by calendar year in Table 6.1 and by reactor age in Table 6.2. The BWR capacity losses are tabulated by year and by reactor age in Table 6.3 and Table 6.4 respectively. The mean and standard deviation for the capacity factors are tabulated in Table 6.5 by year and by reactor age.

6.8.2 CAPACITY FACTOR DISTRIBUTION

The Swiss PWR capacity factors are shown graphically in Figure 6.12. Performance of the Swiss PWR's has been excellent, with a ten year average of 85.8%. Two periods of improvement are visible in this figure. The first is from 1975 to 1978 with small standard deviations associated with the mean capacity factors. The second period of improvement is from 1980 to 1984 with larger standard deviations than during 1975 to 1979. A drop in performance occurred between these two periods in 1980 as a third plant came online and did not perform as well as the others. The increased standard deviations after this plant came online result not only from the new plant's lower performance but also from more variation in the performance of the other two PWR's.

The PWR capacity factors are plotted by age in Figure 6.13. Performance shows improvement over the first five years and finally levels off after age 6 as the plants get older. As with the previous plot, the lower performance during the first five years is the result of

Table 6.1

Swiss PWR Capacity Losses
By Year

CAPACITY LOSSES
1975 - 1979

SWITZERLAND
ALL PWR'S

03/25/86

			1975	1976	1977	1978	1979
		DATA:	(2)	(2)	(2)	(2)	(2)
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.000	0.002	0.001	0.001	0.000
		SG	0.028	0.007	0.011	0.009	0.011
		REFUEL					
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.028	0.009	0.011	0.010	0.011
	BOP	TURBINE	0.009	0.002	0.000	0.001	0.001
		GEN	0.000	0.001	0.002	0.000	0.000
		COND					
		CW/SW/CCW	0.005	0.006	0.001	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.015	0.008	0.003	0.001	0.001
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.000	0.000	0.000	0.000	0.000
	TOTAL		0.043	0.017	0.014	0.011	0.011
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.037	0.050	0.034	0.028	0.038
		SG	0.024	0.016	0.015	0.008	0.024
		REFUEL	0.039	0.036	0.043	0.027	0.019
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.100	0.102	0.092	0.062	0.081
	BOP	TURBINE	0.025	0.027	0.025	0.021	0.027
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.001	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.025	0.027	0.025	0.021	0.027
	ECONOMIC		0.009	0.006	0.004	0.004	0.004
	HUMAN						
	OTHER						
	TOTAL		0.133	0.136	0.121	0.087	0.112
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.176	0.151	0.135	0.098	0.123
** CAPACITY FACTOR **			0.825	0.849	0.865	0.902	0.877

Table 6.1 (Continued)

CAPACITY LOSSES
1980 - 1984

SWITZERLAND
ALL PWR'S

03/25/86

			1980	1981	1982	1983	1984
DATA:			(3)	(3)	(3)	(3)	(3)
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.011	0.010	0.006	0.001	0.001
		SG	0.017	0.005	0.007	0.000	0.000
		REFUEL					
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.028	0.015	0.013	0.001	0.001
	BOP	TURBINE	0.002	0.002	0.000	0.002	0.001
		GEN	0.000	0.000	0.000	0.000	0.001
		COND					
		CW/SW/CCW	0.016	0.000	0.000	0.000	0.000
		OTHER	0.005	0.000	0.000	0.002	0.000
			0.023	0.002	0.001	0.004	0.001
	ECONOMIC		0.004	0.003	0.009	0.003	0.003
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.000	0.001	0.000	0.000	0.000
	TOTAL		0.055	0.021	0.024	0.008	0.005
SCHEDULED	NSSS	FUEL	0.001	0.003	0.006	0.002	0.000
		RCS	0.037	0.017	0.027	0.032	0.018
		SG	0.010	0.023	0.022	0.018	0.023
		REFUEL	0.065	0.063	0.059	0.050	0.044
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.112	0.105	0.114	0.102	0.085
	BOP	TURBINE	0.012	0.010	0.010	0.012	0.010
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.012	0.010	0.010	0.012	0.010
	ECONOMIC		0.001	0.002	0.006	0.005	0.007
	HUMAN						
	OTHER						
	TOTAL		0.126	0.118	0.130	0.118	0.102
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.008	0.008	0.000	0.004	0.004
** TOTAL CAPACITY LOSS **			0.189	0.147	0.153	0.129	0.110
** CAPACITY FACTOR **			0.811	0.853	0.847	0.871	0.890

Table 6.1 (Continued)

CAPACITY LOSSES
1975 - 1984

SWITZERLAND
ALL PWR'S

03/25/86 DATA: 3 PLANTS 25 PLANT-YEARS

			AVERAGE OVER ALL YEARS
FORCED	NSSS	FUEL	0.000
		RCS	0.004
		SG	0.009
		REFUEL	
		OTHER	0.000
			0.012
	BOP	TURBINE	0.002
		GEN	0.000
		COND	
		CW/SW/CCW	0.003
		OTHER	0.001
			0.006
	ECONOMIC		0.003
	HUMAN		0.000
	OTHER		0.000
	TOTAL		0.021
SCHEDULED	NSSS	FUEL	0.001
		RCS	0.031
		SG	0.018
		REFUEL	0.047
		OTHER	0.000
			0.097
	BOP	TURBINE	0.016
		GEN	0.000
		COND	
		CW/SW/CCW	0.000
		OTHER	0.000
			0.016
	ECONOMIC		0.004
	HUMAN		
	OTHER		
	TOTAL		0.118
REGULATORY			0.000
UNKNOWN			0.003

** TOTAL CAPACITY LOSS ** 0.142

** CAPACITY FACTOR ** 0.858

Table 6.2

Swiss PWR Capacity Losses By Reactor Age

CAPACITY LOSSES BY REACTOR AGE
1975 - 1984

SWITZERLAND
ALL PWR'S

03/23/86

		DATA:	(1)	(1)	(1)	(2)	(2)
		AGE:	1	2	3	4	5
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.000	0.000	0.014	0.000	0.001
		SG	0.006	0.000	0.000	0.009	0.000
		REFUEL					
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.006	0.000	0.014	0.009	0.001
	BOP	TURBINE	0.000	0.005	0.000	0.000	0.001
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.048	0.000	0.000	0.004	0.000
		OTHER	0.015	0.000	0.001	0.002	0.000
			0.063	0.005	0.001	0.006	0.001
	ECONOMIC		0.011	0.010	0.027	0.005	0.004
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.000	0.004	0.000	0.000	0.000
	TOTAL		0.080	0.018	0.043	0.020	0.006
SCHEDULED	NSSS	FUEL	0.004	0.009	0.016	0.003	0.000
		RCS	0.000	0.000	0.000	0.019	0.025
		SG	0.000	0.000	0.000	0.014	0.009
		REFUEL	0.159	0.139	0.132	0.074	0.060
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.163	0.148	0.148	0.110	0.094
	BOP	TURBINE	0.000	0.000	0.000	0.014	0.013
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.000	0.000	0.000	0.014	0.013
	ECONOMIC		0.000	0.000	0.002	0.003	0.003
	HUMAN						
	OTHER						
	TOTAL		0.163	0.148	0.151	0.127	0.112
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.024	0.024	0.000	0.005	0.005
** TOTAL CAPACITY LOSS **			0.267	0.190	0.194	0.152	0.123
** CAPACITY FACTOR **			0.733	0.810	0.806	0.848	0.877

Table 6.2 (Continued)

CAPACITY LOSSES BY REACTOR AGE
1975 - 1984

SWITZERLAND
ALL PWR'S

03/23/86

		DATA:	(2)	(2)	(2)	(2)	(2)
		AGE:	6	7	8	9	10
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.000	0.002	0.001	0.012	0.001
		SG	0.018	0.017	0.022	0.009	0.000
		REFUEL					
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.018	0.019	0.023	0.021	0.001
	BOP	TURBINE	0.009	0.002	0.001	0.003	0.000
		GEN	0.002	0.001	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.002	0.006	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.013	0.009	0.001	0.003	0.000
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.000	0.000	0.000	0.000	0.000
	TOTAL		0.032	0.027	0.022	0.024	0.001
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.024	0.033	0.037	0.051	0.038
		SG	0.025	0.014	0.014	0.010	0.026
		REFUEL	0.044	0.033	0.029	0.025	0.022
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.093	0.080	0.080	0.086	0.086
	BOP	TURBINE	0.022	0.025	0.026	0.018	0.022
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.001	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.023	0.025	0.026	0.018	0.022
	ECONOMIC		0.006	0.003	0.005	0.003	0.003
	HUMAN						
	OTHER						
	TOTAL		0.120	0.107	0.111	0.108	0.111
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.152	0.134	0.133	0.132	0.112
** CAPACITY FACTOR **			0.848	0.866	0.867	0.868	0.888

Table 6.2 (Continued)

CAPACITY LOSSES BY REACTOR AGE
1975 - 1984

SWITZERLAND
ALL PWR'S

03/23/86

		DATA:	(2)	(2)	(2)	(1)	(1)
		AGE:	11	12	13	14	15
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.005	0.015	0.002	0.000	0.000
		SG	0.014	0.008	0.011	0.000	0.000
		REFUEL					
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.019	0.023	0.013	0.000	0.000
	BOP	TURBINE	0.001	0.002	0.000	0.005	0.002
		GEN	0.000	0.000	0.000	0.000	0.001
		COND					
		CW/SW/CCW	0.000	0.001	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.001	0.003	0.000	0.005	0.003
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.000	0.000	0.000	0.000	0.000
	TOTAL		0.021	0.026	0.014	0.005	0.003
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.049	0.025	0.029	0.075	0.029
		SG	0.015	0.030	0.042	0.028	0.030
		REFUEL	0.016	0.022	0.024	0.022	0.021
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.080	0.077	0.095	0.125	0.080
	BOP	TURBINE	0.018	0.015	0.015	0.020	0.014
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.018	0.015	0.015	0.020	0.014
	ECONOMIC		0.003	0.004	0.010	0.014	0.010
	HUMAN						
	OTHER						
	TOTAL		0.101	0.097	0.121	0.159	0.104
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.122	0.122	0.135	0.164	0.107
** CAPACITY FACTOR **			0.878	0.878	0.865	0.836	0.893

Table 6.3
Swiss BWR Capacity Losses
By Year

CAPACITY LOSSES — SWITZERLAND
1975 - 1979 — ALL BWR'S

03/25/86

			1975	1976	1977	1978	1979
		DATA:	(1)	(1)	(1)	(1)	(1)
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.009	0.003	0.017	0.003	0.001
		SG					
		REFUEL					
		OTHER	0.000	0.000	0.001	0.000	0.001
			0.009	0.003	0.019	0.003	0.002
	BOP	TURBINE	0.011	0.010	0.006	0.007	0.004
		GEN	0.000	0.000	0.001	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.003	0.000	0.000	0.002
		OTHER	0.000	0.001	0.001	0.001	0.001
			0.011	0.014	0.008	0.008	0.007
	ECONOMIC		0.000	0.000	0.000	0.000	0.000
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.000	0.000	0.000	0.002	0.000
	TOTAL		0.020	0.017	0.028	0.012	0.008
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.001	0.000	0.000	0.000	0.000
		SG					
		REFUEL	0.084	0.096	0.079	0.096	0.093
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.085	0.096	0.079	0.096	0.093
	BOP	TURBINE	0.002	0.000	0.000	0.000	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND					
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.000	0.000	0.000	0.000	0.000
			0.002	0.000	0.000	0.000	0.000
	ECONOMIC		0.023	0.028	0.031	0.019	0.018
	HUMAN						
	OTHER						
	TOTAL		0.111	0.124	0.111	0.115	0.111
REGULATORY			0.000	0.000	0.000	0.000	0.000
UNKNOWN			0.000	0.000	0.000	0.000	0.000
** TOTAL CAPACITY LOSS **			0.131	0.141	0.137	0.127	0.120
** CAPACITY FACTOR **			0 869	0.859	0.863	0.873	0.880

Table 6.3 (Continued)

```
CAPACITY LOSSES                                                SWITZERLAND
1980 - 1984                                                      ALL BWR'S

03/25/86                     DATA:( 1)   ( 1)   ( 1)   ( 1)   ( 1)
:------------------------------------------------------------------------:
:                                 1980   1981   1982   1983   1984       :
:------------------------------------------------------------------------:
: FORCED     : NSSS : FUEL        0.000  0.000  0.000  0.000  0.000      :
:            :      : RCS         0.004  0.001  0.004  0.000  0.010      :
:            :      : SG                                                  :
:            :      : REFUEL                                              :
:            :      : OTHER       0.000  0.000  0.000  0.000  0.000      :
:            :      :             -----  -----  -----  -----  -----      :
:            :      :             0.004  0.001  0.004  0.001  0.010      :
:            :-----------------------------------------------------------:
:            : BOP  : TURBINE     0.007  0.004  0.003  0.004  0.003      :
:            :      : GEN         0.000  0.000  0.000  0.000  0.000      :
:            :      : COND                                                :
:            :      : CW/SW/CCW   0.000  0.000  0.001  0.000  0.000      :
:            :      : OTHER       0.000  0.001  0.001  0.001  0.001      :
:            :      :             -----  -----  -----  -----  -----      :
:            :      :             0.007  0.005  0.005  0.005  0.004      :
:            :-----------------------------------------------------------:
:            : ECONOMIC           0.000  0.000  0.000  0.000  0.000      :
:            :-----------------------------------------------------------:
:            : HUMAN              0.000  0.000  0.000  0.000  0.000      :
:            :-----------------------------------------------------------:
:            : OTHER              0.001  0.001  0.001  0.001  0.000      :
:             -----------------------------------------------------------:
:              TOTAL              0.012  0.008  0.009  0.006  0.014      :
:------------------------------------------------------------------------:
: SCHEDULED  : NSSS : FUEL        0.000  0.000  0.000  0.000  0.000      :
:            :      : RCS         0.000  0.000  0.000  0.000  0.000      :
:            :      : SG                                                  :
:            :      : REFUEL      0.096  0.085  0.085  0.082  0.087      :
:            :      : OTHER       0.000  0.000  0.000  0.000  0.000      :
:            :      :             -----  -----  -----  -----  -----      :
:            :      :             0.096  0.085  0.085  0.082  0.087      :
:            :-----------------------------------------------------------:
:            : BOP  : TURBINE     0.000  0.000  0.000  0.000  0.000      :
:            :      : GEN         0.000  0.000  0.000  0.000  0.000      :
:            :      : COND                                                :
:            :      : CW/SW/CCW   0.000  0.000  0.000  0.000  0.000      :
:            :      : OTHER       0.000  0.000  0.000  0.000  0.000      :
:            :      :             -----  -----  -----  -----  -----      :
:            :      :             0.000  0.000  0.000  0.000  0.000      :
:            :-----------------------------------------------------------:
:            : ECONOMIC           0.012  0.012  0.012  0.011  0.015      :
:            :-----------------------------------------------------------:
:            : HUMAN                                                      :
:            :-----------------------------------------------------------:
:            : OTHER                                                      :
:             -----------------------------------------------------------:
:              TOTAL              0.108  0.097  0.097  0.093  0.102      :
:------------------------------------------------------------------------:
: REGULATORY :                    0.000  0.000  0.000  0.000  0.000      :
:------------------------------------------------------------------------:
: UNKNOWN    :                    0.000  0.000  0.000  0.000  0.000      :
:------------------------------------------------------------------------:

** TOTAL CAPACITY LOSS **         0.121  0.105  0.106  0.099  0.115

** CAPACITY FACTOR **             0.879  0.895  0.894  0.901  0.885
```

Table 6.3 (Continued)

CAPACITY LOSSES
1975 - 1984

SWITZERLAND
ALL BWR'S

03/25/86 DATA: 1 PLANTS 10 PLANT-YEARS

			AVERAGE OVER ALL YEARS
FORCED	NSSS	FUEL	0.000
		RCS	0.005
		SG	
		REFUEL	
		OTHER	0.000
			0.006
	BOP	TURBINE	0.006
		GEN	0.000
		COND	
		CW/SW/CCW	0.001
		OTHER	0.001
			0.007
	ECONOMIC		0.000
	HUMAN		0.000
	OTHER		0.000
	TOTAL		0.013
SCHEDULED	NSSS	FUEL	0.000
		RCS	0.000
		SG	
		REFUEL	0.088
		OTHER	0.000
			0.089
	BOP	TURBINE	0.000
		GEN	0.000
		COND	
		CW/SW/CCW	0.000
		OTHER	0.000
			0.000
	ECONOMIC		0.018
	HUMAN		
	OTHER		
	TOTAL		0.107
REGULATORY			0.000
UNKNOWN			0.000

** TOTAL CAPACITY LOSS ** 0.120

** CAPACITY FACTOR ** 0.880

Table 6.4

Swiss BWR Capacity Losses
By Reactor Age

CAPACITY LOSSES BY REACTOR AGE — SWITZERLAND
1975 - 1984 — ALL BWR'S

03/23/86

		DATA:	(0)	(0)	(1)	(1)	(1)
		AGE:	1	2	3	4	5
FORCED	NSSS	FUEL			0.000	0.000	0.000
		RCS			0.009	0.003	0.017
		SG					
		REFUEL					
		OTHER			0.000	0.000	0.001
					0.009	0.003	0.018
	BOP	TURBINE			0.011	0.010	0.006
		GEN			0.000	0.000	0.001
		COND					
		CW/SW/CCW			0.000	0.003	0.000
		OTHER			0.000	0.001	0.001
					0.011	0.014	0.008
	ECONOMIC				0.000	0.000	0.000
	HUMAN				0.000	0.000	0.000
	OTHER				0.000	0.000	0.000
	TOTAL				0.020	0.017	0.026
SCHEDULED	NSSS	FUEL			0.000	0.000	0.000
		RCS			0.001	0.000	0.000
		SG					
		REFUEL			0.084	0.096	0.079
		OTHER			0.000	0.000	0.000
					0.085	0.096	0.079
	BOP	TURBINE			0.002	0.000	0.000
		GEN			0.000	0.000	0.000
		COND					
		CW/SW/CCW			0.000	0.000	0.000
		OTHER			0.000	0.000	0.000
					0.002	0.000	0.000
	ECONOMIC				0.023	0.028	0.031
	HUMAN						
	OTHER						
	TOTAL				0.111	0.124	0.111
REGULATORY					0.000	0.000	0.000
UNKNOWN					0.000	0.000	0.000
** TOTAL CAPACITY LOSS **					0.131	0.141	0.137
** CAPACITY FACTOR **					0.869	0.859	0.863

Table 6.4 (Continued)

```
CAPACITY LOSSES BY REACTOR AGE                                    SWITZERLAND
1975 - 1984                                                        ALL BWR'S

03/23/86                   DATA:( 1)   ( 1)   ( 1)   ( 1)   ( 1)
:-----------------------------------------------------------------------:
:                          AGE:      6      7      8      9     10      :
:-----------------------------------------------------------------------:
: FORCED       : NSSS : FUEL      0.000  0.000  0.000  0.000  0.000     :
:              :      : RCS       0.003  0.001  0.004  0.001  0.004     :
:              :      : SG                                              :
:              :      : REFUEL                                          :
:              :      : OTHER     0.000  0.001  0.000  0.000  0.000     :
:              :      :           -----  -----  -----  -----  -----     :
:              :      :           0.003  0.002  0.004  0.001  0.004     :
:              :--------------------------------------------------------:
:              : BOP  : TURBINE   0.007  0.004  0.007  0.004  0.003     :
:              :      : GEN       0.000  0.000  0.000  0.000  0.000     :
:              :      : COND                                            :
:              :      : CW/SW/CCW 0.000  0.002  0.000  0.000  0.001     :
:              :      : OTHER     0.001  0.001  0.000  0.001  0.001     :
:              :      :           -----  -----  -----  -----  -----     :
:              :      :           0.008  0.007  0.007  0.005  0.005     :
:              :--------------------------------------------------------:
:              : ECONOMIC         0.000  0.000  0.000  0.000  0.000     :
:              :--------------------------------------------------------:
:              : HUMAN            0.000  0.000  0.000  0.000  0.000     :
:              :--------------------------------------------------------:
:              : OTHER            0.002  0.000  0.001  0.001  0.001     :
:              ---------------------------------------------------------:
:                TOTAL            0.012  0.008  0.012  0.008  0.009     :
:-----------------------------------------------------------------------:
: SCHEDULED    : NSSS : FUEL      0.000  0.000  0.000  0.000  0.000     :
:              :      : RCS       0.000  0.000  0.000  0.000  0.000     :
:              :      : SG                                              :
:              :      : REFUEL    0.096  0.093  0.096  0.085  0.085     :
:              :      : OTHER     0.000  0.000  0.000  0.000  0.000     :
:              :      :           -----  -----  -----  -----  -----     :
:              :      :           0.096  0.093  0.096  0.085  0.085     :
:              :--------------------------------------------------------:
:              : BOP  : TURBINE   0.000  0.000  0.000  0.000  0.000     :
:              :      : GEN       0.000  0.000  0.000  0.000  0.000     :
:              :      : COND                                            :
:              :      : CW/SW/CCW 0.000  0.000  0.000  0.000  0.000     :
:              :      : OTHER     0.000  0.000  0.000  0.000  0.000     :
:              :      :           -----  -----  -----  -----  -----     :
:              :      :           0.000  0.000  0.000  0.000  0.000     :
:              :--------------------------------------------------------:
:              : ECONOMIC         0.019  0.018  0.012  0.012  0.012     :
:              :--------------------------------------------------------:
:              : HUMAN                                                  :
:              :--------------------------------------------------------:
:              : OTHER                                                  :
:              ---------------------------------------------------------:
:                TOTAL            0.115  0.111  0.108  0.097  0.097     :
:-----------------------------------------------------------------------:
: REGULATORY :                    0.000  0.000  0.000  0.000  0.000     :
:-----------------------------------------------------------------------:
: UNKNOWN    :                    0.000  0.000  0.000  0.000  0.000     :
:-----------------------------------------------------------------------:

** TOTAL CAPACITY LOSS **         0.127  0.119  0.120  0.105  0.106

** CAPACITY FACTOR **             0.873  0.881  0.880  0.895  0.894
```

/

Table 6.4 (Continued)

CAPACITY LOSSES BY REACTOR AGE
1975 - 1984

SWITZERLAND
ALL BWR'S

03/23/86

			11	12	13	14	15
		DATA:	(1)	(1)	(0)	(0)	(0)
FORCED	NSSS	FUEL	0.000	0.000			
		RCS	0.000	0.010			
		SG					
		REFUEL					
		OTHER	0.000	0.000			
			0.000	0.010			
	BOP	TURBINE	0.004	0.003			
		GEN	0.000	0.000			
		COND					
		CW/SW/CCW	0.000	0.000			
		OTHER	0.001	0.001			
			0.005	0.004			
	ECONOMIC		0.000	0.000			
	HUMAN		0.000	0.000			
	OTHER		0.001	0.000			
	TOTAL		0.006	0.014			
SCHEDULED	NSSS	FUEL	0.000	0.000			
		RCS	0.000	0.000			
		SG					
		REFUEL	0.082	0.087			
		OTHER	0.000	0.000			
			0.082	0.087			
	BOP	TURBINE	0.000	0.000			
		GEN	0.000	0.000			
		COND					
		CW/SW/CCW	0.000	0.000			
		OTHER	0.000	0.000			
			0.000	0.000			
	ECONOMIC		0.011	0.015			
	HUMAN						
	OTHER						
	TOTAL		0.093	0.102			
REGULATORY			0.000	0.000			
UNKNOWN			0.000	0.000			

** TOTAL CAPACITY LOSS ** 0.099 0.116

** CAPACITY FACTOR ** 0.901 0.884

Table 6.5 - Swiss Capacity Factor Distributions

By	PWR			BWR		
Year	Mean	σ	# Data	Mean	σ	# Data
75	0.825	0.008	2	0.869	0.000	1
76	0.849	0.017	2	0.859	0.000	1
77	0.865	0.015	2	0.863	0.000	1
78	0.902	0.001	2	0.873	0.000	1
79	0.877	0.007	2	0.880	0.000	1
80	0.811	0.056	3	0.879	0.000	1
81	0.853	0.040	3	0.895	0.000	1
82	0.847	0.035	3	0.894	0.000	1
83	0.871	0.032	3	0.901	0.000	1
84	0.890	0.002	3	0.885	0.000	1

By	PWR			BWR		
Age	Mean	σ	# Data	Mean	σ	# Data
1	0.734	0.000	1			
2	0.810	0.000	1			
3	0.807	0.000	1	0.869	0.000	1
4	0.847	0.014	2	0.859	0.000	1
5	0.877	0.012	2	0.863	0.000	1
6	0.848	0.032	2	0.873	0.000	1
7	0.867	0.035	2	0.880	0.000	1
8	0.867	0.017	2	0.879	0.000	1
9	0.869	0.034	2	0.895	0.000	1
10	0.889	0.019	2	0.894	0.000	1
11	0.879	0.014	2	0.901	0.000	1
12	0.878	0.036	2	0.885	0.000	1
13	0.865	0.023	2			
14	0.836	0.000	1			
15	0.893	0.000	1			
16						
17						

FIGURE 6.12

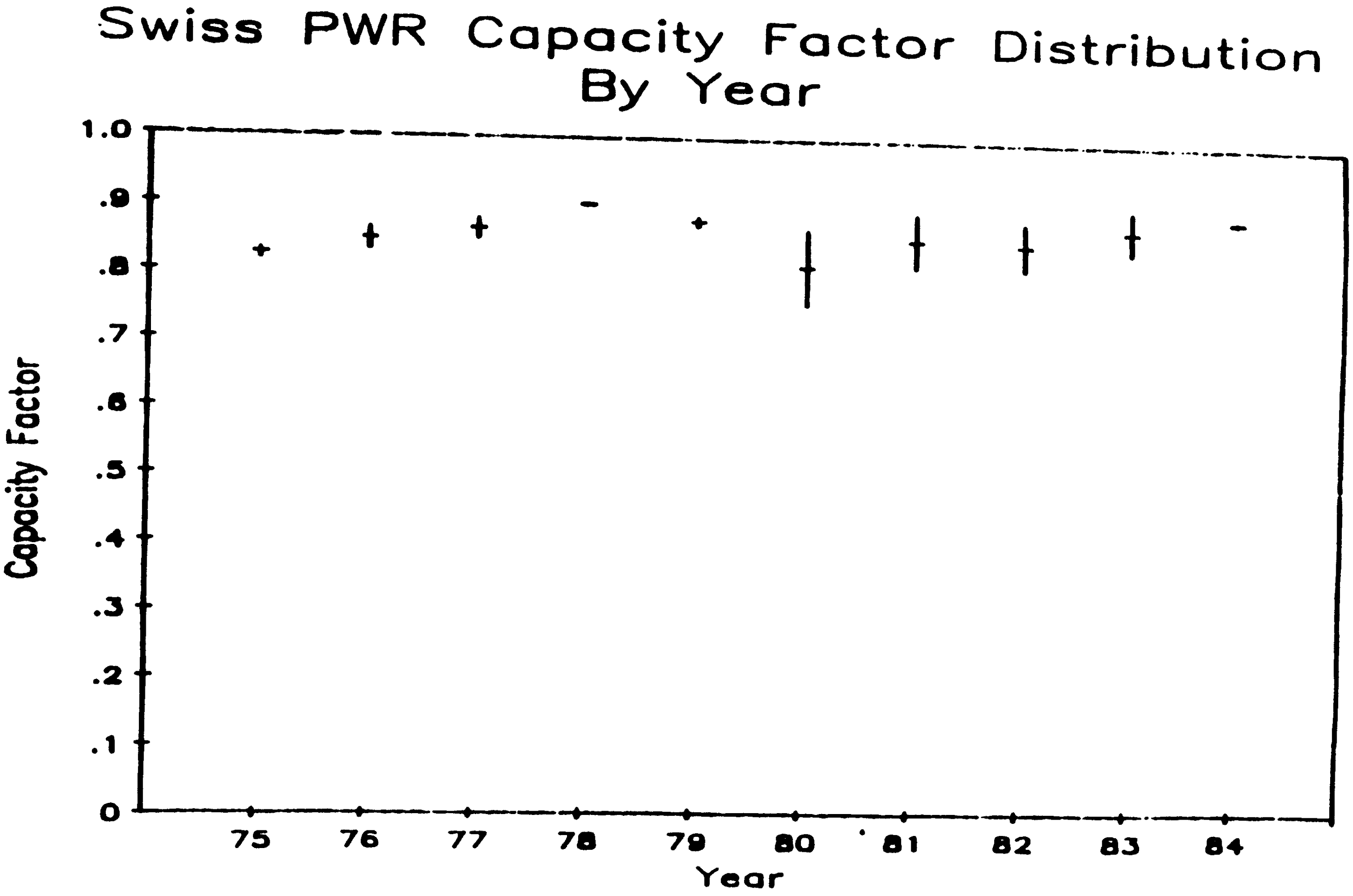
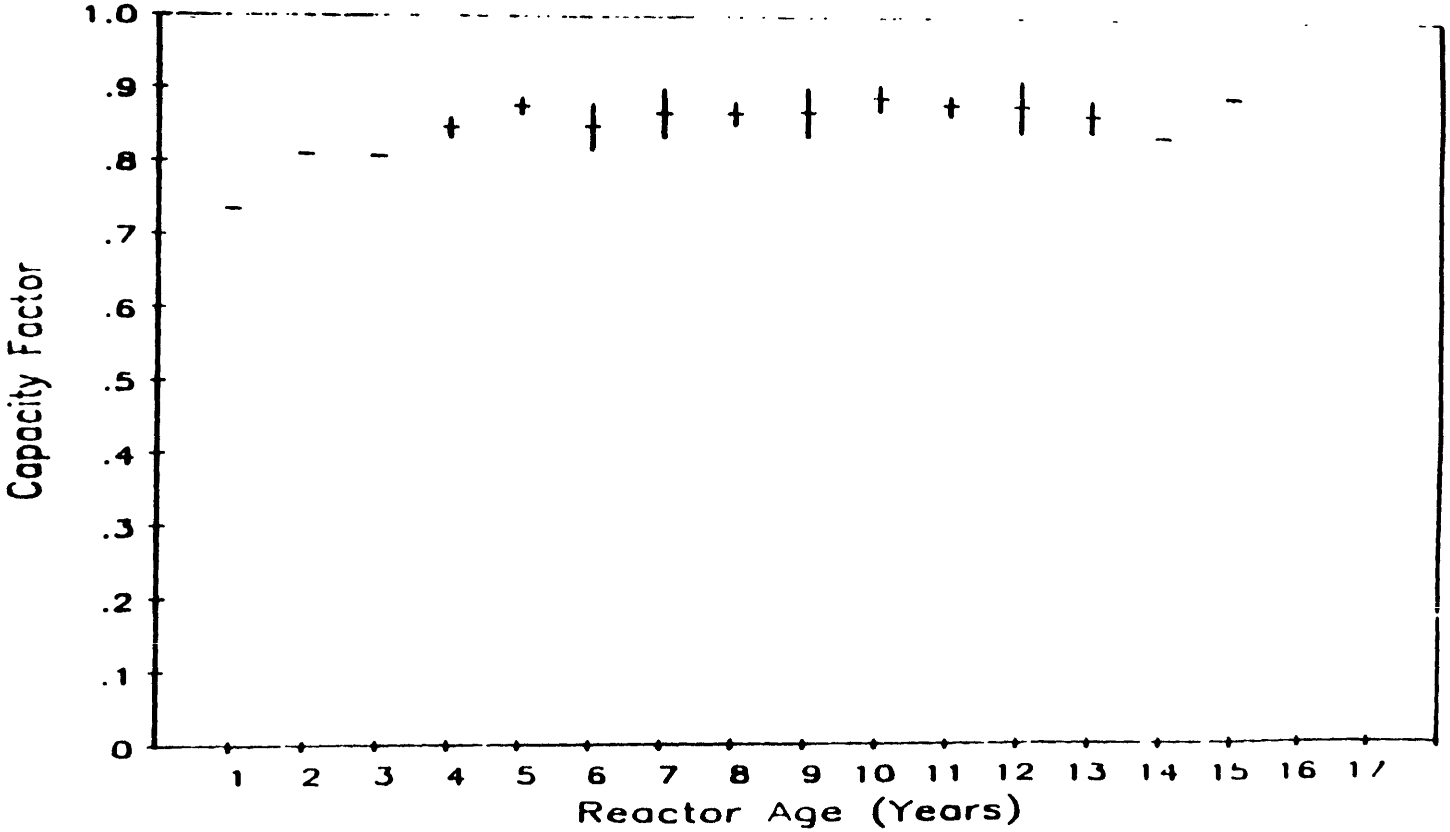

Swiss PWR Capacity Factor Distribution
By Year
Capacity Factor
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
75
76
77
78
79
80
81
82
83
84
Year

FIGURE 6.13

Swiss PWR Capacity Factor Distribution By Reactor Age



the third PWR coming online in 1980 and not operating as well as the other two reactors. The standard deviations are generally small and exhibit no age dependence.

6.8.3 LOSSES BY OUTAGE TYPE

In this subsection, forced, scheduled, and regulatory losses for the Swiss nuclear plants are displayed and examined as functions of time and age.

Forced, scheduled, and regulatory losses of Swiss PWR's are plotted by year in Figure 6.14. The total losses of the Swiss PWR's have been the lowest of the six countries investigated, with a 10 year average of 14.2%. The figure shows the the total losses display two periods of improvement. Scheduled losses are the largest contributor to the total losses responsible for 83.1%. The scheduled losses have been generally constant with a small amount of fluctuation from year to year. The forced outages have been very small, averaging only 2.1% per year. In addition, the forced losses also account for the two periods of improvement seen in the curve of the total losses. The first of these periods was from 1975 to 1979 when losses decreased as a result of improvements in steam generator, turbine, and CW/SW/CCW performance. In 1980, a new PWR came online which did not perform as well as the two already operating, causing an increase in losses. From 1980 to 1984 losses again decreased but this time from a combination of different improvements from all three of the PWR's. There were no regulatory losses reported for the Swiss PWR's.

The Swiss PWR losses are plotted by reactor age in Figure 6.15. In this figure it can be seen that all the losses have generally decreased each year up to age 5, after which they have remained essentially

FIGURE 6.14

Swiss PWR Capacity Losses By Year
Forced, Scheduled, and Regulatory

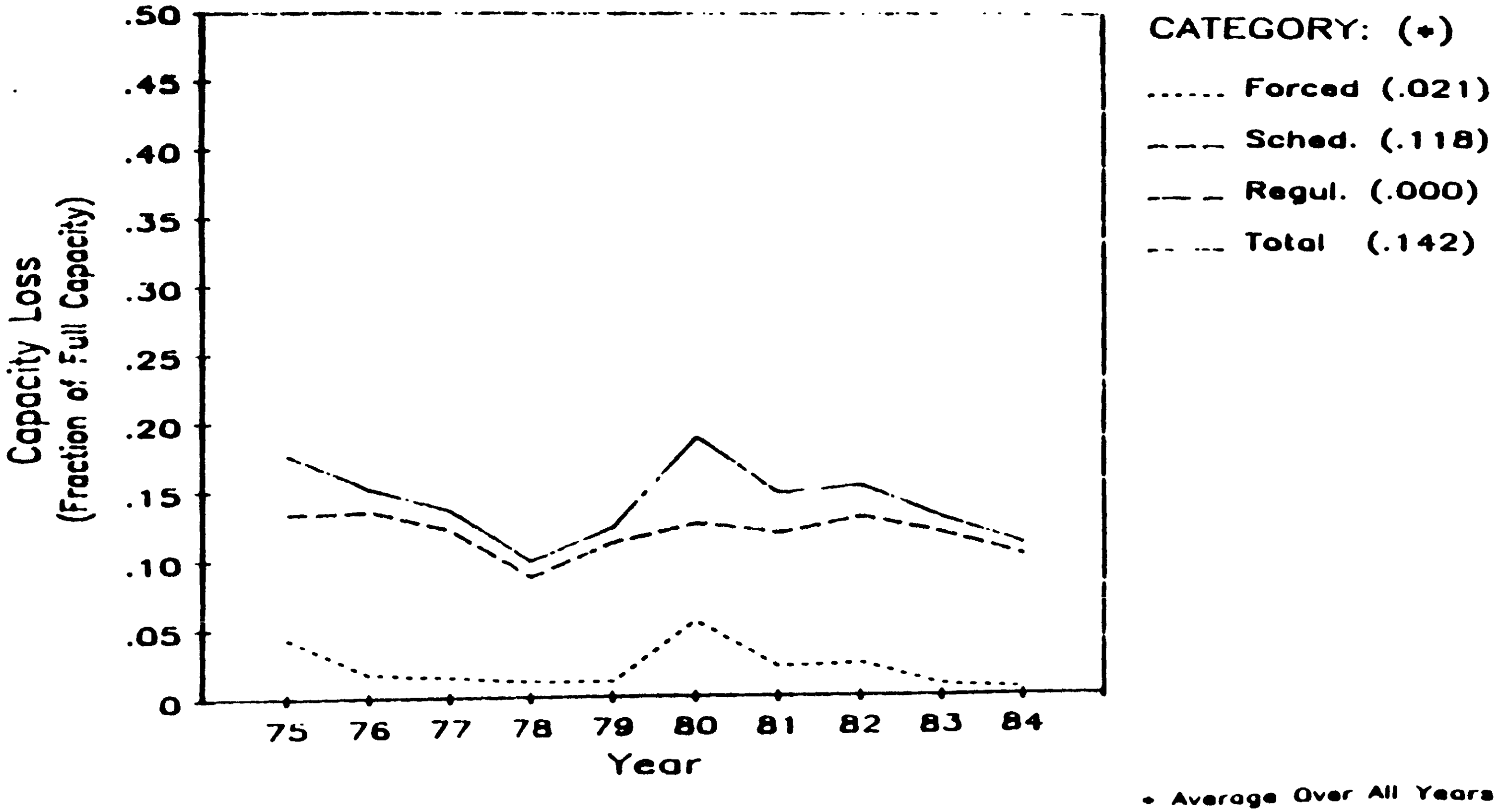
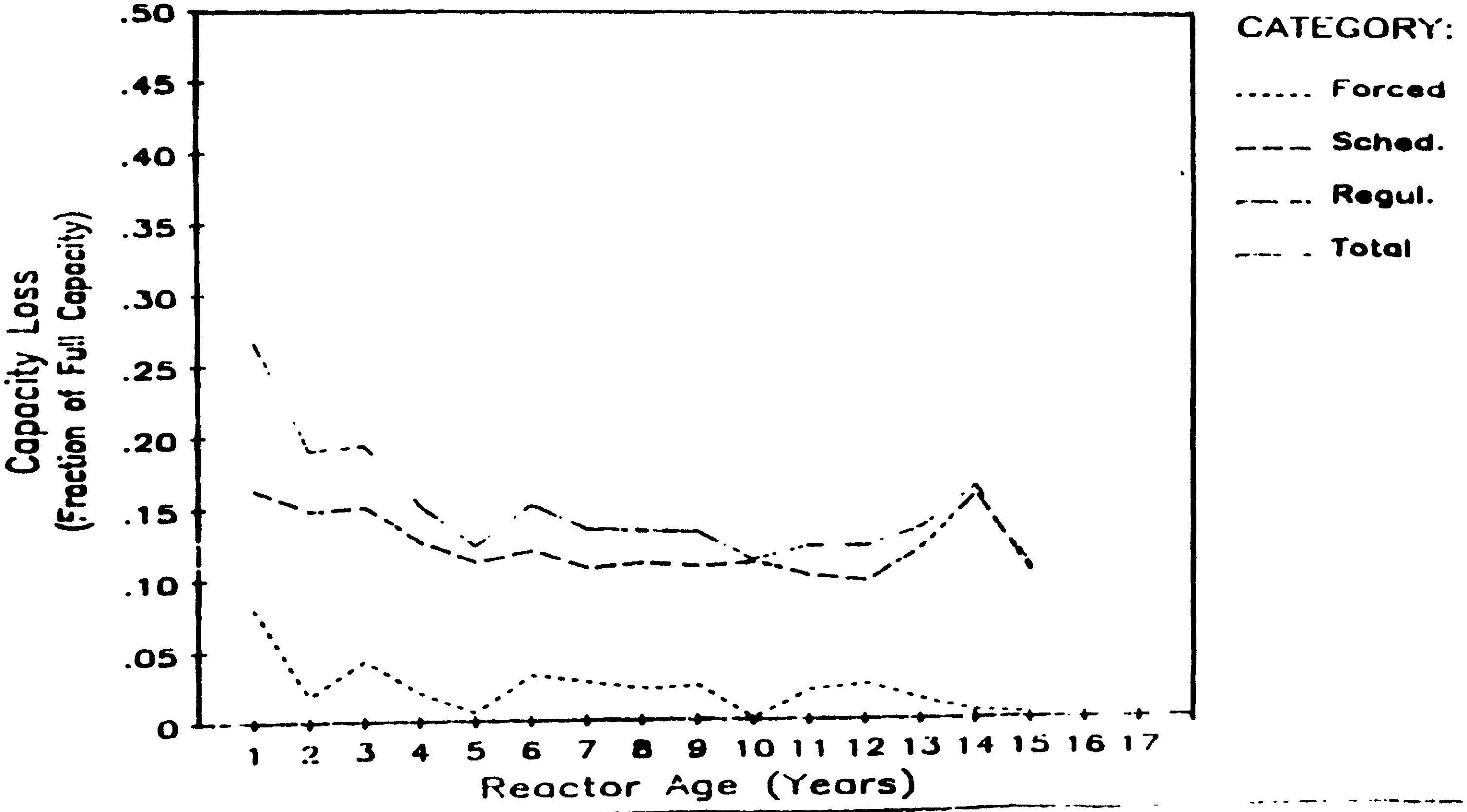


FIGURE 6.15

Swiss PWR Capacity Losses By Reactor Age
Forced, Scheduled, and Regulatory

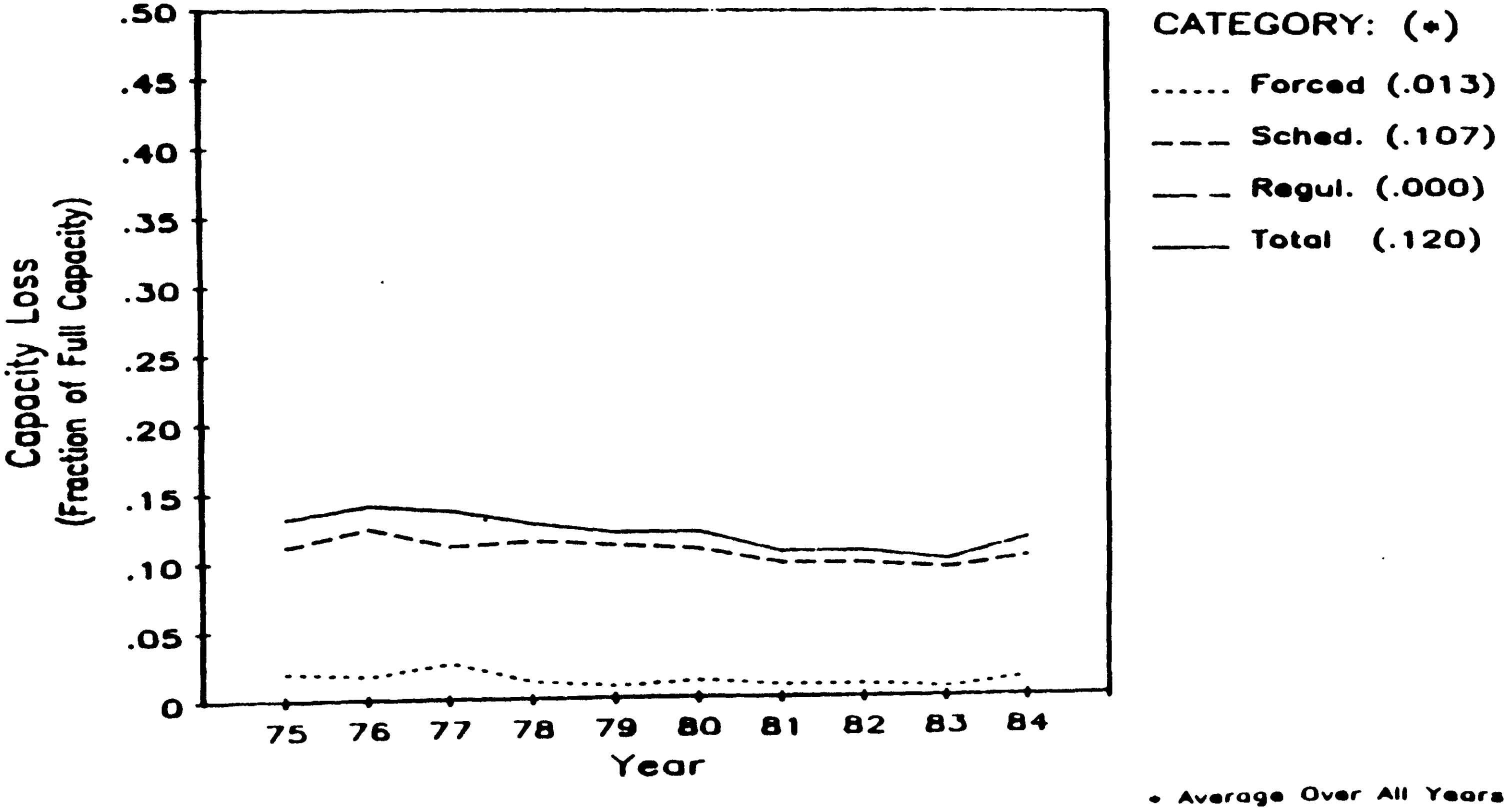


constant. The peak at age 14 is due to increased reactor coolant system problems at the only plant with that age.

The forced, scheduled and regulatory losses for the only Swiss BWR are plotted by year in Figure 6.16. As illustrated, the losses in all categories have decreased slightly with time. The scheduled losses, with a ten year average of 10.7%, make up the largest fraction of the total losses, representing 89.2% of the total. Forced losses are small, averaging only 1.3% per year over the 10 year period. There were no reported regulatory losses for the Swiss BWR. The magnitude of the decrease in losses was approximately 2.5 percentage points and is too small to allow the identification of the specific systems responsible.

FIGURE 6.16

Swiss BWR Capacity Losses By Year
Forced, Scheduled, and Regulatory



6.9 OBSERVATION

At first glance the Swiss nuclear power industry contains many elements which could lead to the conclusion that this could hinder good performance, but Swiss nuclear power plants show the best operation results of all investigated nations.

The utility industry is fragmented and the LWR population is very small. The power plants have been constructed by a variety of different vendors and/or designed by different architect/engineers. But the capabilities of utilities management and their good professional relations to suppliers and to safety authorities seem to play decisive roles for the achievement of high capacity factors. It does not appear that safety regulation as well as economic reputation hamper the operation procedure of the plant management.

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4. OECD, "Licensing Systems and Inspection of Nuclear Installations," Paris, 1986.

5. OECD, "Projected Costs of Generating Electricity," Paris, 1986.

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7. Schweizerische Vereinigung fur Atomenergie (SVA), Jahresbericht, 1984.

CHAPTER 7

NUCLEAR POWER IN THE UNITED STATES

7.1 STRUCTURE OF THE ELECTRIC POWER INDUSTRY

Compared to the five other countries examined in this report, the U.S. nuclear power system is the largest and most complex. The total installed capacity of the U.S. electric power industry in 1984 was approximately 604,000* MWe, of which approximately 43 percent was coal-fired, 32 percent oil- and natural gas-fired, 10 percent nuclear-fired, and 15 percent supplied by other technologies. This capacity is operated mainly by approximately 200 privately-owned and two federally-owned utilities - The Tennessee Valley Authority and the Bonneville Power Authority. However, as shown by Table 7.1, many other organizations are involved at all levels of utility function. The three largest U.S. utilities are the Tennessee Valley Authority (32,000 MWe total, 5,500 MWe nuclear), Commonwealth Edison Company (21,000 MWe total, 8,500 MWe nuclear), and Duke Power Company (13,900 MWe total, 6,100 MWe nuclear). The smallest generating companies typically have less than 1,000 MWe capacity.

The total capacity of the nuclear power sector is approximately 62,000 MWe, with another 56,000 MWe under construction. Approximately 115 nuclear power stations are expected to be operating by the year 1995, as illustrated by Figure 7.1. The nuclear sector involves 54 lead utility companies (see Table 7.2), nearly half of which operate only a single reactor, while the three largest are responsible for approximately 24 percent of the expected total nuclear capacity. The U.S. nuclear

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* Source: "1985 Electric Power Supply and Demand," North American Electric Reliability Council (1985).

Table 7.1

Structure of the Electric Power Industry

Type of Utility	Number in each Group	Number of customers		Sales		Operating Revenue		Installed Nameplate Capacity		Generation	
		(millions)	%	(billion kWh)	%	(billion dollars)	%	(gigawatts)	%	(billion kWh)	%
Investor-Owned[a]	199	73.8	76.5	1,645.1	76 0	117.3	74.5	505.5	76.8	1,764.1	76 4
Cooperatives	936	9.6	9.9	144.0	6.8	15.5	9.8	22.2	3.4	84.7	3.7
Municipals	1,736	11.3	11.7	258.9	12.3	15.8	10.0	36.6	5.6	73.1	3.2
Federal	10	*	—	53.7	2.5	6.6	4.2	63.0	9.6	258.2	11 2
Other Public Entities[b]	156	1.8	1 9	49.3	2.3	2.3	1.5	30 9	4.7	130 2	5 6
Totals	3,037	96.5	100.0	2,151.0	100.0	157.4	100.0	658.2	100.0	2,310.3	100.0

* Fewer than 50,000 customers.

[a] Class A and B utilities only (those having annual operating revenues of $1 million or more); these utilities are believed to provide over 90 percent of generation by investor-owned utilities.

[b] Other public entities include public power districts, State authorities, irrigation districts, and State organizations.

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

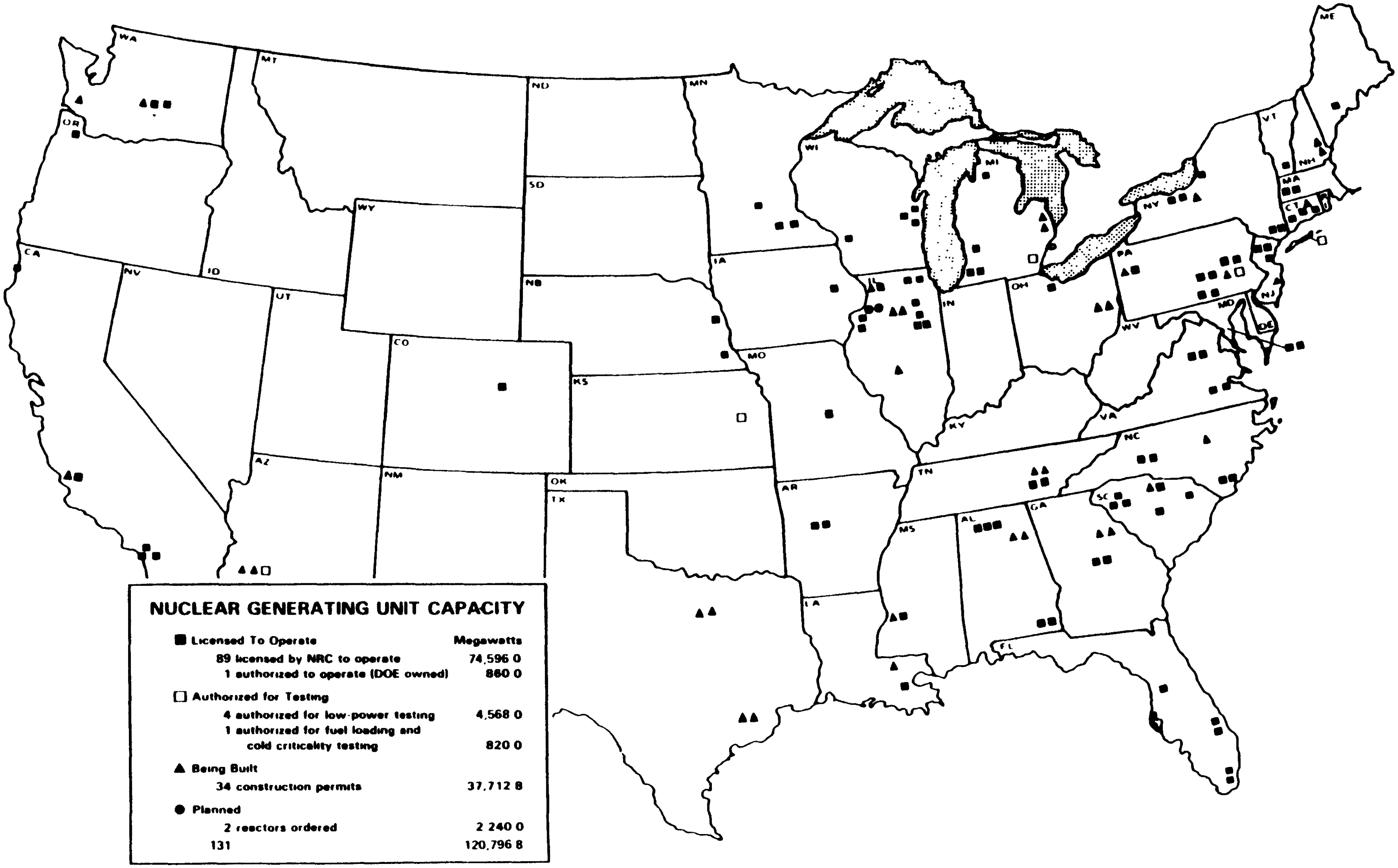
Sources: eInstalled capacity and generation data, Edison Electric Institute, **Statistical Yearbook of the Electric Utility Industry** (1983) pp. 8, 20; eInvestor-owned utility data, Energy Information Administration, **Financial Statistics of Selected Electric Utilities 1983** (February 1985), pp. vi, 32; eCooperatives, municipals and other public entities data, **Electrical World Directory of Electric Utilities,** McGraw-Hill Publications Co. (1984); Rural Electrification Administration, **1983 Statistical Report,** Rural Electric Borrowers, Bulletin 1-1; Tennessee Valley Authority, **Annual Report of the Tennessee Valley Authority,** Volume II, 1983 (April 1984); Bonneville Power Administration, **1983 Program and Financial Summary** (March 1984); Southwestern Power Administration, **1983 Annual Report;** Western Area Power Administration, **1983 Annual Report** (March 1984); Alaska Power Administration, "Annual Report of Public Electric Utilities" (1983) Form EIA-412; Southeastern Power Administration, Annual Report 1983 (1984); unpublished data from the Bureau of Indian Affairs and the Western Area Power Administration.

[34] This chapter presents 1983 rather than 1984 data because sufficient 1984 data are not yet available.

Source: Energy Information Administration, Department of Energy, Annual Outlook for U.S. Electric Power 1985, U.S. Government Printing Office, Washington, D.C., 1986.

Figure 7.1

Commercial Nuclear Power Reactors in the United States



NUCLEAR GENERATING UNIT CAPACITY

■ Licensed To Operate	Megawatts
89 licensed by NRC to operate	74,596 0
1 authorized to operate (DOE owned)	860 0
☐ Authorized for Testing	
4 authorized for low-power testing	4,568 0
1 authorized for fuel loading and cold criticality testing	820 0
▲ Being Built	
34 construction permits	37,712 8
● Planned	
2 reactors ordered	2 240 0
131	120,796 8

There are no symbols for units planned but not sited
Because of space limitations symbols do not reflect precise locations

DOE/TIC 0007(3/85)

Office of Scientific and Technical Information
U S Department of Energy
Revised March 1986

TABLE 7.2

UNITED STATES NUCLEAR POWER STATIONS

United States NORTHEAST	Net MWe	Type	Reactor Supplier	Generator Supplier	Architect Engineer	Constructor	Con-struc-tion stage (%)	Commercial Operation orig. sched-ule†	Commercial Operation actual or ex-pected
Baltimore Gas & Electric Co.									
● Calvert Cliffs 1 (Lusby, Md.)	850	PWR	C-E	GE	Bechtel	Bechtel	100	1/73	5/75
● Calvert Cliffs 2 (Lusby, Md.)	850	PWR	C-E	W	Bechtel	Bechtel	100	1 74	4/77
Boston Edison Co.									
● Pilgrim 1 (Plymouth, Mass.)	670	BWR	GE	GE	Bechtel	Bechtel	100	10/71	12/72
Connecticut Yankee Atomic Power Co.									
● Haddam Neck (Haddam Neck, Conn.)	582	PWR	W	W	S&W	S&W	100	11 67	1 68
Consolidated Edison Co.									
● Indian Point 2 (Indian Point, N.Y.)	873	PWR	W	W	UE&C	Wedco	100	6/69	7 74
Duquesne Light Co.									
● Beaver Valley 1 (Shippingport, Pa.)	833	PWR	W	W	S&W	S&W/DLC	100	6/73	4 77
Beaver Valley 2 (Shippingport, Pa.)	833	PWR	W	W	S&W	DLC	83 3	10/78	10 86
GPU Nuclear Corporation									
● Oyster Creek 1 (Forked River, N.J.)	620	BWR	GE	GE	B&R/GE	B&R	100	2 68	12 69
● Three Mile Island 1* (Londonderry Twp., Pa.)	792	PWR	B&W	GE	Gilbert	UE&C	100	9/71	9/74
● Three Mile Island 2* (Londonderry Twp., Pa.)	880	PWR	B&W	W	B&R	UE&C	100	5/73	12 78
Long Island Lighting Co.									
Shoreham (Brookhaven, N Y)	809	BWR	GE	GE	S&W	Utility	100	75	10 85
Maine Yankee Atomic Power Co.									
● Maine Yankee (Wiscasset, Me.)	825	PWR	C-E	W	S&W	S&W	100		12 72
New Hampshire Yankee, Inc.									
Seabrook 1 (Seabrook, N H.)	1150	PWR	W	GE	UE&C	UE&C	80	11 79	8 86
Seabrook 2 (Seabrook, N H.)	1150	PWR	W	GE	UE&C	UE&C	23	8/81	indef
New York Power Authority									
● Indian Point 3 (Indian Point, N.Y)	965	PWR	W	W	UE&C	Wedco	100	7 71	8 76
● James A FitzPatrick (Scriba, N.Y.)	821	BWR	GE	GE	S&W	S&W	100	1 73	7 75
Niagara Mohawk Power Corp.									
● Nine Mile Point 1 (Scriba, N.Y)	610	BWR	GE	GE	Utility	S&W	100	11 68	12 69
Nine Mile Point 2 (Scriba, N Y)	1080	BWR	GE	GE	S&W	S&W	85	7 78	10 86
Northeast Utilities									
● Millstone 1 (Waterford, Conn.)	660	BWR	GE	GE	Ebasco	Ebasco	100	6 69	12 70
● Millstone 2 (Waterford, Conn)	870	PWR	C-E	GE	Bechtel	Bechtel	100	4/74	12 75
Millstone 3 (Waterford, Conn.)	1150	PWR	W	GE	S&W	S&W	92	3/78	5 86
Pennsylvania Power & Light Co.									
● Susquehanna 1 (Berwick, Pa.)	1050	BWR	GE	GE	Bechtel	Bechtel	100	5/79	6 83
Susquehanna 2 (Berwick, Pa.)	1050	BWR	GE	GE	Bechtel	Bechtel	100	5/81	1 85
Philadelphia Electric Co.									
● Peach Bottom 2 (Peach Bottom, Pa.)	1065	BWR	GE	GE	Bechtel	Bechtel	100	71	7 74
● Peach Bottom 3 (Peach Bottom, Pa.)	1065	BWR	GE	GE	Bechtel	Bechtel	100	73	12 74
Limerick 1 (Pottstown, Pa.)	1055	BWR	GE	GE	Bechtel	Bechtel	100	8/78	9 85
Limerick 2 (Pottstown, Pa.)	1055	BWR	GE	GE	Bechtel	Bechtel	31	1 80	10/88
Public Service Electric & Gas Co.									
● Salem 1 (Salem, N J)	1079	PWR	W	W	Utility	UE&C	100	71	6 77
● Salem 2 (Salem, N.J.)	1106	PWR	W	W	Utility	UE&C	100	73	10/81
Hope Creek 1 (Salem, N.J.)	1070	BWR	GE	GE	Bechtel	Bechtel	94 5	3/75	12 86
Rochester Gas & Electric Corp.									
● Robert E. Ginna (Ontario, N.Y.)	490	PWR	W	W	Gilbert	Bechtel	100	11 69	3 70
Vermont Yankee Nuclear Power Corp.									
● Vermont Yankee (Vernon, Vt.)	514	BWR	GE	GE	Ebasco	Ebasco	100	10/70	11 72
Yankee Atomic Electric Co.									
● Yankee (Rowe, Mass.)	175	PWR	W	W	S&W	S&W	100	1 61	6 61

NOTE: Removed from this list is Dresden 1 Commonwealth Edison Company announced that this unit, long out of operation, will be cleaned and eventually decommissioned Also removed from this list are Marble Hill 1 and 2, Hartsville A1 and A2, and Yellow Creek 1 and 2. All of these have been canceled. Please also note that Public Service Company of New Hampshire has changed its name to New Hampshire Yankee

*Retained on this list are GPU Nuclear s Three Mile Island 1 and 2 units even though these have long been out of commercial operation

TABLE 7.2 (Continued)

MIDWEST	Net MWe	Type	Reactor Supplier	Generator Supplier	Architect Engineer	Constructor	Construction stage (%)	Commercial Operation orig. schedule†	Commercial Operation actual or expected
The Cleveland Electric Illuminating Co.									
Perry 1 (North Perry, Ohio)	1205	BWR	GE	GE	Gilbert	Utility	97	7 79	12 85
Perry 2 (North Perry, Ohio)	1205	BWR	GE	GE	Gilbert	Utility	44	7 80	indef
Commonwealth Edison Company									
● Dresden 2 (Morris, Ill.)	794	BWR	GE	GE	S&L	UE&C	100	2 69	8/70
● Dresden 3 (Morris, Ill.)	794	BWR	GE	GE	S&L	UE&C	100	2 70	10/71
● LaSalle County 1 (Seneca, Ill.)	1078	BWR	GE	GE	S&L	Utility	100	2 76	10/82
● LaSalle County 2 (Seneca, Ill.)	1078	BWR	GE	GE	S&L	Utility	100	2 77	6 84
● Zion 1 (Zion, Ill.)	1040	PWR	W	W	S&L	Utility	100	4 72	12 73
● Zion 2 (Zion, Ill.)	1040	PWR	W	W	S&L	Utility	100	5/73	9/74
Byron 1 (Byron, Ill.)	1120	PWR	W	W	S&L	Utility	97	5/79	2 85
Byron 2 (Byron, Ill.)	1120	PWR	W	W	S&L	Utility	67	3/80	10 86
Braidwood 1 (Braidwood, Ill.)	1120	PWR	W	W	S&L	Utility	80	10/79	10 86
Braidwood 2 (Braidwood, Ill.)	1120	PWR	W	W	S&L	Utility	54	10/80	12 87
Commonwealth Edison Company, Interstate Power Company, and Iowa-Illinois Gas and Electric Company									
Carroll County 1 (Savanna, Ill.)	1120	PWR	W		S&L		0	10/87	2001
Carroll County 2 (Savanna, Ill.)	1120	PWR	W		S&L		0	10/88	2002

NORTHEAST: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont.
SOUTH: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia.
MIDWEST: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin
SOUTHWEST: Arizona, New Mexico, Oklahoma, Texas
WEST AND NORTHWEST: California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming.

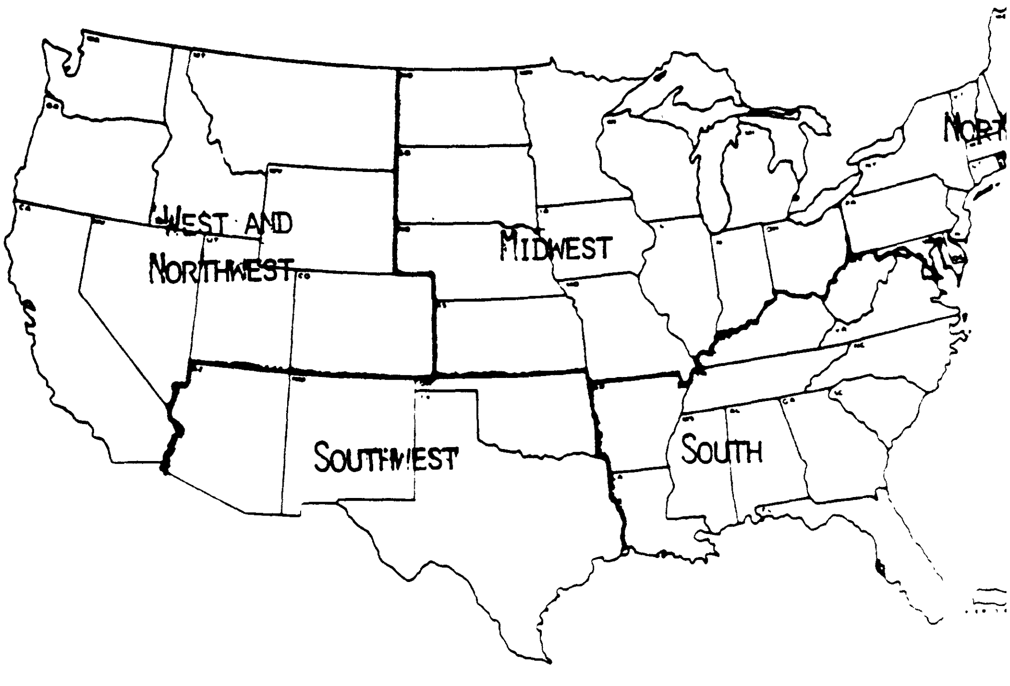


TABLE 7.2 (Continued)

	Net MWe	Type	Reactor Supplier	Generator Supplier	Architect Engineer	Constructor	Con-struc-tion stage (%)	Commercial Operation	
								orig. sched-ule⁺	actual or ex-pected
U S.—MIDWEST, cont'd									
Commonwealth Edison Co. and Iowa-Illinois Gas & Electric Co.									
● Quad-Cities 1 (Cordova, Ill)	789	BWR	GE	GE	S&L	UE&C	100	3/70	8/72
● Quad-Cities 2 (Cordova, Ill)	789	BWR	GE	GE	S&L	UE&C	100	3/71	10/72
Consumers Power Co.									
● Big Rock Point (Charlevoix, Mich.)	63	BWR	GE	GE	Bechtel	Bechtel	100	12/62	12/62
● Palisades (South Haven, Mich)	757	PWR	C-E	W	Bechtel	Bechtel	100	7/70	12/71
Dairyland Power Cooperative									
● La Crosse BWR (Genoa, Wis.)	50	BWR	Allis	Allis	S&L	Maxon	100	10/66	11/69
Detroit Edison Co.									
Fermi 2 (Newport, Mich.)	1100	BWR	GE	GEC	Utility	Daniel	100	2/74	6/85
Illinois Power Co.									
Clinton 1 (Clinton, Ill)	933	BWR	GE	GE	S&L	Baldwin	88 7	6/80	7 86
Indiana & Michigan Electric Co.									
● Donald C. Cook 1 (Bridgman, Mich)	1030	PWR	W	GE	AEPSC	AEPSC	100	4/72	8/75
● Donald C. Cook 2 (Bridgman, Mich)	1100	PWR	W	BBC	AEPSC	AEPSC	100	4.73	7 78
Iowa Electric Light & Power Co.									
● Duane Arnold (Palo, Iowa)	545	BWR	GE	GE	Bechtel	Bechtel	100	12/73	5/74
Kansas Gas & Electric Co., Kansas City Power & Light Co. and Kansas Electric Power Cooperative, Inc.									
Wolf Creek (Burlington, Kans.)	1150	PWR	W	GE	Bech/S&L	Daniel	99 4	4/81	5 85
Nebraska Public Power District									
● Cooper (Brownville, Neb.)	778	BWR	GE	W	B&R	B&R	100	4/71	7 74
Northern States Power Co.									
● Monticello (Monticello, Minn)	536	BWR	GE	GE	Bechtel	Bechtel	100	5/70	7 71
● Prairie Island 1 (Red Wing, Minn)	520	PWR	W	W	FPS	Utility	100	5/72	12/73
● Prairie Island 2 (Red Wing, Minn)	520	PWR	W	W	FPS	Utility	100	5/74	12.74
Omaha Public Power District									
● Fort Calhoun 1 (Fort Calhoun, Neb.)	486	PWR	C-E	GE	G&H	G&H	100	6/71	9/73
Toledo Edison Co.									
● Davis-Besse 1 (Oak Harbor, Ohio)	906	PWR	B&W	GE	Bechtel	Bechtel	100	12 74	11 77
Union Electric Co.									
Callaway 1 (Fulton, Mo)	1150	PWR	W	GE	Bechtel	Daniel	100	10 81	1 85
Wisconsin Electric Power Co.									
● Point Beach 1 (Two Creeks, Wis)	485	PWR	W	W	Bechtel	Bechtel	100	4 70	12 70
● Point Beach 2 (Two Creeks, Wis)	485	PWR	W	W	Bechtel	Bechtel	100	4.71	10 72
Wisconsin Public Service Corporation									
● Kewaunee (Carlton, Wis)	535	PWR	W	W	FPS	FPS	100	6/72	6.74
SOUTH									
Alabama Power Company									
● Joseph M. Farley 1 (Dothan, Ala.)	829	PWR	W	W	SCSI/Bechtel	Daniel	100	4/75	12 77
● Joseph M Farley 2 (Dothan, Ala.)	829	PWR	W	W	SCSI/Bechtel	Daniel	100	4/76	7 81
Arkansas Power & Light Co.									
● Nuclear One 1 (Russellville, Ark.)	836	PWR	B&W	W	Bechtel	Bechtel	100	7 72	12 74
● Nuclear One 2 (Russellville, Ark.)	858	PWR	C-E	GE	Bechtel	Bechtel	100	12/75	3 80
Carolina Power & Light Co.									
● Robinson 2 (Hartsville, S C.)	665	PWR	W	W	Ebasco	Ebasco	100	5/70	3.71
● Brunswick 1 (Southport, N.C.)	790	BWR	GE	GE	UE&C	Brown	100	3/75	3 77
● Brunswick 2 (Southport, N C)	790	BWR	GE	GE	UE&C	Brown	100	3/74	11 75
Shearon Harris 1 (Newhill, N C.)	900	PWR	W	W	Ebasco	Daniel	90	3/77	9 86
Duke Power Co.									
● Oconee 1 (Seneca, S.C)	860	PWR	B&W	GE	Utility/Bech	Utility	100	5/71	7 73
● Oconee 2 (Seneca, S C)	860	PWR	B&W	GE	Utility/Bech	Utility	100	5/72	9/74
● Oconee 3 (Seneca, S C)	860	PWR	B&W	GE	Utility/Bech	Utility	100	6/73	12 74
● McGuire 1 (Cornelius, N C.)	1180	PWR	W	W	Utility	Utility	100	3/76	12 81
● McGuire 2 (Cornelius, N C)	1180	PWR	W	W	Utility	Utility	100	3.77	3 84
Catawba 1 (Clover, S C)	1145	PWR	W	GE	Utility	Utility	99	3.79	6 85
Catawba 2 (Clover, S C)	1145	PWR	W	GE	Utility	Utility	84 1	3.80	6 87
Florida Power & Light Co.									
● Turkey Point 3 (Florida City, Fla)	666	PWR	W	W	Bechtel	Bechtel	100	8 70	12 72
● Turkey Point 4 (Florida City, Fla)	666	PWR	W	W	Bechtel	Bechtel	100	8 71	9 73

CONTINUED

● Units in commercial operation

⁺ Estimated date of startup, announced at time reactor was ordered

TABLE 7.2 (Continued)

	Net MWe	Type	Reactor Supplier	Generator Supplier	Architect Engineer	Constructor	Con-struction stage (%)	Commercial Operation	
								orig. sched-ule†	actual or ex-pected
U S.—SOUTH, cont'd									
Florida Power & Light Co., cont'd									
● St. Lucie 1 (Hutchinson Island, Fla.)	822	PWR	C-E	W	Ebasco	Ebasco	100	1 73	12 76
● St Lucie 2 (Hutchinson Island, Fla.)	802	PWR	C-E	W	Ebasco	Ebasco	100	9/79	8/83
Florida Power Corporation									
● Crystal River 3 (Red Level, Fla.)	875	PWR	B&W	W	Gilbert	Jones	100	9/72	3/77
Georgia Power Co.									
● Edwin I. Hatch 1 (Baxley, Ga.)	810	BWR	GE	GE	SS/Bechtel	Utility	100	4/73	12/75
● Edwin I Hatch 2 (Baxley, Ga.)	820	BWR	GE	GE	Bechtel	Utility	100	4/76	8/79
Vogtle 1 (Waynesboro, Ga.)	1100	PWR	W	GE	SS/Bechtel	Utility	73	2/78	3/87
Vogtle 2 (Waynesboro, Ga.)	1100	PWR	W	GE	SS/Bechtel	Utility	50	2/79	9/88
Gulf States Utilities Co.									
River Bend 1 (St. Francisville, La.)	940	BWR	GE	GE	S&W	S&W	93	10/79	12 85
Louisiana Power & Light Co.									
Waterford 3 (Taft, La.)	1104	PWR	C-E	W	Ebasco	Ebasco	100	1/77	6/85
Mississippi Power & Light Co.									
Grand Gulf 1 (Port Gibson, Miss.)	1250	BWR	GE	Allis	Bechtel	Bechtel	100	9/79	3 85
Grand Gulf 2 (Port Gibson, Miss.)	1250	BWR	GE	Allis	Bechtel	Bechtel	33	9/81	indef
South Carolina Electric & Gas Co.									
● Virgil C. Summer 1 (Parr, S.C.)	900	PWR	W	GE	Gilbert	Daniel	100	10/77	1 84
Tennessee Valley Authority									
● Browns Ferry 1 (Decatur, Ala.)	1067	BWR	GE	GE	Utility	Utility	100	10/70	8/74
● Browns Ferry 2 (Decatur, Ala.)	1067	BWR	GE	GE	Utility	Utility	100	10/71	3 75
● Browns Ferry 3 (Decatur, Ala.)	1067	BWR	GE	GE	Utility	Utility	100	10/72	3.77
● Sequoyah 1 (Daisy, Tenn)	1148	PWR	W	W	Utility	Utility	100	10/73	7 81
● Sequoyah 2 (Daisy, Tenn.)	1148	PWR	W	W	Utility	Utility	100	4/74	6/82
Watts Bar 1 (Spring City, Tenn.)	1177	PWR	W	W	Utility	Utility	99	10/76	10/85
Watts Bar 2 (Spring City, Tenn.)	1177	PWR	W	W	Utility	Utility	68	4/77	4/88
Bellefonte 1 (Scottsboro, Ala.)	1213	PWR	B&W	BBC	Utility	Utility	81	7/77	4/89
Bellefonte 2 (Scottsboro, Ala.)	1213	PWR	B&W	BBC	Utility	Utility	54	4/78	4/91
Virginia Electric & Power Co.									
● Surry 1 (Gravel Neck, Va.)	775	PWR	W	W	S&W	S&W	100	3/71	12 72
● Surry 2 (Gravel Neck, Va.)	775	PWR	W	W	S&W	S&W	100	3/72	5/73
● North Anna 1 (Mineral, Va.)	890	PWR	W	W	S&W	S&W	100	3/74	6 78
● North Anna 2 (Mineral, Va.)	890	PWR	W	W	S&W	S&W	100	7 75	12 80
SOUTHWEST									
Arizona Public Service Co.									
Palo Verde 1 (Wintersburg, Ariz)	1270	PWR	C-E	GE	Bechtel	Bechtel	100	5/81	late 85
Palo Verde 2 (Wintersburg, Ariz.)	1270	PWR	C-E	GE	Bechtel	Bechtel	99 6	11 82	mid 86
Palo Verde 3 (Wintersburg, Ariz.)	1270	PWR	C-E	GE	Bechtel	Bechtel	95 5	5/84	mid 87
Houston Lighting & Power Company									
South Texas Project 1 (Palacios, Tex.)	1250	PWR	W	W	Bechtel	Ebasco	72	10/80	6/87
South Texas Project 2 (Palacios, Tex.)	1250	PWR	W	W	Bechtel	Ebasco	43	3/82	6/89
Texas Utilities Generating Company									
Comanche Peak 1 (Glen Rose, Tex.)	1150	PWR	W	Allis	G&H	B&R	99	1/80	85
Comanche Peak 2 (Glen Rose, Tex.)	1150	PWR	W	Allis	G&H	B&R	65	1 82	86
WEST AND NORTHWEST									
Pacific Gas & Electric Co.									
Diablo Canyon 1 (Avila Beach, Calif.)	1084	PWR	W	W	Utility	Utility	100	5 72	5 85
Diablo Canyon 2 (Avila Beach, Calif.)	1106	PWR	W	W	Utility	Utility	99	7 74	7 85
Portland General Electric Co.									
● Trojan (Prescott, Ore.)	1130	PWR	W	GE	Bechtel	Indep	100	9/74	5/76
Public Service Company of Colorado									
● Fort St. Vrain (Platteville, Colo)	330	HTGR	GA	GE	S&L	GA	100	4 72	1 79
Sacramento Municipal Utility District									
● Rancho Seco (Clay Station, Calif)	913	PWR	B&W	W	Bechtel	Bechtel	100	5 73	4 75
Southern California Edison and San Diego Gas & Electric Co.									
● San Onofre 1 (San Clemente, Calif)	436	PWR	W	W	Bechtel	Bechtel	100		1 68
● San Onofre 2 (San Clemente, Calif)	1100	PWR	C-E	GEC	Bechtel	Bechtel	100	6 75	3 83
● San Onofre 3 (San Clemente, Calif)	1100	PWR	C-E	GEC	Bechtel	Bechtel	100	6 75	4 84

TABLE 7.2 (Continued)

	Net MWe	Type	Reactor Supplier	Generator Supplier	Architect Engineer	Constructor	Construction stage (%)	Commercial Operation orig. schedule†	Commercial Operation actual or expected
U.S.—WEST & NORTHWEST, cont'd									
United States Department of Energy*									
● Hanford-N (Richland, Wash.)	860	LGR	GE	GE	B&R	B&R	100		7 66
Washington Public Power Supply System									
● WNP-2 (Richland, Wash.)	1100	BWR	GE	W	B&R	Bechtel	100	9/77	12 84
WNP-1 (Richland, Wash.)	1250	PWR	B&W	W	UE&C	Bechtel	62 5	9/80	indef
WNP-3 (Satsop, Wash.)	1240	PWR	C-E	W	Ebasco	Ebasco	75	3/82	indef
U.S. Total (129 units)	**119 006**								

Source: Nuclear News (February 1985)

power system involves roughly as many lead nuclear utilities as the rest of the western democracies combined.

In most cases, U.S. nuclear power stations are owned by a consortium of utilities, with construction and operation being the responsiblity of the consortium member with the largest investment. This arrangement originally was conceived as a means of building plants that would capture the benefits of economies of scale, while concurrently making the power produced available to utilities that individually were too small to accommodate such large generating units. In many cases this arrangement has worked well, with power stations operating successfully and with joint owners sharing in the energy produced.

However, recent experience has shown that in some cases these arrangements can become unwieldy, especially when they bring into the oversight process the economic regulatory authorities of several states, each of which may bring to bear a different set of policies, practices, and schedules. Examples include the Seabrook, Marble Hill, and Palo Verde projects. Further, disagreements almong plant owners can lead to costly and confusing litigation, the mere possibility of which can pose a large potential liabiity for the lead utility. In the adversarial environment typical of U.S. public life, the possiblity of such complications arising subsequent to unanticipated project mishaps now is perceived by many utilities to be so great that they are unwilling to undertake future projects on a shared-ownership basis. This problem also is reflected in recent projects by the Electric Power Research Institute (EPRI) to investigate the merits of intermediate-size power stations, which could be owned by individual U.S. utilities.

7.2 STRUCTURE OF THE NUCLEAR SUPPLY INDUSTRY

The first tier of the U.S. nuclear supply industry consists of the 5 reactor manufacturer companies listed in Table 7.3 and the 9 Architect/Engineer (A/E) organizations listed in Table 7.4. The United States is unique among major industrialized countries in that currently it uses bifurcated teams for its nuclear projects, each consisting of a reactor manufacturer and an A/E. Each of these organizations operates reasonably independently in its respective sphere of responsibility. In most other industrialized countries a single project organization, usually controlled by the reactor manufacturer, is responsible for both design and construction, although a consortium of contractor organizations also may be used. The problems of handling the "Manufacturer-A/E interface" and of ensuring effective coordination between them has been recognized as a major difficulty in the U.S. approach to nuclear project management.

The reactor manufacturers and A/E organizations typically use a host of supplier organizations for specialized plant components (e.g., pumps, valves, computers, electrical components, and so forth) and services. The management of these second tier organizations, and the verification of the quality of their products, is a major project management task for the first-tier organizations, and constitutes a substantial area of potential project weakness.

In a typical U.S. nuclear power plant construction project, the A/E serves as the plant designer and constructor, although in some cases utilities have performed these functions themselves (see Table 7.5). The reactor manufacturer designs and fabricates the nuclear steam supply system (NSSS). The NSSS typically is designed without regard to the unique details of the plant in which it will be used. Rather, once a NSSS

Table 7.3

United States Nuclear Power Reactor Manufacturers

Organization	Reactor Type	Number of Units
Babcock and Wilcox	PWR	12
Combustion Engineering	PWR	16
General Atomic	HTGR	1
General Electric	BWR	41
Westinghouse	PWR	57

Table 7.4

United States Architect/Engineer Firms

Organization	Number of Plants	Number of Utilities	Constructor?
Bechtel	45	24	Yes
Brown & Root	4	3	Yes
Ebasco	7	6	Yes
Fluor Engineers	3	2	Yes
Gibbs & Hill	3	2	Yes
Gilbert Associates	5	3	No
Sargent & Lundy	18	5	No
Stone & Webster	13	9	Yes
United Engineers & Constructors	7	5	Yes

Table 7.5

United States Nuclear Utilities Performing Plant Design or Construction

Utility	Plants Designed*	Plants Constructed*
American Electric Power	2	2
Commonwealth Edison		8
Detroit Edison	1	
Duke Power	7	7
Duquesne Light		2
Northern States Power		2
Pacific Gas & Electric	2	2
Public Service Electric & Gas	2	
Southern Services	5	4
Tennessee Valley Authority	9	9

*Sometimes with the assitance of an Architect/Engineer firm.

design has been evolved, the rest of the plant ("balance of plant", or BOP) is designed to accommodate the NSSS. With earlier members of the current generation of nuclear power stations, the A/E sometimes was left to pursue the project with only weak supervision from the lead nuclear utility. However, a pattern of active utility supervision has been more typical with more recent stations, as utilities have become aware of the liabilities of failing to ensure that such projects are managed competently.

This historical pattern of weak involvement in the management of project design and construction reflects a problem common within utilities, that is, poor communication between the portions of organization responsible for plant operation and construction. The personnel involved in these two areas often are different, and further, organizational structures are sometimes not created so as to ensure that the operating staff articulates its requirements effectively in determination of a plant's design. Consequently, it often occurs that the resulting plants are more difficult to operate and maintain and less efficient than desired.

Power plant construction is most often performed by an Architect/Engineer-Constructor firm, such as those listed in Table 7.4. In some cases the utility either managed the construction itself or also used its own employees to perform much of the construction (see Table 7.5).

The market is very competitive among both 12 reactor manufacturers and A/Es. Traditional relationships between utilities and such organizations have changed during the past two decades. Previously, it was common for a utility to deal exclusively with only a small set of equipment vendors and contractors. Such relationships were long term, and provided incentives for teamwork, loyalty, and cooperation that went beyond the strict obligations of existing contracts. In recent years this pattern of interaction has become the exception rather than the rule. Consequently, the previously-common commitment of a product vendor to the lifelong good performance of its product has become rare. Rather, today the practice is--in practical terms--that most of the liability for poor product performance is borne by the utility, which will shop around for the best contractor on a case-by-case basis.

7.3 UTILITY INTERNAL ORGANIZATION AND CAPABILITIES

The U.S. utility industry displays a broad spectrum of management styles, organization structures, technical sophistication and competence and staff size. Consequently, it is difficult to make clearly valid generalizations, as important exceptions are likely to be found. U.S. utilities are variously organized with separate nuclear management entities or with integrated power generation management entities; with power stations being operated autonomously or with operations being centralized; with many levels of authority or with few. To the extent that patterns exist, more successful operations appear to reflect the following practices:

- Existence of an internal organization overseeing nuclear generation separate from that for the remainder of generation. This is done because the technical requirements, the required capabilities of the staff, and the necessity of intimate management involvement in operations is much greater with nuclear units than with others.
- Delegation of responsiblity and authority for successful operation to the plant manager, coupled with sufficient incentives to ensure a commitment to excellence.
- Creation of a management climate where detailed knowledge and concern for the operational status of each nuclear plant extends to top management.

The last requirement should preclude from leadership positions individuals not equipped to understand and respond to the specific and technical issues of nuclear power station operations. One area where utility organizations typically have difficulty in this regard is in coordinating the concerns of operational and construction groups within their organizations. Often a utility will be organized with separate semi-autonomous staffs for capital construction projects and for plant operations. Interviews with utility and A/E staffs consistently indicated that communication between the two is often poor, with the result that overall operational needs are poorly accomodated by the plant's design.

No single model typifies how U.S. utilities design and construct nuclear power stations. Utilities have varied from undertaking the Architect/Engineer-Constructor roles themselves or, undertaking complete responsiblity for project management and design, to the opposite extreme of delegating such responsibilities to an A/E contractor, with little oversight from the utility. In the most successful construction projects, one consistent feature has been the utility's assumption of responsibility for the overall outcome of the project. This responsibility typically is reflected in vigorous project management, along with a commitment to maintain project quality and schedule and design integrity. Such commitment often requires a larger utility staff than when such responsiblity is shared or abdicated to contractors, but it usually results in a more satisfactory product. It is notable that efficiency in construction does not always correlate with subsequent success in plant operation.

All the problems of managing a construction project and of defining performance requirements appear to be greatest when a utility undertakes such a project for the first time. This is a significant point, because nearly the majority of U.S. nuclear utilities are responsible for only a single station. Consequently, the majority of nuclear power stations was built under circumstances adverse to salutary project management and communications. In retrospect it is apparent that many utilities did not appreciate the demands that would be made upon their organizations in obtaining success with nuclear power. Many utilities have shown that such success can be obtained very beneficially. However, for others the demands of the technology appear to have been too great.

In U.S. nuclear power station operations, the size of the utility staff commonly numbers around 400 per plant, including personnel in such support functions as engineering. However, staffs as small as 200 are found. Further, some utilities rely almost exclusively on outside contractors to perform engineering analysis and other plant functions not requiring a full-time staff. In other utilities, the company will have a large professional staff and will try to accomplish internally as many tasks as possible.

One interesting organizational alternative to those above is provided by the Yankee Atomic Electric Company. This company was originally established by a group of New England utilities to design and provide operational support of the New England regional nuclear power stations. Ultimately it has evolved to supporting a total of four plants, each owned by a separate consortium of utilities (five other plants in the region are not supported by the Yankee organization). By most reports this arrangement has worked well. However, it is notable that this arrangement has not been adopted elsewhere in the United States. It would be worthwhile to explore the reasons for this and to pursue any corrections which would be indicated.

The operational staffs of U.S. utilities often are composed of high school graduates, although some personnel with college degrees also are found. The staffs usually are recruited directly after graduating from high school, or--in many cases--after service in the U.S. Navy. Currently the utility or contracted organizations train the operational staff. The career path typically goes from entry level positions as technicians or assistants to reactor operators, through a Senior Reactor Operator, Shift Supervisor, or Shift Technical Advisor. Workers at the highest levels can earn up to $100,000 annually.

As in other areas, the technical capabilities of utilities vary greatly--ranging from the comprehensive capabilities of Duke Power Corporation to the meager abilities of some single-reactor utilities. In many cases, a utility is responsible for fuel management, much of plant maintenance, and some outage management and safety analysis. Usually the utility has no substantial design capability.

The most important feature of the U.S. utility industy is the near-total autonomy of each company, and the diversity of approaches to generating electricity. This autonomy is beneficial insofar that it clearly assigns responsibility for success or failure to each utility, but it is harmful insofar that it hinders the communication and discipline necessary to achieve the most efficient approaches to utility functions throughout the industry.

In reviewing the operational experiences of U.S. utilities the importance of good management was evident. The essential elements of good management are the following:

- An understanding at the highest levels of the organization of the technical, human, and social requirements for success with nuclear power;

- An attitude that all factors that can threaten the successful operation of a plant must be anticipated and forestalled;
- A commitment of the resources necessary to identify and correct such problems effectively; and
- An ability to motivate and reward utility staff to achieve success.

In many cases these elements of leadership are lacking, and the results obtained with nuclear power have reflected this fact.

EPRI AND INPO

The fragmentation of the utility industry into many small independent units has been accompanied by a tradition that technological innovation has been performed by the firms that supply components and services to the utilities, but not by the utilities themselves. Rather, the utilities most often have functioned as somewhat conservative consumers of technological innovations, not as stimuli or sources of innovation. With the advent of nuclear power, the federal government entered the field of electrical technology innovation. This pattern of utility passivity has hindered innovation due to poor communication of utility operational needs to supplier companies and among one another, and in many instances, due to the small sizes of the companies involved, through a restriction of the resources available to finance innovation projects.

In the early 1970s this situation, where one of the most heavily capital-intensive industries in the United States traditionally applied only a negligible share of its resources to advancing technologies unique to its function, led to criticism and to proposals that a tax upon utility revenues be established to fund technology innovation. To forestall implementation of such proposals, the utility industry in 1973 established the Electric Power Research Institute (EPRI). EPRI is funded and directed by participating companies from the U.S. electric utility industry. Initially EPRI mounted a vigorous program of research, reflecting both short- and long-term concerns. However, since then, EPRI's focus gradually has evolved to one almost exclusively short range (e.g., five years). It may be argued that this evolution illustrates a lack of vision and strategic leadership. To the extent that this characteristic is reflected in the management of the U.S. nuclear utility industry it may also explain performance failures discussed elsewhere in this report.

Following the 1979 accident at the Three Mile Island 2 nuclear power station, the utilities formed the utility-funded Institute for Nuclear Power Operations (INPO). The utilities were motivated by the reality that a serious reactor accident involving any one utility can damage the fortunes of all utilities. INPO was founded in recognition of the need to improve the level of U.S. nuclear utility operations, and especially to improve the performance of the poorest members of the industry. That INPO was necessary in the first place reflects both of the lack of coordination common among U.S. utilities and the low level of operational performance plaguing some utility organizations. Since its creation INPO has conducted periodic plant evaluation visits, and has broadened its programs to include maintenance of records of U.S. plant operational experience, sharing of experience among utilities and analyses of the causes of important classes of poor performance. In many areas (e.g., human error in operations), the Nuclear Regulatory Commission permits INPO to act as an industry-wide self-policing agency, as an alternative to the assumption of such responsibilities by federal authorities. INPO is a vitally important factor in attempts to improve nuclear power performance in the United States. In the view of most observers the creation of INPO is the best thing which has happened to nuclear power during recent years, and is the best hope for ultimate success of the nuclear power enterprise.

However, there are some important limits to INPO's effectiveness. The most important is that INPO is not independent. Rather, it is the creation of the U.S. nuclear power utility industry (although some foreign utilities also are members). It derives its budget and mandate from the utilties which it monitors. Consequently, it can only undertake initiatives which are acceptable to the dominant utilities. This implies that INPO can be vigorous in the correction of the poorer-performing minority of the utility population. However, it is unlikely to be as effective in imposing substantial discipline upon the majority of the utilities, unless they can be persuaded that such discipline is in their best economic interests. Further, INPO operates inside the utility community and outside public view. Consequently, it is constrained from publicly criticizing the organizations under its purview, and from broadly to the formulation of public policy. Since INPO is in a position to be one of the best-informed organizations regarding the needs for improvement of the U.S. nuclear power industry, the wisdom of these two constraints is questionable.

7.4 ECONOMICS OF NUCLEAR POWER

In recent years, the economics of nuclear power in the United States have become much more unfavorable than before. From the late 1960s to the late 1970s, nuclear power was seen as being economically superior to coal-fired power, except in areas close to domestic coal fields. However, this situation has changed greatly since 1980, after which the capital costs required to complete nuclear plants ranged from around \$2000 to \$4000/kWe. (During the same interval the capital cost of a typical coal-fired station was approximately \$1800/kWe). Thus, although at its most favorable economic range nuclear power remains superior to coal-generated electricity, at its most unfavorable range it is totally uncompetitive.

There exist many demonstrations that nuclear technology can be built and used competitively and economically. However, the uncertainty associated with any expectations of economic success currently are so great as to deter U.S. utilities from undertaking new nuclear projects.

7.5 ECONOMIC REGULATION

As stated earlier, most U.S. utilities are owned by private investors and operated under franchise as regulated monopolies. Such regulation is conducted by state Public Utility Commissions (PUC) or their surrogates. There is no standard set of utility regulations to which most states subscribe; rather, there are as many sets of regulations and practices as there are states. Generally, economic regulation is based on allowing a "fair" rate of return to utility bond- and shareholders on the capital that the PUC has admitted into the utility "rate base" of investment. This basis of regulation is both expedient and necessary if the utility is to remain able to finance future capital projects.

It has been suggested, but not demonstrated, that practices for financial regulation of utilities have inhibited use of designs which would be initially expensive, but economically attractive over-life. The following discussion describes the United States environment of utility financial regulation. In most cases, PUC members are political appointees, serve terms of only a few years, and often have little prior experience with utility technology or management, or in some cases with economic analysis. PUC staffs are often overburdened and underpaid, and to have no particular expertise concerning nuclear power technology and the problems particular to it. Consequently, reports of communication problems between PUCs and utilities are not surprising, as the backgrounds and unspoken assumptions that each group brings to the process of economic regulation often are different and incompatible. Further, in recent years as electricity prices have risen steeply the climate in which this process is pursued has become highly politicized, with pressure groups lobbying the PUCs to hold down electricity price increases. These pressures, along with the discretionary authority of PUCs and the absence of a standarized set of PUC practices, have combined to create a situation where utilities are required to defend the correctness of their prior decisons at a punishing level of detail. Much of the uncertainty created by these proceedings arises because PUCs are concerned equally with defining criteria for prudent decision-making and with determining whether utility decisions can be shown to conform to criteria defined, in some cases, after the fact.

PUCs are allowed considerable discretionary scope in determining whether prior utility capital expenditures should be allowed into the rate base. The test used by most PUCs is whether the expenditures are either "reasonable and prudent" or for a plant that is "used and useful." If a PUC applies the former criteria, it attempts to reconstruct the decision-making environment that existed at the various stages of the plant's life and to determine whether, in terms of prevailing conditions, the utility's decisions were "prudent" in terms of providing reliable, economic electric power. However, the practical difficulties involved in excluding _post_ _facto_ knowledge and in determining the specific, quantifiable degree of a decision's success renders this method susceptible to a variety of biases in regulatory judgments.

In recent years, the "used and useful" criteria increasingly have come into use. In practice, these criteria require that the investment that investors are allowed to recover must be for a plant that is actually in service and that such investment was necessary for the provision of service. Reliance on these criteria rather than on "reasonable and prudent" criteria has been justified on the basis that the former introduces a greater element of market feedback into utility decisionmaking, thereby leading to more efficient utility functioning. On the other hand, this approach is criticized on that grounds that, in practice, PUCs using these criteria do so in a one-sided fashion, inflicting on utilities the punishments of the market for decisions that turn out badly, but denying the corresponding rewards for those that turn out well.

During the past decade, when expensive nuclear plants have come on-line at a time of considerable excess capacity in utility systems, the question of whether prior investments should be allowed into the rate base *in toto* often has become fiercely contested. To a large degree such contests arose from resistance of electric power consumers to the substantial increases in electricity prices that would follow the admission of such investments into the rate base. Consequently, utilities for the first time are faced with uncertainty as to whether PUCs will allow them to recover multi-billion dollar investments in nuclear power stations. Such recovery could be denied, at least in part, if a PUC found either that a plant was not needed to meet current demand levels, or if the investments for the plant were not incurred "prudently." The proceedings through which such questions are decided are highly adversarial, formal, acrimonious, and politicized. Consequently, their outcomes are difficult to predict.

One aspect of applying the "used and useful" criteria in rate-base decision-making is that the full capital value of a new facility is entered into the rate base upon initial operation of the unit. When the cost of such a facility is very large, as it is with a nuclear power plant, the resultant increases in electricity prices also can be very large. (During recent years expected price increases in the range of 20 percent to 50 percent have been encountered.) Some states have avoided this phenomenon, termed "rate shock," either by allowing the plant's capital costs to be absorbed into the rate base incrementally during construction, or by imposing post-operational phase-in formulae. The political problems created by rate shock are especially adverse for nuclear power and are unique to the United States, which is the only major industrialized country to employ the "used and useful" criterion in electricity rate setting. Most other countries allow utility investments to be entered into the rate base as they are incurred, and prior to initial operation.

In recent years, PUC reviews have begun to focus not just on construction performance, but on operational performance as well. Such reviews mainly are concerned with whether nuclear power station shutdowns have been prudently incurred and managed, but not very much (to date) with whether investments made for plant maintenance or improvements have been incurred prudently (However, in some instances, prior PUC approval of such investments have been required). The effect of a PUC finding of imprudently lost plant capacity due to utility mismanagement could be removal of the shutdown plant from the rate base for the duration of the imprudently-lost operation, or of permitting the utility to recover revenues at the rates that would have obtained had the plant continued to operated for sales of power obtained (usually more expensively) from other electric systems. During recent years, some instances of PUCs requiring utilities to meet plant capacity factor goals also have been reported. However, most of those interviewed in the work of this project reported that direct PUC interference with nuclear power operations has been rare.

Many observers are concerned that the U.S approach to utility regulation is so heavily laden with punishments and offers so few rewards that beneficial utility operational practices, especially those involving utility risk-taking, are effectively prohibited. In many instances, U.S. utility managers report that they are aware of the risks and uncertainty this situation imposes, to the extent that many such executives now state that the PUC is the single most important external party affecting the behavior of the company. Often such managers also state that the decision-making constraints imposed by PUCs are arbitrarty, inconsistent, and incompetently formulated--to such an extent that they make rational management impossible. However, many such executives also report that it is possible to fashion accommodations with PUCs that make life bearable, if not comfortable. Presumably, if these criticisms are correct, financial markets will respond by demanding premia for future utility financing to reflect these increased risks imported by evolving PUC practices.

In contrast, some PUC members tend to regard such sentiments of utility managments merely as the expected complaints of a group that is being forced to abandon the comforts derived from long-established and wasteful business practices. Even among more moderate PUC members there appears to be a consensus that, while over the past 15 years there may have been an evolution in the vigor and level of detail with which PUCs have challenged utility actions, the basic principles applied by PUCs consistently have been that utility actions must be demonstrably in the interests of electricity ratepayers. Rather, it is not the basic rules that have changed, but that the exceptions to these rules--which were tolerated during an earlier era of declining real prices for electricity--are no longer being sanctioned. Further, the changes introduced by this evolution are inducing utilities to manage their activities more efficiently, which is in the long-term interests of all concerned. Thus, the effective rules under which utilities operate have changed considerably, but the bases on which these rules are founded have not. Although observers may disagree about these interpretations of events, the net result of PUC-utility interactions in the nuclear arena during the last decade often has been creation of a climate of mutual antipathy and distrust.

7.6 SAFETY REGULATION

The safety of nuclear power is regulated primarily by the Nuclear Regulatory Commission (NRC). The NRC is a federal agency created in 1975 as a successor to the Atomic Energy Commission. Other agencies that play significant roles in the safety and environmental regulation of nuclear power are, at the federal level, the Environmental Protection Administration (EPA), the Federal Emergency Management Agency (FEMA), and the U.S. Army Corps of Engineers. At the state level, various agencies are concerned with environmental protection and emergency preparedness. Until recently, when controversies arose regarding emergency planning, local agencies played little part in such regulation.

The federal legislation that created the NRC assigned it responsiblity for almost all nuclear safety regulation in the United States. As a result, nuclear power is one of the few technologies in the

United States for which there exists a single agency having broad oversight authority. For example, all other technologies involved in the production of electric power are regulated by different agencies, under different legislation, at different levels of government, based upon the type of public or occupational or environmental risk that technology might present. Further, the implementation of such laws is commonly a function of the individual states, subject to oversight by a lead federal agency. Thus, the regulation of nuclear power is carried out by a central authority at the national level, while that of all other electric power technologies is carried out at the state level. One consequence of this arrangement is that the scope of nuclear power regulation is much more consistent and comprehensive than is that for alternative technologies.

Under the U.S. Constitution, state laws are pre-empted when they conflict with those of the federal government. Because of the broad scope of NRC's enabling legislation, there are very few areas where the states may play important roles in regulating the risks of nuclear power. The most significant area of state authority concerns state and local participation in formulating and executing emergency response plant for nuclear power stations. In the examples of the Indian Point, Shoreham, and Seabrook stations, the operation of these plants has been opposed by local authorities through their refusal to participate in the preparation and demonstration of such emergency plant.

The following discussion describes the process of licensing and regulatory enforcement of U.S. nuclear power stations. The purpose is to illustrate the degree to which the U.S. approach to nuclear safety regulation is complex and unpredictable, and thus very different from the regulatory treatments experienced by the other countries examined in this study.

The regulation of nuclear power stations in the United States begins with the issuance of a Construction Permit (CP), which is issued prior to the start of construction. The Operating Licence (OL) is issued at the end of construction, before commercial operation may begin. These are the only two federal licenses that a nuclear power station requires. The processes used for granting these two licenses are illustrated schematically in Figure 7.2. The process for the OL differs from that for the CP mainly in that it does not require an anti-trust review. Although both licensing processes are structurally the same, the allowable content of the technical reviews preceeding the public hearing stage of each process is different.

Both licenses are granted by the NRC only after public hearings. Public hearings are conducted by the Atomic Safety and Licensing Board (ASLB), which is employed by the NRC. The ASLB has three members: a lawyer, who acts as chairman, an expert in life sciences, and an engineer.

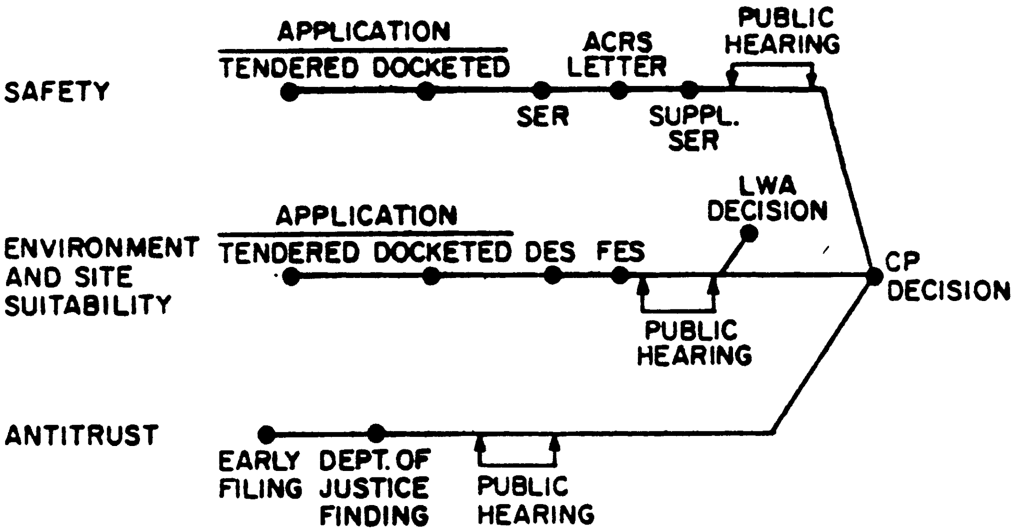
Prior to the public hearing stage, material submitted by the utility is reviewed by the NRC staff. This review occurs in two parallel efforts, focusing on safety and environmental effects, each of which is examined below.

7.6.1 The Safety Review

In the safety review, the NRC staff attempts to determine whether the plant will pose a threat to the public safety. In practice this is done by requiring the design of the plant to be such that the plant could survive without substantial damage a set of prescribed accident scenarios (earthquake, flood, tornado, etc.), by ascertaining that the plant design meets a specified set of safety-related equipment standards, and by determing that the plant design is subject to constraints of diversity

Figure 7.2

Parallel Tracks in Construction Permit Review Process



ABBREVIATIONS:

SER-SAFETY EVALUATION REPORT

FES-FINAL ENVIRONMENTAL STATEMENT

DES-DRAFT ENVIRONMENTAL STATEMENT

LWA-LIMITED WORK AUTHORIZATION

ACRS-ADVISORY COMMITTEE ON REACTOR SAFEGUARDS and redundancy. Over time a standard set of accident cases and a standard approach to plant design has evolved; these are now well-codified and accepted by the NRC as satisfactory.

These sets of criteria today are highly detailed and prescriptive, and focuses upon specifying the types of hardware that should appear in an acceptable plant. These criteria amount to an effective set of design recipes, which the license applicant has strong incentives to utilize. A license application is always free to propose an alternative set of requirements or design approaches, but in practice this is not done. Doing so would impose upon the license applicant the additional burdens of demonstrating the adequacy of this proposed set of regulatory criteria, as well as later coping with the additional uncertainty in project management that this licensing strategy would engender.

The literature on this prescriptive approach to regulation is large and diverse, contained variously in the General Design Criteria, in NRC regulations, and in various forms of NRC guidelines to license applicants.

This approach to regulation was instituted during the early 1970s, when an avalanche of license applications was submitted from many utilities spanning a wide range of capabilities and approaches to plant design and operation. To standardize the processing of this large number of applications a detailed, formal, and prescriptive regulatory structure was created to replace the much more functionally-oriented and informal system that had existed previously. This highly prescriptive approach to safety regulation has been criticized for diluting the responsibility of the license applicant for overseeing the safety of the plant and for stifling the creativity of plant designers and operators.

At the end of its review, the NRC staff issues the Safety Evaluation Report (SER) relevant to the license application. This report describes the design of the plant and clarifies any areas where the applicant and the NRC staff disagree regarding the adequacy of the design. Prior to the public hearing portion of the Safety Review, the SER is reviewed by the Advisory Committee on Reactor Safeguards (ACRS), an independent panel composed of senior technologists and scientists. The ACRS issues a letter stating its evaluation of the plant's design and detailing any areas of disagreement with the positions of the NRC staff or with the license applicant.

7.6.2 The Environmental Review

The NRC staff is required by the National Environmental Policy Act of 1969 to prepare an Environmental Statement in conjunction with any nuclear power station license it issues. The Environmental Statement is not required to demonstrate that the design of the power station being considered minimizes damage to the environment. Rather, it must show that the effects of the proposed project the environment of the proposed project have been recognized realistically and seriously taken into account in the tradeoff analysis that is the heart of project planning. The staff prepares the environmental statement, in part using information provided by the license applicant. The Environmental Review is concerned with gathering a sufficient set of information for preparation of the Environmental Statement, with preparation and public criticism of the Draft Environmental Statement and with revision of it into the Final Environmental Statement. As with the Safety Review, the process is highly formalized, with the required categories of information and analysis stipulated according to a standard format. At this point the Environmental Review is important mainly as an arena of potential opposition to the granting of a license, which must be based upon procedural objections.

7.6.3 The Public Hearing

Following issuance of both the Final Environmental Statement and the Safety Evaluation Report, separate public hearings are held as part of the Environmental and Safety Reviews, respectively. The hearings are held by the ASLB, acting as an administrative court of law, and as such features sworn testimony, cross examination, and creation of a formal record, which is the basis of any subsequent legal reviews regarding the legitimacy of the proceedings. The purpose of the hearing is to weigh evidence regarding whether the proposed plant is likely to cause substantial harm to public health or to the environment. Evidence is provided by the license applicant, by the NRC staff, by the ACRS, and by interested members of the public. In most cases the license is granted, subject to restrictions stated in the Technical Specifications. These restrictions enumerate design modifications and operational limitations to which the license-holder agrees to abide and which are subsequently enforced by the NRC.

The decisions of the ASLB may be appealed by an interested party through two levels of review within the NRC, through three levels of the federal court system, and ultimately to the Supreme Court.

The second level of appeal within the NRC is to the five NRC Commissioners. This function of the Commissioners as an appeal board has had the important effect of diminishing the strength of management discipline between commissioners and NRC staff. This situation arises because the potential exists that the Commissioners could be required to review the correctness of prior staff actions. This requirement effectively prohibits the Commissioners from becoming involved in the management of the workings of the staff. Further, the legal requirement that all Commission meetings be held in public commonly leads to policy formulations that are weakly stated and often incoherent. This happens because the Commissioners are effectively prohibited from conducting the private discussions necessary, if any group is attempting to formulate a consensus and identify shared values. This restriction regarding the functioning of the staff, coupled with the _ex parte_ role of the Commissioners, leads to a situation both where the policy guidance given to staff often is unclear and where the enforcement of those policies may be accomplished only indirectly, through instructions from the Chairman of the Commission to the Executive Director for Operations.

The basis of any appeal rests on an assertion of inadequacy, as reflected in the record and in supporting evidence of the ASLB hearing. The formality of this process makes the regulation of nuclear power highly legalistic, adversarial, time-consuming, and unpredictable. The latter two factors have the potential to affect nuclear power projects adversely in economic terms.

7.6.4 Intervenors

A unique aspect of nuclear safety regulation in the United States is the direct participation of individual citizens in the regulatory process. Such participation can occur at the public hearing stage of the licensing process, when an individual citizen may join the proceedings as a party potentially affected by the station under review. In order to gain standing to participate--or "intervene"--the affected party is required to identify a substantal technical concern affecting the safety of the plant. In practice this requirement has been interpreted loosely, so most persons wishing to intervene have been able to do so. Such intervention demands that the participant be well versed about the technology of the plant in question, and able to devote substantial resources to the licensing interaction. These requirements have been reflected in recent years in the emergence of nationally-supported groups, such as the Union of Concerned Scientists, which have provided substantial technical support to opponents of nuclear projects.

The opportunity for private citizens to intervene in the actions taken by the national government is consistent with Constitutionally-imbedded distrust of governmental interference in the affairs of individual citizens and, as observed in the early 19th century by de Toqueville, with the concept that the people are the ultimate source of authority in society. Such participation also reflects an aspect of U.S. culture where many aspects of human life and natural phenomena are viewed as contests between opposing forces. In the case of nuclear safety issues it is assumed implicitly that the best approach will be illuminated during the free expression of arguments offered by contending parties. Seen from this perspective, it is accepted as natural that for all persons or entities potentially affected by a project have a voice in determining of its form and its success or failure. It has been proposed several times in Congress that the licensing process be made more of an "even fight" by providing funds to intervenors to enhance the effectiveness of their work.

No other industrialized country allows citizen participation in nuclear safety regulation to the extent the United States does. Outside the United States, a commonly encountered attitude is that the individual citizen, no matter how directly he or she may be affected by a nuclear power project, is incompetent to participate in the process. Following this view, the function of the U.S. government would be, through the process of safety regulation, to protect him or her potential harm. In most other countries the power of the citizen who disagrees with this view is limited. (For example, in France a citizen who disagrees with the government's stance on the construction of a nuclear power station or with some aspect of the station has no recourse except to vote against the government in the next election.)

This aside, intervention has been criticized for the following reasons:

- Intervenors very rarely have identified new technical issues of importance, and instead typically have publicized previously-identified issues and have amplified concern regarding such issues;
- Intervenors have used the licensing process in a political guerilla warfare to advance an agenda in opposition to nuclear power in general through a series of skirmishes involving individual nuclear power plants; and
- Ultimately the costs of this guerilla warfare, which are mainly in the form of increased interest charges associated with the project being contested, are large and borne mainly by ratepayers.

7.6.5 Regulation of Plant Operations

After obtaining an Operating License (OL), the utility may operate the plant for 40 years before it must request a license amendment to continue operation. The operation of a plant must conform to the OL, including the Technical Specifications. Such conformity is enforced by a resident NRC inspector at each plant, by surprise inspections, and through periodic reviews by the regional NRC staff. Adverse findings by the NRC during any of these inspections can result in the imposition of operational limitations, including plant shutdown. The NRC also can impose financial penalties.

The purview of the NRC extends to virtually all aspects of plant operation. Among the more important are occupational radiation exposures, release of radioactive material to the environment, reactor operator training, radioactive waste treatment and storage, and the operational readiness of plant safety systems. During the recently-instituted program of NRC reviews of operational performance the scope of NRC activity has been broadened to include the structure of the system and the competence of the utility management to operate the plant.

Another important area concerns NRC requirements for modifying operating plants. Modifications have been required for reasons such as the following:

- Safety hazards that became known only after the plant began operation. Such hazards include the pressurized thermal shock phenomenon in PWRs, intergranular stress corrosion cracking in BWR piping, and potential reactions involving hydrogen, which can be generated during severe core damage accidents; and
- Revised safety standards. These requirements for emergency power supplies include those for separation of redundant systems in order to prevent common cause system failures.

Especially during the period following the accident at Three Mile Island, a large number of plant modifications or "backfits" were required by the NRC. The result was that for several years many utilities chronically fell behind as they schedule instituted expensive programs to comply with NRC requirements, some of which were ultimately rescinded.

From interviews conducted during the drafting of this report, it is possible to describe stereotypical criticisms of the various participants in the safety regulatory system. Overall, all participants involved are dissatisfied with the system and its results, each for different reasons. The least dissatisfied group is the safety regulatory authorities, which is mainly concerned with the poor performance records and unconcerned attitudes of a minority of utility managements. The latter are considered to be insufficiently aware of the need for and level of effort required to sustain safe nuclear power plant operation. In the utilities and associated support industries a spectrum of attitudes exist, ranging from viewing the safety regulatory system as difficult but possible to deal with provided sufficient efforts are brought to the task, to another extreme of viewing the system as being utterly incoherent and hostile to nuclear power. Among opponents of nuclear power a spectrum of attitudes also exists, with the extremes ranging from a view that the NRC and the utility industry are in effective collusion to promote nuclear power to the view that the NRC is fair, but lax, and that the utilities have only their own inadequacies to blame for the problems they have encountered.

7.7 PUBLIC ATTITUDE AND INFLUENCE

Over the past 20 years, nuclear power in the United States has gone from being much-favored by the public to being greatly feared and opposed. This progression results from many factors, of which the following are among the more important:

- A succession of well-publicized nuclear power station accidents and management failures;
- The work of a determined and effective group of nuclear power opponents;
- Public policy positions hostile to use and development of nuclear power; and
- A complex dynamic concerning how the public becomes informed about complex technical issues, involving the news media, the public, and nuclear power information sources where consistent emphasis on the risks of nuclear power has greatly alarmed the public.

The evolution of public opinion toward nuclear power also consists of several, distinct stages:

- 1952-1968--Following the 1954 debut of the Atoms for Peace Plan, a period of widespread public acceptance and admiration of nuclear power.
- 1968 through 1974--A period coincident with the Vietnam war, and serious domestic social unrest, when public unease concerning nuclear power and opposition to specific projects began to grow and when the great majority of nuclear power plant orders were placed.

- 1974 through 1979--A period of opposition within the federal government to the expansion of nuclear power, widespread cancellation of power station orders, increasing public distrust of nuclear technology, and the reactor accidents at Browns Ferry and Three Mile Island.
- 1979 through 1984--A period of consolidation and realignment within the nuclear enterprise, neglect of nuclear power by the federal government, continually growing public concern regarding nuclear technology in reaction to the TMI accident, several economic failures of nuclear projects.

Ultimately public attitudes in the United States will determine the possibilities for the success of nuclear power. This is because the climate in which the nuclear enterprise exists is defined by the influence of public attitudes on important institutions. All six countries studied in this report are democracies; however, the United States is distinguished by the great degree to which individual citizens may influence both the policies and functioning of the government at all levels, and by the decentralization of the U.S. government. Consequently, the degree of public support of nuclear power is reflected far more directly in the policies and practices of all branches and levels of government than in nations such as France and Japan, where democracy is more representative than participatory.

In the United States, the major institutions and organizations that display strong sensitivities to shifts in public attitudes to nuclear power include: the Congress, the NRC, the utilities, and the anti-nuclear power lobbies. The interactions among these groups are very complex. The role of the media is very important, as they are the main conduits through which the various interest groups influence the public. This is true to an extent greater than in the other countries studied, where media influence is supplemented importantly by such organizations as labor unions and political parties. In the United States the news media often have been criticized for oversimplification and for a bias toward reporting the risks rather than the benefits of nuclear power. They also are criticized for often exaggerating these risks, with the result that the public has become unjustifiably frightened of nuclear power. The consequence of this pattern of public opinion formation has been to create climate of fear and distrust among much of the public such that dispassionate discussion of nuclear power issues in public forums has become difficult, if not impossible.

7.8 NUCLEAR PLANT PERFORMANCE

In this section the performance losses for the U.S. nuclear power plants are presented and briefly examined. U.S. performance data were compiled using energy availability as the performance index.

7.8.1 Aggregated Data

The U.S. PWR energy availability losses are tabulated by calendar year and by reactor age in Tables 7.6 and 7.7, respectively. The BWR energy availability losses are tabulated by year in Table 7.8 and by reactor age in Table 7.9. The mean and standard deviations of the U.S. energy availability factors are tabulated in Table 7.10.

7.8.2 Capacity Factor Distribution

U.S. PWR energy availability factors are plotted by year in Figure 7.3. The performance of the PWR's averaged 60.2% over the 10 years with two distinct periods. From 1975 to 1978, the energy availability factor averaged 64.5% with a small amount of fluctuation. In 1979 the energy availability for U.S. PWR's dropped 10.7 percentage points as a result of the accident at Three Mile Island (TMI). Since the accident, performance has been slowly improving but has not yet reached its pre-TMI level. The magnitude of the standard deviation of the energy availability factors noticeably increased during this period. This indicates that there were large variations in the performance of the plants in each year, possibly as a result of the non-uniform impact of post-TMI safety regulation. From 3.5 to 5.0 percentage points of the U.S. PWR losses from 1979 to 1984 can be directly attributed to the two out-of-service TMI reactors.

The U.S. PWR energy availability factors as functions of reactor age are shown graphically in Figure 7.4. This figure shows that performance improved up to age 12 after which it started to decrease. The decrease is due to large regulatory losses in those plants. The standard deviations of the mean also significantly increased after age 12 indicating that the regulatory losses were not spread evenly over all the plants.

Energy availability factors for U.S. BWR's are plotted as functions of time in Figure 7.5. The average energy availability factor over the 10 year period was 58.0%. The curve shown has a peak of 67% in 1978 and 1979 with the performance falling off to less than 50% on either side of the peak. The increase in performance prior to 1979 was due to reductions in balance of plant losses. The decrease in performance after 1979 was due to increased regulatory losses in the wake of the Three Mile Island accident. The standard deviation of the mean availability increases in magnitude after 1979 and became larger with each successive year. This was probably caused by the uneven impact of the increased regulation during those years.

The BWR energy availability factors are plotted as functions of reactor age in Figure 7.6. The data show a slight improvement in performance over the first five years, and then level off until age 13 where there is a large drop. This trend is very similar to that exhibited by the PWR's in Figure 7.4. The low performance and high standard deviations beyond age 12 were from large steam generator and regulatory losses at only a few plants.

7.8.3 Losses by Outage Type

In this subsection, forced, scheduled, and regulatory losses for the U.S. nuclear plants are examined as functions of time and age.

Forced, scheduled and regulatory losses are plotted by year in Figure 7.7. The total losses were high over the 10 year period, averaging 39.8% and increasing from 1975 to 1984. Scheduled losses were the largest component of the total with a 10 year average of 16.3%, or 41.0% of the total losses. No trend is exhibited by the scheduled losses, as they were relatively constant throughout the entire period of interest. Forced losses were also a large fraction of the total, contributing 31.4%. The forced losses were also relatively constant from 1975 to 1984. Finally, regulatory losses, averaging 10.9% and representing an average of 27.4% of the total losses each year, increased in magnitude from 1975 to 1984. In 1979 there was in increase in the regulatory losses of 10.7 percentage points to 16% as a result of the accident at Three Mile Island. Since the accident, this category has subsided slightly and remained constant at approximately 13%.

The PWR outage category losses are plotted as a functions of age in Figure 7.8. In this figure, the total losses exhibit a slight decrease from age one to age 12 after which they fluctuate and increase. Scheduled losses showed some fluctuations but remain mostly constant until age 12. The forced losses exhibited a definite age dependency, with losses decreasing over the entire range of ages. The cause of this decrease is difficult to determine, but it appears to be a result of a general reduction in many of the forced outage categories.

The forced, scheduled, and regulatory losses for the U.S. BWR's are shown by year in Figure 7.9. The total losses show a decrease from 1975 to 1979 and then a rise again from 1980 to 1984. Scheduled outages were the largest component of total losses, contributing 40.7%. Scheduled losses fluctuated from year to year but remained relatively constant during 10 years. Forced losses represented 34.3% of total losses and decreased as a function of time. Reductions in the balance-of-plant-OTHER losses over time were the main cause of the trend. Regulatory losses have increased since 1977 from 2.4% to 21.8% in 1984 and represent 27.4% of the total loss.

The same BWR outage categories are plotted as functions of reactor age in Figure 7.10. The U.S. BWR scheduled losses remained constant, with some fluctuation, and did not display an age dependency. The forced losses showed a decline through age 10 after which there was a large amount of fluctuation. No specific category of loss was responsible for the decline in forced losses. Regulatory losses exhibited a very gradual increase over all ages.

7.8.4 NSSS and BOP Losses

In this subsection the losses in the Nuclear Steam Supply System (NSSS) and the Balance of Plant (BOP) are displayed and examined as functions of time and reactor age for the U.S. nuclear power plants.

NSSS and BOP losses are displayed over time for the U.S. PWR's in Figure 7.11. NSSS losses remained essentially constant during the 10 year period, averaging 18.0% and representing 45.2% of the total losses. Refueling losses made up almost 60% of the NSSS losses while the reactor coolant system and steam generator problems accounted for 18.3% and 13.9% respectively. BOP losses have also been essentially constant, averaging

5.9% and contributing 14.8% of the total losses. Turbine losses were the largest fraction of the BOP losses accounting for 33.9%. Condenser problems also contributed to 30.5% of the losses.

U.S. PWR NSSS and BOP losses are shown as a functions of reactor age in Figure 7.12. Both NSSS and BOP losses showed more variation by age than by year. The NSSS losses generally remained constant as a function of age while the BOP losses showed a decrease with increasing age. The decrease in BOP losses was primarily the result of similar trends in the turbines and condensers.

NSSS and BOP losses are illustrated by year for the U.S. BWR's in Figure 7.13. NSSS losses have averaged 18.6% and have accounted for 44.3% of the total losses each year. The largest fraction (48.9%) of the NSSS losses was from refueling losses while reactor coolant system losses accounted for 24.2%. The BWR NSSS losses exhibit a slight decrease over-time as a result of a decrease due to fuel losses. The BOP losses for U.S. BWR's have averaged 7.3%, representing 17.4% of the average total losses. Approximately 80% of these losses were evenly attributed to turbine, condenser, and BOP OTHER losses. From 1975 to 1978 the BOP losses declined as a result of reductions in BOP-OTHER losses. From 1978 to 1984 the BOP losses slowly grew as a result of increasing turbine losses.

The BWR's NSSS and BOP losses are plotted by reactor age in Figure 7.14. From age three to age 10 the U.S. NSSS losses have slowly improved as a result of decreased losses in several categories. The peak of the data at ages 13 and 14 was due to high reactor coolant system losses at several plants. The BOP losses show a steep drop from age one to age four which occurred as a result of decreases in BOP OTHER losses. After age four the BOP losses flattened out and fluctuate with age.

Table 7.6
U.S. PWR Energy Availability Losses By Year

ENERGY AVAIL. LOSSES
1975 - 1979

UNITED STATES
ALL PWR'S

04/11/86

			DATA: (27)	(30)	(36)	(39)	(40)
			1975	1976	1977	1978	1979
FORCED	NSSS	FUEL	0.001	0.000	0.000	0.000	0.001
		RCS	0.044	0.037	0.017	0.020	0.020
		SG	0.005	0.014	0.015	0.001	0.002
		REFUEL	0.000	0.002	0.000	0.001	0.001
		OTHER	0.013	0.012	0.011	0.033	0.007
			0.064	0.065	0.044	0.055	0.030
	BOP	TURBINE	0.029	0.020	0.004	0.014	0.017
		GEN	0.004	0.023	0.004	0.002	0.002
		COND	0.022	0.012	0.012	0.015	0.015
		CW/SW/CCW	0.001	0.001	0.001	0.001	0.001
		OTHER	0.001	0.002	0.003	0.017	0.002
			0.057	0.058	0.024	0.049	0.036
	ECONOMIC		0.029	0.020	0.025	0.022	0.017
	HUMAN		0.004	0.005	0.002	0.006	0.003
	OTHER		0.007	0.006	0.006	0.004	0.023
	TOTAL		0.161	0.155	0.101	0.136	0.109
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.018	0.026	0.006	0.006	0.004
		SG	0.017	0.006	0.009	0.002	0.022
		REFUEL	0.071	0.117	0.107	0.103	0.109
		OTHER	0.008	0.004	0.006	0.007	0.002
			0.114	0.152	0.128	0.117	0.138
	BOP	TURBINE	0.006	0.003	0.021	0.011	0.006
		GEN	0.001	0.003	0.001	0.000	0.000
		COND	0.009	0.002	0.006	0.001	0.002
		CW/SW/CCW	0.001	0.001	0.001	0.000	0.000
		OTHER	0.000	0.001	0.000	0.001	0.000
			0.016	0.011	0.029	0.014	0.008
	ECONOMIC		0.002	0.005	0.007	0.006	0.009
	HUMAN		0.000	0.001	0.000	0.000	0.000
	OTHER		0.006	0.007	0.008	0.003	0.006
	TOTAL		0.138	0.175	0.172	0.141	0.161
REGULATORY			0.036	0.047	0.031	0.053	0.164
UNKNOWN			0.000	0.000	0.000	0.000	0.003
** TOTAL ENERGY AVAIL. LOSS **			0.336	0.377	0.304	0.330	0.437
** ENERGY AVAIL. FACTOR **			0.664	0.623	0.696	0.670	0.563

Table 7.6 (Continued)

ENERGY AVAIL. LOSSES
1980 - 1984

UNITED STATES
ALL PWR'S

04/11/86

			1980	1981	1982	1983	1984
		DATA:	(41)	(46)	(47)	(49)	(52)
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.021	0.034	0.036	0.012	0.021
		SG	0.015	0.008	0.033	0.009	0.008
		REFUEL	0.000	0.000	0.000	0.001	0.000
		OTHER	0.017	0.010	0.010	0.006	0.007
			0.053	0.053	0.078	0.029	0.036
	BOP	TURBINE	0.013	0.020	0.013	0.007	0.003
		GEN	0.006	0.015	0.009	0.027	0.021
		COND	0.016	0.018	0.018	0.009	0.012
		CW/SW/CCW	0.002	0.001	0.005	0.005	0.001
		OTHER	0.003	0.011	0.006	0.002	0.002
			0.040	0.065	0.050	0.049	0.039
	ECONOMIC		0.016	0.020	0.015	0.016	0.015
	HUMAN		0.003	0.004	0.004	0.003	0.009
	OTHER		0.003	0.004	0.004	0.002	0.002
	TOTAL		0.115	0.146	0.151	0.099	0.101
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.002	0.004	0.003	0.010	0.009
		SG	0.016	0.013	0.009	0.016	0.019
		REFUEL	0.119	0.131	0.111	0.102	0.088
		OTHER	0.001	0.001	0.001	0.001	0.002
			0.137	0.150	0.123	0.130	0.118
	BOP	TURBINE	0.012	0.004	0.001	0.004	0.002
		GEN	0.000	0.000	0.003	0.002	0.004
		COND	0.002	0.003	0.006	0.002	0.003
		CW/SW/CCW	0.000	0.000	0.003	0.000	0.001
		OTHER	0.003	0.001	0.000	0.000	0.000
			0.017	0.008	0.012	0.009	0.011
	ECONOMIC		0.012	0.008	0.004	0.007	0.004
	HUMAN		0.000	0.002	0.000	0.000	0.000
	OTHER		0.000	0.004	0.009	0.049	0.026
	TOTAL		0.166	0.171	0.148	0.196	0.158
REGULATORY			0.169	0.102	0.135	0.136	0.137
UNKNOWN			0.000	0.000	0.001	0.002	0.001
** TOTAL ENERGY AVAIL. LOSS **			0.450	0.420	0.434	0.432	0.398
** ENERGY AVAIL. FACTOR **			0.550	0.580	0.566	0.568	0.602

Table 7.6 - (Continued)

```
ENERGY AVAIL. LOSSES                                              UNITED STATES
1975 - 1984                                                           ALL PWR'S

04/11/86                     DATA:52 PLANTS              407 PLANT-YEARS
:----------------------------------------------------------------------------:
:                                     AVERAGE OVER ALL YEARS                 :
:----------------------------------------------------------------------------:
: FORCED        : NSSS : FUEL                      0.000                     :
:               :      : RCS                       0.025                     :
:               :      : SG                        0.012                     :
:               :      : REFUEL                    0.000                     :
:               :      : OTHER                     0.012                     :
:               :      :                          ------                     :
:               :      :                           0.050                     :
:               :------------------------------------------------------------:
:               : BOP  : TURBINE                   0.013                     :
:               :      : GEN                       0.012                     :
:               :      : COND                      0.015                     :
:               :      : CW/SW/CCW                 0.002                     :
:               :      : OTHER                     0.005                     :
:               :      :                          ------                     :
:               :      :                           0.046                     :
:               :------------------------------------------------------------:
:               : ECONOMIC                         0.019                     :
:               :------------------------------------------------------------:
:               : HUMAN                            0.004                     :
:               :------------------------------------------------------------:
:               : OTHER                            0.006                     :
:                -------------------------------------------------------------:
:                 TOTAL                            0.125                     :
:----------------------------------------------------------------------------:
: SCHEDULED     : NSSS : FUEL                      0.000                     :
:               :      : RCS                       0.008                     :
:               :      : SG                        0.013                     :
:               :      : REFUEL                    0.106                     :
:               :      : OTHER                     0.003                     :
:               :      :                          ------                     :
:               :      :                           0.130                     :
:               :------------------------------------------------------------:
:               : BOP  : TURBINE                   0.007                     :
:               :      : GEN                       0.002                     :
:               :      : COND                      0.003                     :
:               :      : CW/SW/CCW                 0.001                     :
:               :      : OTHER                     0.001                     :
:               :      :                          ------                     :
:               :      :                           0.013                     :
:               :------------------------------------------------------------:
:               : ECONOMIC                         0.006                     :
:               :------------------------------------------------------------:
:               : HUMAN                            0.000                     :
:               :------------------------------------------------------------:
:               : OTHER                            0.013                     :
:                -------------------------------------------------------------:
:                 TOTAL                            0.163                     :
:----------------------------------------------------------------------------:
: REGULATORY    :                                  0.109                     :
:----------------------------------------------------------------------------:
: UNKNOWN       :                                  0.001                     :
:----------------------------------------------------------------------------:

** TOTAL ENERGY AVAIL. LOSS **                     0.398

** ENERGY AVAIL. FACTOR **                         0.602
```

Table 7.7

U.S. PWR Energy Availability Losses
By Reactor Age

```
ENERGY AVAIL. LOSSES BY REACTOR AGE                              UNITED STATES
1975 - 1984                                                          ALL PWR'S

04/11/86                   DATA:(37)    (36)    (41)    (37)    (38)
:-----------------------------------------------------------------------------:
:                        AGE:       1       2       3       4       5        :
:-----------------------------------------------------------------------------:
: FORCED     : NSSS : FUEL      0.000   0.000   0.001   0.001   0.000        :
:            :      : RCS       0.041   0.040   0.020   0.040   0.021        :
:            :      : SG        0.005   0.004   0.011   0.011   0.013        :
:            :      : REFUEL    0.000   0.003   0.000   0.000   0.000        :
:            :      : OTHER     0.021   0.027   0.022   0.006   0.007        :
:            :      :           ------  ------  ------  ------  ------       :
:            :      :           0.067   0.074   0.054   0.058   0.041        :
:            :----------------------------------------------------------------:
:            : BOP  : TURBINE   0.034   0.011   0.006   0.012   0.017        :
:            :      : GEN       0.009   0.033   0.010   0.009   0.012        :
:            :      : COND      0.027   0.015   0.016   0.014   0.013        :
:            :      : CW/SW/CCW 0.003   0.003   0.000   0.003   0.001        :
:            :      : OTHER     0.011   0.014   0.002   0.008   0.007        :
:            :      :           ------  ------  ------  ------  ------       :
:            :      :           0.084   0.076   0.034   0.046   0.050        :
:            :----------------------------------------------------------------:
:            : ECONOMIC         0.022   0.019   0.023   0.023   0.022        :
:            :----------------------------------------------------------------:
:            : HUMAN            0.005   0.009   0.004   0.005   0.003        :
:            :----------------------------------------------------------------:
:            : OTHER            0.029   0.006   0.006   0.004   0.003        :
:             ----------------------------------------------------------------:
:              TOTAL            0.206   0.184   0.121   0.136   0.119        :
:-----------------------------------------------------------------------------:
: SCHEDULED  : NSSS : FUEL      0.000   0.000   0.000   0.000   0.000        :
:            :      : RCS       0.016   0.023   0.007   0.004   0.004        :
:            :      : SG        0.007   0.010   0.006   0.009   0.005        :
:            :      : REFUEL    0.045   0.099   0.147   0.126   0.110        :
:            :      : OTHER     0.011   0.004   0.001   0.004   0.000        :
:            :      :           ------  ------  ------  ------  ------       :
:            :      :           0.079   0.136   0.161   0.143   0.119        :
:            :----------------------------------------------------------------:
:            : BOP  : TURBINE   0.011   0.011   0.002   0.004   0.002        :
:            :      : GEN       0.004   0.005   0.004   0.001   0.001        :
:            :      : COND      0.006   0.006   0.002   0.004   0.002        :
:            :      : CW/SW/CCW 0.001   0.001   0.001   0.000   0.002        :
:            :      : OTHER     0.001   0.002   0.000   0.002   0.001        :
:            :      :           ------  ------  ------  ------  ------       :
:            :      :           0.023   0.025   0.009   0.011   0.008        :
:            :----------------------------------------------------------------:
:            : ECONOMIC         0.002   0.006   0.007   0.009   0.007        :
:            :----------------------------------------------------------------:
:            : HUMAN            0.000   0.001   0.000   0.000   0.000        :
:            :----------------------------------------------------------------:
:            : OTHER            0.017   0.009   0.009   0.010   0.002        :
:             ----------------------------------------------------------------:
:              TOTAL            0.123   0.175   0.186   0.172   0.135        :
:-----------------------------------------------------------------------------:
: REGULATORY :                  0.053   0.101   0.085   0.090   0.118        :
:-----------------------------------------------------------------------------:
: UNKNOWN    :                  0.001   0.000   0.000   0.000   0.002      . :
:-----------------------------------------------------------------------------:

** TOTAL ENERGY AVAIL. LOSS **  0.383   0.460   0.392   0.398   0.374

** ENERGY AVAIL. FACTOR **      0.617   0.540   0.608   0.602   0.626
```

Table 7.7 (Continued)

ENERGY AVAIL. LOSSES BY REACTOR AGE
1975 - 1984

UNITED STATES
ALL PWR'S

04/11/86

		DATA:	(38)	(35)	(34)	(29)	(26)
		AGE:	6	7	8	9	10
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.022	0.032	0.014	0.016	0.014
		SG	0.005	0.005	0.014	0.012	0.024
		REFUEL	0.000	0.000	0.000	0.000	0.000
		OTHER	0.011	0.012	0.005	0.006	0.008
			0.038	0.049	0.033	0.034	0.046
	BOP	TURBINE	0.013	0.019	0.014	0.010	0.002
		GEN	0.001	0.030	0.004	0.009	0.006
		COND	0.015	0.014	0.014	0.010	0.009
		CW/SW/CCW	0.004	0.000	0.001	0.000	0.001
		OTHER	0.003	0.002	0.001	0.002	0.001
			0.036	0.065	0.034	0.031	0.019
	ECONOMIC		0.018	0.019	0.016	0.018	0.015
	HUMAN		0.003	0.006	0.002	0.004	0.004
	OTHER		0.002	0.002	0.004	0.004	0.003
	TOTAL		0.098	0.141	0.090	0.092	0.086
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.001	0.010	0.006	0.012	0.005
		SG	0.006	0.026	0.015	0.024	0.018
		REFUEL	0.105	0.126	0.114	0.097	0.101
		OTHER	0.003	0.001	0.001	0.003	0.002
			0.115	0.163	0.136	0.136	0.126
	BOP	TURBINE	0.006	0.011	0.008	0.010	0.002
		GEN	0.000	0.001	0.000	0.001	0.000
		COND	0.005	0.003	0.006	0.002	0.001
		CW/SW/CCW	0.000	0.000	0.002	0.000	0.000
		OTHER	0.001	0.000	0.000	0.000	0.001
			0.012	0.015	0.016	0.013	0.004
	ECONOMIC		0.006	0.009	0.005	0.005	0.013
	HUMAN		0.000	0.002	0.000	0.000	0.000
	OTHER		0.017	0.011	0.009	0.025	0.023
	TOTAL		0.149	0.200	0.166	0.179	0.165
REGULATORY			0.134	0.112	0.132	0.094	0.106
UNKNOWN			0.001	0.001	0.001	0.001	0.001
** TOTAL ENERGY AVAIL. LOSS **			0.382	0.454	0.388	0.366	0.357
** ENERGY AVAIL. FACTOR **			0.618	0.546	0.612	0.634	0.643

Table 7.7 (Continued)

ENERGY AVAIL. LOSSES BY REACTOR AGE — UNITED STATES
1975 - 1984 — ALL PWR'S

04/11/86

		AGE:	11	12	13	14	15
		DATA:	(15)	(11)	(6)	(5)	(3)
FORCED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.015	0.016	0.048	0.001	0.000
		SG	0.016	0.033	0.063	0.007	0.011
		REFUEL	0.000	0.000	0.001	0.000	0.000
		OTHER	0.003	0.001	0.002	0.037	0.000
			0.034	0.050	0.114	0.045	0.011
	BOP	TURBINE	0.007	0.002	0.006	0.004	0.002
		GEN	0.010	0.005	0.000	0.000	0.016
		COND	0.013	0.011	0.005	0.005	0.006
		CW/SW/CCW	0.010	0.000	0.000	0.000	0.000
		OTHER	0.002	0.003	0.000	0.018	0.008
			0.042	0.021	0.011	0.027	0.032
	ECONOMIC		0.017	0.013	0.004	0.009	0.012
	HUMAN		0.005	0.006	0.003	0.000	0.001
	OTHER		0.004	0.003	0.001	0.004	0.001
	TOTAL		0.102	0.096	0.133	0.085	0.058
SCHEDULED	NSSS	FUEL	0.000	0.000	0.000	0.000	0.000
		RCS	0.006	0.002	0.000	0.001	0.000
		SG	0.008	0.000	0.016	0.182	0.012
		REFUEL	0.088	0.123	0.137	0.090	0.054
		OTHER	0.000	0.001	0.000	0.001	0.000
			0.101	0.126	0.153	0.274	0.066
	BOP	TURBINE	0.001	0.001	0.002	0.003	0.002
		GEN	0.000	0.000	0.000	0.000	0.000
		COND	0.003	0.002	0.002	0.001	0.000
		CW/SW/CCW	0.000	0.000	0.000	0.000	0.000
		OTHER	0.001	0.000	0.000	0.000	0.000
			0.005	0.003	0.004	0.004	0.002
	ECONOMIC		0.007	0.003	0.000	0.000	0.001
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.022	0.039	0.000	0.005	0.000
	TOTAL		0.135	0.170	0.158	0.283	0.070
REGULATORY			0.084	0.048	0.263	0.141	0.288
UNKNOWN			0.003	0.002	0.002	0.001	0.001
** TOTAL ENERGY AVAIL. LOSS **			0 324	0.315	0.556	0.510	0.415
** ENERGY AVAIL. FACTOR **			0.676	0.685	0.444	0.490	0.585

Table 7.7 (Continued)

```
ENERGY AVAIL. LOSSES BY REACTOR AGE                                    UNITED STATES
1975 - 1984                                                                ALL PWR'S

04/11/86                        DATA:( 2)   ( 2)    ( 0)    ( 0)    ( 0)
:-----------------------------------------------------------------------------:
:                        AGE:        16      17                               :
:-----------------------------------------------------------------------------:
: FORCED        : NSSS : FUEL       0.000  0.000                              :
:               :      : RCS        0.002  0.025                              :
:               :      : SG         0.000  0.000                              :
:               :      : REFUEL     0.000  0.000                              :
:               :      : OTHER      0.000  0.001                              :
:               :      :           ------ ------ ------ ------ ------         :
:               :      :            0.002  0.026                              :
:               :-------------------------------------------------------------:
:               : BOP  : TURBINE    0.000  0.000                              :
:               :      : GEN        0.000  0.004                              :
:               :      : COND       0.002  0.000                              :
:               :      : CW/SW/CCW  0.000  0.000                              :
:               :      : OTHER      0.000  0.000                              :
:               :      :           ------ ------ ------ ------ ------         :
:               :      :            0.002  0.004                              :
:               :-------------------------------------------------------------:
:               : ECONOMIC          0.010  0.005                              :
:               :-------------------------------------------------------------:
:               : HUMAN             0.000  0.002                              :
:               :-------------------------------------------------------------:
:               : OTHER             0.001  0.000                              :
:               --------------------------------------------------------------:
:                 TOTAL             0.016  0.037                              :
:-----------------------------------------------------------------------------:
: SCHEDULED     : NSSS : FUEL       0.000  0.000                              :
:               :      : RCS        0.000  0.000                              :
:               :      : SG         0.000  0.000                              :
:               :      : REFUEL     0.079  0.077                              :
:               :      : OTHER      0.000  0.000                              :
:               :      :           ------ ------ ------ ------ ------         :
:               :      :            0.079  0.077                              :
:               :-------------------------------------------------------------:
:               : BOP  : TURBINE    0.017  0.001                              :
:               :      : GEN        0.000  0.000                              :
:               :      : COND       0.000  0.003                              :
:               :      : CW/SW/CCW  0.000  0.000                              :
:               :      : OTHER      0.000  0.000                              :
:               :      :           ------ ------ ------ ------ ------         :
:               :      :            0.017  0.004                              :
:               :-------------------------------------------------------------:
:               : ECONOMIC          0.000  0.016                              :
:               :-------------------------------------------------------------:
:               : HUMAN             0.000  0.000                              :
:               :-------------------------------------------------------------:
:               : OTHER             0.000  0.040                              :
:               --------------------------------------------------------------:
:                 TOTAL             0.096  0.136                              :
:-----------------------------------------------------------------------------:
: REGULATORY    :                   0.517  0.460                              :
:-----------------------------------------------------------------------------:
: UNKNOWN       :                   0.000  0.001                              :
:-----------------------------------------------------------------------------:

** TOTAL ENERGY AVAIL. LOSS **      0.629  0.634

** ENERGY AVAIL. FACTOR **          0.371  0.366
```

Table 7.8

U.S. BWR Energy Availability Losses By Year

ENERGY AVAIL. LOSSES
1975 - 1979

UNITED STATES
ALL BWR'S

04/11/86

			DATA: (18)	(19)	(21)	(21)	(22)
			1975	1976	1977	1978	1979
FORCED	NSSS	FUEL	0.032	0.034	0.024	0.014	0.012
		RCS	0.032	0.032	0.019	0.025	0.016
		SG					
		REFUEL	0.000	0.001	0.000	0.000	0.000
		OTHER	0.012	0.010	0.010	0.012	0.004
			0.076	0.077	0.054	0.051	0.033
	BOP	TURBINE	0.004	0.010	0.016	0.007	0.004
		GEN	0.002	0.002	0.014	0.003	0.004
		COND	0.031	0.013	0.023	0.014	0.014
		CW/SW/CCW	0.018	0.009	0.004	0.000	0.001
		OTHER	0.102	0.066	0.006	0.012	0.017
			0.157	0.101	0.062	0.037	0.039
	ECONOMIC		0.017	0.019	0.020	0.021	0.016
	HUMAN		0.004	0.005	0.006	0.006	0.009
	OTHER		0.007	0.006	0.011	0.016	0.010
	TOTAL		0.262	0.208	0.153	0.129	0.108
SCHEDULED	NSSS	FUEL	0.014	0.017	0.016	0.012	0.009
		RCS	0.058	0.015	0.008	0.006	0.005
		SG					
		REFUEL	0.057	0.096	0.166	0.089	0.084
		OTHER	0.026	0.028	0.007	0.006	0.007
			0.156	0.155	0.196	0.113	0.105
	BOP	TURBINE	0.000	0.002	0.002	0.000	0.000
		GEN	0.000	0.005	0.004	0.000	0.001
		COND	0.004	0.007	0.005	0.004	0.004
		CW/SW/CCW	0.001	0.001	0.000	0.000	0.000
		OTHER	0.001	0.001	0.000	0.001	0.002
			0.007	0.015	0.010	0.005	0.007
	ECONOMIC		0.001	0.002	0.011	0.012	0.018
	HUMAN		0.000	0.001	0.000	0.000	0.000
	OTHER		0.005	0.008	0.004	0.002	0.003
	TOTAL		0.169	0.180	0.221	0.131	0.133
REGULATORY			0.074	0.058	0.024	0.059	0.083
UNKNOWN			0.001	0.000	0.000	0.006	0.005
** TOTAL ENERGY AVAIL. LOSS **			0.506	0.446	0.399	0.325	0.329
** ENERGY AVAIL. FACTOR **			0.494	0.554	0.601	0.675	0.671

Table 7.3 (Continued)

ENERGY AVAIL. LOSSES
1980 - 1984

UNITED STATES
ALL BWR'S

04/11/86

			1980	1981	1982	1983	1984
		DATA:	(22)	(22)	(22)	(23)	(25)
FORCED	NSSS	FUEL	0.008	0.010	0.005	0.006	0.004
		RCS	0.036	0.034	0.078	0.021	0.015
		SG					
		REFUEL	0.000	0.007	0.000	0.001	0.000
		OTHER	0.017	0.029	0.014	0.010	0.009
			0.061	0.079	0.097	0.037	0.027
	BOP	TURBINE	0.005	0.019	0.028	0.007	0.024
		GEN	0.003	0.000	0.004	0.004	0.001
		COND	0.018	0.019	0.013	0.009	0.018
		CW/SW/CCW	0.001	0.004	0.001	0.001	0.002
		OTHER	0.006	0.008	0.002	0.003	0.006
			0.033	0.051	0.048	0.024	0.050
	ECONOMIC		0.011	0.011	0.010	0.011	0.008
	HUMAN		0.004	0.006	0.012	0.007	0.011
	OTHER		0.006	0.009	0.006	0.003	0.002
	TOTAL		0.114	0.156	0.172	0.082	0.098
SCHEDULED	NSSS	FUEL	0.007	0.010	0.001	0.007	0.003
		RCS	0.005	0.002	0.007	0.024	0.022
		SG					
		REFUEL	0.118	0.070	0.049	0.091	0.081
		OTHER	0.004	0.037	0.003	0.012	0.010
			0.134	0.119	0.060	0.134	0.116
	BOP	TURBINE	0.012	0.023	0.017	0.011	0.007
		GEN	0.001	0.000	0.000	0.004	0.000
		COND	0.004	0.004	0.001	0.015	0.002
		CW/SW/CCW	0.000	0.000	0.000	0.001	0.001
		OTHER	0.003	0.003	0.000	0.000	0.002
			0.021	0.030	0.018	0.031	0.012
	ECONOMIC		0.024	0.015	0.037	0.024	0.022
	HUMAN		0.000	0.000	0.000	0.002	0.000
	OTHER		0.001	0.001	0.004	0.019	0.050
	TOTAL		0.180	0.166	0.120	0.209	0.199
REGULATORY			0.114	0.092	0.121	0.157	0.218
UNKNOWN			0.001	0.001	0.002	0.003	0.001
** TOTAL ENERGY AVAIL. LOSS **			0.408	0.413	0.415	0.452	0.517
** ENERGY AVAIL. FACTOR **			0.592	0.587	0.585	0.548	0.483

Table 7.8 (Continued)

```
ENERGY AVAIL. LOSSES                                          UNITED STATES
1975 - 1984                                                       ALL BWR'S

04/11/86                    DATA:25 PLANTS              215 PLANT-YEARS
:-----------------------------------------------------------------------:
:                                      AVERAGE OVER ALL YEARS            :
:-----------------------------------------------------------------------:
: FORCED      : NSSS  : FUEL                  0.014                     :
:             :       : RCS                   0.031                     :
:             :       : SG                                              :
:             :       : REFUEL                0.001                     :
:             :       : OTHER                 0.013                     :
:             :       :                       ------                    :
:             :       :                       0.058                     :
:             :---------------------------------------------------------:
:             : BOP   : TURBINE               0.013                     :
:             :       : GEN                   0.004                     :
:             :       : COND                  0.017                     :
:             :       : CW/SW/CCW             0.004                     :
:             :       : OTHER                 0.020                     :
:             :       :                       ------                    :
:             :       :                       0.057                     :
:             :---------------------------------------------------------:
:             : ECONOMIC                      0.014                     :
:             :---------------------------------------------------------:
:             : HUMAN                         0.007                     :
:             :---------------------------------------------------------:
:             : OTHER                         0.007                     :
:              ---------------------------------------------------------:
:               TOTAL                         0.144                     :
:-----------------------------------------------------------------------:
: SCHEDULED   : NSSS  : FUEL                  0.009                     :
:             :       : RCS                   0.014                     :
:             :       : SG                                              :
:             :       : REFUEL                0.090                     :
:             :       : OTHER                 0.014                     :
:             :       :                       ------                    :
:             :       :                       0.127                     :
:             :---------------------------------------------------------:
:             : BOP   : TURBINE               0.008                     :
:             :       : GEN                   0.001                     :
:             :       : COND                  0.006                     :
:             :       : CW/SW/CCW             0.001                     :
:             :       : OTHER                 0.001                     :
:             :       :                       ------                    :
:             :       :                       0.016                     :
:             :---------------------------------------------------------:
:             : ECONOMIC                      0.017                     :
:             :---------------------------------------------------------:
:             : HUMAN                         0.000                     :
:             :---------------------------------------------------------:
:             : OTHER                         0.010                     :
:              ---------------------------------------------------------:
:               TOTAL                         0.171                     :
:-----------------------------------------------------------------------:
: REGULATORY  :                               0.104                     :
:-----------------------------------------------------------------------:
: UNKNOWN     :                               0.002                     :
:-----------------------------------------------------------------------:

** TOTAL ENERGY AVAIL. LOSS **                0.420

** ENERGY AVAIL. FACTOR **                    0.580
```

Table 7.9

U.S. BWR Energy Availability Losses By Reactor Age

ENERGY AVAIL. LOSSES BY REACTOR AGE 1975 - 1984

UNITED STATES ALL BWR'S

04/11/88

		DATA:	(14)	(12)	(17)	(19)	(20)
		AGE:	1	2	3	4	5
FORCED	NSSS	FUEL	0.020	0.026	0.028	0.029	0.022
		RCS	0.043	0.040	0.033	0.020	0.016
		SG					
		REFUEL	0.000	0.000	0.000	0.001	0.001
		OTHER	0.012	0.010	0.011	0.006	0.011
			0.075	0.076	0.072	0.056	0.050
	BOP	TURBINE	0.005	0.015	0.015	0.005	0.006
		GEN	0.022	0.004	0.004	0.004	0.002
		COND	0.026	0.016	0.022	0.015	0.016
		CW/SW/CCW	0.003	0.001	0.015	0.007	0.004
		OTHER	0.122	0.096	0.014	0.003	0.004
			0.178	0.132	0.070	0.034	0.032
	ECONOMIC		0.020	0.021	0.020	0.016	0.016
	HUMAN		0.012	0.009	0.006	0.006	0.010
	OTHER		0.009	0.007	0.009	0.011	0.009
	TOTAL		0.293	0.246	0.177	0.124	0.118
SCHEDULED	NSSS	FUEL	0.010	0.012	0.020	0.014	0.014
		RCS	0.001	0.010	0.036	0.028	0.009
		SG					
		REFUEL	0.000	0.121	0.112	0.139	0.094
		OTHER	0.039	0.011	0.012	0.011	0.033
			0.050	0.154	0.180	0.192	0.150
	BOP	TURBINE	0.000	0.002	0.001	0.001	0.001
		GEN	0.000	0.002	0.000	0.005	0.004
		COND	0.001	0.003	0.004	0.006	0.007
		CW/SW/CCW	0.001	0.000	0.000	0.001	0.000
		OTHER	0.001	0.000	0.001	0.003	0.002
			0.003	0.007	0.006	0.016	0.014
	ECONOMIC		0.001	0.006	0.005	0.006	0.016
	HUMAN		0.000	0.000	0.000	0.001	0.000
	OTHER		0.031	0.007	0.003	0.006	0.002
	TOTAL		0.085	0.174	0.192	0.220	0.182
REGULATORY			0.122	0.073	0.066	0.091	0.072
UNKNOWN			0.001	0.005	0.004	0.002	0.001
** TOTAL ENERGY AVAIL. LOSS **			0.501	0.497	0.439	0.437	0.373
** ENERGY AVAIL. FACTOR **			0.499	0.503	0.561	0.563	0.627

Table 7.9 (Continued)

ENERGY AVAIL. LOSSES BY REACTOR AGE — UNITED STATES
1975 - 1984 — ALL BWR'S

04/11/86

			DATA:	(21)	(21)	(21)	(19)	(16)
		AGE:		6	7	8	9	10
FORCED	NSSS	FUEL		0.014	0.009	0.010	0.004	0.003
		RCS		0.027	0.031	0.018	0.017	0.022
		SG						
		REFUEL		0.000	0.000	0.000	0.000	0.000
		OTHER		0.029	0.008	0.012	0.008	0.017
				0.070	0.048	0.040	0.029	0.042
	BOP	TURBINE		0.012	0.026	0.005	0.014	0.004
		GEN		0.001	0.002	0.003	0.001	0.004
		COND		0.020	0.012	0.017	0.009	0.010
		CW/SW/CCW		0.003	0.003	0.001	0.002	0.001
		OTHER		0.006	0.011	0.016	0.004	0.004
				0.042	0.054	0.042	0.030	0.023
	ECONOMIC			0.017	0.013	0.011	0.011	0.009
	HUMAN			0.005	0.006	0.014	0.003	0.006
	OTHER			0.011	0.007	0.005	0.006	0.005
	TOTAL			0.145	0.128	0.111	0.080	0.083
SCHEDULED	NSSS	FUEL		0.014	0.006	0.008	0.005	0.002
		RCS		0.006	0.015	0.011	0.014	0.014
		SG						
		REFUEL		0.084	0.096	0.086	0.085	0.081
		OTHER		0.005	0.006	0.011	0.019	0.004
				0.109	0.123	0.116	0.123	0.101
	BOP	TURBINE		0.014	0.019	0.009	0.002	0.015
		GEN		0.000	0.000	0.000	0.005	0.000
		COND		0.003	0.014	0.002	0.006	0.006
		CW/SW/CCW		0.000	0.000	0.000	0.000	0.000
		OTHER		0.002	0.003	0.001	0.001	0.001
				0.019	0.036	0.012	0.014	0.022
	ECONOMIC			0.016	0.015	0.023	0.017	0.053
	HUMAN			0.000	0.002	0.000	0.000	0.000
	OTHER			0.001	0.005	0.012	0.022	0.009
	TOTAL			0.144	0.181	0.183	0.174	0.186
REGULATORY				0.089	0.076	0.107	0.172	0.087
UNKNOWN				0.002	0.002	0.002	0.001	0.001
** TOTAL ENERGY AVAIL. LOSS **				0.380	0.387	0.383	0.427	0.357
** ENERGY AVAIL. FACTOR **				0.620	0.613	0.617	0.573	0.643

Table 7.9 (Continued)

ENERGY AVAIL. LOSSES BY REACTOR AGE — UNITED STATES
1975 - 1984 — ALL BWR'S

04/11/86

		DATA:	(10)	(10)	(5)	(3)	(2)
		AGE:	11	12	13	14	15
FORCED	NSSS	FUEL	0.003	0.002	0.002	0.000	0.000
		RCS	0.043	0.013	0.193	0.097	0.010
		SG					
		REFUEL	0.013	0.000	0.000	0.005	0.000
		OTHER	0.014	0.018	0.014	0.003	0.000
			0.073	0.033	0.209	0.105	0.010
	BOP	TURBINE	0.025	0.010	0.073	0.001	0.004
		GEN	0.008	0.000	0.000	0.000	0.000
		COND	0.021	0.023	0.024	0.000	0.014
		CW/SW/CCW	0.001	0.002	0.000	0.000	0.008
		OTHER	0.005	0.003	0.001	0.000	0.023
			0.060	0.038	0.098	0.001	0.049
	ECONOMIC		0.011	0.008	0.004	0.008	0.003
	HUMAN		0.004	0.006	0.003	0.000	0.009
	OTHER		0.003	0.003	0.002	0.002	0.000
	TOTAL		0.151	0.089	0.316	0.117	0.070
SCHEDULED	NSSS	FUEL	0.003	0.002	0.000	0.001	0.004
		RCS	0.003	0.003	0.003	0.011	0.148
		SG					
		REFUEL	0.086	0.107	0.031	0.144	0.079
		OTHER	0.002	0.002	0.000	0.057	0.003
			0.094	0.114	0.034	0.213	0.234
	BOP	TURBINE	0.022	0.003	0.017	0.029	0.000
		GEN	0.000	0.000	0.000	0.000	0.000
		COND	0.006	0.003	0.001	0.002	0.001
		CW/SW/CCW	0.002	0.003	0.000	0.000	0.000
		OTHER	0.000	0.001	0.000	0.000	0.000
			0.029	0.010	0.018	0.031	0.001
	ECONOMIC		0.025	0.015	0.049	0.026	0.008
	HUMAN		0.000	0.000	0.000	0.000	0.000
	OTHER		0.001	0.002	0.000	0.028	0.128
	TOTAL		0.149	0.142	0.103	0.298	0.372
REGULATORY			0.101	0.181	0.210	0.148	0.192
UNKNOWN			0.002	0.003	0.001	0.001	0.000
** TOTAL ENERGY AVAIL. LOSS **			0.403	0.415	0.630	0.564	0.634
** ENERGY AVAIL. FACTOR **			0.597	0.585	0.370	0.436	0.366

Table 7.10 - U.S. Capacity Factor Distribution

By	PWR			BWR		
Year	Mean	σ	# Data	Mean	σ	# Data
75	0.664	0.132	27	0.494	0.177	18
76	0.623	0.150	30	0.554	0.176	19
77	0.696	0.104	36	0.601	0.129	21
78	0.670	0.168	39	0.675	0.125	21
79	0.563	0.209	40	0.671	0.147	22
80	0.550	0.208	41	0.592	0.130	22
81	0.580	0.213	46	0.587	0.142	22
82	0.566	0.220	47	0.585	0.190	22
83	0.568	0.236	49	0.548	0.213	23
84	0.602	0.234	52	0.483	0.261	25

By	PWR			BWR		
Age	Mean	σ	# Data	Mean	σ	# Data
1	0.617	0.156	37	0.499	0.180	14
2	0.540	0.201	36	0.503	0.180	12
3	0.607	0.183	41	0.561	0.112	17
4	0.601	0.201	37	0.563	0.139	19
5	0.626	0.187	38	0.628	0.174	20
6	0.617	0.202	38	0.621	0.120	21
7	0.546	0.230	35	0.614	0.181	21
8	0.612	0.202	34	0.617	0.188	21
9	0.634	0.214	29	0.573	0.184	19
10	0.642	0.189	26	0.643	0.166	16
11	0.675	0.132	15	0.597	0.169	10
12	0.686	0.154	11	0.585	0.225	10
13	0.445	0.206	6	0.371	0.295	5
14	0.490	0.309	5	0.436	0.295	3
15	0.585	0.326	3	0.366	0.312	2
16	0.371	0.371	2			
17	0.366	0.292	2			

FIGURE 7.3

U.S. PWR Capacity Factor Distribution By Year

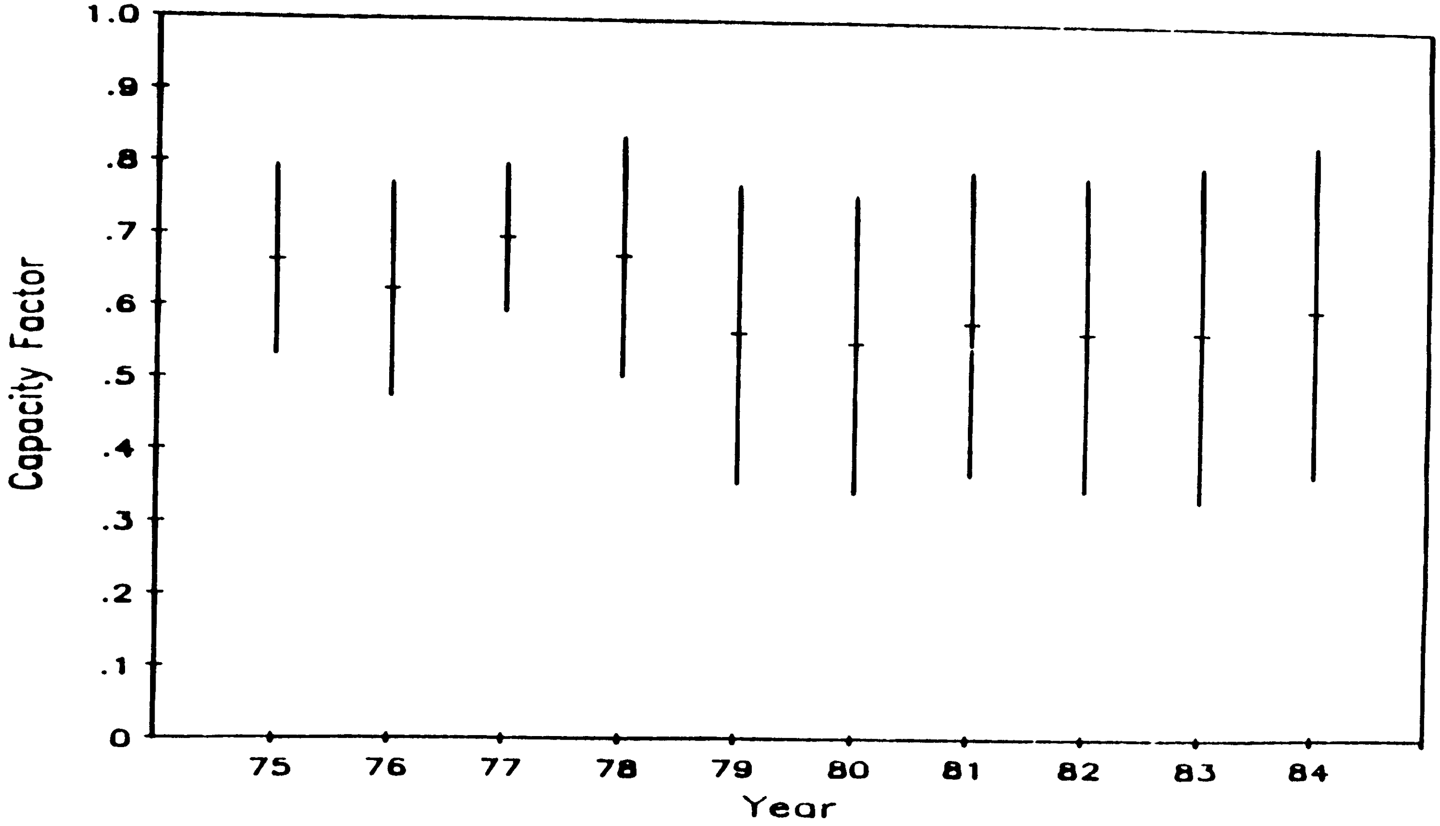


FIGURE 7.4

U.S. PWR Capacity Factor Distribution By Reactor Age

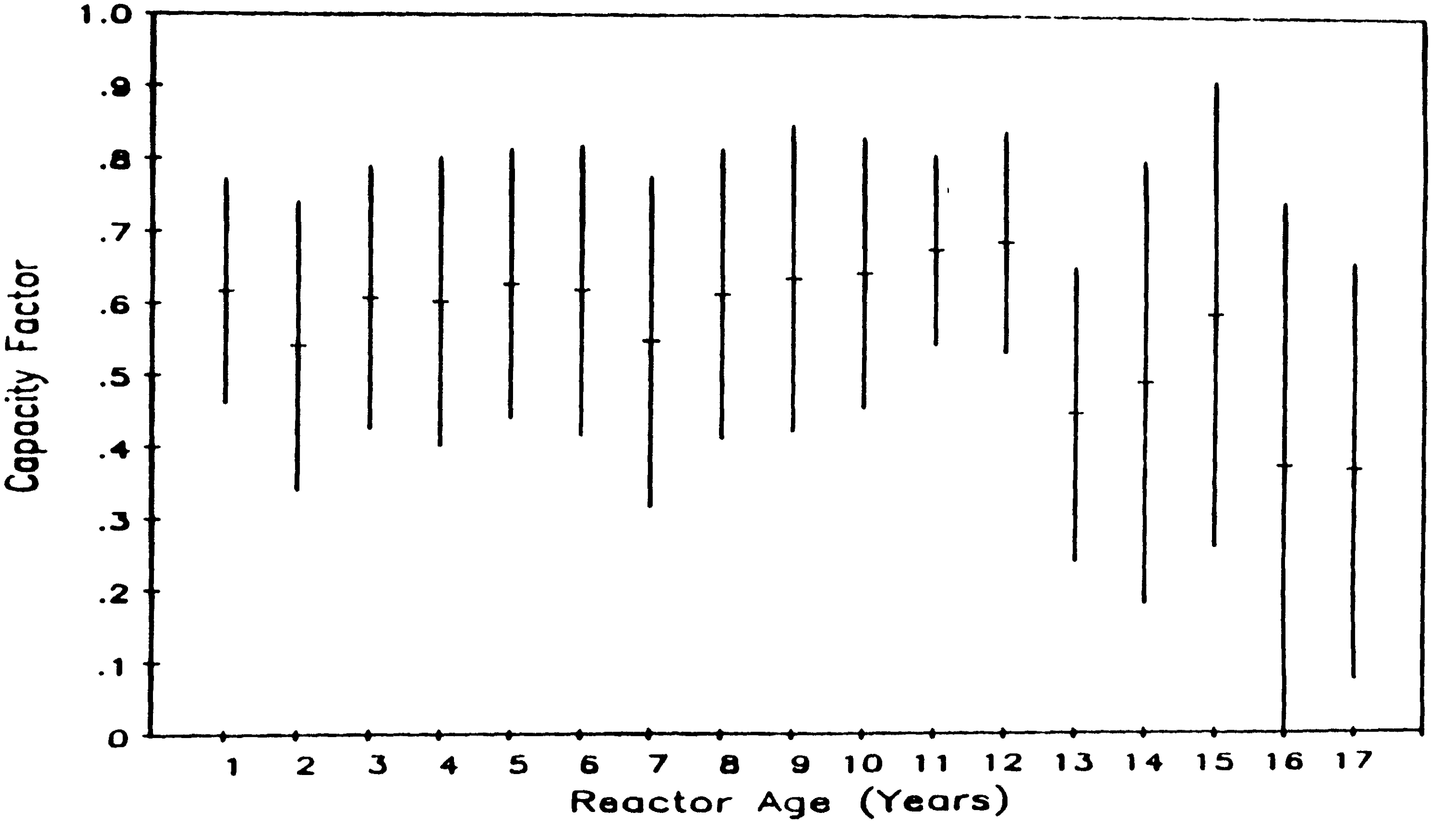


FIGURE 7.5

U.S. BWR Capacity Factor Distribution By Year

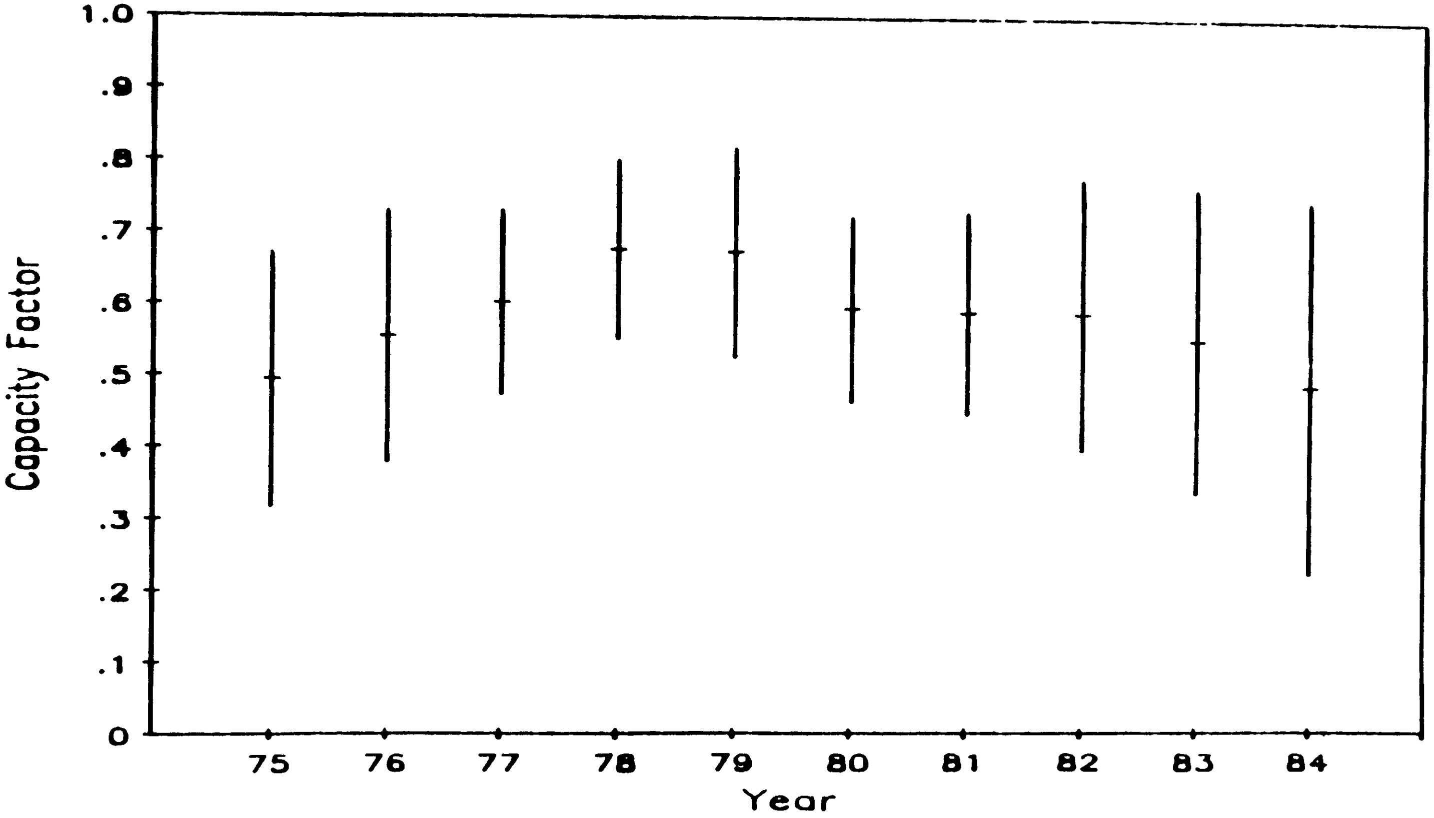


FIGURE 7.6

U.S. BWR Capacity Factor Distribution By Reactor Age

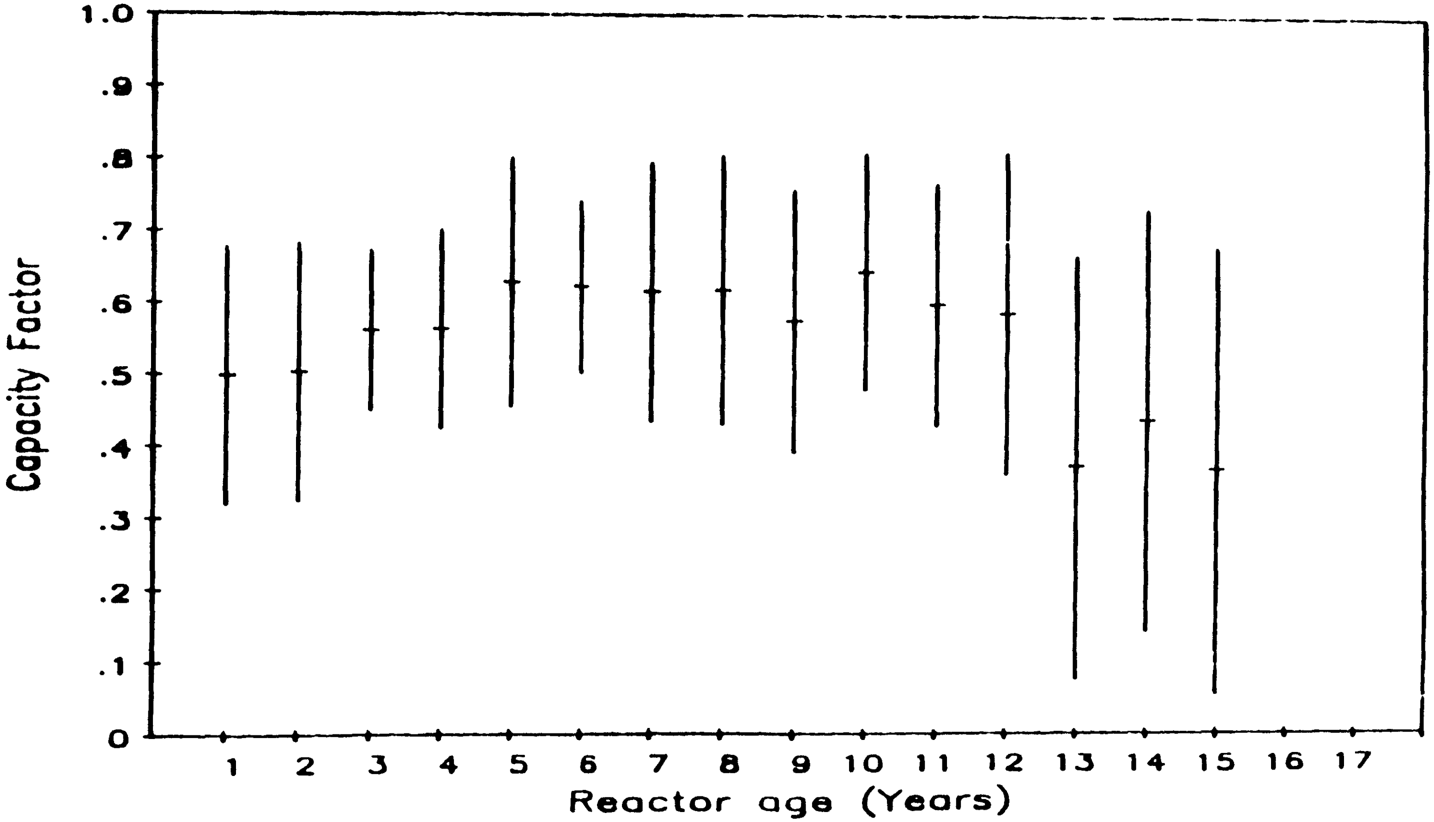


FIGURE 7.7

U.S. PWR Capacity Losses By Year
Forced, Scheduled, and Regulatory

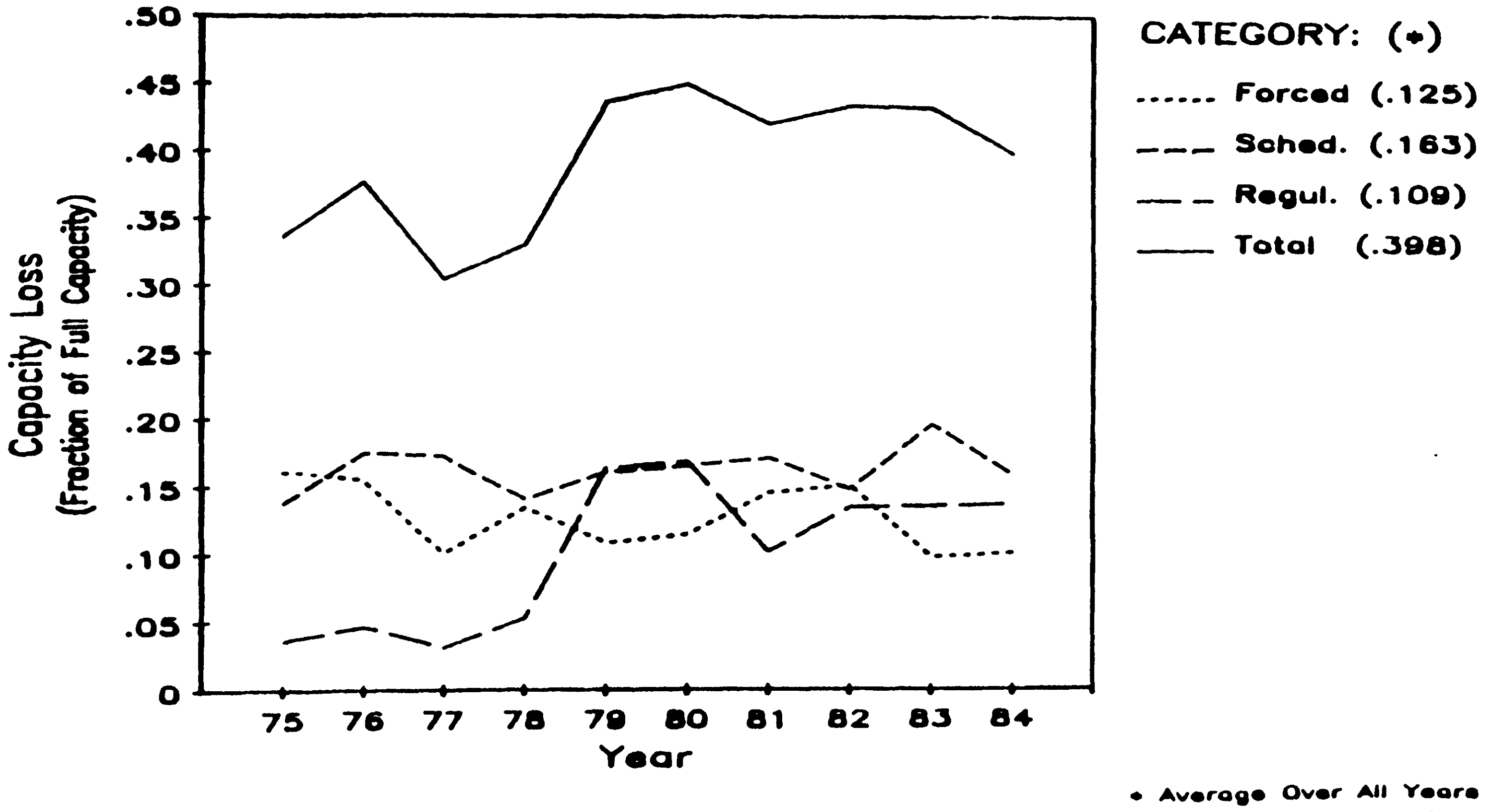


FIGURE 7.8

U.S. PWR Capacity Losses By Reactor Age
Forced, Scheduled, and Regulatory

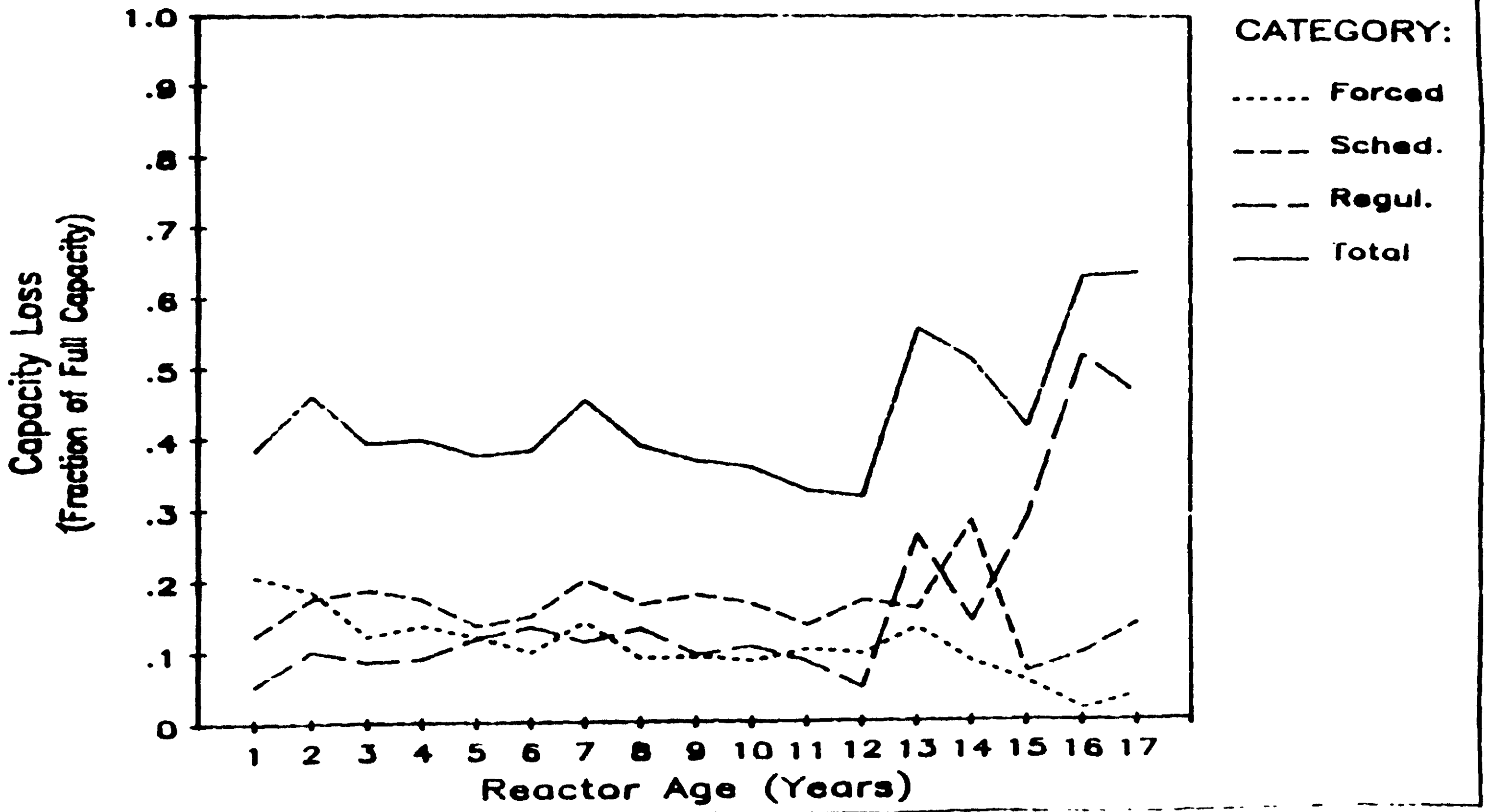


FIGURE 7.9

U.S. BWR Capacity Losses By Year
Forced, Scheduled, and Regulatory

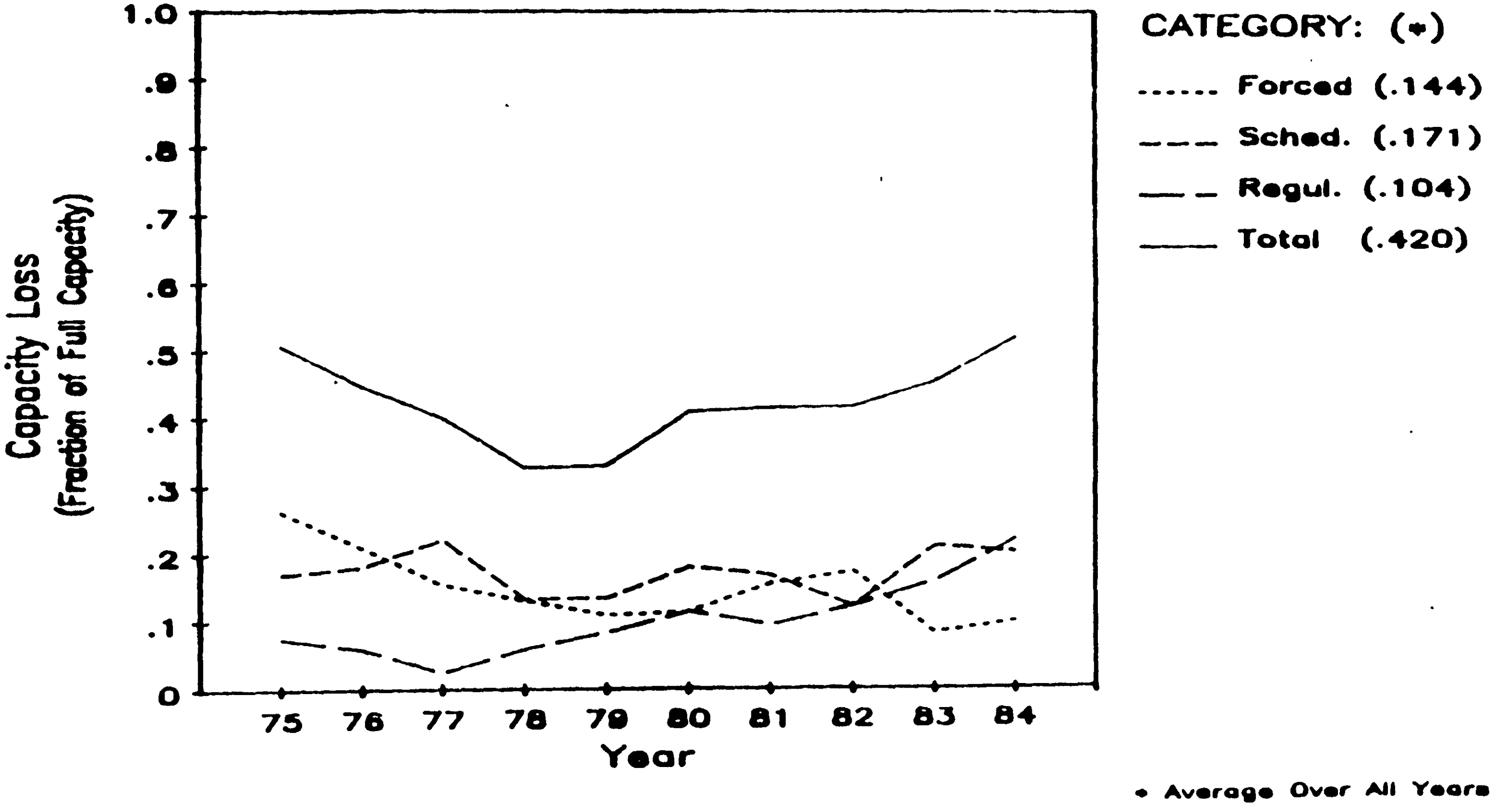


FIGURE 7.10

U.S. BWR Capacity Losses By Reactor Age
Forced, Scheduled, and Regulatory

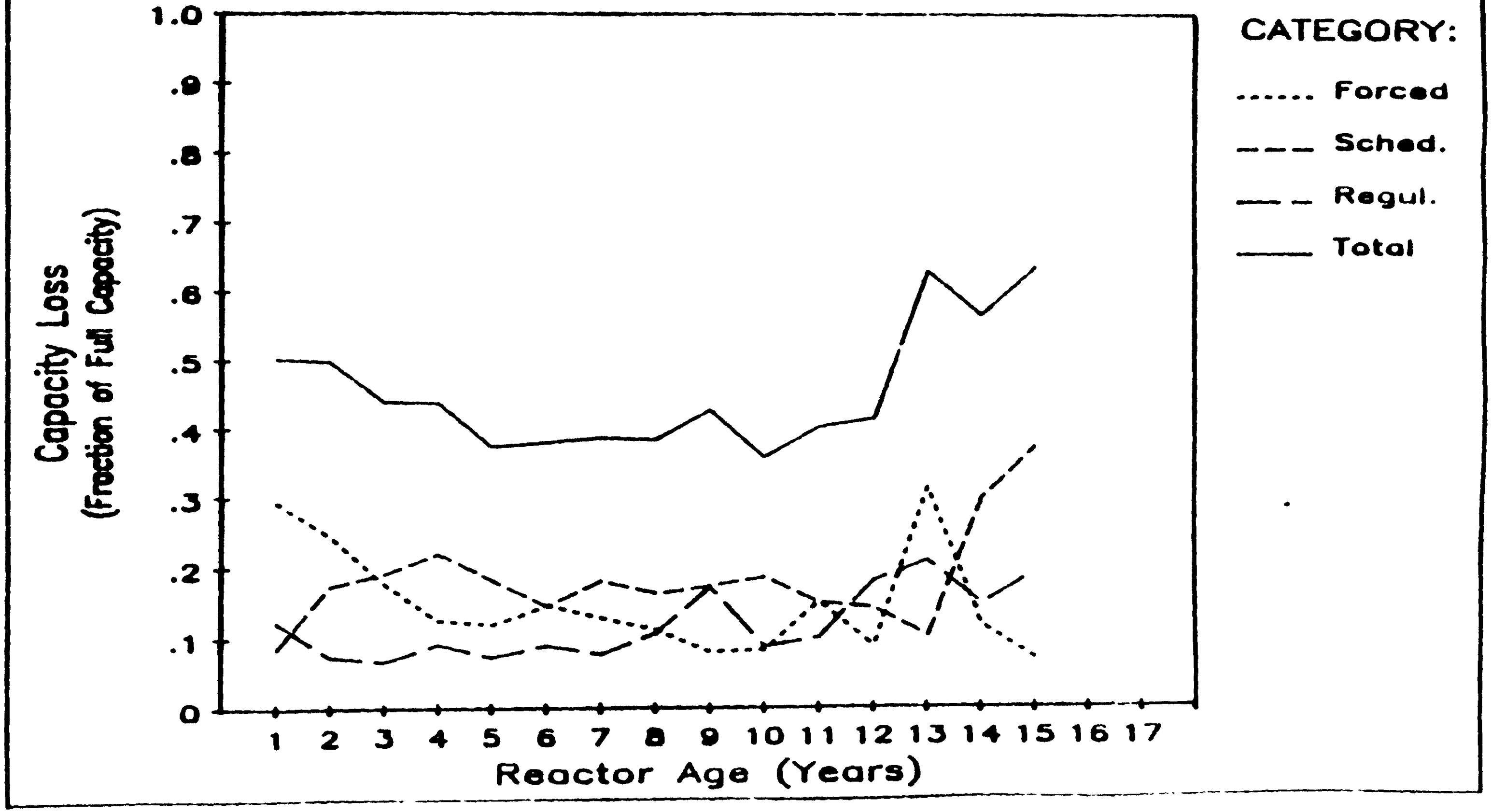


FIGURE 7.11

U.S. PWR Capacity Losses By Year
NSSS and BOP

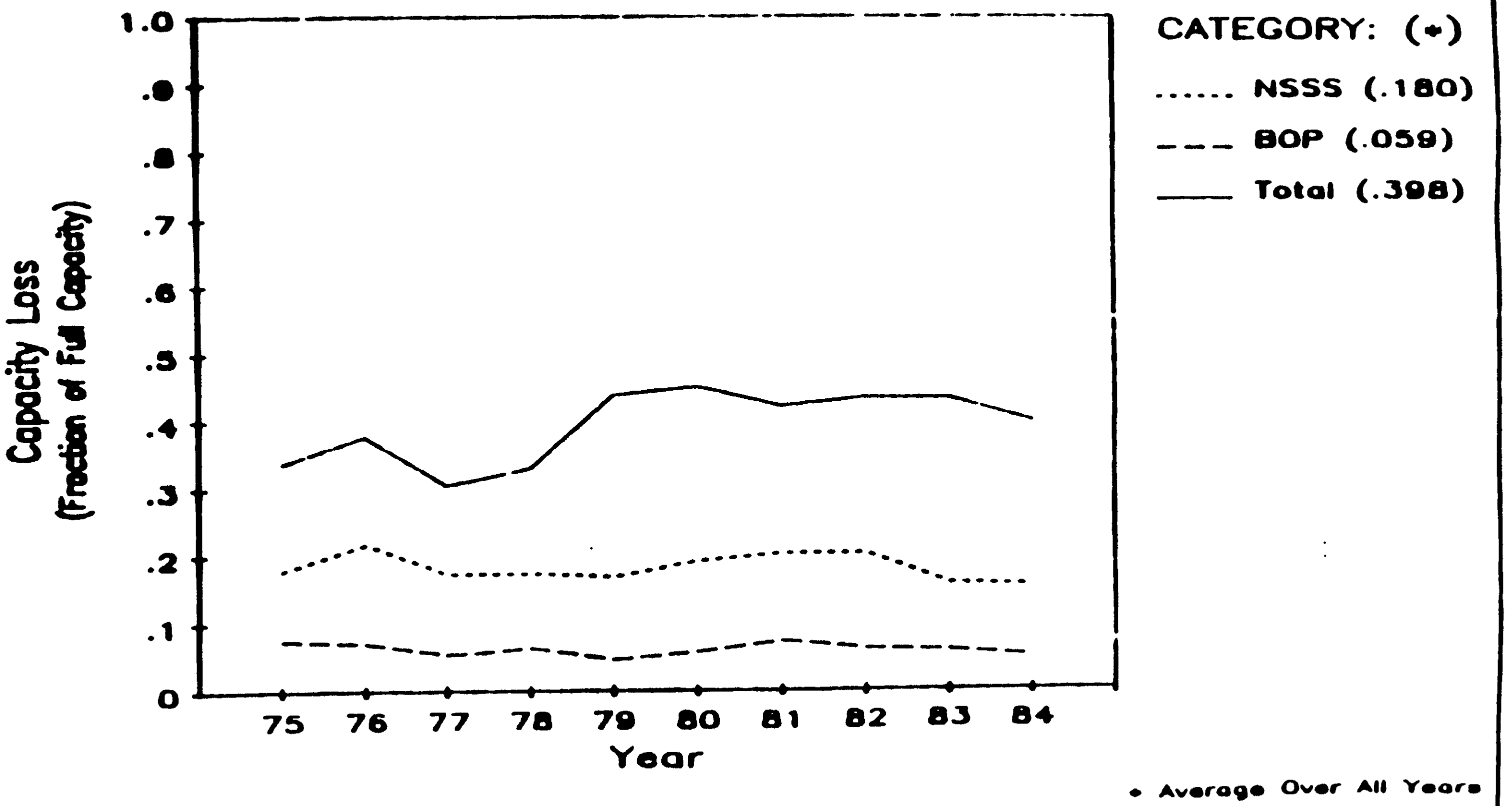


FIGURE 7.12

U.S. PWR Capacity Losses By Reactor Age
NSSS and BOP

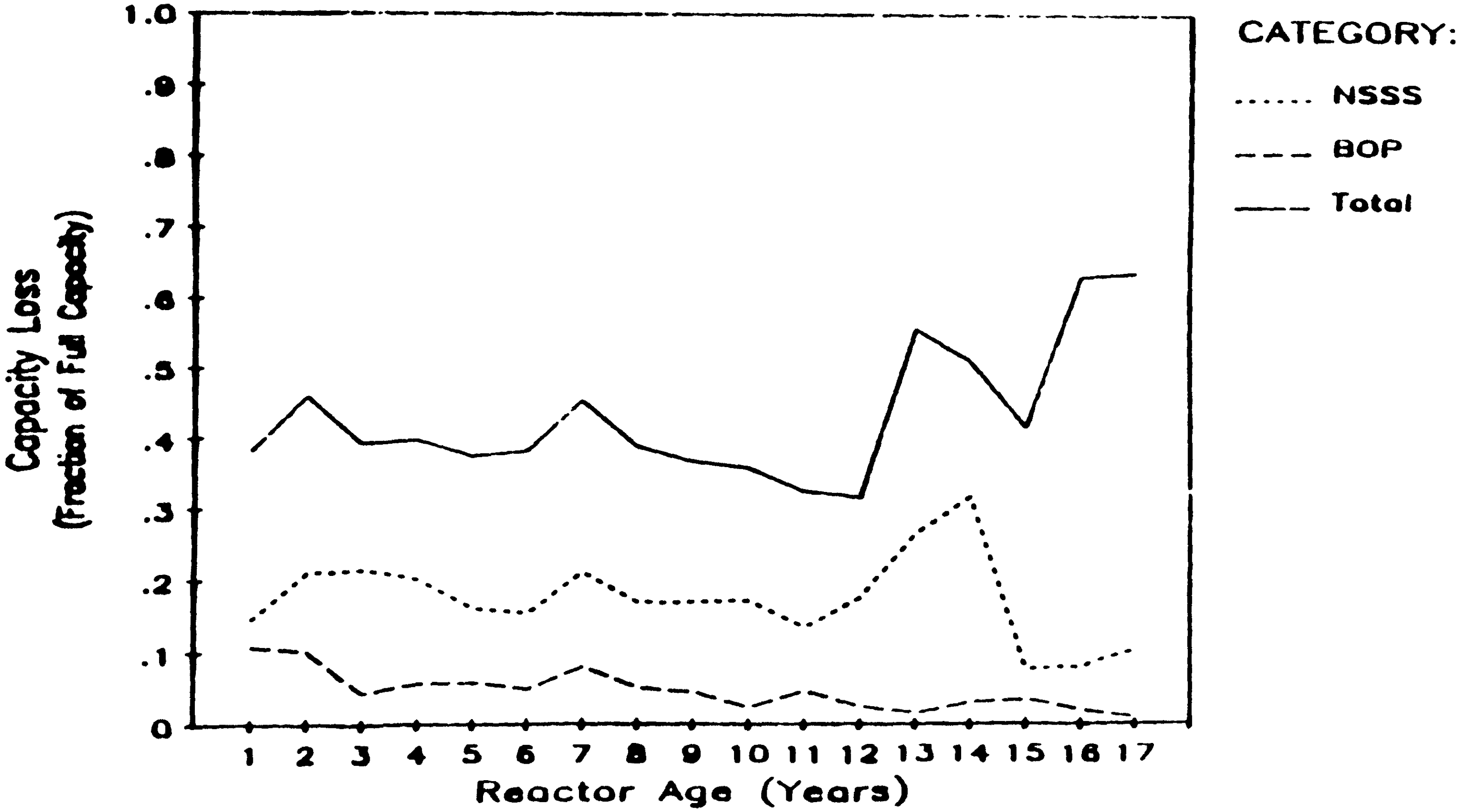
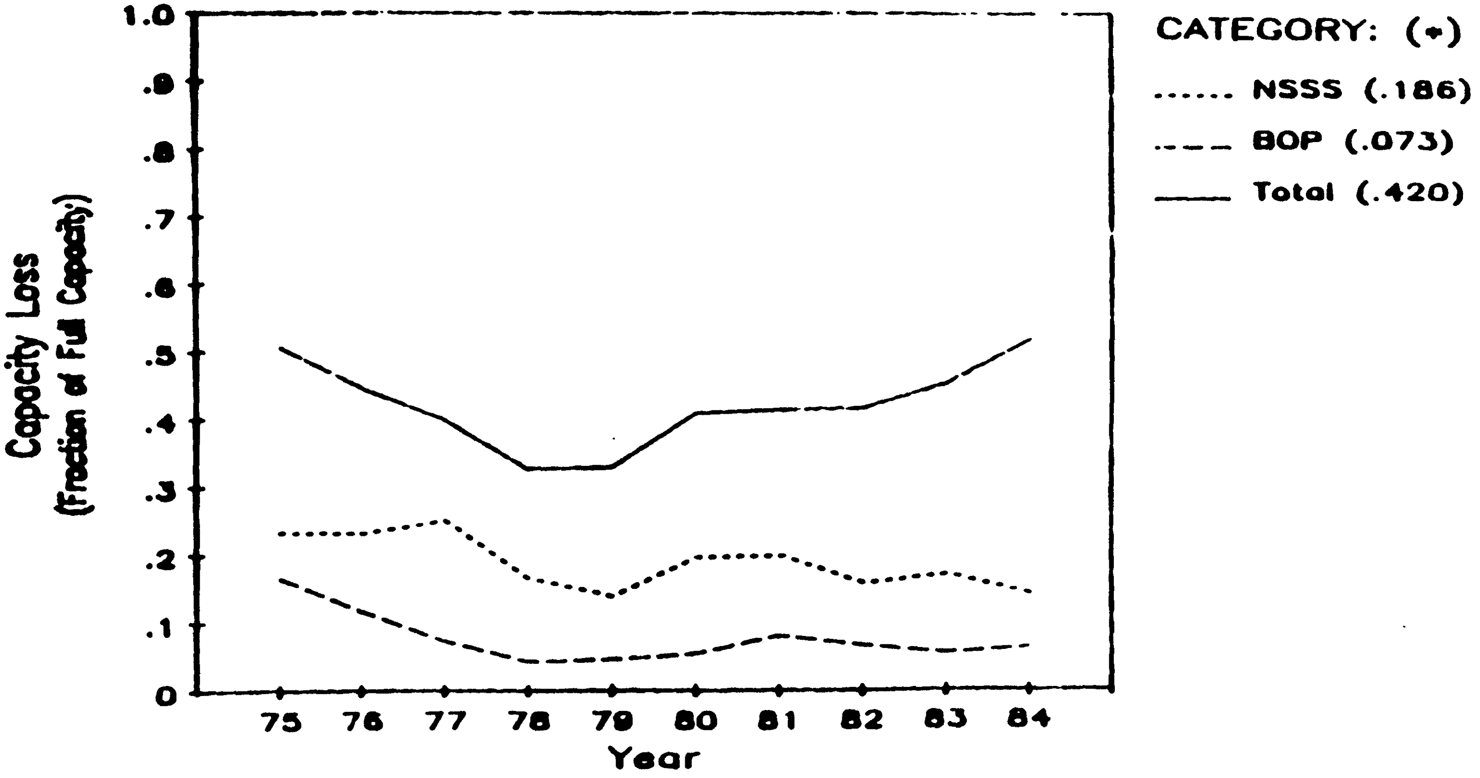


FIGURE 7.13

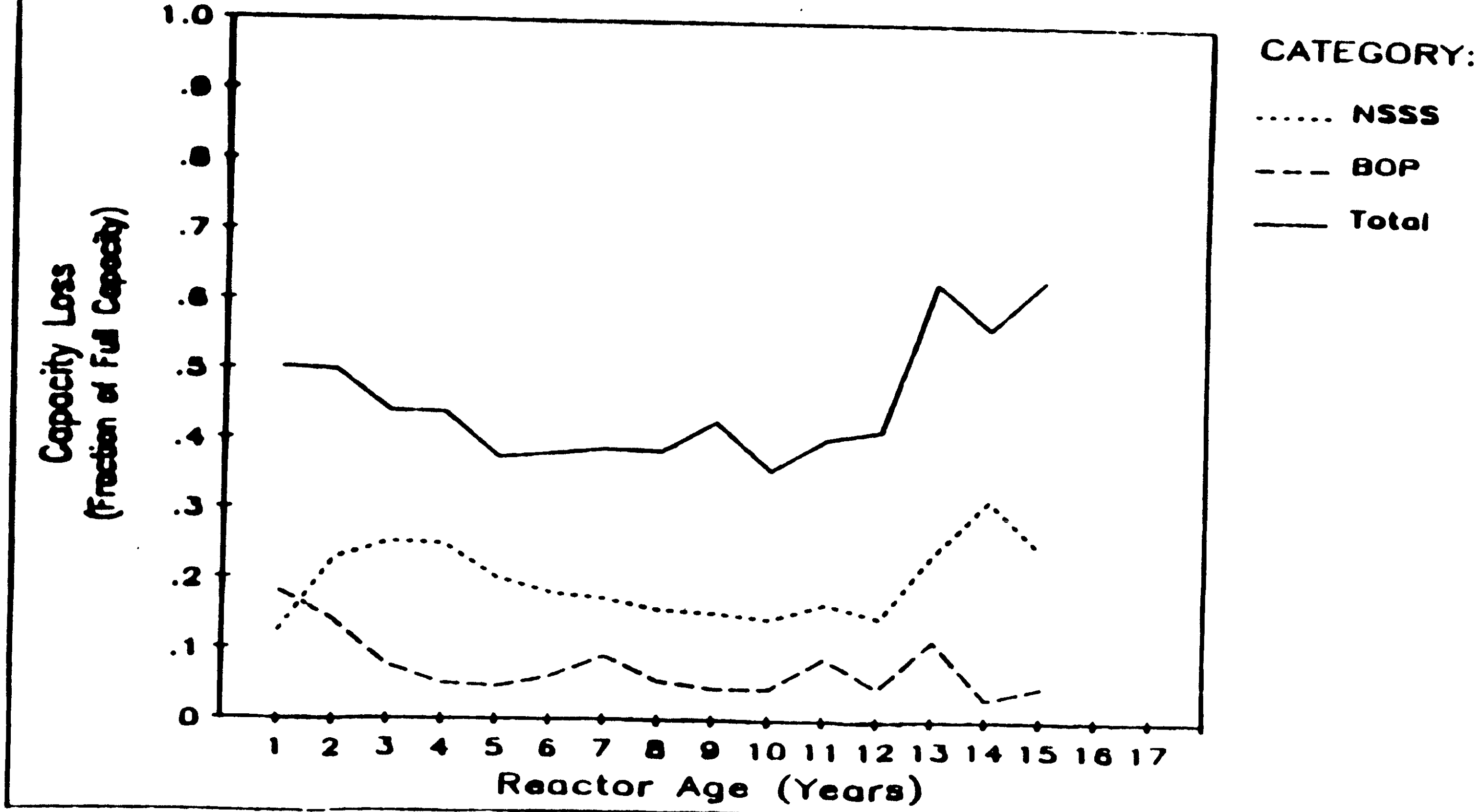
U.S. BWR Capacity Losses By Year
NSSS and BOP



* Average Over All Years

FIGURE 7.14

U.S. BWR Capacity Losses By Reactor Age
NSSS and BOP



7.9 OBSERVATIONS

Several important observations can be made on the basis of the work reported here. To a large degree these observations are derived from the interviews which were conducted with various organizations in the United States, where the purpose of the interviews was to answer questions suggested to the project team by the nuclear power station performance data. The most important suggestions were provided by the great disparities in performance which exist between the United States average plant and those of all other countries studied, and also by disparities among the population of United States plants. In the interviews we sought to understand the degree to which performance in the United States might depend upon such factors as utility organizational structure, utility managerial and technical capabilities, interactions between utilities and the nuclear supply industry, relationships among utilities, interactions between the safety and economic regulatory systems and the effects of political opposition to nuclear power.

Our most important observations are summarized as follows:

- Great diversity exists among utilities in terms of performance, management structures and attitudes and technical capabilities.
- Great diversity exists among the other sectors of the nuclear power industry also.
- The most important association observed in the United States portion of the study is that between high availability and strong utility management involvement in all aspects of plant operation.
- United States utilities tend neither to be coordinated among one another nor able to learn well from the experiences of each other. However, the Institute for Nuclear Power Operations has contributed in recent years to the improvement of such communications.
- It is a characteristic of the United States industry that long-term relationships between utilities and their suppliers have not been developed, although expectations to this rule are evident. The effects of this characteristic upon operational performance are not clear.

- Factors which have been suggested as being important in affecting United States nuclear power station performance, but which do not appear in our work to be directly important are those of utility management structure and technical capabilities, safety and economic regulation and of political opposition to nuclear power.

- The behavior of the safety and financial regulatory systems in affecting nuclear projects is very unpredictable. The consequent uncertainty which has been injected into the environment of utility decision-making has increased the variability of policies and practices from one utility to another.

- Political opposition to nuclear power has been important in affecting the policies and practices of the NRC. Utilities have recognized such influences as important factors which much be taken into account in dealing with the NRC, however, the degree to which utility practices have been modified by such recognition remains unclear. The only case where public opposition to operation of a nuclear plant having an Operating License has been successful over a long duration is that of the Three Mile Island 1 plant.

CHAPTER 8

DATA COMPARISONS

PRESSURIZED WATER REACTORS

Overall Comparisons

Figure 8.1 shows PWR Capacity Factors (CF) as a function of time for the six countries examined in this study. Each shows some variations with time, as would be expected. Notably, it appears that the TMI accident had an impact on performance in all six countries.

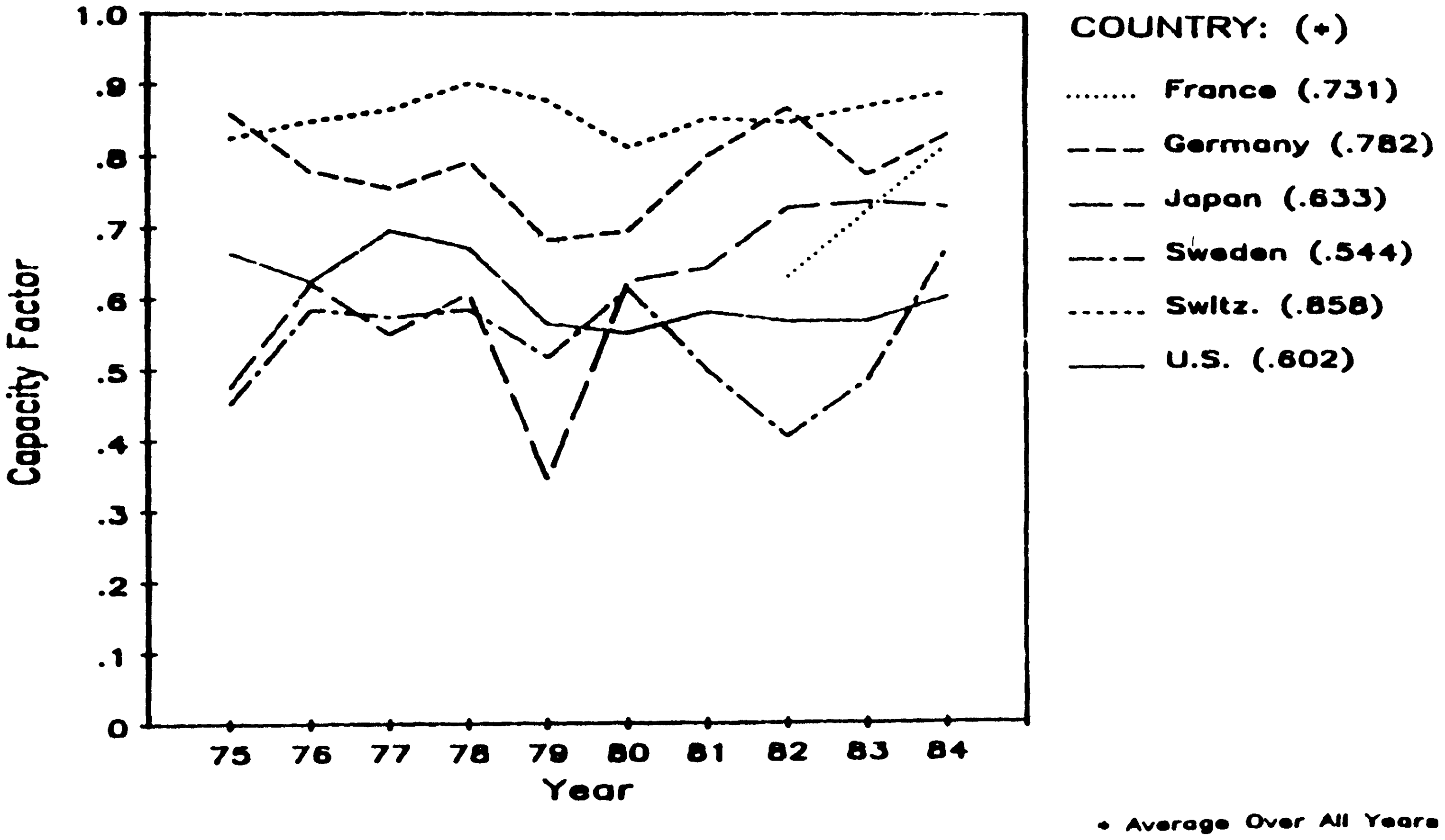
The Swiss have the largest 10-year average CF (85.8 percent). The smallest annual value is 81.1 percent (1980) and the largest is 90.2 percent (1978). The performance of the Swiss PWR industry clearly has been consistently outstanding.

The Federal Republic of Germany has the second best 10-year average CF (78.2 percent). The smallest annual value is 68.1 percent (1979) and the largest is 86.8 percent (1982). The shape of the performance curve with time suggests declining performance from 1975 to 1979, followed by reasonably steady improvement. Discussions with German experts suggest that the post-1979 improvement arose due to collective efforts by the utilities and KWU to improve performance through better outage planning, equipment upgrades, and reduced economic losses.

The French data are only available for three years (1982-84) and display a continuous improvement with time. French experts place considerable emphasis on their detailed planning and on integration into planning of lessons learned. The results are a monotonic decline in both the forced and scheduled outage losses with time.

FIGURE 8.1

PWR Capacity Factors By Year



The Japanese experience is very dramatic. From 1975 to 1979, the CF was relatively low, averaging 52 percent, followed by dramatic improvement after 1979, with an average of near 70 percent. Available evidence suggests that the fruits of an industry-wide approach to performance improvement begun in the mid-70's are coming evident.

U.S. CF performance shows some early improvement, followed by a slow decline from 1977 on. (It should be pointed out that in 1985 PWR CF improved dramatically.) The data also show very large regulatory losses compared to other countries. From 1975 to 1979, U.S. regulatory losses averaged 6.6 percent, while for 1980-1984 they averaged 13.6 percent.

The Swedish PWR performance has the lowest 10-year average (54 percent). However, it should be borne in mind that there are only 3 plants in the data base, 2 of which came on line in 1981 and 1983, respectively. The Swedish plants are the only ones that show sizeable losses due to regulatory factors, other than in the United States. The 10-year average is only 4.4 percent. However, in 1975, 1982, and 1983, regulatory losses were greater than 10 percent. The other major problem has been with steam generators, but, given the small data base, any one problem can produce a significant fluctuation in performance, as Figure 8.1 clearly shows.

Forced Outages

Table 8.1 shows 10-year average values of forced loss categories. The forced outage rates in Sweden and the United States are significantly larger than in the other countries. France shows an intermediate level of forced outages, while Japan, Switzerland, and the Federal Republic of Germany are notably low. (Recall that in France any outage not part of the scheduled refueling is considered forced, a stricter definition than that used by most other countries.)

Table 8.1

PWR Forced Outage Losses (1975-1984 Average)

	France	Germany	Japan	Sweden	Switzerland	United States
NSSS						
RCS	.005	.002	.002	.000	.004	.025
SG	.005	.004	.016	.084	.009	.012
Other	.026	.002	.003	.033	.000	.012
TOTAL NSSS	.036	.008	.021	.117	.012	.050
BOP						
Turbine	.006	.002	.001	.005	.002	.013
Generator	.007	.008	.000	.011	.000	.012
Condensor	.003	.001	.000	.000	.000	.015
Other	.012	.002	.002	.072	.004	.005
TOTAL BOP	.029	.014	.003	.084	.006	.046
TOTAL FORCED OUTAGE	.086	.023	.026	.239	.021	.125

It is evident from the data that steam generators have dominated the Swedish losses and represent over one-third of total losses. A variety of other components make up the rest of the Swedish losses. The United States shows the greatest forced losses in the reactor coolant system (RCS), turbine-generators, and condensor systems.

Scheduled Outages

Table 8.2 summarizes scheduled outages and regulatory outages. France, Germany, Sweden, and the United States show similar scheduled outage losses. The Swiss show an ability to perform refueling in significantly less time than other countries. Conversely, the Japanese show very long scheduled outages, roughly four months. Japan schedules long outages, during which extensive service and maintenance activities are performed, resulting in relatively good overall performance. Long scheduled outages also help keep the Japanese forced outage rate very low.

Regulatory Losses

Regulatory losses are low in all countries but in Sweden and the United States, whose regulatory losses are more than double Sweden's. The French, Japanese, and Swiss report no regulatory losses.

Over the past years Germany reports losses averaging only 0.9 percent, with peak levels of 2.6 percent in 1976 and 2.8 percent in 1984. Discussions with German engineers suggest that regulatory procedures may help account for these relatively low losses. It appears that the close communication and interaction between the nuclear utilities, KWU, and the various regulatory bodies help derive solutions to potential safety problems by consensus. If a problem requires plant modifications, the utilities and regulators agree on a time schedule for

Table 8.2

PWR Scheduled and Regulatory Losses (1975-1984 Average)

	France	Germany	Japan	Sweden	Switzerland	United States
Scheduled						
NSSS	*	.164	.325	*	.097	.130
BOP	*	.005	.002	*	.016	.013
Subtotal	.178	.185	.340	.174	.118	.163
Regulatory	.000	.009	.000	.044	.000	.109
TOTAL	.178	.194	.340	.218	.118	.272

*Detailed Data not available.

work completion without issuing an order for a shutdown. The utilities then schedule the work to be done during regularly scheduled outages, thus eliminating a loss appearing as a regulatory loss. Furthermore, in a number of cases an event is reported differently in the United States and Germany. (It should be pointed out that some work in the United States is done in the same manner, and also is reported as scheduled losses.)

Annual Swedish regulatory losses averaged 4.4 percent from 1975 to 1984. Peak losses occurred in 1975 (11.2 percent), 1982 (12.0 percent), and 1983 (12.4 percent). The latter two were due to required steam generator inspections at two of Sweden's three PWRs. We have not been able to gather information on the 1975 loss, nor on scattered small losses in other years.

U.S. regulatory losses are much larger than in any other country. In general, the annual average losses were relatively small (4 percent) until TMI, after which they leapt to around 14 percent. The losses were largest in 1979 and 1980, both exceeding 16 percent, and since 1981 have averaged 13 percent. About two-thirds of these losses are associated with seismic issues, primary system piping, and steam generators.

There is some ambiguity in the data with regard to steam generator losses. Some utilities classify steam generator replacement or retubing as a regulatory loss while others do not. Thus, the same cause can be recorded under different loss categories by different utilities. If all steam generator capacity losses were assumed to be technological rather than regulatory matters, then U.S. regulatory losses would dip by about 16 percent. Still, the large remaining losses are much greater than those reported by the other countries. It would be interesting to pursue the specific technical problems that accounted for U.S. losses, and try to understand how the issue was treated in other countries.

BOILING WATER REACTORS

Overall Comparisons

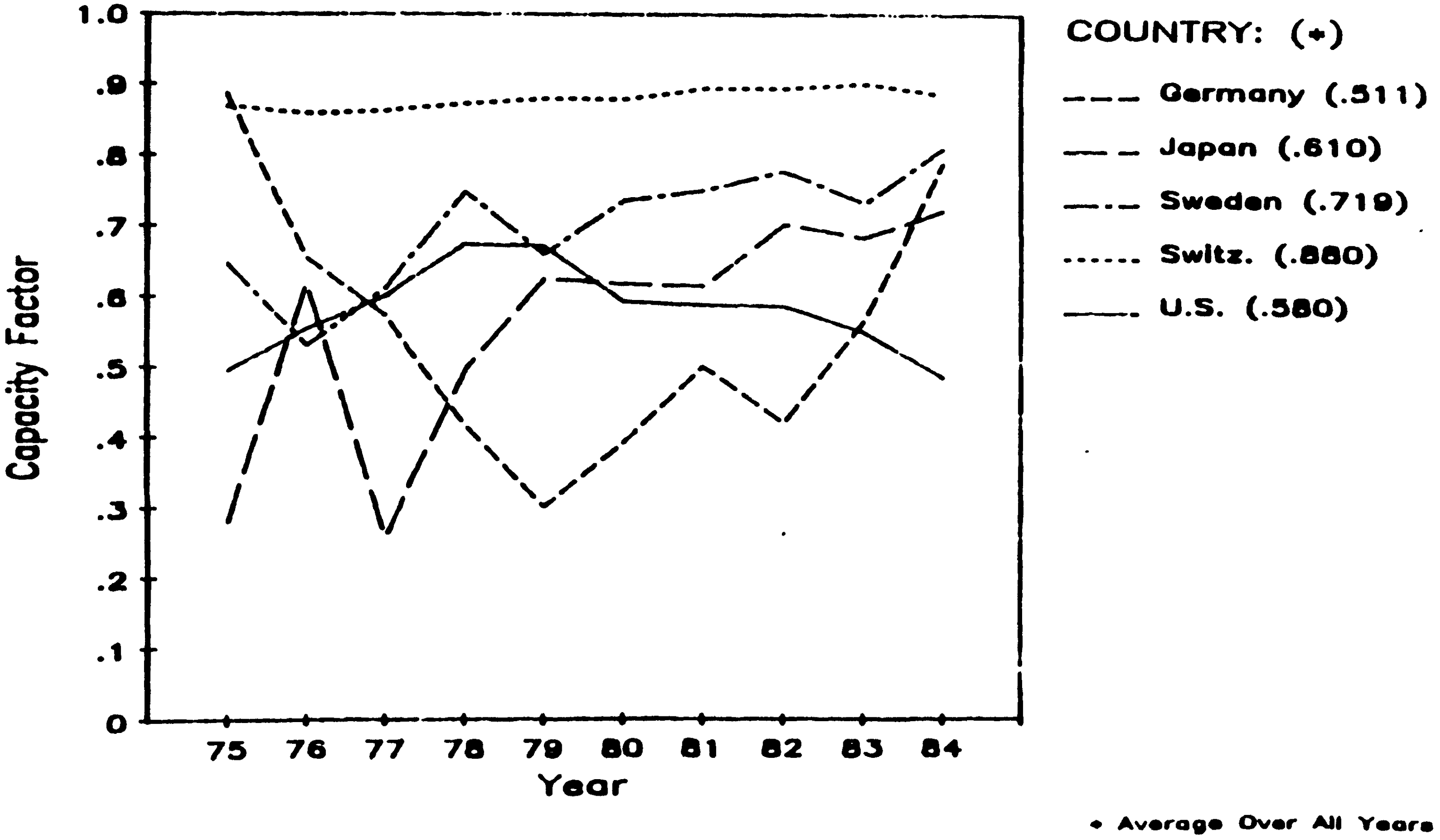
Figure 8.2 shows BWR capacity factors over 1975-84 for the Federal Republic of Germany, Japan, Sweden, Switzerland, and the United States. In general, there are sizeable fluctuations in performance, with the exception of Switzerland (which has only one BWR in its data base). Fluctuations in the remaining countries are large, and most striking in Japan, Germany, and Sweden. In particular each country had some performance problems in the interval 1975 to 1979, but after 1979 there is steady improvement. By the end of 1984 these countries had CFs of 70 percent or better. In contrast, U.S. performance has deteriorated since 1979 and was about 59 percent in 1984.

The one Swiss BWR has a 10-year average CF of 88 percent, which exceeds the 85.8 percent PWR CF. The BWR plant performance is remarkably smooth: The worst annual CF was 85.9 percent and the best was 90.1 percent. All in all, Swiss nuclear performance is outstanding. It would be interesting to have further discussions with Swiss experts to better understand how such consistently excellent results are achieved.

There are only four BWR plants in the German data base, and they show the lowest 10-year average (51.1 percent) of all five countries. The very large drop from 1976 to 1980 was due to the primary coolant pipe replacement program, which took over a year to complete at each plant. The program was not completed until 1982. Performance has climbed dramatically in the last two years and reached 79.3 percent in 1984.

FIGURE 8.2

BWR Capacity Factors By Year



A similar large drop occurred in Japan in the late 1970s. It is difficult to determine specific causes because the large losses all are associated in available data with refueling. In recent years there has been steady improvement. Information acquired from INPO reports suggest that Japanese BWRs are serviced and maintained in a mode similar to PWRs. Thus, annual refueling lasts about three months, during which time much service and maintenance work is performed.

The Swedish performance has been less variable than in other countries. Sweden has the second highest average 10-year performance (71.9 percent). For 1980 to 1984, the average was 76 percent.

The U.S. trend is counter to all the other countries. In particular, performance has been declining in the 1980s rather than improving. Some of the causes are examined in detail below.

Forced Outages

Table 8.3 shows BWR forced outage rates from 1975 to 1984 for the five countries. The Japanese and Swiss have extremely low levels (.014 and .013), the losses in the Federal Republic of Germany are intermediate (6.5 percent), and Sweden and the United States have the highest rates (.129 and .144).

Examination of detailed causes in the NSSS shows that the RCS is a major problem in the United States, and has been a significant factor in the Federal Republic of Germany. Fuel losses in the United States have been much bigger than in other countries, although in recent years they have been trending downward.

Balance-of-plant forced outages are highest in Sweden and appear to be distributed widely among turbine, generators, cooling water/secondary water, and other causes. Detailed review shows that the losses were

Table 8.3

BWR Forced Outage Losses (1975-1984 Average)

	Germany	Japan	Sweden	Switzerland	United States
NSSS					
RCS	.016	.003	.002	.005	.031
Other	.024	.002	.020	.001	.027
TOTAL NSSS	.040	.005	.022	.006	.058
BOP					
Turbine	.008	.002	.011	.006	.013
Generator	.001	.001	.015	.000	.004
Condensor	.008	.000	.000	.000	.017
Other	.005	.002	.062	.001	.023
TOTAL BOP	.022	.006	.088	.007	.057
TOTAL FORCED OUTAGE	.065	.014	.129	.013	.144

largest in the 1975-1979 interval, when a variety of problems occurred. In the last five years losses have averaged less than 5 percent annually. At the same time, the number of plants has risen to seven.

U.S. losses in the BOP average 5.7 percent, while for the Federal Republic of Germany, Switzerland, and Japan they are very small. All countries show small turbine and generator losses. The United States reports an average loss of 1.7 percent attributable to the condensor system. This is larger by a factor of 2 than condensor system losses in the Federal Republic of Germany. No other countries report condensor system-associated losses.

Scheduled Outages

Table 8.4 presents data on scheduled outages and regulatory losses. The Swiss show a surprisingly small loss, less than 11 percent annually. (We have been unable to determine whether or not the Swiss use an annual refueling schedule). Swedish and U.S. losses are relatively small, and are associated with the refueling itself. The Germans and Japanese show much larger losses, both averaging above 30 percent annually. However, the causes are very different. In the Federal Republic of Germany the pipe replacement program led to very large scheduled losses in the RCS for 1980-1983. In other years the total German scheduled outage losses were similar to the United States and Sweden.

Conversely, the Japanese losses appear to be relatively constant, and are associated with their deliberate policy of using long scheduled outages for refueling and extensive maintenance.

Table 8.4

BWR Scheduled and Regulatory Losses (1975-1984 Average)

	Germany	Japan	Sweden	Switzerland	United States
Scheduled					
NSSS	.282	.344	*	.089	.127
BOP	.005	*	*	*	.016
Subtotal	.307	.376	.145	.107	.171
Regulatory	.113	.000	.007	.000	.104
TOTAL	.420	.376	.152	.107	.275

*Detailed Data not available.

Regulatory Outages

The United States and the Federal Republic of Germany show very large regulatory losses, both exceeding 10 percent for the 10-year average. The Swedish show a very small regulatory loss (.7 percent), which is relatively constant with time.

U.S. BWR regulatory losses averaged about 5 percent from 1975-1979, then jumped over 10 percent in the post-TMI era. The principal issues included seismic design criteria, blowdown response of the plant, and RCS piping. A detailed analysis of regulatory losses in the United States and in the Federal Republic of Germany will be presented in a subsequent report.

CHAPTER 9

CONCLUSIONS

The nuclear plants studied in this project all are light water reactors of either PWR or BWR design. The project was limited to these plants because their technologies were essentially the same in all countries. Thus, performance differences must be associated more with operational, regulatory, and management factors than with fundamental technology. With the great diversity in data, it is impossible to be assured that numerical differences are real or that causes for differences can be uniquely identified. Thus, there is a great deal of uncertainty in the results. We draw several inferences from existing (noisy) data, but these are tentative conclusions. Thus, we propose several recommendations to help clarify the situation in the future.

The first conclusion is drawn from the outstanding Swiss performance. The data base is very small: 3 PWRs and 1 BWR. Nevertheless, consistent, high-quality performance suggests that there are imbedded in the swiss system operational and managerial policies that would be helpful to others.

The Swiss plants all were provided by different vendors. Beznau 1 and 2 were Westinghouse designs with Brown, Boveri as contractor. The Gosgen plant is a KWU turnkey plant. The Muehlberg plant was a GE design with Brown, Boveri as contractor. Thus, it appears the diversity of vendors is not a factor in performance.

Our study suggests that Switzerland's strong central focus on all on-site operations, planning, and maintenance is a significant factor in achieving this outstanding performance, as well as a strong emphasis on planning and preparation for outages. Finally, the Swiss system shows a vigorous effort at training and integrating lessons learned from past experiences.

Our second conclusion relates to the ability to learn from experience and to improve performance. We believe the data provide overwhelming evidence that it is possible to create industry-wide programs that lead to substantial performance improvement. Japan's experience provides the clearest example. For both their PWR and BWR programs, the Japanese have shown an ability to systematically overcome problems and achieve consistently high performance. In particular, they have reduced forced outages to very low levels.

The limited French data show the same trend for PWRs.

German BWRs show a marked trend toward improvement in recent years. PWRs show a similar trend, but their performance has been much smoother with time than BWRs. Finally, the Swedish data also show improving performance in recent years.

We emphasize the fact that all these countries have a close-knit nuclear industry where knowledge, experience, and information are widely and rapidly shared. However, the industry structures in these countries have little in common. France has a national utility and a single supplier; Germany has, in effect, a single supplier and a large number of private utilities; Japan has a large number of private utilities and three suppliers; and Sweden has both public and private ownership of plants and one national supplier and one foreign supplier. Thus, we conclude that good performance is possible in a wide variety of industrial structures.

It is clear that the influence of safety regulation can be very large, as the U.S. and German data show. In a companion study we examined some of the causes of regulatory losses in these two countries.

In general, the same technical issues lead to roughly equivalent capacity losses. However, two countries use different reporting practices. Thus, PWR regulatory losses appear small for Germany and large for the United States. However, detailed discussions with German colleagues indicated that they experience losses similar to those in the United States but report them as scheduled losses. Thus, it appears that the 18 percentage point difference between capacity factors in the two countries is not due to different regulatory requirements.

It is difficult to draw meaningful conclusions about U.S. performance. The industry is larger, more diverse, and more fragmented than that of the other countries. Amongst the 79 U.S. reactors included in this study there are both outstanding and poor performers. With such a great spread in the data, it is unclear how useful averages would be. We do offer the following observations:

(1) The technology originated in the United States and the problems associated with learning first occurred in the United States. However, the data do not support a conclusion that the United States is learning from experience.

(2) The U.S. supply industry is the most diverse of all the countries studied. However, without more detailed analysis the data does not reflect any significant correlation of performance with NSSS vendor, A/E, or constructor; nor does the data suggest any significant correlation with age or size.

(3) The safety regulation of the U.S. industry has had a great impact on performance. However, absent greater understanding of safety regulation in other countries, we cannot assess the relative importance of this factor.

(4) The economics of nuclear power may be a significant influence on performance. For example, in countries where alternatives are very expensive it may be possible to make large investments in high quality components, and maintenance friendly designs. However, the relations, if any, between economics and performance have not been studied in this project.

(5) The economic regulation of utilities in the United States is a matter of considerable current interest. The extent to which economic regulation has, or will, influence performance is unknown. The subject merits much further study.

(6) Data suggest that the U.S. industry has not succeeded in learning from experience to the extent that other nations have. Our second conclusion highlighted the fact that improvements have been achieved elsewhere. This observation is clouded by several complicating factors. First, the TMI accident had the greatest (negative) influence on almost all U.S. reactors. As a result of TMI, regulatory losses in the United States since 1980 are greater than 10 percent annually. A second factor is the post-TMI creation of INPO. A major objective of INPO is to provide a vehicle for sharing experience and information. We believe INPO is having a strongly favorable influence on the industry. However, there has probably not been adequate time for INPO activities to influence results.

Our final conclusion is an inference drawn from the above conclusion. The evidence provided by non-U.S. data and our interviews suggests that good performance, as well as improvements in performance, require a strong management role. We interpret strong management to mean several things:

(a) Relations with suppliers of products and services. The non-U.S. utilities all report a management style that includes close times with suppliers as well as an unambiguous chain of command within the supply process. Conversations with U.S. nuclear suppliers indicate that they also prefer clear, well-defined relations with utility management.

(b) Technical capability. We believe that the best utilities all demonstrate strong in-house technical abilities. These include abilities in the areas of nuclear engineering, safety, operations, and maintenance. In those cases to which we were exposed, utility managements expressed great pride in the technical ability of their internal staffs.

(c) Continuous learning. It is an outstanding characteristic of foreign nuclear industries and utilities that the training and integration of lessons learned into planning and operations is a high-priority item. This matter is closely coupled to acquiring and retaining technical capabilities.

(d) Highly professional relations with regulators. The other countries studied are much smaller than the United States, and geographic distances between plants and regulators are small. This facilitates frequent, personal contact between utility staff and regulatory staffs. There has grown into their nuclear industries a strong professional appreciation among counterparts. Part of the task of strong managment is to foster and maintain such positive relations between regulated and regulators.

(e) High expectations of management. It is clear from non-U.S. experiences that utility managments expect excellent performance from their suppliers, their staffs, and themselves. Although this factor is difficult to quantify, it is nontheless real. The non-U.S. experience with regard to suppliers is particularly interesting. In general, a utility deals with the same subcontractors year after year. This relationship develops in a natural manner. The utility expects and demands high-quality goods and services. When it finds suppliers who provide quality work it maintains relations with those suppliers. This is very beneficial to both parties, since the utility can rely on its vendors, while the vendor in turn gains familiarity with the plant and therefore can provide more expert help. We also found that the "espirit de corps" at foreign plants was generally quite high, due to deeply ingrained pride in work and workmanship. (Discussion with some managers at outstanding U.S. plants support this observation regarding high expectations.)

CHAPTER 10

RECOMMENDATIONS

This study has acquired a great deal of data and information about nuclear power plant performance. However, we believe that more insights could be distilled from the available information if further analyses were undertaken. We outline these topics below.

1. International Regulatory Comparison

In the United States, losses due to safety regulation are very large, and relatively large in the Federal Republic of Germany. In examining these two countries, we find that the technical issues are very similar. Further, capacity losses engendered by a given issue tended to be the same in both countries. (Again, note that losses frequently were reported differently, thereby making direct comparison of data somewhat difficult.)

It is remarkable that of the remaining four countries, only Sweden reported any regulatory losses, and these were much smaller than in the United States and Federal Republic of Germany. Since the technology is so similar worldwide, it is important to understand how specific regulation-related issues were treated in Japan, Sweden, France, and Switzerland. Hence, we recommend that a study be undertaken to examine the regulatory treatment of a variety of already identified issues. The result should be a clearer understanding of how safety concerns have influenced performance in the major nuclear nations.

2. Forced Outage Analysis

The information collected by this study highlights the fact that forced outages can be strongly influenced by management actions regarding planning and maintenance. The remarkably low rates in Japan and Switzerland appear due to very specific utility policies. We believe it would be very useful to examine the Swiss nuclear operations very closely. In addition, the Japanese have succeeded in creating a dramatic improvement in performance--particularly in the area of forced outages. A closer examination of how this was achieved and how it relates to their present long-duration scheduled outage, would be useful. Similarly, evidence from France suggests that it too has been continuously reducing forced outage rates, and this merits further study.

The objective of the analysis is to identify clearly how forced outages in specific areas can be reduced. One example is operator errors. The U.S. data show a steady capacity loss due to operator errors. Other countries have addressed this issue and succeeded in reducing errors. The study would try and provide information on such successful efforts.

3. Economics of Nuclear Power

We suggested earlier that the economics of nuclear power in the United States are different than those in other countries. In particular, nuclear electricity is generally the cheapest electricity in countries other than the United States. It is possible that the competitive energy markets in the United States influence the willingness of utilities to invest more capital in their plants either initially or after operations have begun.

It may be that greater capital investments may influence future performance favorably by making service and maintenance easier. Such a conjecture can be analyzed in a relatively straightforward manner. Comparisons can be made between plants with regard to capital investment, volume, and layout space. How space is used during servicing can be studied, as well as the time required to perform selected tasks. It should be possible to obtain reasonable estimates of the outage time lost due to inadequate investments in space and/or auxiliary facilities. The economic impact of lost capacity lost then can be related to added capital costs, to reduce outage time.

Thus, we propose study of if, and how, the economics of nuclear power in different countries influence design and operations decisions that, in turn, influence performance.