Chapter 5

Management of the Nuclear Enterprise

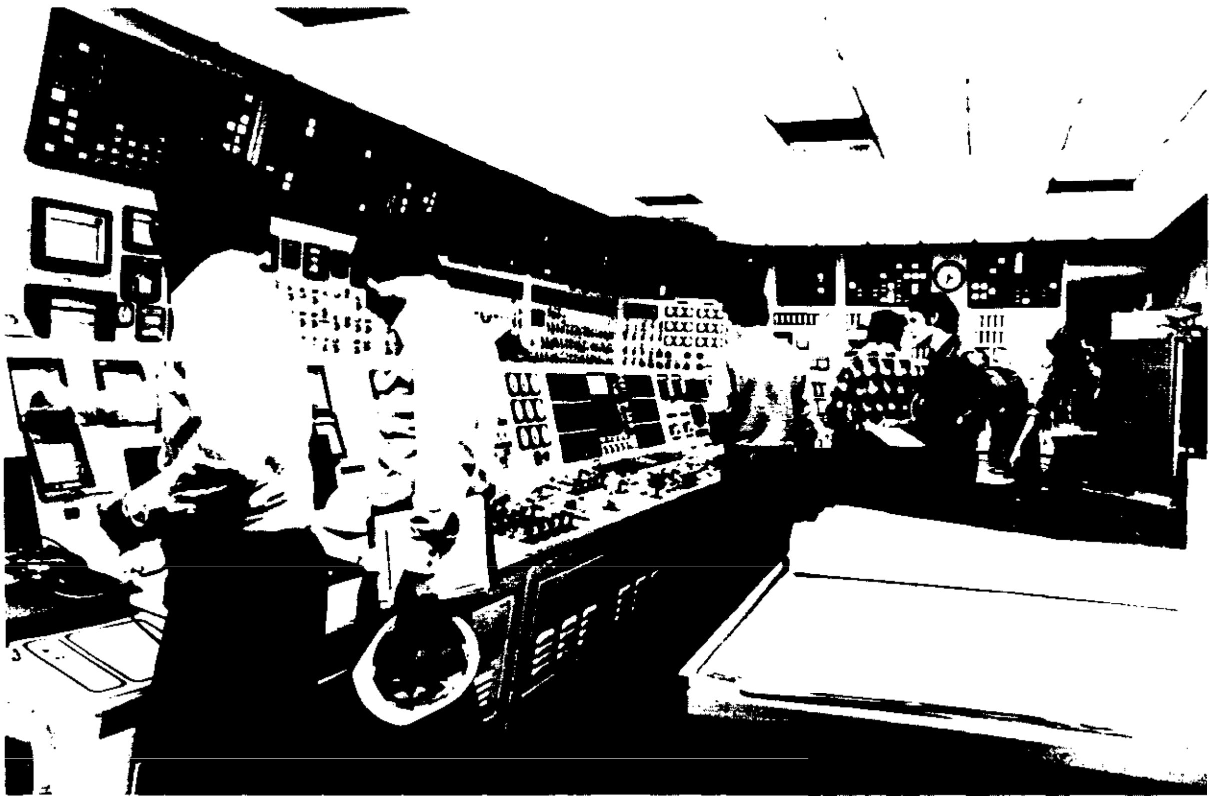

Photo credit: Atomic Industrial Forum

The control room at a typical nuclear plant

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INTRODUCTION

In the previous chapter, alternative reactor types were reviewed in terms of safety, operability, and economics. While light water reactors (LWRs) lack some of the inherent safety features that characterize the alternatives, this comparison yielded no compelling reason to abandon LWR technology in favor of other, reactor types. The excellent performance records of some of the pressurized water reactors (PWRs) and boiling water reactors (BWRs) indicate that LWRs can be very reliable when properly managed. Large and complex nuclear units can also be built within budget and on schedule, as proven by some recent examples. These cases indicate that it is possible to construct and operate nuclear powerplants efficiently and reliably.

Unfortunately, not all utilities perform to the same high standards. Numerous examples of construction malpractice and operating violations have surfaced in recent years, and many of these problems are serious enough to have safety and financial implications. Utilities evidently need to depend on more than government safety requirements and the conservatism of nuclear designs to compensate for errors. As the accident at Three Mile Island so vividly illustrated, LWRs are not entirely forgiving machines; they are susceptible to certain combinations of human error and mechanical failure. Although LWRs are built to accommodate to some problems in construction, maintenance, and operation, there is a limit to the extent of malfunctions and operational error that can be tolerated. The construction and operation of nuclear powerplants are highly sophisticated processes. Because nuclear technology is very complex and has the potential for accidents with major financial and safety implications, management of the nuclear enterprise must be of an intensity that is seldom required in other utility operations, or indeed, in most other commercial endeavors. Many utilities readily grasped the unique characteristics of nuclear technology and devoted their best management resources to its development. Others, unfortunately, seem to have misjudged the level of effort required to manage nuclear power operations successfully. This is not surprising, considering the variability in the nuclear utility industry. Forty-three utilities operate 84* nuclear powerplants, and 15 additional utilities are in the process of constructing their first nuclear units (40). Among these various organizations can be found a wide variety of management structures and philosophies, experience, commitment, and skill. While utilities are not the only organizations that seem to have underestimated the difficulties involved with nuclear powerplants, they must assume the ultimate responsibility for the safety and financial success of their plants.

The diversity of the utility industry has not created major difficulties in managing nonnuclear generating plants. Many different organizational styles and structures have been used successfully to construct and operate fossil fuel stations and distribution systems. With the advent of nuclear technology, however, several new questions can be raised:

- Is the technology so sensitive to its management that it is not adequately safe or reliable when poorly managed?
- If so, can the quality of management be improved to a uniformly acceptable level?
- Alternatively, can the technology be modified so that it is less sensitive to its management?

Management and quality issues will be addressed in this chapter by illustrating the sensitivity of nuclear power operations with a few recent examples, a look at factors that contribute to such problems, and a review of current efforts to ensure uniformly high levels of performance.

"Includes all plants with operating licenses, even though some (Three Mile Island Units 1 and 2, Dresden 1, and Diablo Canyon 1) are not currently in operation.

VARIATIONS IN QUALITY OF CONSTRUCTION AND OPERATION

The following discussion will address variations in quality of construction and operation on three levels:

1. An overview of the nuclear industry will be presented to demonstrate that various projects differ significantly from one another. This will provide a qualitative basis for assessing the sensitivity of the technology to its management.
2. Some of the more successful plants will be examined to identify the conditions under which it is possible for nuclear powerplants to be constructed and operated to the highest standards of quality.
3. Some less successful plants will be examined to identify the factors that contribute to poor management and to understand the cost and safety implications.

The examples that have been selected for discussion are not intended to fully span the range of good and bad practices; they are, however, useful in illustrating the differences in the ways in which nuclear power has been implemented in recent years.

Table 17.—U.S. Reactor Types, Suppliers, Architect/Engineers, and Constructors

Reactor types:
Pressurized water reactors (PWR)
Boiling water reactors (BWR)
High temperature gas-cooled reactors (HTGR)
Reactor suppliers:
Babcock & Wilcox Co. (PWR)
Combustion Engineering, Inc. (PWR)
General Atomic Co. (HTGR)
General Electric Co. (BWR)
Westinghouse Electric Corp. (PWR)
Architect engineers and/or constructors:
American Electric Power Service Corp. (AE, C)
Baldwin (C)
Bechtel Power Corp. (AE, C)
Brown & Root, Inc. (C)
Burns & Roe, Inc. (AE, C)
Daniel Construction Co. (C)
Ebasco **Services,** Inc. (AE, C)
Fluor Power Services (AE, C)
General Atomic Co. (C)
Gibbs & Hill, Inc. (AE, C)
Gilbert Associates, Inc. (AE)
Kaiser Engineers (C)
J.A. Jones Construction Co. (C)
Sargent & Lundy Engineers (AE)
Stone & Webster Engineering Co. (AE, C)
United Engineers & Constructors, Inc., **(AE, C)**
Wedco (a subsidiary of Westinghouse Electric Corp.) (C)

SOURCE: "World List of Nuclear Power Plants," *Nuclear News,* February 1983.

Construction

The construction of nuclear powerplants in the United States is far from being a standardized process. As shown in table 17, a utility must choose among several reactor types and vendors and among an even larger selection of architect engineers (AEs) and constructors. Wide differences in design and construction practices can result from these various combinations. A utility can superimpose additional changes on the basic design to customize its plant according to its special needs or to accommodate to specific site requirements. Such factors partially explain the variations in construction time and quality discussed below.

There are no simple measures of quality in construction, and no attempt will be made to develop comprehensive measures. But efficiency in construction can be partially indexed by construction time and cost, which differ widely among the utilities shown in table 18. Only plants beginning commercial operation after the accident at Three Mile Island were included, so all of these units were affected to some degree by the regulatory changes that have occurred since 1979.

These data should be interpreted with some care. Several of the longer construction times may reflect inordinate licensing delays or a utility's decision to delay construction in response to slow growth in the demand for power. In addition, some of the projections for very short construction times may be overly optimistic. It is also difficult to make direct comparisons of construction costs since they are based on different accounting schemes. Furthermore, both estimates and actual expenditures are reported by the utilities in "current dollars. " Annual expenditures are then summed without accounting for the time value of money, with the total construction costs ex-

Table 18.—Construction Records of Selected U.S. Light Water Reactors

Plant	Construction time[a] (years)	Year of commercial operation (actual or expected)	Cost[c] (actual or expected, $/kWe)
Shortest construction times:			
St. Lucie 2	6	1983	1,800
Hatch 2	7	1979	607
Arkansas Nuclear One 2	7	1980	308
Perry 1	8	1985	2,200
Palo Verde 1	8	1984	1,900
Byron 1	8	1984	1,500
Callaway 1	8	1984	2,500
Longest *construction t/roes:*			
Diablo Canyon 1	16	1984	1,700
Diablo Canyon 2	14	1984	1,700
Salem 2	13	1981	704
Zimmer 1	13	1985	2,400
Midland 1	13	1985	2,700
Sequoyah 2	12	1982	740
Watts Bar 1	12	1984	1,500

[a]Based on construction permit to commercial operation.
[b]"World List Of Nuclear Power Plants," *Nuclear News,* February 1983, and other recent updates.
[c]Komanoff Energy Associates, 1983, expressed in mixed current dollars.

pressed in terms of "mixed current dollars." This accounting system tends to further distort actual costs.

It is interesting to note that the best and worst construction schedules from table 18 differ by an average of about 6 years. In fact, the plants with the longest construction times took twice as long to complete as those with the shortest schedules. Dramatic differences also can be observed in the costs, even when the construction schedules are similar. For example, the Callaway 1 unit is projected to cost $2,500 per kilowatts electrical (kWe) after 8 years of construction, while the Byron 1 plant is projected to cost only 60 percent of that with the same construction schedule.

A recent study by the Electric Power Research Institute (EPRI) attempts to identify the reasons for the variations noted here (3). In a statistical analysis of all nuclear powerplants, it was found that 50 to 70 percent of the variation in leadtime could be accounted for by regulatory differences, deliberate delays, and variations in physical plant characteristics, EPRI ascribed the remaining variation to management practices and uncontrollable events. To more fully understand the importance of utility management in the construction phase, it is valuable to examine a few specific examples.

Two of the more notable nuclear powerplant construction projects are Florida Power & Light Co.'s St. Lucie 2 unit at Hutchinson, Fla. and the Palo Verde 1 plant at Wintersburg, Ariz. owned by Arizona Public Service Co. As shown in table 18, both units are projected to be completed with relatively short construction schedules. Neither utility has encountered significant regulatory difficulty nor much opposition from interveners (6). Both units had to accommodate to the wave of backfit and redesign requirements of the Nuclear Regulatory Commission (NRC) that followed the accident at Three Mile Island, and yet no significant delays have been experienced at either site. These examples indicate that nuclear powerplants can be constructed expeditiously, even in the most difficult regulatory environment.

In contrast to these examples, other plants have had a long history of problems. Quality control in nuclear powerplants, as in other commercial endeavors, is important in assuring consistency and reliability. In industries such as nuclear power and aerospace, where the consequences of failure can be severe, quality is guaranteed by superimposing a formalized, independent audit structure on top of conventional **quality control measures** in design, procurement, manufacturing, and construction (30). Deficiencies in the quality control procedures at nuclear reactors are cause

Photo credit: Atomic industrial Forum

Florida Power & Light used experience gained in building St. Lucie 1 to construct St. Lucie 2 in the record time of 68 months

for serious concern because they may make it impossible to verify that the plants are safe.

Deficiencies in the quality assurance program at the two Diablo Canyon nuclear powerplants were uncovered in 1981 (18). These deficiencies had gone undetected by NRC and the plant owner, Pacific Gas & Electric Co. (PG&E), for years. They did not surface until after NRC had granted PG&E a preliminary license to operate one of the reactors at low power. Since the problems have surfaced, a number of errors in seismic design have been identified, and it is not yet certain that the plants will be able to withstand a design basis earthquake. Diablo Canyon's license has been suspended and will not be reinstated until NRC can be convinced that the safety equipment provides adequate protection to the public and that the quality assurance weaknesses have been corrected. (The Diablo Canyon plants are discussed further in ch. 8.)

Other management control failures have resulted in lengthy construction delays. A recent example is the 97-percent-complete Zimmer 1 plant owned by Cincinnati Gas & Electric Co., in which alleged deficiencies in construction practices have led to an NRC stop-work order. The NRC has uncovered a number of problems at the plant resulting from what it calls a "widespread breakdown of Cincinnati Gas and Electric's management . . . " (20). The Zimmer plant has been troubled for years by poor construction practices and an inadequate quality assurance program. * NRC cited deficiencies in 70 percent of the structural steel welds, inadequate documentation and qualification of welders and quality assurance personnel, unauthorized alteration of records, and inadequate documentation of quality for materials in safety-related components (4).

The examples discussed above represent the extremes of good and bad construction experiences. They indicate that nuclear powerplants can be constructed with varying emphasis on quality, and that such differences in management approach result in noticeable differences in the plants.

Operation

As with construction, it is difficult to identify specific measures of safety or quality in plant operations. There is, however, an intuitive correlation between safe and reliable plant operation. Two parallel arguments for this connection can be made. First, a safe plant is one which is constructed, maintained, and operated to high standards of excellence. Such a plant is also likely to be a reliable performer. Conversely, a reliable plant that operates with few forced outages is less likely to tax its safety-related equipment by frequent cycling. Some caution must be used in equating safety with reliability; it is possible that a plant could be operated outside of its most conservative safety margins in the interest of increasing its capacity factor. But in general, good plant availabilities (or capacity factors for base-loaded plants such as nuclear units) are reasonably good indicators of well-run plants. The average cumulative capacity factor of all U.S. reactors is currently 59 percent. This means that all of the reactors in the United States have operated an average of 59 percent of their design potential

***On Jan. 20, 1984, Cincinnati Gas & Electric announced that Zimmer would be converted to a coal-fired facility.**

throughout their lifetimes. As discussed in chapter 4, this is comparable to the capacity factors of base-loaded generating coal units.

The average data conceal the more interesting variations in individual plants. A number of LWRs have operated for years at much lower capacity factors, while some plants have consistently exceeded the average by wide margins. Table 19, which lists lifetime capacity factors for the best and worst plants in the United States, illustrates the wide range of performance that can be found among reactors of comparable design, Note that the best plants have lifetime load factors that are 20 points greater than the 59-percent average capacity factor discussed above, while the poorest performers have capacity factors 10 points less than the industrywide average. The management of maintenance and operations is one of several factors that contributes to these differences.

The data in table 19 suggest an important point: no single external characteristic can be identified that unambiguously distinguishes between good and poor performers. The lists of best and worst plants each contain both PWRs and BWRs, small and large reactors, new and old units, and utilities with previous nuclear experience as well as those with only a single plant. Although there are more PWRs than BWRs in both lists, this merely reflects the fact that there are nearly twice as many PWRs as BWRs in operation. It should be noted that although size does not appear to be a dominant characteristic of either good or poor performers, there is a tendency for the best performers to be smaller than their less successful counterparts. While 20 percent of all mature reactors are larger than 1,000 megawatts electrical (MWe), 4 of the 10 plants with the worst capacity factors are larger than 1,000 MWe; only 1 plant of this size is in the list of the best performers.

Three of the best plants shown in table 19 have been in operation for more than a decade–Point Beach 2, Connecticut Yankee, and Vermont Yankee. It is clear from the performance records of these units that a nuclear powerplant can be a very reliable source of electricity over many years. Other less fortunate plants have experienced considerable operating difficulties, as indicated by the worst performers listed in table 19. Four of these plants have operated at less than 50-percent capacity factor throughout their lifetime.

Table 19.—Performance of Selected U.S. LWRs

Plant	Lifetime capacity factor	Design capacity (MWe)	Type of reactor	Years of operation[a]	Number of reactors in operation by same utility
Best **capacity factors**[b]:					
Point Beach 2	79	497	PWR	11	2
Connecticut Yankee	76	582	PWR	15	1
Kewaunee	76	535	PWR	9	1
Prairie Island 2	76	530	PWR	8	3
Calvert Cliffs 2	75	845	PWR	6	2
St. Lucie 1	74	830	PWR	6	3
Prairie Island 1	71	530	PWR	9	3
Monticello	71	545	BWR	12	3
Vermont Yankee	70	514	BWR	10	1
Calvert Cliffs 1	70	845	PWR	8	2
Worst capacity factors[b]:					
Beaver Valley 1	34	852	PWR	7	1
Palisades	39	805	PWR	11	2
Davis Besse 1	40	906	PWR	5	1
Brunswick 2	41	821	BWR	7	3
Salem 1	46	1090	PWR	6	2
Indian Point 3	46	965	PWR	6	2
Brunswick 1	48	821	BWR	6	3
Rancho Seco	50	918	PWR	8	1
Duane Arnold	51	538	BWR	8	1

[a]By the end of January 1983.
[b]Includes only plants greater than 100 MWe in operation 3 years or longer.

SOURCE: "Licensed Operating Reactors, Status Summary Report, data as of 01-03 -83," U S Nuclear Regulatory Commission, February 1983

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Operating difficulties also can be inferred from NRC's system of **fines and enforcement actions.** NRC recently proposed several fines for alleged safety violations which it claims resulted from breakdowns in management controls. The largest of these penalties is a proposal for an $850,000 fine to be collected from Public Service Electric & Gas Co. for problems at its Salem 1 nuclear powerplant in New Jersey (21). On two occasions in February 1983, the circuit breakers in the reactor's automatic shutdown system failed to operate as designed to shut the reactor down safely. **In both cases, the plant operators initiated a manual shutdown and avoided damage to the plant. While the problem can be partially attributed to a design flaw in the shutdown equipment, it might have been avoided** if the automatic shutdown equipment had been properly maintained (5). NRC based its fine on evidence of lax management, deficiencies in the training of staff, and inattention to certain safety procedures.

NRC also has proposed stiff fines at other utilities for difficulties related to management controls. Carolina Power & Light Co. has paid $600,000 because it failed to develop certain procedures and conduct tests at its Brunswick plants in North Carolina, and because its quality-assurance staff failed to detect the problem. Boston Edison Co. was fined $550,000 for management problems at its Pilgrim 1 plant. These and other examples demonstrate that there are serious management difficulties in some operational plants and that poor management can have important safety and economic implications.

MANAGEMENT CHALLENGES IN CONSTRUCTION AND OPERATION

The nuclear utilities have identified a number of obstacles to maintaining quality in the construction and operation of nuclear powerplants; other organizations such as NUS Corp. and EPRI also have investigated the difficulties involved in nuclear operations (1 7,38). For discussion purposes, the factors that adversely affect nuclear power operations can be categorized according to their sources. Some problems arise from the nature of the technology itself; others can be attributed to the external conditions that influence all utilities. While these factors affect the management of all nuclear powerplants, there appears to be a great deal of variation in the ability of utilities to cope with them. A third source of problems arises from the utility management itself.

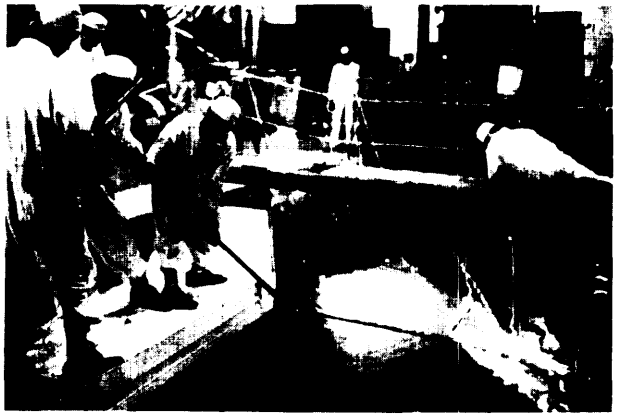


Photo credit: Atomic Industrial Forum

These workers at the Connecticut Yankee nuclear plant are making underwater adjustments to equipment in the reactor vessel. While cumbersome, submersion of the equipment is a protection against radiation

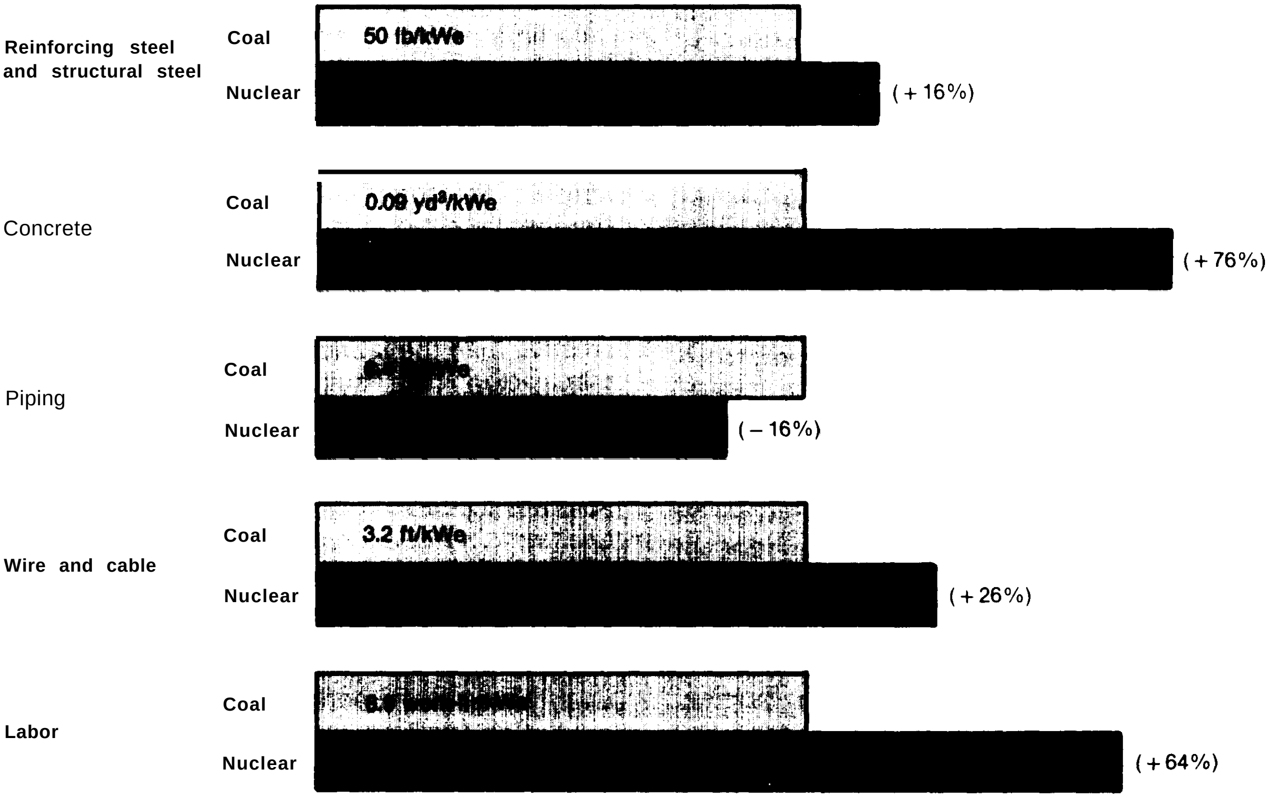
Technological Factors That Influence Construction and Operation

As presently utilized, nuclear technology is much more **complex** than other conventional generating sources; this creates difficulties in construction and operation beyond those experienced in fossil units. Most of the unique characteristics of nuclear powerplants arise from the fission process and efforts to sustain, control, and monitor it during normal operation. Nuclear reactors have other unique features to contain radioactive material produced as a result of the fission process and to protect the work force and the public. Finally, and most importantly, nuclear powerplants are equipped with many levels of safety equipment that prevent the release of radioactive material in the eventofanaccident(19).

Overall, nuclear powerplants are more sophisticated than fossil-fuel stations. This has obvious implications for the construction of nuclear units. As shown in figure 28, nuclear powerplants require greater quantities of most of the major construction materials than coal plants (34). Certain components are also more numerous in nuclear plants than in fossil units. For example, a large nuclear plant may have 40,000 valves, while a fossil plant may have only 4,000 (1 7). Another case in which requirements for nuclear reactors exceed those of coal plants is in the area of piping supports. Because nuclear plants must be able to withstand an earthquake, they are equipped with complex systems of piping supports and hangers designed to absorb shock without damaging the pipes. **A** typical nuclear unit might contain tens of thousands of elaborate pipe hangers, supports, and restraints that must be designed and installed according to highly specific criteria. In contrast, a comparable coal plant might contain only about 5,000 pipe supports whose design and installation is not subject to the same restrictive standards found in nuclear powerplants **(35).** In view of this, it is not surprising that the construction of a nuclear reactor is considerably more labor intensive than that of a coal plant. **As** shown in figure 28 a new nuclear unit might require 64 percent more workhours than a similarly sized coal unit.

The design effort for nuclear reactors also becomes increasingly difficult as the plants become more complex. **A** particularly challenging aspect of nuclear powerplant design is anticipating potential interaction among systems or unexpected failure modes within a single system. As discussed in chapter 4, it is of vital concern to ensure that

Figure 28.—Comparison of Commodity Requirements for Coal and Nuclear Powerplants



SOURCE. United Engineers and Constructors, *Energy Economic Data Base,* September 1981 (Based on 1,139 MWe PWR and 1,240 MWe high. sulfur coal plant) the smooth operation of safety systems is not impaired by malfunctions in unrelated and less critical areas. The risk of such adverse interaction has increased with the steady growth in the number and complexity of nuclear plant components. In fact, it is not always easy to predict the overall impact of changes that superficially seem to contribute to safety. For example, NRC requested one operating utility to install additional pumps to reduce the risk of a Three Mile Island-type accident. An extensive analysis of the system using probabilistic risk assessment indicated that adding the extra pumps would not necessarily reduce the risk. It was discovered that the location, not the number, of pumps was the key to enhancing safety (8).

Finally, the operation of a nuclear plant becomes more difficult as the plant increases in complexity. Many of the routine actions that must be taken to control the reactor during normal operation or to shut it down during an accident are handled automatically. There are, however, unusual combinations of events that could produce problems with these automatic safety systems and which cannot be precisely predicted. For this reason, nuclear reactor operators are trained to respond to unusual situations in the plant. This is not extraordinarily difficult in very simple, small reactors, such as research or test reactors, which can be designed with a great deal of inherent safety and operated with less sophisticated control systems. In today's central power stations, however, there are many complex systems that have the potential to interact, making it difficult for operators to respond correctly and rapidly to abnormal situations. Furthermore, if the control room design is poor, operators may not receive pertinent data in a timely and understandable manner. This was part of the problem at Three Mile Island, where important indicators were on the back of a control panel and unimportant alarms added to the confusion of the accident sequence (15).

Nuclear units also differ from fossil plants in their **size.** The latest generation nuclear powerplants are very large, on the order of 1,000 to 1,300 MWe. It was expected that nuclear units would be cost-sensitive to size changes and would be most economical in very large units. Coal plants, on the other hand, are much less sensitive to scaling factors, and most are less than half the size of the newest nuclear plants (7). Thus nuclear construction projects not only involve more sophisticated systems, but also larger ones, with a work force of 2,000 to 4,000 per unit. This can significantly increase the difficulties in coordinating and monitoring the activities of the various parties involved in nuclear construction.

In addition to being complex, nuclear technology is very **exacting.** As discussed above, the safety of nuclear powerplants is ensured by sophisticated control systems that must respond rapidly and reliably to prevent an accident or mitigate its consequences. These control and safety systems must be constructed, maintained, and operated according to the highest standards of excellence. This is so important that NRC has developed detailed procedures for monitoring and verifying quality. During the construction process, NRC requires extensive inspection and documentation of all safety-related materials, equipment, and installation (13). In response to such requirements, construction practices have become increasingly specific and inspection procedures have become more formalized. An undesirable consequence of this is that it is extremely difficult to construct nuclear powerplants in accordance with very rigid and explicit standards. One example of the complications that can result is in the installation of pipe supports and restraints. It is not uncommon for field engineers to have to work to tolerances of one-sixteenth to one-thirty second of an inch, which can be more restrictive than the fabrication tolerances used in manufacturing the equipment to be installed (35). This results in greater labor requirements than in fossil plants and can increase the level of skill required. In addition, various levels of checks, audits, and signoffs are required for most construction work in nuclear powerplants, adding to the labor requirements necessary to complete installation. One NRC publication has estimated that these checks add 40 to 50 percent to the basic engineering and labor costs (30). Figure 29 compares labor requirements, including quality control and engineering, for typical coal and nuclear plants. Note that for all the items listed here, nuclear reactors require at least half again as much labor as coal plants.

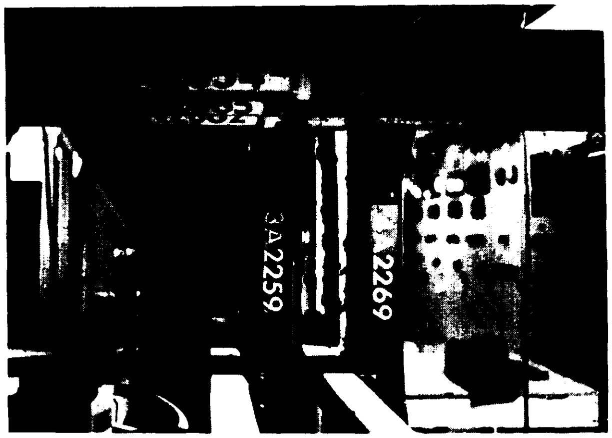


Photo credit: OTA Staff

To keep track of the many components of a nuclear plant under construction, each of which maybe subject to modification, each pipe and pipe support is labeled with a number that corresponds to a number on a blueprint

Another consequence of strict quality control is that a large amount of paperwork is generated. According to one recent estimate, approximately 8 million pages of documents have been produced to support the quality assurance program for a nuclear unit that began operation in 1983 **(32).** In the midst of such massive requirements for paperwork, it can be difficult, if not impossible, to maintain a positive attitude toward quality for its intrinsic value. This becomes even more difficult in an environment where rework is required frequently, since this adds to the paperwork burden and decreases the morale of the workforce.

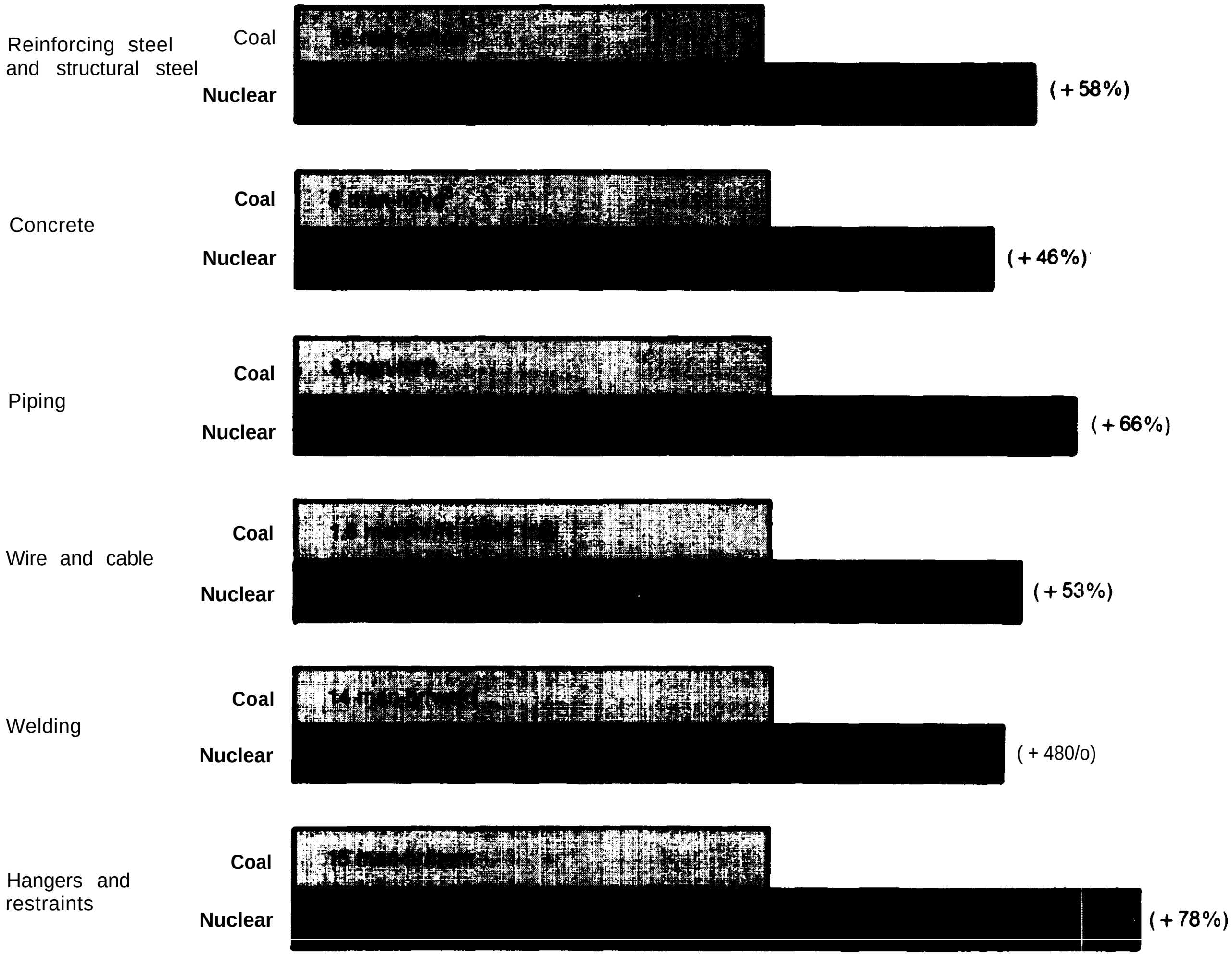
The exacting nature of nuclear technology manifests itself somewhat differently during operation. It often is necessary to maintain extremely tight control of sensitive systems to keep the plant running smoothly. For example, the water chemistry system in LWRs must be carefully monitored and adjusted to prevent corrosion and remove radioactive materials from the cooling water. Failure to maintain these systems within narrow limits can lead to severe damage in such major components as steam generators or condensers and this can ultimately curtail plant operations (36). As discussed in chapter 4, corrosion has been a serious problem in many operating PWRs and has led to replacement of steam generators in four nuclear units.

External Factors That Influence Operation and Construction

Certain other factors appear to be less related to the technology than to the environment in which commercial nuclear plants must operate. For example, the nuclear industry has experienced problems with **shortages of trained personnel.** The commercial nuclear power industry requires engineers, construction crews, and operating teams to be qualified in very specialized and highly technical areas. As shown in figure 30, the demand for technical personnel with nuclear training grew rapidly during the 1970's (2). At the beginning of the 1970's, the nuclear work force was very small, but many reactors had been ordered and were entering the construction phase. Labor requirements grew steadily and peaked in the 4-year period 1973 to 1977, when the number of people employed in the nuclear industry increased at the rate of 13 percent a year. In the early years of the commercial nuclear industry, the greatest shortages were found among reactor designers. This contributed to the practice of initiating construction with incomplete designs. While it was recognized that 60 percent or more of the design should be completed before construction was initiated, some utilities began with half that or less. As plants have progressed from the design phase, through construction, and into operations, the emphasis on personnel has also shifted. Reactor designers are no longer in short supply, but there is a need for more people qualified in plant operations, training, and certain engineering disciplines (1 2).

A second external problem is **inadequate communication** among utilities. Only a few utilities had any experience with nuclear power before the 1970's. A structured method for transferring learning might have accelerated the overall progress by providing warnings about common errors and transmitting effective problem-solving approaches. Such communication networks did not exist in any formal manner until the accident at Three Mile Island stimulated an industrywide effort to improve the transfer of nuclear operations information. Even today there is little structure in sharing information regarding reactor construction, with the primary mechanism being the transfer of trained personnel from one utility to another.

Figure 29.—Comparison of Manpower Requirements for Coal and Nuclear Powerplants



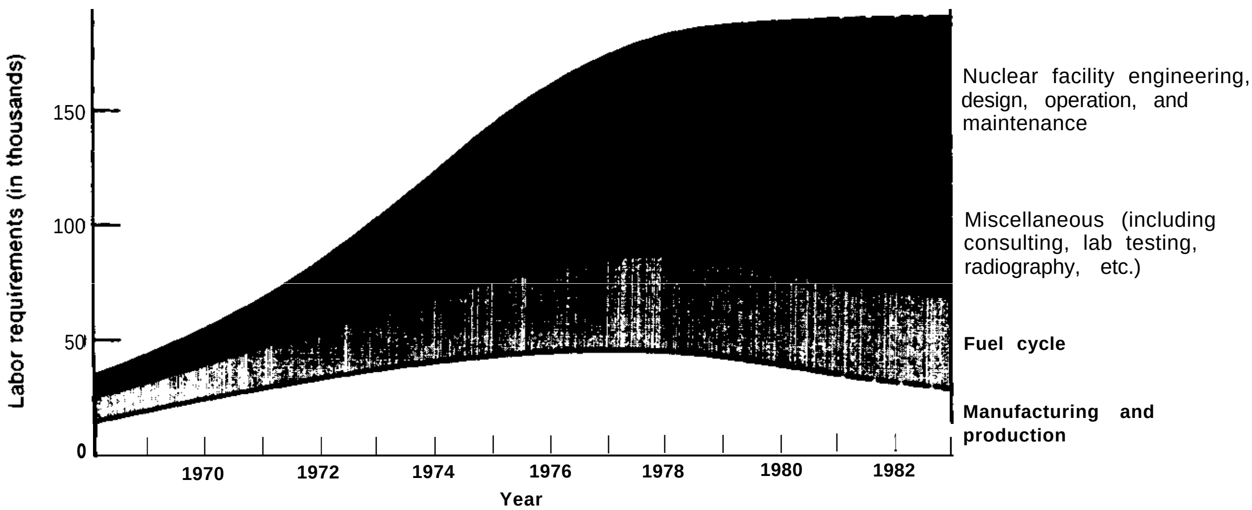
SOURCE. J D. Stevenson and F. A. Thomas, Selected Review of Foreign Licensing *Practices for Nuclear Power Plants,* **April 1982**

An additional consideration is that nuclear reactor owners have had to deal with a rapidly changing regulatory environment throughout the past decade. Frequent revision of quality and safety regulations and backfit requirements have greatly affected construction and operation patterns. As shown in figure **31,** NRC issued and revised regulatory guidelines at an average rate of three per **month in the mid-1970's (33).**

Plants that were under active construction during this time had to continually adjust to the changing regulatory environment. While no single NRC requirement overtaxed the utilities with plants under construction, the scope and number of new regulations were difficult to handle. As a consequence, the utilities had to divert scarce engineering forces from design and review activities to deal **with NRC** (37).

The utilities had to deal with more than a steady increase in regulatory requirements: a series of regulatory "shocks" was superimposed on the cumulative effect of "normal" regulation. A study by EPRI identifies three major events that were followed by a flurry of NRC activity: the Calvert Cliffs decision in **1971 to require Environmental Impact Statements for nuclear plants, the fire at the Browns Ferry nuclear plant in 1975, and the accident at Three Mile Island in 1979 (3).** The aftermath of these incidents has created an atmosphere of regulatory unpredictability that has

Figure 30.—Historical Labor Requirements in the Nuclear Power Industry



SOURCE ' Occupational Employment in Nuclear-Related Activities, 1981 ." Oak Ridge Associated Universities for the Department of Energy, April 1982

particularly affected plants in the construction phase. In some cases, major portions of nuclear construction projects have had to be reworked to comply with changing requirements. For example, after the fire at the Browns Ferry plant, NRC issued new requirements to fireproof all trays carrying electrical cables. While this was not an unreasonable request, it did disrupt many construction schedules.

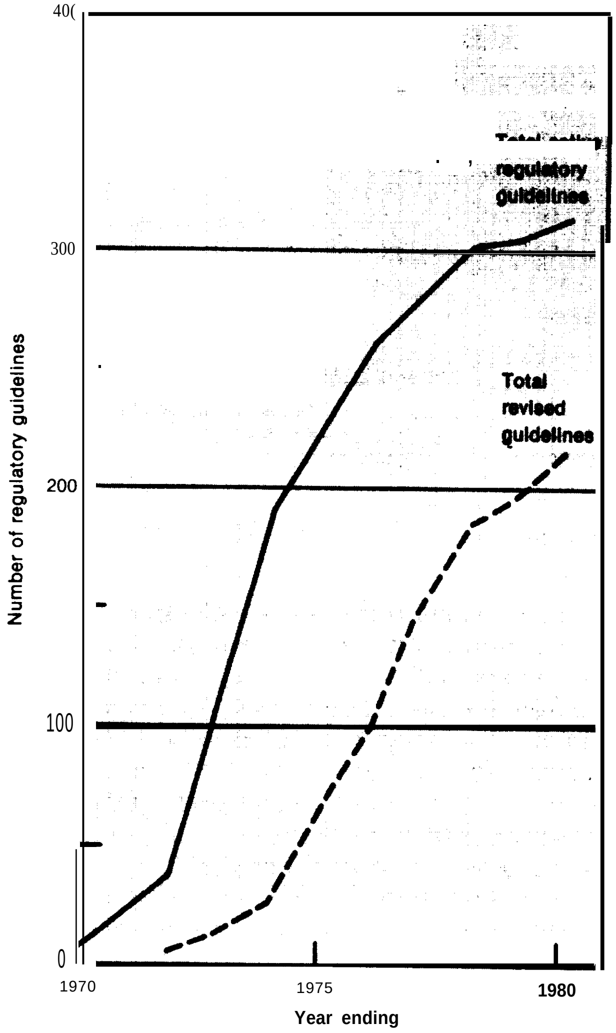
In many cases, changes in NRC regulations obviously enhance plant safety. In other cases, it is not clear that safety is increased by adding or modifying systems and components. As discussed in chapter 6, the adverse impacts of certain regulations include equipment wearout due to excessive surveillance testing and restrictions on accessibility to vital equipment as a result of fire or security barriers **(37).**

Piping system design provides another example of possible adverse effects of regulation. The current trend in NRC guidelines is to require more rigidly supported systems. This is not necessarily because flexible systems are less safe, but analytical techniques cannot unequivocally prove them safe. Rigid systems are easier to analyze, but can present serious operational difficulties during routine changes in temperature (23).

Finally, **rapid technological changes have further complicated nuclear powerplant construction and operation. Nuclear reactors were scaled** up from the earliest demonstration plants of several hundred megawatts to full-scale 1,000-MWe plants within a decade, By 1968, most orders were placed for units greater than 1,000 MWe. As shown in table 20, there were only three LWRs with a generating capacity greater than 100 MWe in operation in the United States when the first of these orders was placed. Thus the designs for the larger plants were not built on the construction and operating experience of gradually scaled units. By the time the first 1,000-MWe units began operation in 1974, an additional 70 large plants had been ordered. There was little opportunity for orderly, deliberate design modification and transfer of knowledge in this rapid scale-up.

The factors discussed above have contributed to the complicated task of maintaining rigid standards of excellence in nuclear powerplants. As a result, the construction and operation of nuclear reactors has demanded the full resources, both technical and financial, of the utilities. Many utilities have failed to fully meet these challenges. Others, however, have managed to cope with all of these complications—plants have been constructed with few major setbacks and operated

Figure 31.— NRC Regulatory Guidelines Issued From *1970* **to 1980**



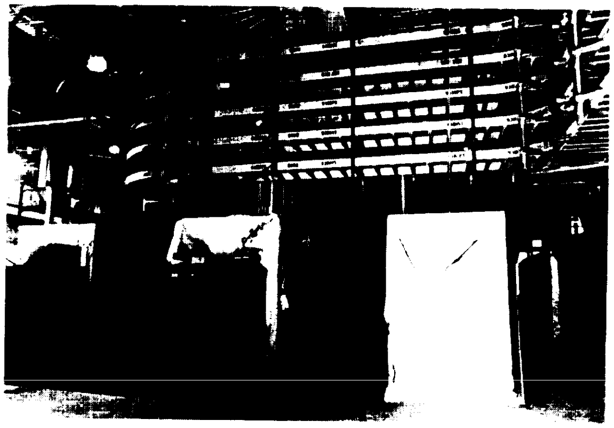


Photo credit: Atomic Industrial Forum

Cable trays increased in weight and complexity because of fire-proofing and separation of function requirements following the fire in the electrical system at Browns Ferry in 1976

Table 20.—Early Operating Experience of U.S. Commercial Light Water Reactors

Unit	Size (MWe)	Date of commercial Operation	Type
Dresden 1	207	8/60	BWR
Yankee Rowe	175	6/61	PWR
Big Rock Point	63	12/62	BWR
Humboldt Bay 3	63	8/63	BWR
Connecticut Yankee	582	1/68	PWR
San Onofre 1	436	1/68	PWR
La Crosse	50	11/69	BWR
Nine Mile Point 1	610	12/69	BWR
Oyster Creek 1	620	12/69	BWR

SOURCE "Update — Nuclear Power Program Information and Data, October-December 1982, " U S. Department of Energy, February 1983

well. This suggests that some of the variability among utilities can be attributed to differences in factors internal to the utility.

Internal Factors That Influence Construction and Operation

Factors related to utility management are difficult to assess since they are less visible than external factors; moreover, they are not easily quantified. Nonetheless, they can influence the financial success of a nuclear project or plant safety. As discussed above, there area number of characteristics that distinguish the management of nuclear technology from that of other conventional power technologies. The complexity of the reactor and the demands for precision and documentation provide significant challenges to utility managers.

Even more important are the difficulties in dealing with a changing environment. Successful utility managers have had to maintain a great deal of flexibility to keep up with the rapid growth in the size and design of nuclear plants and changes in regulatory structure. In fact, some utilities have reorganized several times in an attempt to control their nuclear projects better. The most common changes have been away from traditional line management and towards matrix or project management (3). While this has been successful

in some cases, it is not always sufficient to improve the quality of utility management. Other factors are also very important, as discussed below.

Managing nuclear power projects requires a commitment to safety and quality that is less essential in other electric utility operations. **This implies far more than a concern for schedules and budgets, which pervades all commercial endeavors. Because there is some possibility that an accident could occur in a nuclear reactor, every effort must be made to protect the investment of the utility and the safety of the public. It is important that nuclear managers adhere to the spirit as well as the letter of safety and quality-assurance regulations.**

The Palo Verde plants are good examples of commitment to quality (6). When Arizona Public Service announced its nuclear program in 1972, it thoroughly studied all aspects of designing and constructing nuclear powerplants. Many advanced safety features were incorporated into the Palo Verde design from the beginning of the project. One unexpected consequence of this attention to safety is that Arizona Public Service anticipated many of the Three Mile Island backfit and redesign requirements. As a result, regulatory changes in response to Three Mile Island had less impact on the Palo Verde projects than on many other plants which had not originally planned to incorporate the extra safety features.

Sincerity of commitment can be observed in several ways. Highly committed senior managers can impress their commitment on project managers, who in turn can communicate it to designers, manufacturers, and constructors, The strength of utility commitment is also indicated by the level of quality required in the utility's contractual and procedural arrangements with suppliers of material, equipment, or personnel, For example, if a contract primarily emphasizes the schedule for physical installation, the message from project management is production. On the other hand, if the contract also emphasizes owner-acceptance and adequate documentation, the message is quality as well as production. The latter case provides the proper incentives for high-quality work (1 3).

Corporate commitment also can be indicated by the way in which a utility responds to changes or problems. The more successful utilities have a history of responding rapidly and with adequate financial resources to resolve problems and adapt to new situations. Other utilities with less eagerness to confront their problems directly have experienced construction delays and operational difficulties (3).

An important factor in the management of any powerplant is the distribution of responsibility and authority. This is particularly vital in the construction of nuclear plants because of the complexity of the technology and the need to coordinate the activities of vendors, architects, engineers, construction managers, consultants, quali-

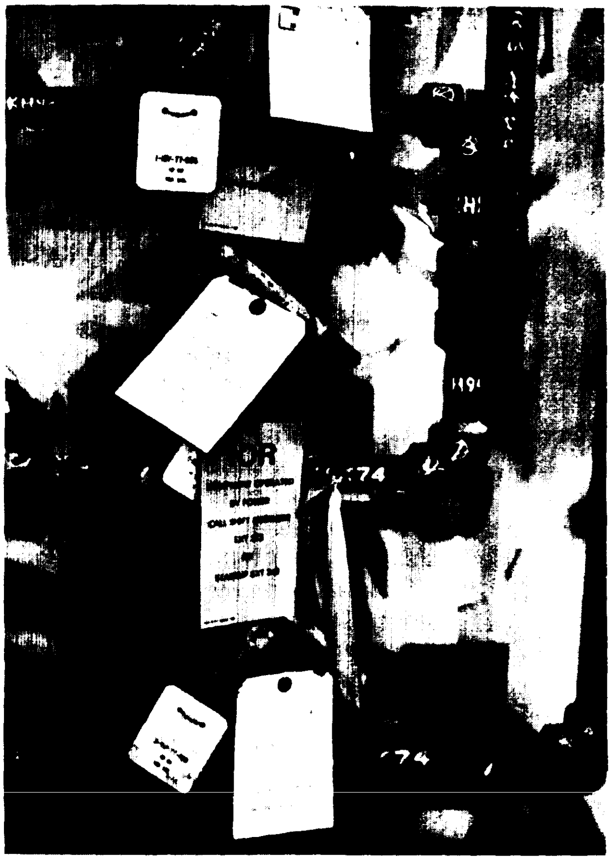


Photo credit: OTA Staff

As a plant nears completion, responsibility is gradually transferred from the construction managers to the operating division. These tags give an idea of the detailed level at which explicit responsibility is assigned ty inspectors, test engineers, operators, and craftsmen. In this environment, it is vital that a utility establish clear lines of authority and specific responsibilities to ensure that its objectives will be met.

When authority and responsibility are diffused throughout an organization rather than focused in a few key positions, widespread problems can result. This occurred at the Washington Public Power Supply System (WPPSS) in the late 1970's, when extensive construction delays and regulatory difficulties plagued the **WNP-2 plant in Richland, Wash. (9). Responsibility for design and construction was distributed between** the owner and the construction company in an obscure manner, with neither the owner nor the construction manager claiming authority in decisionmaking nor accepting responsibility for mistakes. **Additional problems arose** when authority was further delegated to the contractors without sufficient provisions for monitoring feedback. While most contractors assumed the responsibility for maintaining quality, others were less conscientious. In some cases unqualified people were used for construction work, and documentation was incomplete and inconclusive. The project management effectively lost control of the subcontractors and was in no position to detect and correct these problems.

When this situation came to the attention of NRC in 1980, a stop-work order was issued for WNP-2. WPPSS tackled its problems directly by completely restructuring its project management. It established clear and direct lines of responsibility for design and construction by creating the new position of Project Director and by specifying the role of the construction manager reporting to him. New review and surveillance procedures were initiated by the construction manager and overseen by WPPSS. Construction finally was resumed when NRC was satisfied that the major deficiencies had been resolved, and WNP-2 is nearly complete. The four other WPPSS plants under construction were less fortunate. Two units in the early stages of construction were mothballed in 1981, and WPPSS has since defaulted on repaying the outstanding debt on those plants. Subsequently, construction was halted on 2 other plants that were more than 60 percent complete. These four plants were troubled by the inability to assure continued financing and the decreasing need for power in the Northwest. The management restructuring came too late to gracefully reverse the effects of early planning decisions (l).

The example discussed above is only one of many in which utilities learned that it is in their best interests to monitor and control the activities of their constructors and architect/engineers. It was common in the 1970's for utilities, especially those with little experience, to relinquish most of the responsibility for design, cost, and schedule to their contractors. As problems developed, the utilities gradually became more involved with their constructors; this resulted in shifting responsibility to the plant owners. The same oversight could be applied to architect/engineers, and there are recent signs that this is happening in the larger and more experienced nuclear utilities.

Once a utility has developed a workable organizational structure, it is further challenged to **coordinate and motivate** the many diverse groups of people involved in nuclear construction. At the peak of construction on a large nuclear unit, as many as 6,000 craftsmen, engineers, and support personnel may be working together. In such situations, scheduling can become a logistic nightmare, and a sense of teamwork and having common goals can vanish. These problems are exacerbated by changing regulatory requirements that can result in construction rework and delays and by the lack of continuity that results from long construction times (1 7).

Coordination can be equally challenging within a utility's management structure, especially if the utility is undergoing organizational changes. This occurred at Commonwealth Edison Co. in Chicago, where a matrix-management structure was replaced with formal project management. In the new organization, each nuclear construction project was given its own staff, including engineering, construction, testing, and startup personnel. An independent staff of quality and safety engineers was maintained in a central office to provide oversight and ensure uniformity among the project teams. There are some overlapping and conflicting functions in the new system, and strong leadership from the management within

Commonwealth Edison has been required to instill a sense of teamwork among the various groups (25),

Another problem that some utilities face is that nuclear projects may make **excessive demands on their resources.** Some utilities have not been able to hire qualified management personnel, and they have not had sufficient time to gain the management and technical experience independently. As previously discussed, this often resulted in construction being started with incomplete designs. Furthermore, limited resources have made it difficult for some utilities to provide for adequate training in quality inspection and reactor operations while simultaneously constructing a nuclear plant.

A **final consideration is experience** in construction and operation. It is more difficult for a utility with no experience to cope with nuclear power's unique characteristics than it is for a utility with several nuclear plants. In fact, a recent EPRI study concludes that nuclear experience is one of the most significant variables influencing construction times (3). That study further concludes that **a** utility can compensate for lack of experience by relying on an architect/engineer or constructor that has previously dealt with nulear projects.

Lack of experience was a major source of Houson Lighting& Power Co.'s problems in constructing its South Texas projects. It selected the AE firm, Brown & Root, Inc., even though that firm was inexperienced with large-scale nuclear plants. After a number of quality problems came to light, NRC issued a stop-work order in 1980 for all safety-related construction. Houston Lighting & Power is attempting to resolve these difficulties by replacing Brown & Root with the more experienced firms of Bechtel Corp. and Ebasco Services, Inc.; they are also acquiring in-house capability by hiring well-trained engineers (28). This latter approach has been used successfully by other utilities. When Arizona Public Service Co. initiated construction of its first nuclear powerplants, it expanded its staff with engineers and managers experienced in nuclear power.

IMPROVING THE QUALITY OF NUCLEAR POWERPLANT MANAGEMENT

The problems discussed above indicate that great dedication is needed to manage nuclear powerplants. This technology presents many challenges to successful management, and not all utilities have demonstrated that they have the skill, resources, and commitment to meet the challenge.

Several different approaches can be taken to alleviate management problems. One possibility for reactors that will be sold in the future is to redesign them to be simpler and safer, and hence less susceptible to management control failures. This approach suggests reactors that are more "forgiving" of human errors than current LWRs, as discussed in chapter 4. A parallel effort might attempt to raise the quality of management through institutional controls.

Technical Approach

The technical improvements that could be made to the current generation of nuclear reactors range from minor evolutionary modifications to clean-sheet designs. As discussed in detail in chapter 4, **a** recent EPRI survey indicates that many utilities would like to see at least minor changes in new LWRs to enhance conservatism, reliability, operability, and maintainability (1 7). It was proposed that the next generation of LWR designs focus on simplicity, reduced sensitivity to anticipated transients, and reduced system interactions. Modifications of this sort could relieve some of the pressures on management by requiring less precision during both construction and operation.

Management benefits also could be derived from standardizing the LWR, with or without modifications. This would allow the utilities to transfer learning from one unit to another, and all plants could gain from the experience of any plant owner. Another potential benefit of standardization is that the regulatory climate is likely to be less active once an industry-wide design has been selected and approved. As a result, standardization should reduce the frequency of NRC-inspired design changes (22).

The modifications discussed above fit within a pattern of evolutionary development of LWR technology. They do not involve dramatic changes to components or to the basic reactor design, but focus on reconfiguring the current system. These changes would be welcomed by the nuclear utilities, and they could made nuclear reactors somewhat easier to manage. It is unlikely, however, that they would significantly reduce the overall level of management intensity required to handle nuclear projects. It is possible that this could be accomplished by a more innovative and drastic alteration to the present technology.

More extreme technical alternatives include redesigning the LWR to optimize it for safety or replacing the LWR with an alternative design. These reactors might prove to be less sensitive to management control failures than current LWRs. For example, the Fort St. Vrain high temperature gas-cooled reactor (HTGR) has experienced several incidents that have had no significant consequences, but which might have been serious in an LWR. In one incident, forced circulation cooling was interrupted for more than 20 minutes. Because the HTGR has a high heat capacity and the fuel has a high melting point, there was no damage to the core or components.

Even drastic changes in technology, however, cannot eliminate all of the problems that face managers of nuclear projects. In particular, modification of the technology cannot replace high-level commitment to quality and safety, which must accompany the construction and operation of at least the nuclear island of any reactor. Nor would a new design eliminate the demands for management skills during the construction process—effective distribution of responsibilities would continue to be important, as would the need to coordinate and motivate the construction work force. In short, inherently safe reactors might markedly reduce the problems that arise from technological considerations, but new designs cannot alone ensure high-quality construction and safe and reliable operations.

Institutional Approach

Institutional approaches focus on internal and external factors that affect performance rather than on technical considerations; in this sense, they complement the activities taken to reduce the complexity and sensitivity of nuclear reactors. Institutional measures can be divided into two types of activities:

- those that **create a favorable environment** for successful utility management of construction and operation. Such activities would focus on external problems, including efforts to enhance communications, increase the supply of trained personnel, and stabilize the regulatory environment; and
- those that monitor utility operations to detect management failures and elicit better performance from the less successful utilities. Such efforts would focus on problems that are specific to individual utilities.

Two principal organizations are now involved in institutional controls that monitor operations and improve communications. The NRC has long been involved in programs designed to regulate the nuclear industry and to protect the public. In the past, its initiatives were focused primarily on design and licensing issues for reactors in the construction phase. **As** the nuclear industry continues to mature and more plants enter operation, it is expected that the emphasis gradually will shift to operating plants.

The Institute of Nuclear Power Operations (IN PO) is a more recent participant in this area, and its influence is growing rapidly. INPO is spon-

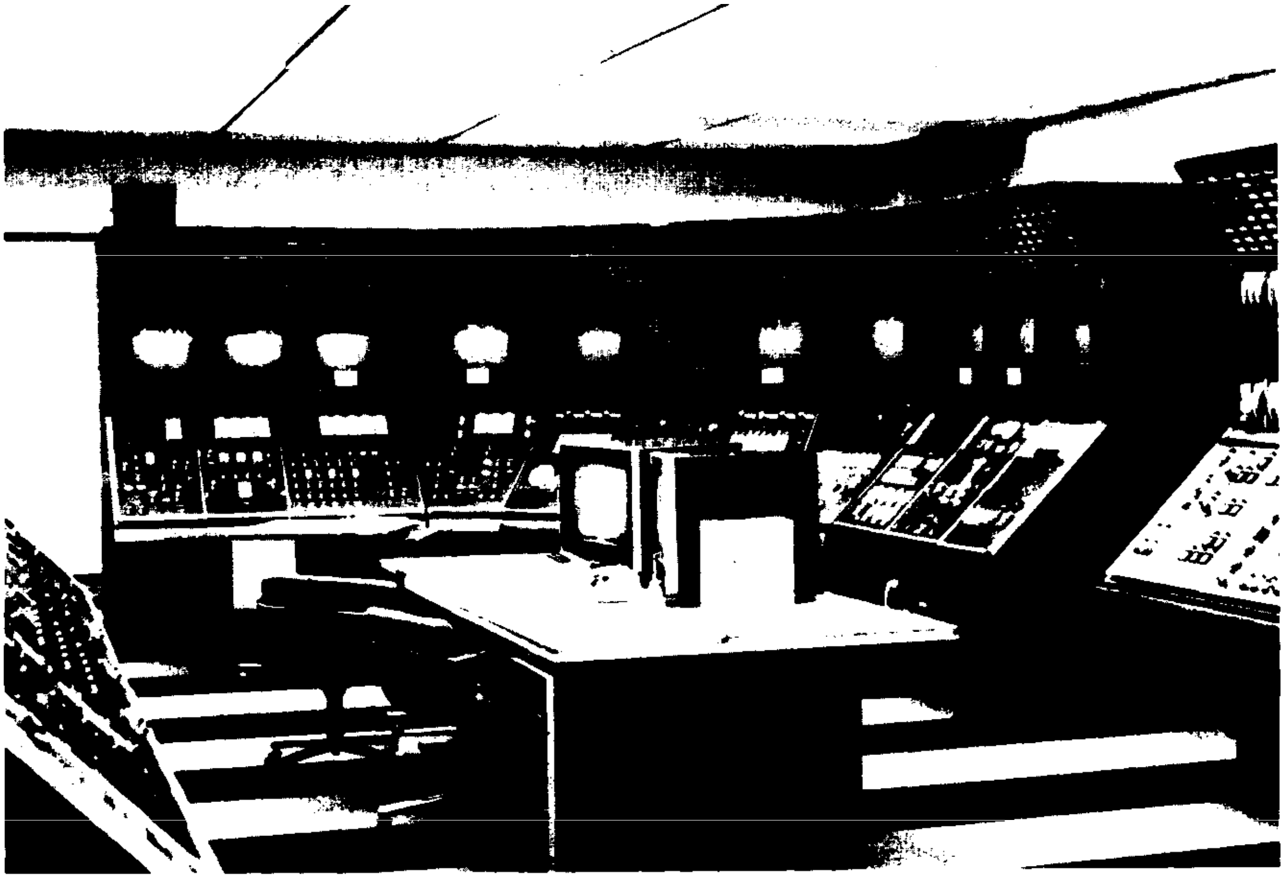


Photo credit: Pennsylvania Power & Light

Site-specific control room simulators, used increasingly by utilities to train nuclear plant operators, are duplicates of actual control rooms. Possible nuclear operating events are simulated on control instruments by computer. The simulator shown here trains operators of PP&L's Susquehanna plant and cost $6 million.

sored by the nuclear utility industry, and every utility with a nuclear plant in operation or under construction is a member. In addition, utility organization in 13 other nations participate in IN PO. It was formed in **1979** in response to the accident at Three Mile Island.

Creating the Right Environment

An area that has received considerable attention is the improvement of communication among utilities. The utilities have combined forces to form the Nuclear Safety Analysis Center **(NSAC) to analyze** technical safety **problems and** solutions. NSAC has already addressed a number of issues, including the accident at Three Mile Island, NRC's unresolved safety items, and degraded cores.

INPO has been active in collecting, evaluating, and redistributing utility reports of operating experience. This is particularly important in view of the massive amount of information that is generated by operating nuclear powerplants. It is a challenging task to distinguish the vitally important from the more mundane reports. INPO developed the Significant Events Evaluation and Information Network (SEE-IN) to handle information on an industrywide basis. **In 1982, more than 5,000 event reports were screened, and approximately 100 significant reports relating directly to plant reliability and safety were identified (41).** The most frequently cited problems involve valves and electrical and instrument controls, closely followed by the reactor coolant system, steam generators, diesel generators, and piping. After additional review, INPO distilled this infor-

mation into a few important recommendations. Among these recommendations are measures to preclude equipment damage, reduce prolonged outages, and minimize radiation exposure.

In addition to identifying generic problems in the industry, the SEE-IN program also checks to see if its recommendations are implemented. Thus far it has been very successful in encouraging utilities to make voluntary changes to comply with its recommendations. Nearly half of all operating plants implemented every "immediate attention" recommendation within a year, and many other plants are making progress in this direction (41).

NRC is planning a similar program in which it will systematically analyze the information that it collects through various reporting mechanisms. NRC plans to computerize its data base and search methods so that it can better detect generic problems *(13).*

A related NRC **activity is focused on construction rather than operation. A long-term effort to** review quality-assurance problems and to propose changes that could improve quality in design, construction, testing, and operation has been initiated. This review will start with an examination of nuclear plants at Diablo Canyon, South Texas, Midland, Marble Hill, and Zimmer to identify specific problems and causes. At various times in the past, NRC has issued stop-work orders at each of these plants due to concerns about the quality of construction. NRC will also examine projects with good records to identify the positive measures that could be applied generically (13).

The data analysis efforts by both NRC and INPO should enhance the formal transfer of learning among the utilities. **Other** INPO activities attempt to improve communication less formally by providing a forum for the exchange of ideas. Managers involved in nuclear plant construction and operation are encouraged to meet at workshops and conferences to share their experiences in detecting and solving problems. Another way in which INPO encourages the exchange of information is through its electronic communication system known as "Nuclear Notepad." This system provides timely transfer of news on important items by linking all operating nuclear plants in a single computer network (1 1).

INPO **also is active** in developing guidelines in the areas of training accreditation, emergency response, and radiation protection (39). These activities are coordinated with NRC needs and requirements. There is currently a great deal of variability in the ways in which utilities handle problems in these areas. **As** greater uniformity develops, the utilities should be better able to learn from one another and raise the level of performance on an aggregate basis.

Another important activity within NRC is the effort to moderate regulatory activity by controlling requirements for changes during construction and operation. In **1981,** NRC established the Committee for Review of Generic Requirements to assess backfitting proposals and to try to reduce the burden of shifting requirements. As discussed in chapter 6, this is a difficult task since safety is not easily quantifiable, and many technical uncertainties remain. However, this effort has the potential for enhancing the ability of utilities to construct new plants in a timely and efficient manner.

Detecting and Improving Poor Performance

Improvements have been made in certain aspects of the commercial nuclear industry in recent years. **The accident at Three** Mile Island convinced many utilities of the importance of attention to quality, and some have made voluntary changes to improve management. For example, a number of utilities have modified their organizational structure in an attempt to find one better suited to building and operating nuclear powerplants (3).

The utilities that are sensitive to quality concerns and responsive to NRC and **INPO** initiatives are probably not a source of great concern; rather, the concern is centered on those utilities that do not seem to be responding to the same motivation. In fact, the most successful utilities claim that they are being "held hostage" by the least capable and least committed utilities (23). They fear that another major nuclear accident in any commercial reactor would have disastrous consequences for all nuclear plant owners in terms of public acceptance. It is, therefore, in the interest of the best performers to ensure that poor practices are detected and eliminated, wherever they occur. This concern has led to INPO's extensive evaluation and assistance programs to attain excellence. NRC also evaluates utility performance, but with a different perspective. **Its** intent is to ensure that construction and operation of all nuclear units meet minimum standards, as defined by NRC.

INPO's evaluation programs appear to be well-structured and in logical relation to one another. The first **INPO efforts were devoted to establishing a comprehensive** system for evaluating operating nuclear reactors. In an operating plant evaluation, special teams of up to 15 people are sent to each nuclear unit to assess the performance of the utility in many different areas, including those shown in table 20. A final report is prepared to summarize the findings, make recommendations for improvements, and identify good practices. This report is reviewed with the highest levels of utility management, who develop a plan of action for implementing INPO recommendations (26).

INPO has completed two rounds of operating plant evaluations and has initiated a program to evaluate construction projects. Construction evaluation procedures have been developed and have been applied to 18 near-term operating licensee plants. The first phase of the construction assessment program was completed in 1982 when 22 utilities with nuclear plants under construction performed self-evaluations. The second phase of evaluations is being conducted by either INPO or independent organizations under contract to the utilities and monitored by IN PO. NRC has been following INPO's evaluation efforts closely and may restructure some of its own quality initiatives around the industry program (39).

In addition to evaluating nuclear plants, INPO is assessing the corporate support of nuclear utilities. Corporate evaluation criteria have been developed by a task force of senior utility executives. These criteria have been field-tested and are in use in INPO evaluation programs (26).

INPO evaluation reports have proven to be valuable in several ways. First, they form the basis for INPO's "good practice" reports, which summarize effective approaches used throughout the nuclear industry. These reports are particularly useful to utility managers who want to identify problem areas and adopt approaches that have been used successfully in other plants.

The second major contribution of INPO evaluations is to highlight problem areas in individual utilities and make recommendations *to* improve performance. In the event there is some reluctance on the part of a utility to comply with INPO recommendations, a number of actions can be taken to encourage cooperation. These actions are designed to raise the performance of all utilities by applying peer pressure, from other leaders in the industry. These pressures could be applied through utility chief executive officers, boards of directors, and insurers. Such actions have not yet been required.

The NRC has its own series of plant inspections. Starting in 1978, resident inspectors were located at each nuclear plant to monitor day-to-day operations. These inspectors provide much of the information that is used to develop the Systematic Assessments of Licensee Performance (SALP), which are prepared by NRC's five regional offices. The SALP's analyze performance in each of 10 categories, which are similar to the INPO categories shown in table 21. The goal of this evaluation is to identify areas in which management excels, areas which call for minor improvements, and those in which major weaknesses are evident. NRC uses this assessment to direct its inspection efforts and to suggest changes to the plant owners.

A more comprehensive NRC evaluation effort involves the Performance Assessment Team (PAT). This team operates from NRC headquarters, and its inspections provide a check on the NRC regional offices and the INPO evaluations. Although the PAT evaluations overlap the SALP's, they are broader in scope, with assessments of management controls and broad recommendations for change (24).

Table 21.—Classifications for INPO Evacuations

Organization and administration:	**Station organization and administration; management objectives; management assessment; personnel planning and qualification; industrial safety; document control; station nuclear-safety review group; quality programs**
Operations.K)perations	**organization and administration; conduct of operations; plant-status controls; operator** knowledge and performance; operations procedures and documentation; operations facilities and equipment
Maintenance:	Maintenance organization and administration; plant material condition; work-control system; conduct of maintenance; preventative maintenance; maintenance procedures and documentation; maintenance history; maintenance facilities and equipment; materials management
Technical support:	Technical-support organization and administration; surveillance-testing program; operations-experience review program; plant modifications; reactor engineering; plant-performance monitoring; technical-support procedures and documentation
Training and qua//f/cation:	Training organization and administration; licensed and nonlicensed operator training and qualification; shift-technical-advisor training and qualification; maintenance-personnel training and qualification; training for technical staff; training for managers and engineers; general employee training; training facilities and equipment
Radiological protection:	Radiological-protection organization and administration; radiological-protection personnel training and qualification; general employee training in radiological protection; external radiation exposure; internal radiation exposure; radiological-protection instrumentation and equipment; solid radioactive waste; personnel dosimetry; radioactive-contamination control
Chemistry:	Chemistry organization and administration; chemistry-personnel training and qualification; chemistry control; laboratory activities; chemical and laboratory safety; radioactive effluents
Emergency preparedness:	Emergency-preparedness organization and administration; emergency plan; emergency-response training; emergency facilities, equipment and resources; emergency assessment and notification; emergency-personnel protection; personnel protection; emergency public information.

SOURCE: Institute of Nuclear Power Operations

In 1982, NRC decided to limit the number of PAT inspections in recognition of the similarity to INPO's programs. The PAT program originally was scheduled to evaluate each reactor on a 3-to 4-year cycle. They were limited to only two to three inspections per year after 1982.

Another phase of the NRC inspection program focuses on near-term operating licensees (NTOL). To **increase its confidence in the quality-assurance programs at plants that will soon begin operation,** NRC now requires a self-evaluation of quality-assurance programs for design and construction at these plants (13). This includes a review of management involvement, audits, significant problems, and corrective actions. The self-evaluations are supplemented by NRC regional office reviews. These assessments examine the inspection and enforcement history of the project to determine whether additional inspections are needed. In addition, NRC encourages independent design reviews at all NTOL utilities.

The purpose of the NRC inspection activities is to identify severe or recurrent deficiencies. There is less effort made to analyze the structure and commitment of utility management than to identify problems that might arise from the failure of management controls. Thus, NRC evaluations serve the purpose of indirectly monitoring the sources of problems by directly monitoring their manifestations. In contrast, the INPO evaluations focus directly on weaknesses in management systems and controls.

In the event that any of the NRC inspections uncover major problems, NRC has recourse to a series of progressively severe penalties. Enforcement actions include: formal notification of a violation; imposition of a fine if the licensee commits a major violation, willfully commits a violation, or knowingly fails to report a violation; and finally, the modification, suspension, or revocation of a license. In the most extreme cases, NRC can refer the case to the U.S. Department of justice for investigation of criminal violations.

ASSESSMENT OF EFFORTS TO IMPROVE QUALITY

The management of commercial nuclear powerplants has proven to be a more difficult task than originally imagined by the early proponents of nuclear technology. While the safety record of U.S. plants is quite good, the reliability of the plants has been less than hoped for, and several accidents have occurred which have reduced the confidence of the public in the industry. Furthermore, construction projects have been plagued with cost and schedule overruns and questions about quality.

Nuclear power is not so intractable that it cannot be managed in an exemplary fashion; this has been demonstrated by the records of the most capable utilities. However, utilities with only average skills and commitment have been much less successful in managing nuclear projects. Better approaches are needed to improve the operation of today's plants and to establish public confidence that the utility industry could manage new reactors if they are needed in the future.

Both technical and institutional changes could help improve the management of nuclear power operations. Technical modifications would be useful insofar as they decrease the complexity and sensitivity of nuclear plants. Some of these changes are relatively simple to make and have been incorporated in the design of new LWRs. It is likely that other more drastic design changes could further decrease the sensitivity of nuclear reactors to their management by making them inherently safer and less dependent on engineered systems.

While a technical solution to all management problems would be welcome, it is not likely to be forthcoming. Even if an ultrasafe reactor could be developed, the demands on its operators to ensure reliable performance would still be greater than in a fossil plant. Furthermore, even drastic changes in reactor design would not significantly decrease the sophistication or complexity of the nuclear island, even though they might allow a reduction in the safety requirements for the remaining of plant systems. Overall, nuclear construction managers still would be taxed to coordinate massive projects amid exacting requirements for high levels of quality and extensive documentation.

Since technological changes cannot by themselves eliminate all the difficulties involved in constructing and operating nuclear units, it is important that they be supplemented with institutional measures to improve the management of the nuclear enterprise. For example, NRC could reduce pressures on utility managers by exercising as much care as possible in expanding regulatory requirements; INPO could further improve the situation by enhancing communication among the utilities. The more difficult and important changes, however, relate to the internal management of nuclear utilities. Utility managers must become aware of the unique demands of nuclear technology, and they must develop the commitment and skills to meet them. INPO could be instrumental in stimulating this awareness and in providing guidance to the utilities. INPO recognizes this point and is striving to develop such utility management awareness. It is likely that the utilities will tend to be more receptive to INPO than to an outside organization since INPO is a creation of the nuclear industry.

It is equally important that the nuclear utilities be evaluated objectively to assure that they are performing well. NRC and INPO have recognized the need for such evaluations, and both organizations currently are engaged in assessment activities. The INPO assessments, which now cover many areas, continue to evolve, and so far appear to have been handled with sensitivity and insight. The INPO evaluations attempt to assess the performance of the utility management to identify the root causes of the problems and recommend corrective actions. The NRC inspection program is more fragmented and somewhat unfocused. The relationships among the various inspection activities are not always clarified, although these activities should complement one another. Furthermore, most of NRC's inspection activities concentrate on the consequences of quality problems rather than on the sources. It should be noted that NRC does try to identify management control failures once a problem surfaces, but that this is not a part of its standard evaluation procedure.

INPO and NRC communicate with one another concerning their respective evaluation and inspection activities, and they are attempting to coordinate their programs. In establishing their respective roles, it should be noted that the INPO evaluation teams may be better able to communicate with utility managers and discover the source of problems. But this does not imply that NRC should turn over its inspection activities to IN PO; the public must have confidence that the utilities are being evaluated objectively and ac-

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curately, and only a government organization can guarantee such objectivity. NRC currently accomplishes this by carefully monitoring INPO activities and by performing independent assessments on a limited basis. However, NRC also performs a variety of other detailed evaluations that are not well-coordinated with **INPO activities.** Some duplication of effort maybe appropriate, since NRC must remain objective and informed in its oversight role. However, it should be possible to better coordinate the activities of the two organizations to make better use of limited resources and relieve the utilities of redundant inspections.

Enforcement activities also can be very important in raising the level of the poorest utility performers. Both NRC and INPO have a number of measures at their disposal to encourage utilities to make changes or penalize them if they don't cooperate. INPO operates through peer pressure, and it is not clear that it would actually invoke its strongest measures. INPO has not yet found it necessary to exercise all its options.

NRC operates on a different level with a series of enforcement actions that can be taken if it detects an unwillingness of the nuclear industry to regulate itself with sufficient stringency. NRC has proven willing to exercise the option of fining utilities when it detects breaches of security or safety regulations.

It is difficult at this time to assess the effectiveness of the efforts of the nuclear industry and its regulators to improve plant performance. There is not yet any clear evidence that the utilities have been able to translate NRC and INPO programs into better reliability and fewer safety-related incidents. **INPO is still in the process of establishing its guidelines and evaluation** procedures, and NRC is just starting to assume a more active role in evaluating management controls. However, the next few years should provide the evidence needed to evaluate these initiatives. It is not yet clear that significant improvements will occur in management of construction since there are few formal mechanisms for transferring learning or developing more successful approaches. It is possible that operational reliability and safety will improve noticeably if the NRC and INPO initiatives are successful. Improvements in plant reliability should be reflected in increased capacity factors and availabilities and in decreased forced outage rates. Industry efforts to improve component reliability and enhance maintenance and operation should start showing results soon.

Improvements in safety are more difficult to measure, but one indication of plant safety is the frequency and severity of events that could lead to accidents. These are known as precursor events, and NRC requires that they be reported routinely. If there is a significant decline in the number or severity of precursor events in the coming years, it is likely that private and Government efforts are achieving some measure of success in increasing safety. Conversely, if incidents such as the loss of the emergency shutdown system at the Salem nuclear plant continue to occur, it will be difficult to place much confidence in the effectiveness of the efforts to improve safety.

It may be very difficult to achieve significant gains in performance in an industry with so many different actors and such diverse interests and talents. The industry's support for IN P<) is a major step in generating a uniform level of excellence. However, only time will tell if INPO can remain both strong and objective and if all utilities will commit themselves to high standards in construction and operation.

NEW INSTITUTIONAL ARRANGEMENTS

In the previous discussions, we saw that many utilities have built and operated nuclear powerplants safely and reliably, and others are now working to improve the quality in construction and operation. The creation of INPO appears to be a significant step in this process of improvement. NRC also is encouraging quality in nuclear power management as a way to achieve safety. However, all of these efforts from within and outside the utility industry may not be sufficient to provide assurances to the public and investors that adequate levels of economy and safety are being achieved.

in the introduction to this report the many actors and institutions involved in nuclear energy were described. One of the keys to breaking the present impasse among these institutions is a clear demonstration that all utilities with nuclear reactors are operating them safely and reliably. If the efforts to improve utility management described thus far are insufficient to satisfy all these actors, it is unlikely that new plants will be ordered. In this case, a future for conventional nuclear power may require changing the existing relationships among the various actors or creating new institutions.

It should be noted that the potential advantages of these new entities are only speculative at this time. Some industry problems such as the overall shortage of qualified personnel would not be helped by simply rearranging people and institutions. However, if current efforts to improve utility management have little impact, these alternatives might be worth further consideration. The various changes are discussed briefly below and the implications of the changes are explored in chapter 9. Some are only incremental adjustments to the current structure of the nuclear industry, while other are major reorganizations requiring legislation. However, they share the common goal of improving overall management of both construction and operation of nuclear powerplants.

A Larger Role for Vendors in Construction

Many of the current problems in plant construction can be traced to the overlapping and conflicting authority of the utility, the nuclear steam supply system (NSSS) vendor, the AE, and the constructor. To overcome this problem, one contractor (probably the NSSS vendor) could assume greater responsibility for overall design, and, in some cases, construction management. **This change already is occurring to some extent.** For example, Wedco, a subsidiary of Westinghouse, has acted as the constructor for nuclear plants in New York State, and Westinghouse itself is constructing a plant in the Philippines.

The trend toward greater vendor responsibility for construction management may be helped indirectly by the current financial problems in the nuclear industry. Cost uncertainties make it unlikely that utilities will order new nuclear plants unless they can be assured of a fixed price. If inflation were more moderate and licensing uncertainties reduced (perhaps through the use of standardized and preapproved designs), vendors might offer some type of fixed price as they did with the turnkey contracts of the early 1960's. However, it is unlikely that vendors would grant this type of contract unless they were assured of greater control over construction. It has been suggested that a single person within the NSSS company be given point-source responsibility for safety, quality control, and construction management of the nuclear island. Westinghouse assumes these responsibilities in its international projects, (where licensing is less complex) and has had good experience with the approach. Because it has greater control, the vendor is able to offer fixed-price contracts to its customers abroad.

A greater role for vendors in construction management offers a number of potential advantages in addition to those just described. The NSSS companies have a long history of experience in nuclear energy, highly trained personnel, and the financial incentive to build the plant well. The major potential disadvantage of this approach is that vendors currently have little experience in construction management. If the vendors do not build up their construction capabilities, this approach may not be an improvement over using a qualified AE and constructor. Other problems could arise after construction, when utilities with little knowledge of their plants must assume responsibility for maintenance and operation.

Another approach to integrating responsibilities for construction management is used in Belgium for all large construction projects, including nuclear powerplants. There, the construction company assumes financial liability for the nuclear plant for a decade after it is completed. The construction company is able to assume this risk because it can purchase insurance after an independent assurance company has certified the quality of its work.

Service Companies

Currently, nuclear consultants and service companies provide a broad range of services to utilities, including: interactions with NRC; systems design and engineering intergration; operational and maintenance tasks; fuel procurement; and quality assurance. These firms can help strengthen the capabilities of the weaker utilities in both construction and operation of nuclear plants. For example, many utilities are now calling on consulting firms to conduct independent audits of construction quality and make recommendations for improvements. Teledyne, Inc., has audited the two Midland units in Michigan and the two Diablo Canyon plants in California, C. F. Braun evaluated the LaSalle generating station in Illinois, and the Quadrex Corp. was called in to examine the two South Texas plants (18).

While services such as these can be useful, they currently are provided only at certain times for one or more specific tasks. To resolve safety and management problems among the weaker utilities, it may become desirable for service companies to play a much larger role. This might also be attractive to a disaffected public living near a troubled nuclear powerplant. These roles could range from handling all quality assurance or all engineering work to actual management of construction or plant operations.

Currently, service companies belonging to utility holding companies such as Southern Co., Middle South Utilities, Inc., American Electric Power Co., Inc., and General Public Utilities Corp. act somewhat like the service organizations discussed above. For example, a centralized nuclear engineering group provides services to all of Middle South's member utilities. In the 1950's, a consortium of New England utilities formed Yankee Atomic Electric Co., which built and operates Yankee Rowe in Massachusetts. Three other corporations, owned by many of the same utilities, were subsequently formed to build and operate Vermont Yankee, Maine Yankee, and Connecticut Yankee. The service division of Yankee Atomic provides a broad range of services to all of these plants (except Connecticut Yankee) and others in New England. A more recent entrant is Fuel Supply Service, a subsidiary of the successful Florida Power & Light Co. This organization has been hired by Public Service Co. of New Hampshire to speed up the construction of the troubled Seabrook projects (27).

While all of the entities just described are owned by utilities, it is possible to envision others that would be independent. A number of businesses might be interested in offering their services to utilities as nuclear operating companies. Duke Power Co., a successful nuclear utility, has expressed interest in operating plants for other utilities. Some present nuclear service 'companies also might be interested, if it were clear that they were being given management responsibility. The fundamental shift in the present relationship between utilities and service companies would have to be clarified for both parties. Finally, high-technology companies, especially those already involved in the nuclear business, might want to provide operating services.

Service companies are commonly used at Government-owned facilities. The successful use of contractors at armament plants, whose operations involve careful attention to safety and quality control, suggests that the complexities of nuclear powerplants could be handled by an independent service company. It has been estimated that the Departments of Defense and Energy and the National Aeronautics and Space Administration have contracts for Government-owned, contractor operated facilities amounting to $5 billion to $10 billion per year (29). An analysis of these facilities indicates that operations are most successful when either the owner or the contractor has the dominant managerial and technical role. In addition, financial liability has not been a problem in these contracts: all liability rests with the facility owner, and the threat of replacement provides the incentive for quality operations by the service company. Such arrangements also might work well in service contracts between a utility and a nuclear powerplant operating company.

The nuclear service company alternative provides a way to pool nuclear expertise and make it available to many utilities at once. During construction, the service company could play the vital role of system integrator. In addition, implementation of this alternative would be greatly **simplified by the fact that it does not require a major change** in the other institutions, such as the utilities, NRC, or the vendors.

However, the proposal also has some disadvantages. First, it seems unlikely that utilities would be willing to give up responsibility for safety and quality while retaining financial liability. Secondly, unless the roles of the actors were made very clear, the arrangement could simply add to the confusion that already exists in nuclear powerplant construction and cause continuing disagreements. In addition, depending on where the owning utility and service company were headquartered, the arrangement could cause problems in dealing with State public Service Commissions. Finally, without some mechanism that required the weaker utilities to hire service companies, the existence of these entities might have little impact on the overall quality of nuclear power management.

Certification of Utilities

An independent review and certification of utilities as capable of constructing or operating nulear powerplants could provide the "stick" needed to make the service company alternative work. NRC currently has the authority to revoke the operating license of any utility the agency feels is not capable of safely operating nuclear plants. However, since the utility industry recognizes that the agency is very reluctant to take such drastic action, this authority may not be sufficiently convincing to assure high-quality operation of all nuclear plants. * Certification **might provide a more politically feasible alternative. It** might be more acceptable to the utilities because the certification review could come from an independent panel of experts, rather than from NRC. If certain management characteristics were found to affect safety negatively, utilities with those characteristics could be decertified until those characteristics were changed.

Certification might involve periodic review of utility management by an independent panel, including representatives of NRC and INFO. The panels could be similar in makeup and activities to those used in accreditation of colleges and universities. Like accreditation panels, the reviewers could issue warnings and allow the utilities time to improve their management prior to denying certification. Because of the unique difficulties of nuclear plant construction, the requirements for certification of utilities proposing to build new plants could be made particularly stringent. Based on the review panel's findings, NRC could either grant or deny the construction certificate.

Once a plant is completed, another review by the panel could determine the company's ability to manage it. Depending on the results of the review, the company might be required to hire an outside service company to take over or supplement operations. Thereafter, the utility and/or the service company could be reviewed periodically to make sure that changes in personnel had not diminished their management capabilities. Utilities presently operating nuclear plants also would be subject to the certification review. One model of such a review- and certification-process is the accreditation procedure for utility training programs currently being developed and implemented by IN PO,

The primary advantage of a certification process is that it could force the weaker utilities to improve their nuclear management capabilities, obtain independent and external expertise, or refrain from entering the nuclear power business. Such a step would be very convincing to the public and skeptics of nuclear power. The primary barrier to implementation is that the utility industry would be reluctant to accept it. Nuclear utilities already feel overburdened by NRC and **INPO** inspections, and the certification panel's review could add yet another layer of "regulation. " Another disadvantage of certification is that its success depends on the existence of an entity (e.g., a service company) which has the expertise the utility lacks. Unless such entities are available and have the appropriate management characteristics, the certification procedure will not improve the construction and operation of nuclear powerplants.

***The recent refusal by the Atomic Safety Licensing Board to grant an operating license to Commonwealth Edison's Byron plant may indicate a change in NRC's reluctance on this issue.**

Privately Owned Regional Nuclear Power Company

Since the 1920's, electric utilities has become increasingly coordinated through horizontal integration and power pooling. This trend has captured economies-of-scale, fostered the sharing of expertise, and eased the task of planning **(31). The regional nuclear power company (RN PC) discussed** here is one approach to increased integration that does not involve restructuring the whole industry. It is seen as a logical extension of the current trend toward multiple utility ownership and single utility management of many existing nuclear plants.

The RNPC would be created expressly to finance construction and/or operate nuclear powerplants. It could be owned by a consortium of utilities, vendors, and AEs, and might place an order for several plants at once, based on a standardized, preapproved design. All RNPC proposals currently under discussion call for a confined siting policy to take advantage of the benefits of clustered reactors. While some analysts feel the RNPC should be applied only to new construction, others think that existing plants could be transferred to RNPC authority. Federal legislation probably would be required to transfer ownership of existing plants because of the tax and financial complications (10).

One possible advantage of an RNPC from a financial perspective is that its electricity output might not be subject to some of the difficulties posed by State rate regulation discussed in chapter 3. Presumably, the RNPC would sell power to the utility grid at wholesale rates, and the utilities in turn would distribute the power to their customers. Interstate wholesale rates are regulated by the Federal Energy Regulatory Commission (FERC). With appropriate legislation, the power generated by an RNPC could be deregulated totally or granted special treatment in ratemaking. Congress could exempt the RNPC from FERC price regulation, and the electricity purchased by local utilities could be exempted from State rate regulation when sold to customers. The Public Utility Regulatory Policies Act (PURPA) provides the precedent of a special pricing mechanism, legislated by Congress, for a particular class of electricity (in that case, power from small producers). The law has been upheld as constitutional over objections from State government.

While the initial attraction of the RNPC model may be these financial benefits, such companies also could be expected to improve nuclear power management by their larger staffs, allowing a greater concentration of expertise. The proposed change would leave nonnuclear utility operations untouched, and would avoid the complications of mixed financial liability and authority in the service company scheme. In addition, the greater expertise of the larger company could make it less reliant on vendors and AEs during construction.

The size of the RNPC could prove as much a disadvantage as an advantage. A bureaucratic operation could decrease the sense of individual responsibility for the reactors, which in turn could lead to a decrease in safety and reliability. Additionally, while shared utility ownership of the RNPC could help share the financial risks and burdens, it might be difficult to obtain financing for a company whose only assets were nuclear powerplants. in the past 2 years, the utilities owning the Yankee nuclear corporations in New England have had to back financial offerings with their full utility assets.

Government-Owned Regional Nuclear Power Authority

This option is basically the same as that just described, except that the Government would either own the entity or provide financial assistance to it. The Federal Government has previously assumed this role in the creation of the Tennessee Valley Authority and the Bonneville Power Administration (B PA) to tap hydropower. Ontario Hydro in Canada and TVA, which have succesfully built and operated nuclear plants, are the closest **models** to such an authority. However, both of these entities own nonnuclear as well as nuclear power. The RNPA envisioned here would be involved only in nuclear projects,

Several factors would justify the creation of one or more Government-owned RNPAs. First, it may be the only way to maintain nuclear power as a national energy option. Given utilities' current reluctance to order new nuclear plants, the Federal Government might use the RNPA as a vehicle to demonstrate that newly designed, standardized plants could be built and licensed economically. Second, because of nuclear power's unique characteristics, the Federal Government has always had a major role in the development and regulation of this technology, and Government ownership might be a logical extension of that role. Finally, the advantages of large-scale operations cited for the privately owned regional utilities would apply to RNPAs as well.

The primary barrier to creation of a Government-owned RNPA is that it involves greater Government intervention in the private sector. However, this problem could be alleviated if the RNPA were primarily a financing entity, assisting private utilities with construction of new nuclear plants. Another model would be RNPA ownership of the plants, with operations handled by private service companies. A Government-owned RNPA could also face the problem of public opposition encountered by the RN PC. In addition, there is no guarantee that management by the Federal Government would be superior to private-utility management. Finally, if existing plants were to be included in the RNPA scheme, the transfer of these plants to Government ownership could be difficult.

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