Nuclear Power in an Age of Uncertainty

February 1984

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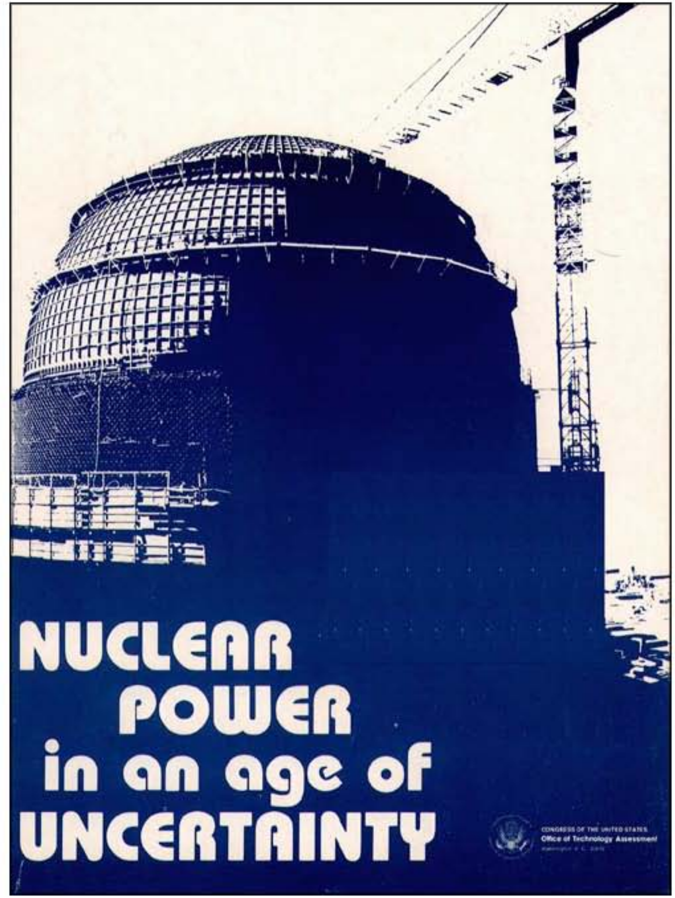

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Foreword

This report responds to a request by the House Committee on Science and Technology, with the endorsement of the Senate Committee on Energy and Natural Resources, to assess the future of nuclear power in this country, and how the technology and institutions might be changed to reduce the problems now besetting the nuclear option. The report builds on an earlier OTA report, Nuclear *Powerplant Standardization,* and complements a current *report, Managing Commerical High-Level Radioactive Waste.*

The present nuclear era is drawing to a close. The cover of this report show Unit I of the Washington Public Power Supply System, which was indefinitely, perhaps permanently, deferred even though it was 60 percent complete and $2.1 billion had been invested. This plant and others such as Zimmer and Marble Hill epitomize the difficulties facing the nuclear industry. It is important to remember, however, that other nuclear plants have been very successful and produce reliable, low cost electricity. The future of nuclear power poses a complex dilemma of policy makers. It has advantages that may prove crucial to this Nation's energy system in the coming decades, but at present it is an option that no electric utility would seriously consider.

OTA examined questions of demand growth, costs, regulation, and public acceptance to evaluate how these factors affect nuclear power's future. We reviewed research directions which could improve conventional light water reactor technology and opportunities to develop other types of reactor concepts that might enhance safe and reliable operation. In addition, the crucial role of utility management in constructing and operating nuclear powerplants is examined at length. The controversy about nuclear safety regulation is also analyzed, and is presented with a review of current proposals for regulatory reform. Finally, the study discusses policy approaches that could assist a revival of the nuclear option should that be a choice of Congress.

In the course of this assessment, OTA drew on the experience of many organizations and individuals. In particular, we appreciate the generous assistance of our distinguished advisory panel and workshop participants, as well as the efforts of the project's consultants and contractors. We would also like to acknowledge the help of the numerous reviewers who gave their time to ensure the accuracy and comprehensiveness of this report. To all of the above goes the gratitude of OTA, and the personal thanks of the project staff.

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OVERVIEW AND FINDINGS

Without significant changes in the technology, management, and level of public acceptance, nuclear power in the United States is unlikely to be expanded in this century beyond the reactors already under construction. Currently nuclear powerplants present too many financial risks as a result of uncertainties in electric demand growth, very high capital costs, operating problems, increasing regulatory requirements, and growing public opposition.

If all these risks were inherent to nuclear power, there would be little concern over its demise. However, enough utilities have built nuclear reactors within acceptable cost limits, and operated them safely and reliably to demonstrate that the difficulties with this technology are not insurmountable. Furthermore, there are national policy reasons why it could be highly desirable to have a nuclear option in the future if present problems can be overcome. Demand for electricity could grow to a level that would mandate the construction of many new powerplants. Uncertainties over the long-term environmental acceptability of coal and the adequacy of economical alternative energy sources are also great and underscore the potential importance of nuclear power.

Some of the problems that have plagued the present generation of reactors are due to the immaturity of the technology, and an underestimation by some utilities and their contractors of the difficulty of managing it. A major commitment was made to build large reactors before any had been completed. Many of these problems should not reoccur if new reactors are ordered. The changes that have been applied retroactively to existing reactors at great cost would be incorporated easily in new designs. Safety and reliability should be better. It is also likely that only those utilities that have adequately managed their nuclear projects would consider a new plant.

While important and essential, these improvements by themselves are probably not adequate to break the present impasse. Problems such as large cost overruns and subsequent rate increases, inadequate quality control, uneven reliability, operating mishaps, and accidents, have been numerous enough that the confidence of the public, investors, rate and safety regulators, and the utilities themselves is too low to be restored easily. Unless this trust is restored, nuclear power will not be a credible energy option for this country.

It appears possible, however, that additional improvements in technology and the way nuclear power is managed and regulated might be sufficient to restore the required confidence. Technological improvements, while insufficient by themselves, can nevertheless be very important in that effort. One approach would be to focus research and development (R&D) on improving current light water reactor (LWR) designs. The goal would be standardized designs representing an optimal balance of costs, safety, and operability. Private industry is unlikely to undertake all the R&D needed, so a Federal presence is probably necessary.

It is also possible, however, that even greatly improved LWRs will not be viewed by the public as acceptably safe. Therefore, R&D on alternative reactors could be essential in restoring the nuclear option if they have inherently safe characteristics rather than relying on active, engineered systems to protect against accidents. Several concepts appear promising, including the high temperature gas-cooled reactor (HTGR), the PIUS reactor, and heavy water reactors. Such R&D should also be directed toward design and developing smaller reactors such as the modular HTGR.

Improvements in areas outside the technology itself must start with the management of existing reactors. The Nuclear Regulatory Commission, as well as the Institute for Nuclear Power Operations, must ensure a commitment to excellence in construction and operation at the highest levels of nuclear utility management. Improved training programs, tightened procedures, and heightened awareness of opportunities for improved safety and reliability would follow. If some utilities still prove unable to improve sufficiently, consideration could be given to the suspension of operating licenses until their nuclear operations reflect the required competence, perhaps by employing other utilities or service companies, Similarly, certification of utilities or operating companies could be considered as a prerequisite for permits for new plants in order to guarantee that only qulaified companies would have responsibility. These are drastic steps, but they may be warranted because all nuclear reactors are hostage, in a sense, to the poorest performing units. Public acceptance, which is necessary if the nuclear option is to revive, depends in part on *all* reactors performing reliably and safely.

Nuclear safety regulation also can be improved even without substantial new legislation. Several utilities recently have shown that current regulatory procedures need not preclude meeting construction budgets and schedules. The regulatory process, however, is more unpredictable than necessary, and there is no assurance that safety and efficiency are being optimized. Encouraging preapproved standardized designs and developing procedures and the requisite analytical tools for evaluating proposed safety backfits would help make licensing more efficient without sacrificing safety.

The improvements in technology and operations described above should produce gains in public acceptance. Additional steps may be required, however, considering the current very low levels of support for more reactors. Addressing the concerns of the critics and providing assurance of a controlled rate of nuclear expansion could eliminate much of the reason for public disaffection. An important contribution to restoring public confidence could be made by a greater degree of openness by all parties concerned about the problems and benefits of nuclear power.

If progress can be made in all these areas, nuclear power would be much more likely to be considered when new electric-generation capacity is needed. Such progress will be difficult, however, because many divergent groups will have to work together and substantial technical and institutional change may be necessary.

Chapter 1

Introduction: The Seven-Sided Coin

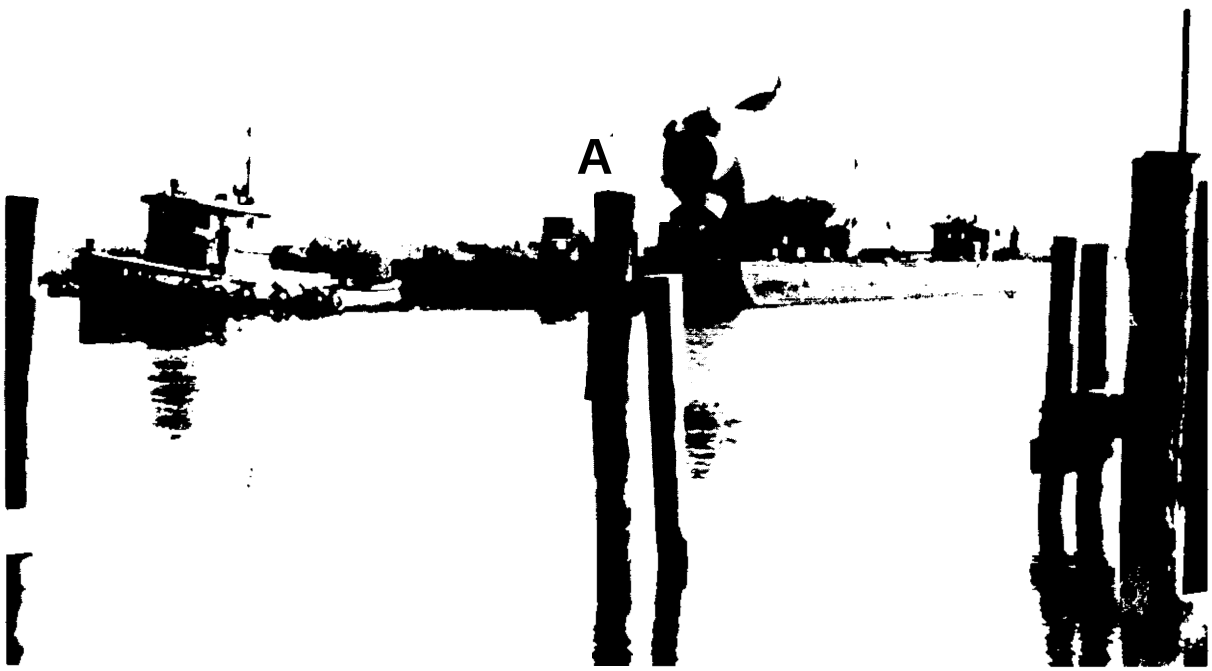

Photo credit: Atom/c Industrial Forum

Steam generator for a pressurized water reactor (PWR) arrives by barge

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Chapter 1
Introduction: The Seven-Sided Coin

THE POLICY PROBLEM

The nuclear power industry is facing a period of extreme uncertainty. No nuclear plant now operating or still under active construction has been ordered since 1974, and every year since then has seen a decrease in the total utility commitment to nuclear power. By the end of this decade, almost all the projects still under construction will have been completed or canceled. Prospects for new domestic orders during the next few years are dim.

Such a bleak set of conditions has led some observers to conclude that the industry has no future aside from operating the existing plants. Some conclude further that such an end is entirely appropriate because they believe that nuclear reactors will not be needed due to the low growth in demand for electricity, and that the present problems are largely a result of the industry's own mistakes.

If nuclear power were irrelevant to future energy needs, it would not be of great interest to policy makers. However, several other factors must be taken into account. While electric growth has been very low over the last decade (in fact, it was negative in 1982), there is no assurance that this trend will continue. Even growth that is quite modest by historical standards would mandate new plants—that have not been ordered yet–coming online in the 1990's. Replacement of aging plants will call for still more new generating capacity. The industrial capability already exits to meet new demand with nuclear reactors even if high electric growth resumes. In addition, reactors use an abundant resource. Oil is not a realistic option for new electric-generating plants because of already high costs and vulnerability to import disruptions which are likely to increase by the end of the century. Natural gas may also be too costly or unavailable for generating large quantities of electricity.

The use of coal can and will be expanded considerably. All the plausible growth projections considered in this study could be met entirely by coal. Such a dependence, however, would leave the Nation's electric system vulnerable to price increases and disruptions of supply. Furthermore, coal carries significant liabilities. The continued combustion of fossil fuels, especially coal, has the potential to release enough carbon dioxide to cause serious climatic changes. We do not know enough about this problem yet to say when it could happen or how severe it might be, but the possibility exists that even in the early 21st century it may become essential to reduce sharply the use of fossil fuels especially coal. Another potentially serious problem with coal is pollution in the form of acid rain, which already is causing considerable concern. Even with the strictest current control technology, a coal plant emits large quantities of the oxides of sulfur and nitrogen that are believed to be the primary source of the problem. There are great uncertainties in our understanding of this problem also, but the potential exists for large-scale coal combustion to become unacceptable or much more expensive due to tighter restrictions on emissions.

There are other possible alternatives to coal, of course. Improving the performance of existing powerplants would make more electricity available without building new capacity. Cogeneration and improved efficiency in the use of electricity also are equivalent to adding new supply. These approaches are likely to be the biggest contributors to meeting new electric service requirements over the next few decades. Various forms of solar and geothermal energy also appear promising. Uncertainties of economics and applicability of these technologies, however, are too great to demonstrate that they will obviate the need for nuclear power over the next several decades.

Therefore, there may be good national-policy reasons for wanting to see the nuclear option preserved. However, the purpose of the preceding discussion is not to show that nuclear power necessarily is vital to this Nation's well-being, It is, rather, to suggest that there are conditions under which nuclear power would be the preferred choice, and that these conditions might not be recognized before the industry has lost its ability to supply reactors efficiently and exseditiously. If the nuclear option is foreclosed, it should at least happen with foresight, not by accident or neglect. This report analyzes the technical and institutional prospects for the future of nuclear power and addresses the question of what Congress could do to revitalize the nuclear option if that should prove necessary as a national policy objective.

NUCLEAR DISINCENTIVES

No efforts-whether by Government or the industry itself–to restore the vitality of the industry will succeed without addressing the very real problems now facing the technology. To illustrate this, consider a utility whose projections show a need for new generating capacity by the mid-**1990's. in comparing coal and nuclear plants, current estimates** of the cost of power over the plant's lifetime give a small advantage–perhaps 10 percent–to nuclear. Fifteen years ago, that advantage would have been decisive. Now, however, the utility managers can see difficulties at some current nuclear projects which, if repeated at a new plant, would eliminate any projected cost advantage and seriously strain the utility:

- The cost projections may be inaccurate. Some plants are being finished at many times their originally estimated cost. Major portions of a plant may have to be rebuilt because of design inadequacy, sloppy workmanship, or regulatory changes. Construction lead-times can approach 15 years, leaving the utility dangerously exposed financially. The severe cash flow shortages of the Washington Public Power Supply System (WPPSS) are an extreme example of this problem.
- Demand growth may continue to fall below projections. A utility may commit large sums of capital to a plant only to find part way through construction that it is not needed. If the plant has to be canceled, the utility and its shareholders must absorb all the losses even though it looked like a reasonable investment at the beginning. The long construction schedules and great capital demands of nuclear plants make them especially risky in the light of such uncertainty.
- The Nuclear Regulatory Commission (NRC) continues to tighten restrictions and mandate major changes in plant designs. Although the reasons for these changes often are valid, they lead to increases in costs and schedules that are unpredictable when the plant is ordered. In addition, the paperwork and time demands on utility management are much greater burdens than for other generating options.
- Once a plant is completed, the high capital costs often lead to rate increases to utility customers, at least until the plant has been partially amortized. This can cause considerable difficulty with both the customers and the public utility commission (PUC), If rate increases are delayed to ease the shock, net payback to the utility is postponed further.
- Most of the money to pay for a plant has to be raised from the financial market, where nuclear reactors increasingly are viewed as risky investments. The huge demands for capital to pay construction costs (and the high interest costs on this capital) make unprecedented financial demands on utilities at a time when capital is costly.
- There are many opportunities for opponents of a plant to voice their concerns. Some plants have been the focus of suits over specific environmental or safety issues. in the licensing process, critics may raise a wide variety of issues to which the utility has to be prepared to respond. These responses call for a significant legal and technical effort as well as long delays, regardless of the ultimate disposition of the issue.
- Plant operation may not meet expectations, Some reactors have suffered chronic reliability problems, operating less than 50 percent of the time. Others have had to replace major components, such as steam generators,

at a cost of tens of millions of dollars because of unexpectedly rapid deterioration. While there is no specific reason to think a new plant would not operate its full life expectancy without major repairs, no reactor is yet old enough to have demonstrated it. There also is the possibility of long-term shutdowns because of accidents such as Three Mile Island. Furthermore, a nuclear utility is vulnerable to shutdowns and major modifications not only from accidents at its own facility, but also from accidents at any other reactor.

- Public support for nuclear power has been slipping, largely due to concerns about safety and costs. Public concerns can manifest themselves in political opposition. Several states have held referenda banning nuclear power or restricting future construction. None has passed that would mandate shutting down operating reactors, but some have come close. Furthermore, State and local governments have considerable control over the plant through rate regulation, permitting, transportation of waste, and approval of emergency plans. If the public does not want the plant, all these levers are likely to be used against it.

Given all these uncertainties and risks, few utilities would now consider nuclear reactors to be a reasonable choice. Moreover, the pressures arising from virtually continuous interactions with contractors, NRC, the PUCs, financial institutions, and perhaps lawsuits by opponents, make nuclear power far more burdensome to a utility than any other choice. The future of nuclear power would appear to be bleak.

Yet there is more to nuclear power than the well-publicized problems affecting some reactors. In fact, many have been constructed expeditiously, and are operating with acceptable reliability. Some have enjoyed spectacular success. For instance, the McGuire unit 2 of Duke Power in North Carolina was completed in 1982 at a cost of $900/kW, less than a third of the cost of the Shoreham plant in New York. The Vermont Yankee plant operated in 1982 at 93 percent availability, one of the best records in the world for any kind of generating plant. Calvert Cliffs supplies electricity to Baltimore Gas & Electric customers at 1.7¢/kWh. Finally, safety analyses are improving steadily, and none has indicated that nuclear plants pose a level of risk to the public as high as that accepted readily from other technologies. These well-managed plants have operated safely while providing substantial economic benefits for their customers.

Such examples, however, are insufficient to counterbalance the problems others have encountered. Nuclear power has become entangled in a complex web of such conflicting interests and emotions that matters are at an impasse. The utility viewpoint discussed above shows that there is little advantage and a great many disadvantages to the selection of a nuclear plant when new capacity is needed. Therefore, there will be few–if any—more orders for reactors in this century without significant changes in the way the industry and the Government handle nuclear power.

THE IMPASSE

Consider now the perspective of those Federal energy policy makers who believe the nuclear option should be maintained in the national interest. It is unlikely that the U.S. Government will heavily subsidize the purchase of reactors by utilities or that it will build and operate reactors itself. Therefore, new orders will be stimulated only by alleviating those concerns and problems that now preclude such orders. Any policy initiative that is proposed, however, is likely to be controversial, because there are at least seven parties with distinct–and often conflicting–interests:

- utilities,
- nuclear safety regulators,
- critics of nuclear power,
- the public,
- the nuclear supply industry,
- investors and the financial community, and
- State public utility commissions.

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To illustrate how these interests pull in different directions for different reasons, consider just one issue. Changes in plant licensing and safety regulation often are cited as necessary elements of any strategy to revitalize the option, but there is little agreement on either the type or extent of reform that should be instituted.

- Before **utilities** will make a commitment to invest several billion dollars in a nuclear plant, they want assurances that extensive modifications will not be necessary and that the regulations will remain relatively stable. Utilities contend that such regulatory changes delay construction and add greatly to costs without a clear demonstration of a significant risk to public health and safety. To the utilities, such assurances do not appear to be impossible to grant. They point out that NRC has licensed 80 plants and should know what is necessary to ensure operating safety. Therefore, they would support revisions to the regulatory process that would make it more predictable and stable,
- However, there is another side to this coin. No plant design has been analyzed exhaustively for every possible serious accident sequence, and operating experience is still too limited for all the potential problems to have been identified. Accidents at Three Mile Island and at the Browns Ferry reactor involved sequences of events that were not understood clearly enough until they occurred. if they had been, both could have been prevented easily. As the **NRC** and the industry recognize different accident sequences, backfits are needed to prevent future occurrences. Proposals to reduce NRC's ability to impose changes in accordance with its engineering judgment will be seen by safety regulators as hampering their mission of ensuring safety.
- But there is a third side to this coin. Not only do the industry and NRC see regulatory reform very differently, but **critics** of nuclear power find much to fault with both the utilities and the NRC. In particular, they feel that the NRC does not even enforce its present rules fully when such enforcement would be too costly to the industry. Furthermore, they believe that the technology has so many uncertainties that much greater margins of safety are warranted. Thus, nuclear critics strenuously oppose any changes in the NRC regulations that might limit their access to the regulatory process or constrain the implementation of potential improvements in reactor safety.
- The **public** is yet a fourth side. Public opinion polls show a long-term trend against nuclear power. The public demands that nuclear reactors pose no significant risks, is frustrated by the confusing controversy surrounding them, and is growing increasingly skeptical about any benefits from nuclear power. These conditions do not give rise to a clear mandate for regulatory reform in order to facilitate more reactor orders. Such a mandate will depend largely on improved public confidence in the management ability of utilities and their contractors, in the safety of the technology, in the effectiveness of the regulatory process, and on a perception that nuclear energy offers real benefits.
- The **nuclear supply industry's** interests are not synonymous with the utilities' and thus represent a fifth side of the coin. The utilities need to meet demand with whatever option appears least expensive. If that option is not nuclear power, something else will suffice. The supply industry, however, has a large vested interest in promoting nuclear reactors, and the careers of thousands of industry employees may hinge on policy changes to revitalize the nuclear option, including regulatory reform.
- **Investors** may be ambivalent about licensing reform. Lengthy and uncertain licensing makes nuclear power a riskier investment during construction, but any accident during operation can have the same, if not greater, effect. Insofar as more stringent licensing makes accidents less likely, it reduces the financial risk. However, investors probably will be more concerned with the near-term risks involved in getting a plant online and would be more supportive of streamlined licensing if it reduced those risks.
- As representatives of consumers' economic interest, **public utility commissions'** share

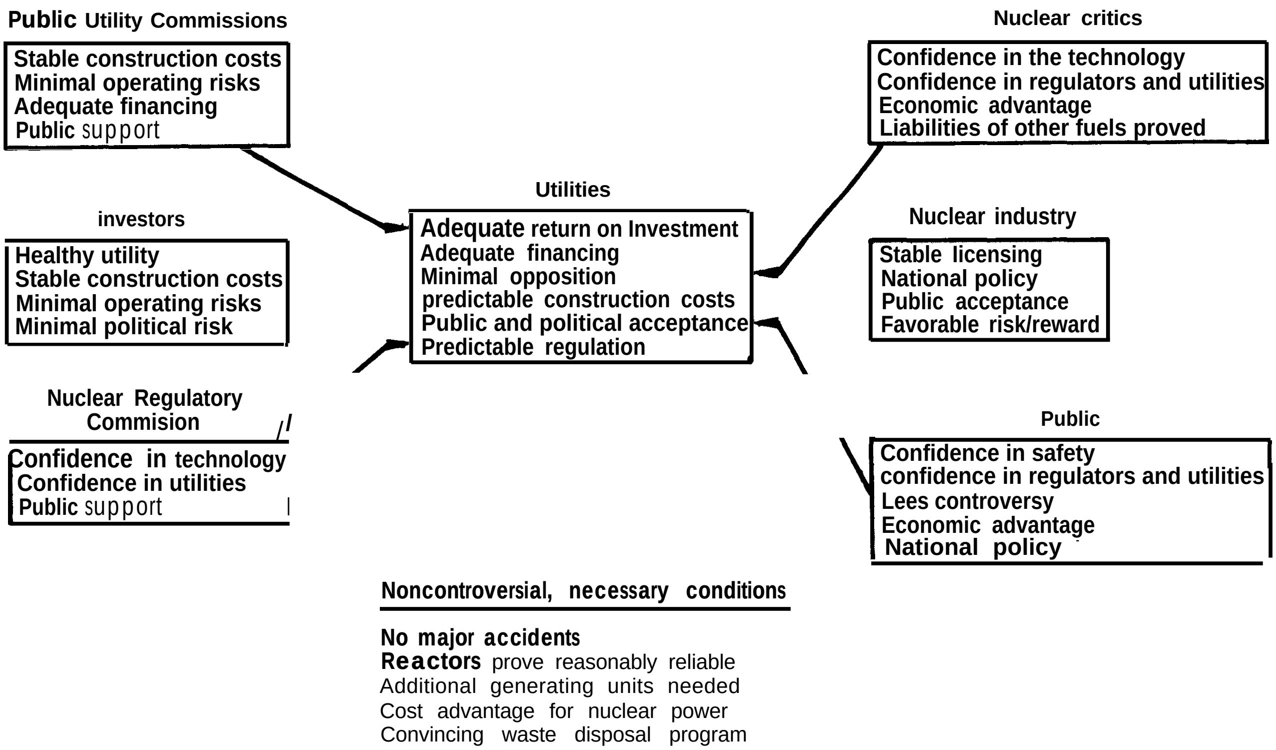
the investors' ambivalence, but they might give more weight to operating safety because an accident that shuts down a reactor for a prolonged period usually will mean the substitution of more expensive sources of electricity.

Thus, there are at least seven different parties in each policy debate on nuclear power: seven sides to the coin of each issue. No doubt others could be added, but those described above represent the major positions. Each party is a collection of somewhat differing interests, and each will look for different things in any policy initiative. Given such a multiplicity of interests, it is not surprising that the present impasse has developed.

Figure 1 illustrates these concepts. Utilities are at the center because they make the ultimate decision about whether to order a nuclear plant or something else. The other parties have considerable, sometimes decisive, influence over whether a nuclear plant will be built, how much it will cost, and how well it will work. Each of these parties has its own agenda of conditions that must be met before it would support a decision by a utility to order a reactor. These conditions are listed with each party. Those conditions that are common to all are listed at the bottom of the figure. For instance, nuclear power must be very safe, with a very low risk of core meltdowns or major releases of radioactivity. Disputes over this point relate to the degree of safety required, the adequacy of the methodology in determining safety, the assumptions of the analyses, and the actual degree of compliance with regulations. in any case, however, existing reactors must be demonstrably safe, and future reactors probably will be held to even higher standards.

A closely related issue is reliability. A smoothly operating reactor is more productive for its owners, and it also is likely to be safer than one that frequently suffers mishaps, even if those mishaps

Figure A.—The Seven Sides to the Nuclear Debate



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have no immediate safety consequences. Thus, it also will be considerably more reassuring to the public.

Other common criteria are that there must be a clear need for new generating capacity and a significant cost advantage for nuclear power. In addition, a credible waste disposal program is a prerequisite for any more orders.

Other conditions are especially important to some groups but less important to others. Some of these conditions already are met to some degree. The arrows in figure A drawn to the conditions under utilities indicate the major areas that are related to the other parties.

Many of the conditions in figure 1 are **necessary** before enough of the participants in the debate will be satisfied that nuclear power is a viable energy source for the future. It is much more difficult to know how many must be met to be **sufficient.** All the groups discussed above have considerable influence over the future of nuclear power. Efforts to revive the option—whether initiated legislatively, administratively, or by industry—are unlikely to be successful if some of the interests find them unacceptable. The task of breaking the impasse therefore is formidable.

THE PURPOSE OF THIS STUDY

This report responds to requests from the House Committee on Science and Technology and the Senate Committee on Energy and Natural Resources asking OTA to "assess how nuclear technology could evolve if the option is to be made more attractive to all the parties of concern" and to identify possible technical and institutional approaches for the Congress "that could contribute to the maintenance of this important industry." The report describes the major impediments to nuclear power relative to other types of generating capacity, identifies options that might be considered to remove those impediments in light of the problems and conflicts discussed above, and explores the consequences of not maintaining the nuclear option.

Changes could be made in the technology and in the institutions that manage it. If a reactor were to be developed that physically could not suffer a major accident or pose health and safety risks for the public, it might allay some of the concerns of the regulators, the interveners, and the public. Such a reactor might not require the ever more stringent standards of quality required for current light water reactors (LWRs), thus reducing the economic risks. Improvements also could be considered in management of the construction, operation, and regulation of reactors. If all reactors were to match the experiences of the best managed plants, there would be much less concern over the future prospects for the nuclear option.

It is the intent of this study to explore these possibilities in the light of the different interests and different concerns discussed above. The report details the various difficulties facing the future of nuclear power and the measures that would be useful and practical in overcoming these difficulties if the Nation wishes nuclear power to once again be a well accepted, viable energy option. The technological options are restricted to converter reactors similar to those now available on the international market. These are the reactors that could be deployed in the United States by the end of the century. Breeder reactors are not included because their development program will not make them commercially available until sometime in the next century. The other elements of the fuel cycle—uranium resources and enrichment, reprocessing and waste disposal–are not included either. Waste has been considered in great detail in a recent OTA report. The other elements need not pose constraints to reactor orders, which is the key issue addressed in this report.

This assessment was carried out with the assistance of a large number of experts from all sides of the nuclear debate—utilities, nuclear critics,

reactor vendors, consumer groups, NRC, academics, State PUCs, nuclear insurers, executive branch agencies, the financial community, architect-engineering (AE) **firms, and interested members** of the public, As in all OTA studies, an advisory panel representing most of these interests met periodically during the course of the assessment to review and critique interim products and this report. Contractors supplied analyses and background papers in support of the assessment (these are compiled in vol. **II).** In addition, OTA held three workshops to review and expand on the contractors' reports and to ensure that all the relevant interests on each issue would be considered. The first workshop examined the energy and economic context for nuclear power, including projections of electricity demand, capital costs for powerplant construction, and the financing and rate regulation of electricity generation. The second workshop focused on the technological, managerial, and regulatory context for nuclear power, identifying the problems with current LWRs and the licensing process for them, and assessing alternative reactor technologies and proposals for licensing revision. The third workshop examined institutional changes, public acceptance, and policy options for revitalizing nuclear power. Based on these and other discussions, the OTA staff developed a set of policy options. Advisory panel members, contractors, and workshop participants are listed at the front of the report.

The nuclear debate long has been characterized by inflexible, polarized positions. We see some evidence that this polarization is softening For the most part, the OTA workshop participants and advisory panel members showed a willingness to compromise, including admissions by industry representatives that many mistakes had been made, and by nuclear critics that nuclear power could be a viable source of electricity if managed properly.

Volume I of this report is organized as follows:

- Chapter 2 presents a summary of the report.
- *Chapter 3* sets the context for decisions on the future role of nuclear power–factors affecting electricity demand, financial considerations including rate regulation and the costs of nuclear plants, and other elements in utility planning.
- *Chapter* 4 considers the technological alternatives to today's light water reactor: improved LWRs; the high-temperature gas reactor as evolving from the demonstration plant at Fort St. Vrain, Colo.; the heavy water reactor as developed in Canada; the PIUS concept—an LWR redesigned to make catastrophic accidents essentially impossible; the effects of standardization and sealing down reactor size.
- *Chapter 5* examines the human element in building and operating reactors and ways to improve the quality of these efforts; it analyzes the wide range of experiences in construction costs and schedules and in reactor operation, new measures that may improve quality control (e.g., the Institute for Nuclear Power Operations), and further steps that could be implemented if existing efforts prove inadequate.
- *Chapter* 6 describes the present regulatory process and the various concerns with it, and evaluates the major proposals for revision.
- *Chapter 7* reviews the long term viability of the nuclear industry if no new orders are forthcoming to see if the option would be foreclosed without stimulation, and how the operation of existing reactors would be affected; and examines the management of nuclear power in other countries to see what lessons can be learned from alternative approaches.
- *Chapter* 8 focuses on trends and influential factors in public acceptance as one of the key elements in a revival of nuclear power, and evaluates measures designed to improve public acceptance.
- *Chapter* 9 analyzes a series of policy options that Congress might consider. Depending on one's views of the desirability of and necessity for nuclear power, a policy maker might see little need to do anything, want to improve the operation of existing reactors, or make the option more attractive so that it can play an expanded role in the Nation's energy future. The options are analyzed for effec-

tiveness and for acceptability by the various parties to the debate. Packages of options are considered to see if compromises might be possible.

Volume II of the report, which includes contractor reports and background papers prepared in support of the assessment, will be available through the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Chapter 2

Summary

Photo *credit: Department of Energy*

Oconee nuclear units owned by Duke Power Co.

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Chapter 2
Summary

THE UNCERTAIN FINANCIAL AND ECONOMIC FUTURE

Future orders for nuclear plants depend in part on electricity demand and on the financial comparisons that utilities will make with alternatives to nuclear power. Utilities ordered far more generating capacity in the early 1970's than they turned out to need, and have canceled many of their planned plants. Nuclear plants have borne the brunt of the slowdown in construction.

There has been a pronounced decline in the growth rate of electricity demand. Demand growth has averaged about 2.5 percent annually since 1973, compared to about 7.0 percent from 1960 to 1972. Utility executives contemplating the construction of long leadtime coal or nuclear powerplants must contend with considerable uncertainty about the probable future growth rates in electricity demand. With certain assumptions about the future, it is reasonable to expect fairly slow growth rates of 1 to 2 percent per year. Very few large new powerplants would be required to meet this demand. With other plausible assumptions, electricity load growth could resume at rates of 3 to 4 percent per year, which would require the construction of several hundred gigawatts* of new powerplants by the year 2000. The actual need for new powerplants will depend on the growth rate of the economy, the rate of increase in the efficiency of use of electricity, price increases for electricity vis a vis other energy sources, new uses for electricity, and the rate of retirement of existing plants. None of these variables can be predicted with certainty. The effects of the electric growth rate and the replacement rate on the capacity that would have to be ordered in time to be completed by 2000 are shown in table 1.

Table 1.–Additional Capacity Required by 2000 (gigawatts)

Levels of replacement of existing plants	Electricity demand growth 1.5%/yr	2.5%/yr	3.5%/yr
Low: 50 GW to replace all plants over 50 years old	9	144	303
Moderate: 125 GW to replace all plants over 40 years old, plus 20 GW of oil and gas capacity	84	219	379
High: 200 GW to replace all plants over 40 years plus two thirds of the oil and gas capacity	159	294	454

NOTES: 1. Planned generating capacity for 1991 is 740 GW, 158 GW more than 1982 generating sources of 582 GW. Starting point for demand calculations Is 1982 summer peak demand of 428 GW.
2. The calculations assume a 20-percent reserve margin, excess of planned generating resources over peak demand.

SOURCE Office of Technology Assessment

in addition to the slowdown in electric load growth, powerplants have also been canceled and deferred due to deterioration in the financial condition of utilities. Although the industry's financial picture is improving as external financing needs decline and allowed rates of return increase, current rate structures still may not provide adequate returns for new investment in large nuclear projects. **Without changes in rate regulation, utilities may not be able to attract capital when they need it for construction, because investment advisers associate construction with a deterioration in financial health.**

The primary targets for rate reform include the current lag between allowed and earned rates of return, the "rate shock" which results in the first few years after a large, capital-intensive plant is added to the rate base, and the absence of explicit incentives to reduce fuel costs. Options for resolving these problems assume that the investors and State public utility commissions will take a long-term perspective and will maintain a particular method of determining revenue requirements for several decades. Yet when commissioners may only remain in office for a few years, or when State legislatures adopt a short-term perspective, methods that take a long-term view of rate regulation are difficult to achieve.

*One gigawatt equals 1000 MW (1 ,000,000 kW) or slightly less than the typical large nuclear powerplant of 1100 to 1300 MW.

Although ratemaking changes to increase the attractiveness of capital investment would eliminate some disincentives, utilities and their investors and ratepayers would still face substantial financial risks from nuclear power. These risks include the unpredictability of the capital costs of a nuclear plant at the beginning of construction, the difficulty of predicting construction leadtimes, the very high costs of cleanup and replacement power in the event of a major accident, and the possibility of future regulatory changes.

Nuclear plant average construction costs more than doubled in constant dollars during the **1970's** and are expected to increase by another 80 percent for plants now under construction. Some of this increase has come from new regulatory requirements which are applied to all plants, whether operating or under construction. Some utilities, however, have adapted better to these new regulatory conditions, as shown by the increasing variability in capital costs. Of the group of plants now under construction, the most expensive is expected to cost more than four times the least expensive. The variation in cost has been due in part to regional differences in the cost of labor and materials and the weather, **but more to differences in the experience and ability of utility and construction managers. Only the best**

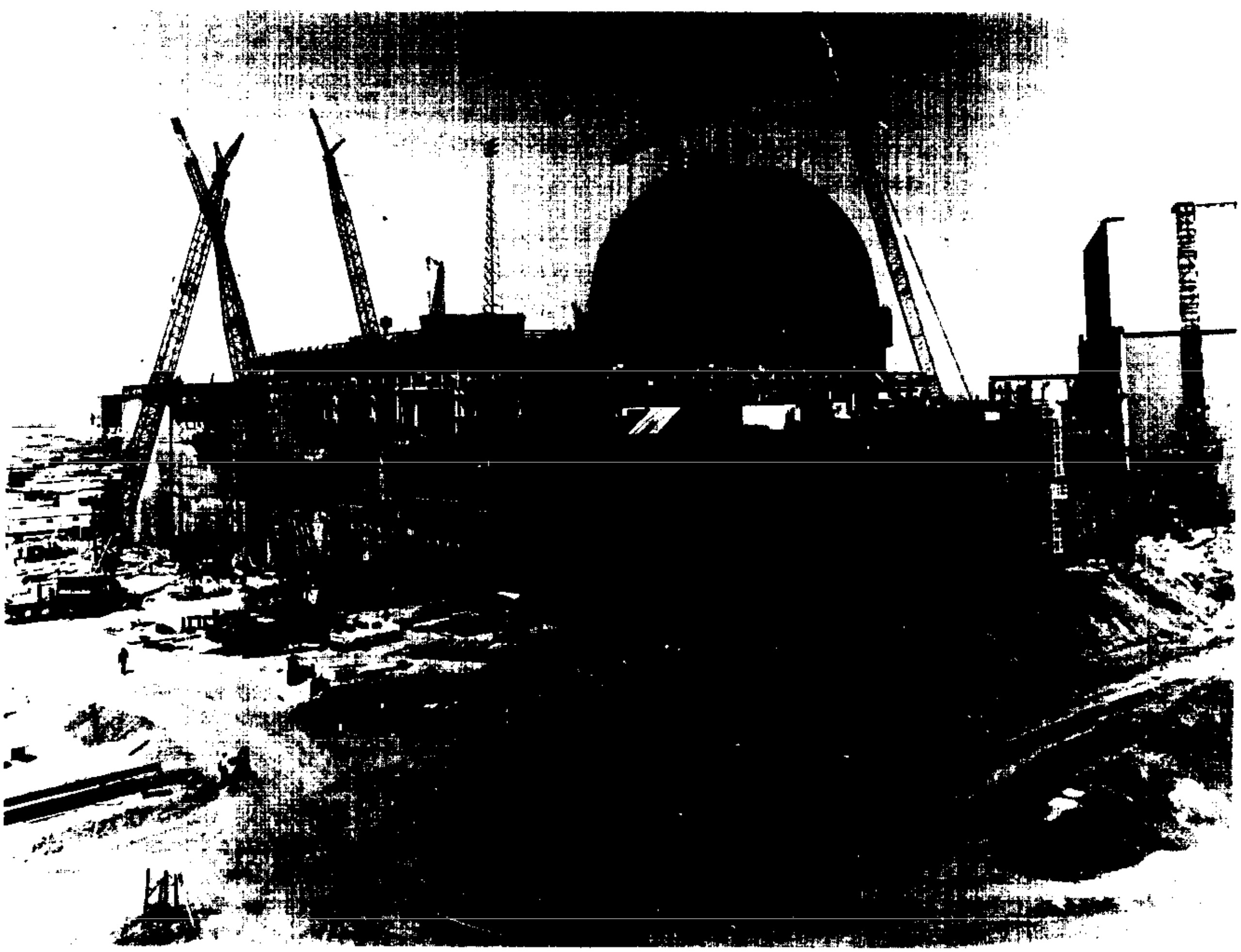


Photo credit: United Engineers & Constructors

Managing a multibillion dollar nuclear construction project is difficult, complex, and subject to uncertainty. The most expensive nuclear plant under construction is estimated to cost about four times the least expensive (per unit of generating capacity)

managed construction projects are now competitive with new coal plants.

Average nuclear plant construction leadtimes doubled over the decade (from about 60 to about 120 months) and are now about 40 percent longer than coal plant leadtimes. Very long leadtimes increase interest costs and the difficulty of matching capacity with demand. **Average plant construction costs and leadtimes could be reduced in the future in several ways:** 1) Plants could be built only by experienced and competent utilities and contractors, who would work under contracts with incentives to control costs and use innovative construction techniques. 2) Standardization of design and licensing could bring the lowest U.S. construction costs down by another 20 to 25 percent. 3) Further reductions in plant carrying costs could come about if leadtimes were cut by 25 to 30 percent and interest rates were reduced. It should also be recognized, however, that there are circumstances under which costs might increase. In particular, further serious accidents or resolution of important safety issues could lead to a new round of costly changes.

Utility executives are also aware that single events could occur causing the loss of the entire value of a nuclear plant. The accident at Three Mile island will have cost the owner $1 billion in cleanup costs alone, plus the cost of replacement power, the carrying costs and amortization of the original capital used to build the plant, and the cost of restarting the plant (if possible). Only $300 million of the cleanup cost was covered by property insurance. Nuclear plants can also be closed by referenda such as the narrowly defeated vote in 1982 that would have closed Maine Yankee.

Utility executives have other options to meet future load growth than constructing new generating plants including: converting oil or gas plants to coal, building transmission lines to facilitate purchase of bulk power, developing small hydro, wind or cogeneration sources, or load management and energy conservation programs. Some of these alternatives may prove more attractive to utilities than nuclear plants given the uncertain demand and financial situation. Even if rate regulatory policies across the country were to shift to favoring longer leadtime capital-intensive technologies, smaller coal-fired powerplants would be preferred because they have shorter leadtimes, lower financial risk, and greater public acceptance than current nuclear designs.

NUCLEAR REACTOR TECHNOLOGY

Virtually all nuclear powerplants in this country and most in other countries are light water reactors (LWRs). This concept was developed for the nuclear-powered submarine program, and was adapted to electric utility needs. Since then, many questions have been raised over the safety and reliability of LWRs in utility service, costs have risen dramatically and regulatory requirements have proliferated. There is no specific indication that LWRs cannot operate safely for their expected lifetimes, but it appears that current LWR designs are unlikely to be viable choices in the future unless concerns over costs, regulatory uncertainties and safety can be alleviated. Either LWR designs will have to be upgraded, or alternative reactor concepts will have to be considered.

There is no standardized LWR design in the United States. This is due to two major factors. First, the different combinations of vendors, architect-engineers (AEs), constructors, and utilities produced custom-built plants for each site. In addition, the reactor designs themselves have changed greatly since introduction of LWR technology. The pace of development from prototype to nearly 100 commercial reactors was very rapid. Large, new reactors were designed and construction started prior to significant operating experience of their predecessors. As hardware problems developed or new safety issues surfaced, changes had to be made *to existing reactors*, rather than integrating them into new designs, As regulatory agencies improved their understanding of nuclear power safety, criteria changed, and many features had to be mandated as retrofits. Thus the light water reactors under construction and in operation today do not represent an optimized LWR design.

Utilities' experience with the LWR range from excellent to poor. Some reactors have operated at up to an 80-percent capacity factor for years with no significant problems, while others have been plagued with continual hardware problems that lead to low-capacity utilization. While the safety record to date is very good, the accident at Three Mile Island (TMI) and other potentially severe incidents raise concerns about the ability of all utilities to maintain that record.

Many of the concerns over safety and reliability have been fueled by the seemingly constant stream of hardware problems and backfits associated with LWRs. Many of those in the nuclear industry feel that such problems reflect normal progress along the learning curve of a very complex technology, and they assert that the reactors are nearing a plateau on that curve. Nuclear critics observe that there are still many unresolved safety issues associated with LWRs, and the technology must continue to change until these are addressed adequately.

The design and operation of LWRs has unquestionably improved over time. The training of operators has been upgraded, human factors considerations have been incorporated into control room design, information on operating experience is shared, and numerous retrofits have been made to existing reactors.

Whether these steps have made LWRs safe enough cannot be demonstrated unambiguously, however. There is no consensus on how to determine the present level of safety, nor on the magnitude of risk represented by particular problems or the cost-benefit criteria for assessing possible solutions. In some cases, retrofits in one area can possibly reduce safety in other areas, either because of unanticipated system interactions, or simply because the additional hardware makes it difficult to get into part of the plant for maintenance or repairs. Even if all the parties to the debate could agree that the risks are acceptably small, the public still might not perceive nuclear power as safe.

It is clear that, before they order new nuclear plants, utilities will want assurances that the plants will operate reliably and will not require expensive retrofits or repairs due to unanticipated design problems or new Nuclear Regulatory Commission (NRC) regulations which may be needed to solve such problems, and that they will not run an unacceptable risk of a TMI-type accident that could bankrupt them.

Many of the nuclear industry's concerns about the current generation of LWRs are being addressed in designs for advanced reactors. An advanced pressurized water reactor is being designed to be safer and easier to operate than the present generation, and to have improved fuel burnup and higher availability (90 percent is the goal) through resolution of some of the more critical hardware problems. An advanced boiling water reactor is being designed to operate at a relatively high capacity factor and to incorporate advanced safety features that will reduce the risk of core-melting even if the primary cooling system fails.

If the utilities and the public cannot be convinced that new LWRs would be acceptably safe and reliable, however, renewed interest may develop in using alternative reactor technologies. Among the more promising near-term possibilities are high temperature gas-cooled reactors, LWRs with inherently safe features, and the heavy water reactor.

The high temperature gas-cooled reactor (HTGR) has attracted considerable interest because of its high thermal efficiency (nearly 40 percent—compared to 33 percent for an LWR) and its inherent safety features. The core of the HTGR is slow to heat up even if coolant flow is interrupted; this reduces the urgency of the actions that must be taken to respond to an accident. In addition, the entire core and the primary cooling loops are enclosed by a vessel which would prevent the release of radioactive materials even after an accident. Lessons learned on the only U.S. operating HTGR are being applied to the design of a 900-megawatt (MW) prototype. Small, modular versions (fig. 1) also have been proposed that might have very attractive safety characteristics and be especially suitable as a

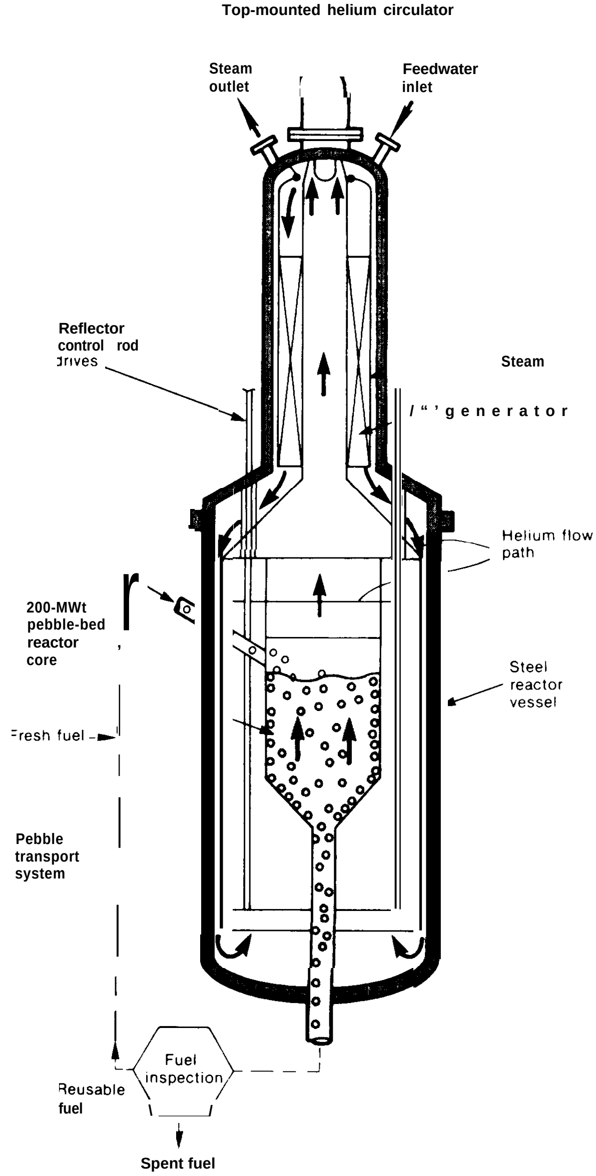
Photo credit: Gas-cooled Reactor Associates (GCRA)

The fuel in a high temperature gas-cooled reactor is inserted into graphite blocks like the one shown above. The fuel form is one of the key features of the HTGR, since graphite can absorb a great deal of heat before melting

source of process heat. While HTGRs appear to be potentially safer than LWRs, there are still many questions concerning HTGR reliability and economics. **Continued research and development (R&D) of the HTGR is necessary if these questions are to be resolved.**

The heavy water reactor (HWR) has attractive safety and reliability features, but there are several roadblocks to its adoption in this country. The HWR has performed well in Canada, but the process of adapting it to the American environment might introduce modifications which would lower its performance. In addition, much of its good performance may be the result of skillful management and not a consequence of the reactor design. Without significant evidence that the reactor is inherently superior to other options, the HWR is not a strong candidate for the U.S.

Figure 1.—Conceptual Design of a Modular, Pebble-Bed HTGR



SOURCE: Office of Technology Assessment.

market, unless the Canadian technology can be easily adapted, or the U.S. experience with HWRs in the weapons program can be utilized.

The process inherent ultimately safe (PIUS) reactor, a new LWR concept being developed in Sweden, is designed with safety as the primary objective. protective against large releases of radioactivity would be provided by passive means that are independent of operator intervention and mechanical or electrical components. Because the PIUS is designed so that a meltdown is virtually impossible, it might be the reactor most suited to restoring public confidence in nuclear power. The PIUS reactor is still in the initial design phase, however, and has not yet been tested, although computer simulations have been initiated to address questions about operational stability. Extensive R&D is needed to narrow the uncertainties about cost, operation, and maintenance. This R&D and eventual deployment of the PIUS, would be expedited by its similarity, in some respects, to conventional LWRs.

Features that might be applied to any reactor technology include smaller sizes and standardized designs. **Smaller nuclear plants would provide greater flexibility in utility planning—especially in times of uncertain demand growth —and less extreme economic consequences from an unscheduled outage.** The shorter construction periods and lower interest costs during construction would reduce the utilities' financial exposure. The ability to build more of the subsystems in the factory rather than onsite might reduce some construction costs, offsetting the lost economies of scale. Moreover, smaller reactors **might** be easier to understand, more manageable to construct, and safer to operate. Federal R&D would probably be required to achieve designs that exploit the favorable characteristics of small reactors.

The potential benefit of a standardized design appears to be especially high in view of the problems of today's nuclear industry. **Many of the problems with construction and operation stem from mismanagement and inexperience, and a standardized plant would help all utilities learn from those who have been successful.** France and Canada seem to have done well with building many plants of one basic design. Still, the implementation of standardized plants in the United States faces many obstacles. Reactor system designs differ from vendor to vendor and grow further apart when coupled with the different balance of plant designs supplied by the numerous AEs. They are additionally modified by the requirements of NRC, the utilities, and the specific sites. **Despite these obstacles, the industry may be motivated to converge on one or two standardized designs if that path seemed to offer streamlined licensing, stabilized regulation, faster construction, and better management.** The help of the Federal Government may be required to develop and approve of a common design, especially if it is significantly different from the LWR.

MANAGEMENT OF NUCLEAR POWERPLANTS

The management of commercial nuclear powerplants has proven to be a more difficult task than originally anticipated by the early proponents of nuclear technology. While the overall safety record of U.S. plants is very good, there has been great variability in construction times and capacity factors (see table 2). Some utilities have demonstrated that nuclear power can be well managed, but many utilities have encountered difficulties, Some of these problems have been serious enough to have safety and financial implications. **Since the entire industry is often judged by the worst cases, it is important that all nuclear utilities be able to demonstrate the capability to manage their powerplants safely and reliably.**

There are many special problems associated with managing a nuclear powerplant. Nuclear reactors are typically half again as large and considerably more complex than coal plants. **The job of building and operating a nuclear powerplant has been further complicated by the rapid pace of development.** As new lessons were learned from the maturing technology, they had to be incorporated as retrofits rather than integrated into the original design. The regulatory structure was evolving along with the plants, and the additional engineering associated with changing NRC regulations and with retrofits strained the already scarce resources of many utilities. Some utilities have also had difficulty coordinating the various participants in a construction project.

Table 2.—Comparison of Construction and Reliability Records for Selected U.S. Light Water Reactors

Construction[a]	Date of commercial operation	Years to construct	Reliability[b]	Date of commercial operation	Lifetime capacity factor (%)
Best:			**Best:**		
St. Lucie 2	1983	6	Point Beach 2	1972	79
Hatch 2	1979	7	Connecticut Yankee	1968	76
Arkansas Nuclear One 2	1980	7	Kewaunee	1974	76
Perry 1	1985	8	Prairie Island 2	1974	76
Palo Verde 1	1984	8	Calvert Cliffs 2	1977	75
Byron 1	1984	8	St. Lucie 1	1976	74
Callaway 1	1984	8			
Worst:			Worst:		
Watts Bar 1	1984	12	Brunswick 1	1977	48
Sequoyah 2	1982	12	Indian Point 3	1976	46
Midland 1	1985	13	Salem 1	1976	46
Zimmer 1	1985	13	Brunswick 2	1975	41
Salem 2	1981	13	Davis Besse 1	1977	40
Diablo Canyon 2	1984	14	Palisades	1971	39
Diablo Canyon 1	1984	16	Beaver Valley 1	1977	34

[a]Includes only plants licensed t. operate after the accident at Three Mile Island in March of 1979
[b]Includes only plants greater than 100 MWe in operation for longer than 3 years.

SOURCE *Nuclear* News, February 1983 and U S Nuclear Regulatory Commission

Both technical and institutional changes are needed to improve the management of the nuclear enterprise. Technical modifications would be useful insofar as they reduce the complexity and sophistication of nuclear plants and their sensitivity to system interactions and human error. More substantial design changes, such as the **PIUS reactor concept, might be considered as an option** since they have the potential to additionally decrease the sensitivity of nuclear plants to variations in management ability.

Technological changes, by themselves, however, cannot eliminate all the difficulties involved in building and operating nuclear units since they cannot replace commitment to quality and safety. It **is important that design changes be supplemented with institutional measures to improve the management of the nuclear enterprise.** One example is the Institute of Nuclear Power Operations **(INPO),** * which is attempting to improve the quality of nuclear powerplant operation, and to enhance communication among the various segments of the industry.

*The Institute for Nuclear Power Operations is a self-regulatory nonprofit organization organized by the electric utilities to establish industrywide standards for the operation of nuclear powerplants, including personnel and training standards, and to ensure that utilities meet those standards.

The most important improvement required is in the internal management of nuclear utilities. **Top utility executives must become aware of the unique demands of nuclear technology. They not only must develop the commitment and skills to meet those demands, but they must become directly involved in their nuclear projects and they must impress on their project managers and contractors a commitment to safety that goes beyond the need to meet regulatory requirements. They also need to establish clear lines of authority and specific responsibilities to ensure that their objectives will be met. INPO** could be instrumental in stimulating an awareness of the unique management needs of nuclear power and in providing guidance to the utilities.

It **is also important that utilities be evaluated objectively to assure that they are performing well.** Both NRC and INPO have recognized the **need** for such evaluations, and currently are engaged in assessment activities. INPO attempts to assess the performance of utility management in order to identify the root causes of the problems as well as their consequences. The **NRC** conducts several inspection programs with the purpose of identifying severe or recurrent deficiencies. NRC's program is more fragmented than INPO's,

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and the relationships among its various inspection activities appear to be uncoordinated.

Enforcement activities also can be important in encouraging better management. Both NRC and INPO can take actions to encourage utilities to make changes or penalize them if their performance is below standard. If measures taken by NRC and INPO prove to be ineffective in promoting quality construction and safe operation of nuclear powerplants, however, more aggressive action might be required. A future for nuclear power could depend on institutional changes that demonstrate the ability of **all** utilities with nuclear powerplants to operate them safely and reliably. It is not yet clear whether these efforts will prove adequate.

Another approach might be for the NRC to require that a utility be certified as to its fitness to build and operate nuclear powerplants. Certification could force the poor performers to either improve their management capabilities, obtain the expertise from outside, or choose other types of generating capacity.

Many of the current management problems can also be traced to the overlapping and conflicting authority of the the utility, the reactor vendor, the AE, and the constructor. Centralized responsibility for overall design and, in some cases, actual construction could alleviate this problem. Increased vendor responsibility might encourage fixed-price contracts for nuclear plants, but it could detract from utilities' ability to manage the plant if they are not involved actively in all stages of construction.

A second means of centralizing responsibility is through nuclear service companies, which already offer a broad range of regulatory, engineering, and other services to utilities. **Nuclear service companies could help strengthen the capabilities of the weaker utilities by providing all the services needed to build and/or operate a nuclear plant.** However, utilities may be reluctant to forego their responsibility for safety and quality while retaining financial liability. Also, without some mechanism that required weaker utilities to hire service companies, their existence might have little effect on the overall quality of nuclear management.

Privately owned regional or national nuclear power companies would extend the service company concept into the actual ownership of nuclear powerplants. Such companies could be owned by a consortium of utilities, vendors, AEs, and/or constructors and would be created expressly to build and operate nuclear powerplants.

REGULATORY CONSIDERATIONS

Nuclear power is one of the most intensively regulated industries in the United States, and the scope and practice of regulation is a volatile issue, Strong—and usually conflicting—opinions abound among the actors in the nuclear debate on the adequacy and efficiency of the current regulatory system.

The utilities and the nuclear industry have been outspoken critics of the current system of nuclear plant regulation, claiming that neither the criteria nor the schedules for siting, designing, building, and operating nuclear plants are predictable under the current licensing scheme. They argue that public participation has been misused to prolong licensing hearings unnecessarily. They believe that these factors have been the primary cause of higher costs and longer construction leadtimes and may have been detrimental to safety.

Nuclear critics, on the other hand, have been less critical of Federal regulation of nuclear powerplants than of the industry that designs, constructs, and operates them. They argue that the lack of predictability and the increase in leadtimes were due to the immaturity of the technology and growing pains due to rapid escalation. They attribute many safety concerns to utility and constructor inattention to quality assurance, and inconsistent interpretation and enforcement of regulations within the NRC. While some critics feel that nuclear plants will never be safe enough, others believe that the current regulatory process could ensure safety if it were interpreted consistently and enforced adequately, but that limiting the opportunities for interested members of the public to participate in licensing will detract from safety.

As a result of these concerns, a number of modifications in reactor regulation have been proposed, either through legislation, rulemaking, or better management of the regulatory process. The primary targets of the various packages are backfitting, the hearing process, siting, and the licensing of designs and plants. **The evaluation of proposals for regulatory revision must depend first on whether they will ensure adequate protection of public health and safety and national security, and only secondarily on additional benefits, such as reducing the cost of nuclear plants. It is also important to recognize that licensing changes alone cannot resolve the problems of the nuclear industry. All parties to nuclear regulation must commit themselves to excellence in the management of licensing, construction, and operation, as well as to resolving outstanding safety and reliability issues.**

Many nuclear utilities are adamant that they will not order another reactor until licensing is more predictable and consistent. These characteristics should also be welcomed by the critics since they are prerequisites for uniformly high safety standards. The primary source of current uncertainty is the potential for imposition of backfits. Backfits serve an important safety function, since unanticipated safety problems do arise after construction permits are granted. **But careful revision of the backfit rule could make the process more rational and ensure that plant safety is not inadvertently decreased by installation or maintenance problems or by unexpected interactions with other systems.** Proposed changes to the backfit rule focus on making the criteria for ordering backfits more explicit, such as the use of cost-benefit analysis. **While a cost-benefit approach would "improve" consistency, it should not be used as the sole criterion since the available methodologies are inadequate to fully quantify safety improvements.** A process to review proposed backfits could also involve a centralized group either within the NRC or as an independent panel drawn from utilities, the public, and the nuclear industry to ensure that criteria and standards are consistently applied.

Legislative amendment of the Atomic Energy Act is not necessary to reform the backfit regulations, since the changes discussed above can be accomplished through rulemaking. Moreover, legislative definitions and standards may actually reduce flexibility needed to adjust to changing construction and operating experience. Legislative action would be more likely, however, to ensure predictability.

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Another issue in regulatory reform is the use of formal trial-type hearings in reactor licensing. Because adjudicatory hearings can be long and costly, proposals have been made to replace them with hybrid hearings, which would be more restricted. A hybrid hearing format might be attractive to the owners of nuclear powerplants, but it might also limit the opportunities for public inquiry and foreclose debate on safety issues. **The hearings could be made more efficient without changing the format if they were managed better. They could also be improved by making greater use of rulemaking to resolve generic issues and by eliminating issues not germane to safety. Only the last of these changes would require legislative amendment of the Atomic Energy Act.**

It has also been suggested that construction permits and operating licenses in the current system be combined into a single step to improve predictability and efficiency. One-step licensing, however, raises questions on how to manage outstanding safety issues and backfits during construction without any guarantee that the licensing process would not be even lengthier and more uncertain.

Two other proposals for changes to the current regulatory system would allow for binding preapproval of reactor designs and sites. Proapproval of standardized plant designs could make the licensing process more predictable and efficient by removing most design questions from licensing. It also raises new issues, such as the degree of specificity required for proapproval and the conditions under which a utility and its contractors could deviate from a preapproved design. Proapproval of reactor sites is a less controversial proposal. **As long as safety issues related to the combination of a site and a proposed plant are considered in subsequent licensing process, binding site approval would not detract from plant safety.** Moreover, it would contribute to shorter construction leadtimes since it would take siting off the critical path for licensing. This procedure, which is followed in France, Great Britain, and Japan, could even enhance public participation by encouraging in-depth analysis at an earlier phase.

SURVIVAL OF THE NUCLEAR INDUSTRY IN THE UNITED STATES AND ABROAD

The bleak outlook for nuclear power, at least in the near future, raises concern about the long-term viability of the nuclear industry in the United States and its ability to compete internationally.

Reactor vendors may remain busy for many years by providing operating plant services and fuel loading. These companies are also expanding their scope and competing with the service contractors for jobs. **However, in the absence of at least a few new-plant orders each year, the vendors will not survive in their present form.**

The AEs will also have substantial work finishing construction on plants now in progress, installing retrofits and dealing with special problems such as replacement of steam generators. The AEs may find additional activity by “recommissioning,” or extending the useful life of older plants.

The companies that supply nuclear components may keep going by supplying parts for backfits and repairs, but their numbers are expected to shrink by two-thirds in the next 3 to 5 years. **Utilities will have increasing difficulty purchasing parts when needed and at expected costs.** The cessation of new-plant orders has already caused some shortages in parts and services needed by operating plants.

Shortages are also developing in some personnel areas. The industry has vacancies for health physicists and for reactor and radiation-protection engineers, but it has a surplus of design engineers. Enrollment for nuclear engineering degrees has declined since the mid-1970’s, and the graduate levels will barely be enough to fill the anticipated need for 6,000 engineers for operation of plants by 1991, even if enrollments drop no more. **With no fresh orders, the industry is not likely to attract the best students.**

The ability of the nuclear industry to respond to an influx of new orders depends on the length of time before those orders arrive. **If utilities request new powerplants within 5 years, the industry could supply them, although perhaps with delays of a year or so to restart design teams and manufacturing processes. If the hiatus in plant orders lasts 10 years, the recovery would be slow and not at all certain-especially if U.S. vendors have not been selling reactors abroad in that period. In that case, U.S. utilities may have to buy components, if not entire powerplants, from foreign suppliers.**

Many of the problems that have beset the U.S. nuclear industry have hampered the nuclear industries abroad, but with less severe impact in general. Worldwide forecasts of the future role of nuclear power have experienced the same boom and bust that they have in the United States. West Germany, France, Japan, and Canada all are intending to compete with the United States in what is expected to be a very competitive international market for nuclear plants.

In most nations with nuclear power programs, the public has expressed some opposition. In several cases (e.g., Sweden), this has been strong enough to stop new plants from being ordered. All nuclear industries have experienced delays in building plants, but the costs have typically been lower. The licensing process in West Germany is as complex as that in the United States, but licensing in nations such as France is streamlined by strong government control and support and the use of standardized designs.

The efforts by the major reactor vendor in West Germany to standardize its plants might prove to be a useful model for the U.S. nuclear industry. The German vendor plans to produce a series of powerplants in groups of five or six whose standardized features will reduce delays, engineering workhours, and paperwork. Each series of standardized designs would build on the experience of the previous group of plants.

PUBLIC ATTITUDES ON NUCLEAR POWER

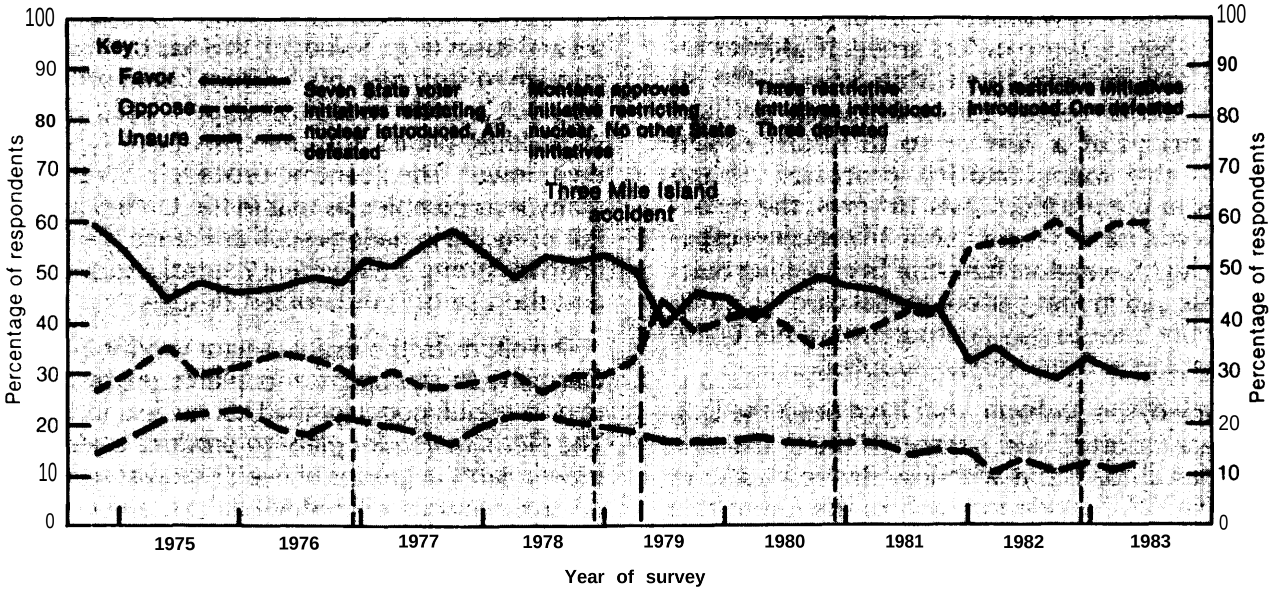
public attitudes towards nuclear power have become increasingly negative over the past decade, largely because of growing concern over safety and economics. The most recent polls indicate that only a third of the public supports construction of nuclear plants, while over so **percent are opposed (see fig. 2).**

Public support is an essential ingredient in any strategy for recovery of the nuclear power option. Negative public attitudes are most directly manifested through referenda. Although all binding referenda that would have shut existing plants have been rejected to date, some have been close. Referenda and legislation have been approved in 11 States that will prevent construction of any new nuclear plants unless prescribed conditions are met. Indirectly, public worry over nuclear risks has been a principal reason for NRC's imposition of safety backfits to existing reactors. State public utility commissions are unlikely to adopt rate structures favoring nuclear projects unless a majority of the public is in favor.

A central factor in public concern is the fear of a nuclear accident with severe consequences. Surveys indicate that most people view death due to a nuclear accident as no worse than other causes of death, but they fear nuclear plants because the technology is unfamiliar and foreboding. Much of the loss of public confidence is a result of a series of safety-related incidents at several reactors, especially the accident at TMI, and the evident mishandling of these incidents by utilities. **The likelihood of a catastrophic accident is perceived as greater than that estimated by safety analysts in industry and government, creating a credibility gap.**

Another factor in public concern about nuclear power is the ongoing debate about nuclear plant safety among scientists and other experts. As the public has listened to the experts debate, they have grown increasingly dubious about plant safety. If the experts cannot agree, the public concludes, then there must be a serious question about the safety of nuclear power.

Figure 2.—Trends in Public Opinion on Nuclear Power



Question asked" "Do you favor or oppose the construction of more nuclear powerplants?"

SOURCE: Cambridge Reports, Inc.

Concerns other than accidents have caused some people to turn away from nuclear power. Perhaps the largest concern after the possibility of an accident is the disposal of high-level wastes generated by nuclear reactors. In addition, the potential esthetic and environmental damage caused by nuclear plant construction also raises objections. Some groups see a link between the military and commercial applications of atomic power. Finally, distrust of large government and institutions has carried over, to some degree, to both the nuclear industry and NRC.

People are prepared to accept some risk if they see a compensating benefit. The high cost of some nuclear plants and current excess generating capacity, however, lead many to question if there is any advantage.

While media coverage of nuclear power has become more extensive in recent years, there is no evidence of overall bias against nuclear power. The spectrum of opinion among reporters is the same as that for the population as a whole. Their coverage is more likely to reflect than to determine society's concerns.

The credibility of both the industry and NRC is low, so words and studies alone will have little impact on the public. Steps to improve public attitudes towards nuclear power must rely on an actual demonstration of the safety, economics, and reliability of nuclear power. If the reactors currently under construction experience continued cost escalation, the next generation will have to be much more economic to gain public support. Alternative reactor concepts that have inherent safety features, and studies of other energy sources, including analysis of the environmental costs and benefits, also might help change public attitudes, though other concerns such as over waste disposal would still remain.

One of the most important steps in reducing public fears of a nuclear accident would be to improve utility management of the technology. Improved management could greatly reduce the likelihood of accidents which the public views as precursors to a catastrophe. **While making every effort to minimize both minor incidents and more serious accidents, however, the nuclear industry should be more open about the possibility of accidents.**

Improved communications with nuclear critics might also alleviate public concerns about reactor safety. A concerted effort to identify and respond to the substance of critic's concerns could reduce acrimonious debate which contributes to negative public opinion.

POLICY OPTIONS

Further orders for nuclear powerplants are unlikely without some government action and support. If Congress chooses to improve the chances of nuclear reactors being ordered in the future, Federal initiatives could be directed to the following goals:

- reduce capital costs and uncertainties,
- improve reactor operations and economics,
- reduce the risks of accidents that have public safety or utility financial impacts, and
- alleviate public concerns and reduce political risks.

These general goals are neither new nor as controversial as the specific steps designed to achieve the goals. The initiatives discussed in this report that-are likely to be the most effective are:

1. **Support a design effort to re-optimize reactor designs for safety, reliability, and overall economy.** This initiative would extend the efforts of the reactor vendors. Designs would incorporate the backfits that have occurred in existing plants and address the outstanding safety issues, thereby significantly reducing the possibility of costly changes during construction and the concern for safety in current LWRs. It would be expensive, however, especially if a demonstration plant is necessary.
2. **Improve the management of reactors under construction or in operation.** Inadequate management has been one of the major causes of construction cost overruns and erratic operation. Efforts are underway by the NRC and INPO to upgrade reactor management, and they should show results in improved training programs, better quality control and more reliable performance. The congressional role in improving reactor management would be oversight of the NRC, and support for improvements in analytical techniques and resolution of the remaining safety issues.

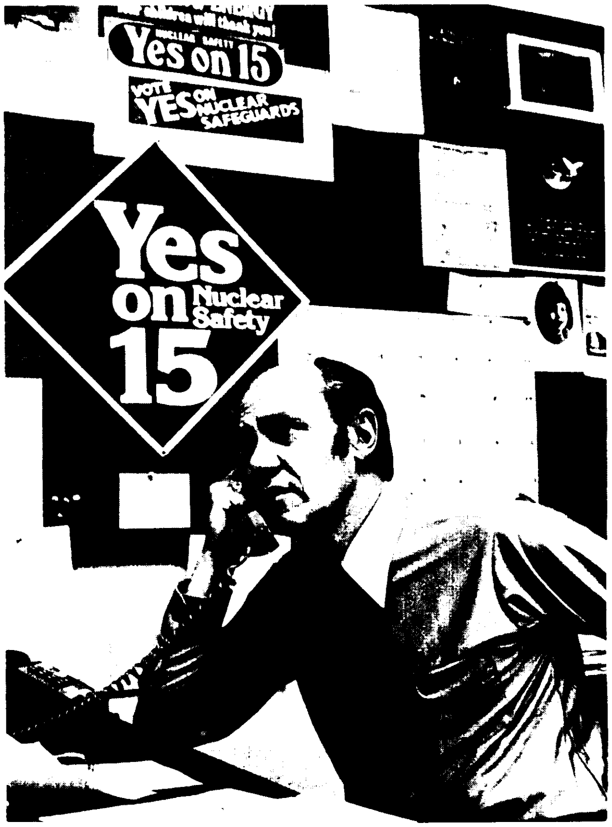


Photo credit: William J. Lanouette

This photo shows the campaign headquarters of the Project Survival Group which supported Proposition 15, a California referendum prohibiting further construction of nuclear plants without a definitive resolution of nuclear waste storage. The referendum was defeated in 1976, but a similar California law was recently upheld by the Supreme Court

3. **Revise the regulatory process.** Many of the difficulties experienced with licensing would be avoided with future plants through improved technology and management. Improving the predictability and efficiency of licensing is a prerequisite for any further orders, however. To a large extent this could be done administratively by the NRC without

legislation. Some of the elements such as consistent backfit evaluations and preapproval of reactor designs and sites discussed in the regulatory section above will probably require at least strong congressional oversight and possibly legislation. Legislation that makes the process inflexible or restricts public access could be counterproductive.

4. **Certify utilities and contractors.** If efforts to improve reactor management are only partially successful, stronger measures could be warranted. A poorly performing utility can affect the entire nuclear industry through the response of the public and the NRC to incidents with safety implications. The NRC might consider withdrawing the operating licenses of utilities that do not demonstrate competence or commitment in managing their nuclear plants. Evidence of capability of the utility and its contractors might be made a prerequisite for a new construction permit to alleviate concerns of the public, investors, and critics about the quality and cost of the plant.
5. **Support R&Don new reactors. Some new reactor concepts have features that, if proven out, could make them inherently safer than current operating plants, thus alleviating some of the concerns of the utilities and the public. If advanced LWRs do not appear adequate to overcome these concerns, then the availability of an alternative reactor,** such as the HTGR, would be important. Research, development, and demonstration of these technologies will be necessary to make them available.
6. **Address the concerns of the critics. Improved public acceptance is a prerequisite for any new orders. At present, the public is confused by the controversy over safety and is therefore opposed to accepting the risks of new reactors. The best way to reduce controversy would be to resolve some of the disagreements between the nuclear industry and its critics. This could be initiated by involving the critics more directly in the regulatory** process. Involving knowledgeable critics in regulation or in the design and analysis of new reactors may be the only way to assure the public that safety concerns are being addressed adequately.
7. **Control the rate of nuclear construction.** Many of the concerns over nuclear power originated from the early projections of rapid growth, and expectations of a pervasive "nuclear economy." The present modest projections appear less threatening, but some people will oppose all nuclear power as long as a major resurgence is possible. Controlling the growth rate might alleviate these concerns, thus reducing the controversy, rebuilding public acceptance, and making some new construction possible.

None of the options described above will be very effective by itself. Some could be very difficult to implement. It appears at least possible, however, that **combinations of these options could contribute to a much more favorable environment for nuclear power.**

Whether any of these strategies would "work" is a function of several factors including:

- the extent to which Federal policy strategies resolve the problems and make nuclear power more attractive,
- the electricity demand growth rate and the eventual need for new powerplants, and
- the improvement in designs and operations in the absence of policy initiatives.

The future of the nuclear industry will be shaped by the evolution of these factors. The degree to which the Federal Government should become involved (the first factor above) depends on an assessment of the uncertainties surrounding the other two factors. Under some conditions (e.g., relatively rapid growth in demand for electricity, reliable operation of existing plants and improved technology available) a revival is quite possible. Under other conditions, even a strongly supportive policy strategy could fail. Successful implementation of any strategy will depend on how well the concerns of all interested parties have been addressed.

Chapter 3

The Uncertain Financial and Economic Future

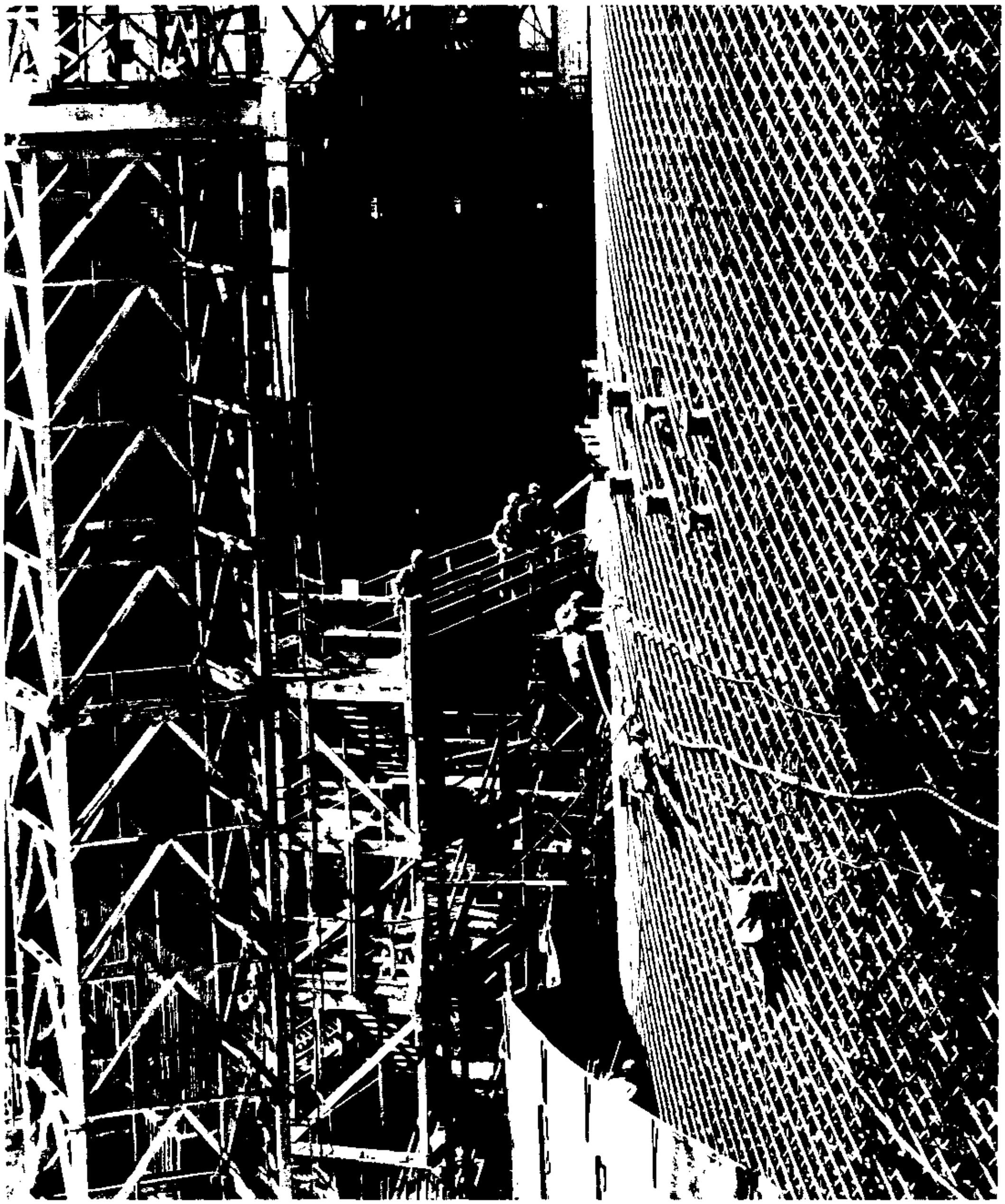


Photo credit: United Engineers & Constructors

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Chapter 3
The Uncertain Financial and Economic Future

If significant new electric-generating capacity **is** needed in the 1990's and beyond, and if nuclear power is to provide a major fraction of that capacity, utilities must order reactors some time before the end of the decade. Utility executives will compare the reliability, safety, and public acceptance of nuclear power (issues that are explored in other chapters in this report) relative to other types of generating capacity, especially to coal. But above all, they will treat the question of whether to order a nuclear plant as a strategic decision to be taken in the context of expected demand for electricity and the current and future financial status of the utility. Utility executives will compare the risks and returns from construction of more nuclear powerplants with the risks and returns of several other options for meeting their public obligation to provide adequate electric power.

This chapter will explore the elements of strategic choice for utilities that arise from the uncertainty of future rates of growth in electricity demand, the uncertainty of economic return on investment, and the uncertainty of construction and operating costs of nuclear powerplants. The chapter will also assess the regional and national implications of individual utility choices.

THE RECENT PAST: UTILITIES HAVE BUILT FAR LESS THAN THEY PLANNED

Utilities have built far less new electric-generating capacity in the 1970's and early 1980's than they expected to a decade ago. In 1972, the peak-year of generating capacity forecasts, utilities overestimated construction in the last half of the 1970's by 25 percent and overestimated construction in the first half of the 1980's by 60 percent (46). Utility predictions of future generating capacity declined over the decade but still greatly exceeded actual construction. The actual **generating capacity of 580 gigawatts** (GW) * in the summer of 1982 was about 75 GW lower than what had been forecast as recently as 1977 (70).

Both nuclear and coal plants were canceled in the late 1970's and early 1980's, but nuclear plants were canceled in far greater numbers and with far greater cost in sunk investments. Over 100 nuclear units were canceled from 1972 to 1983, more than twice the number of coal units (29,35). Almost $10 billion (1982 dollars) in investment costs was tied up in the 26 sites (some with 2 units) where at least $50 million per site had already been spent (35). Another 11 nuclear units totaling $2.5 billion to $3 billion in construction costs are expected to be canceled and another 5 units with $3 billion to $4 billion costs may be canceled (35,53).

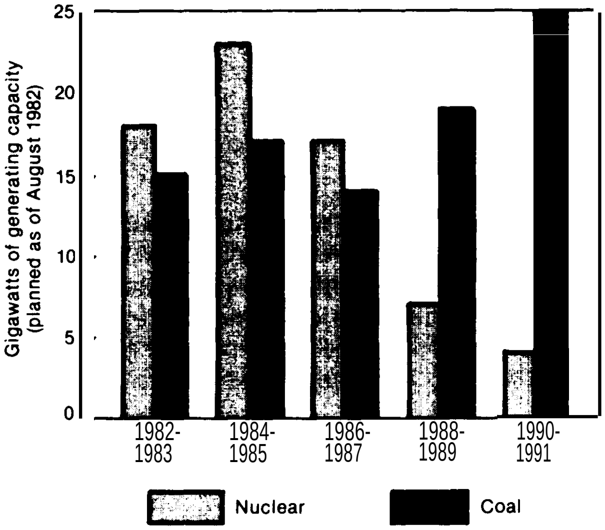
Of 246 GW of orders for nuclear plants ever placed, about 110 GW have been canceled. All of the 13 orders placed since 1975 have been canceled or deferred indefinitely and no new orders have been placed since 1978.

Utilities expect to complete many of the nuclear plants under construction but have not planned to build any more. Utilities still, however, are planning to build new coal plants. A total of about 43 GW of coal construction is planned for completion from 1988 to 1991 (see fig. 3) but only 11 GW of nuclear capacity is planned (much of which is likely to be canceled) (68).

One obvious reason for so many canceled and deferred plants is that from 1973 to 1982, electricity load grew at less than half the pace (2.6 percent per year) that it had grown from 1960 to 1972 **(7.1 percent per year). Most utilities in** the early 1970's used simple trend-line forecasts that took neither gross national product (GNP) or response to electricity price into account. They were unprepared for the change in electricity growth rates. Figure 4 shows a remarkable down-

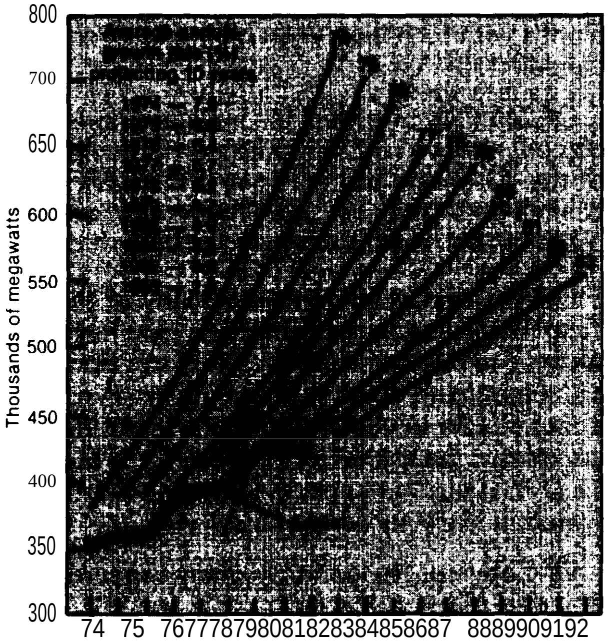
***One gigawatt equals 1,000 MW (1,000,000 kW) or slightly less than the capacity of the typical large nuclear powerplant of 1,100 to 1,300 MW. GW as used in this chapter always refers to GWe or gigawatts of electricity.**

Figure 3.–Planned Construction of Coal and Nuclear-Generating Capacity, 1982=91



SOURCE: North American Reliability Council, Electric *Power Supply and Demand 1982-1991,* August 1982.

Figure 4.—Comparison of Annual Ten-Year Forecasts of Summer Peak Demand (contiguous U.S.)



SOURCE: North American Electric Reliability Council, *Electric Power Supply and* Demand, 1981-1991, August 1982 and advanced release of the projections for 1983-1992 in April 1983.

ward trend in utility forecasts of future load growth. it is no surprise that utilities, making plans in the late 1960's and early 1970's, and unable to foresee the economic changes of the 1970's, planned to build more generating capacity than was eventually needed. Even with all the cancellations and deferrals, there was almost a 50-percent increase in electric-generating capacity from 1973 to 1982 while the average reserve margin* increased from about 21 percent in 1973 to about 33 percent (68,70). In between, the reserve margin peaked at about 37 percent as utilities completed and brought online plants that had begun construction before the slower load growth was recognized as the norm rather than as an anomaly (58).

In addition to the slowdown in electric load growth, powerplants also have been canceled and deferred due to the widely acknowledged deterioration in the financial condition of utilities. At the beginning of the *1970's,* utilities enjoyed good financial health. Almost 80 percent had bond ratings (Standard and Poors) of AA or AAA. Utility stock sold well above book value so that there was little difficulty financing new generating capacity from new issues of either debt or equity.

By 1981, however, utilities were in a greatly weakened financial condition. Currently, there are no electric utilities with AAA bond ratings and less than a fourth with AA ratings. At its low point in 1981, utility stock sold on average at only 70 percent of book value. This meant that any issue of new stock to pay for new generating plant would dilute the value of the existing stock (see box A later in this chapter). The financial deterioration was influenced in part by the general financial conditions of the decade, especially the rapid rates of inflation and the poor performance of the stock market. Beyond the influence of general economic conditions, however, the financial status of utilities deteriorated because of the enor-

*"Reserve margin" is defined as the percent excess of "planned resources" over "peak demand" where "planned resources" includes installed generating capacity plus scheduled capacity purchases less sales.

mous strain of financing requirements for new plants. Despite many cancellations and deferrals of powerplants, new plant financing increased from about $10 billion in 1970 to over $28 billion in 1982, of which more than two-thirds had to be financed externally (45).

The biggest incentive for utilities to cancel and postpone more nuclear than coal plants, was the more than fivefold increase in the constant dollar cost of nuclear plants from plants completed in 1971 to plants scheduled for completion in the 1980's compared to the approximately threefold increase in the constant dollar cost of coal plants (55,56). Another incentive to favor coal plants was their shorter leadtime, an average of 40 to 50 percent fewer months than for a nuclear plant (l).

Looking ahead, the prospects for substantial numbers of new central station powerplants appear fairly uncertain. The prospects for more nuclear plants appear even more uncertain. The reasons why this is so are laid out in the rest of the chapter. The next section describes the uncertainty about the future growth rates in electricity demand. With some assumptions about the future it is reasonable to expect that the fairly slow growth rates (1 or 2 percent per year) of the past few years will continue. With equally plausible assumptions, however, electricity load growth could resume at rates of 3 to 4 percent per year. The sources of uncertainty are described in the next section.

The third section explains why utilities can afford to wait awhile before ordering powerplants in large numbers, since reserve margins are now so high. Sooner or later, however, as this section points out, some number of new powerplants will need to be built to replace aging powerplants and meet even modest increases in electric load.

The fourth section of the chapter presents an argument that there may be systematic biases in rate regulation that discourage those types of generating capacity that are of high capital cost and high risk relative to other types. Over the long run such rate regulation would discourage further construction of large coal and nuclear plants even when increased load and replacement of existing plants would make it sensible to construct central station plants, for which capital costs are high relative to fuel cost.

The fifth section of the chapter lays out the uncertainties involved in constructing and operating a nuclear plant which discourage utilities from ordering more nuclear plants even when they decide to order more central station powerplants. Construction costs have risen much faster than general price increases and vary severalfold from plant to plant even when built the same year. In addition, there is a financial risk of at least several billion dollars from an accident that disables a powerplant and more from one that causes damage to public health and property. To date insurance is available to cover only a fraction of this risk.

Given the uncertainties of demand and nuclear construction cost, utility decisions to cancel nuclear powerplants and some coal plants have been sensible, and in the short-term interests of the ratepayers. Over the long run, however, if ratemaking discourages electric-generating technologies of greater capital cost and greater risk, further investment in nuclear powerplants could be discouraged even if it were in the longer term interests of ratepayers.

The final section of the chapter describes the choices utilities have and the choices they seem to be making. Under a few specific assumptions about changes in outside circumstances and rate regulation incentives, utilities could order nuclear plants again. It appears now, however, that they will avoid central station construction as long as possible and then build coal plants.

THE UNCERTAIN OUTLOOK FOR ELECTRICITY DEMAND

From 1973 to 1982, annual increases in electricity demand averaged 2.6 percent. If these growth rates were to continue for the next 20 years, they would provide no more than a weak stimulus to further building of central station powerplants, including nuclear powerplants. (See the detailed discussion of capacity requirements in the next section.) It would be possible for most utilities, with some effort, to avoid building central station powerplants altogether until the late 1990's by encouraging conservation, load management, cogeneration, and small sources of power from hydro and wind; or by purchasing from U.S. utilities with excess capacity or from Canadian utilities; or by keeping existing plants online past normal retirement age. These strategies are discussed later in the chapter.

What are the chances that the average electricity demand growth rate will be significantly higher or lower than 2.6 percent per year? A significantly lower growth rate would make it difficult to justify any major construction of central station powerplants. A significantly higher growth rate would make a strategy of little or no powerplant construction difficult to sustain.

Published projections of electricity demand reflect considerable uncertainty about future growth rates. As is clear from figure 4 above, the utilities' own estimates of future peak demand have dropped each year since 1974 and now average an annual increase of 2.9 percent from 1983 to 1992 (70). Some studies (e.g., the Energy Information Agency and Starr and Searl of EPRI) project higher rates of electricity growth than the electric utilities do, although none project more than 4 percent annual growth through 1990 (27, 51 ,83). Only one (Edison Electric Institute) projects more than 5 percent from 1990 to 2000. Several studies (e.g., Audubon and the Solar Energy Research Institute) on the other hand, project very low rates of annual electricity growth of O to 1.5 percent (77,84).

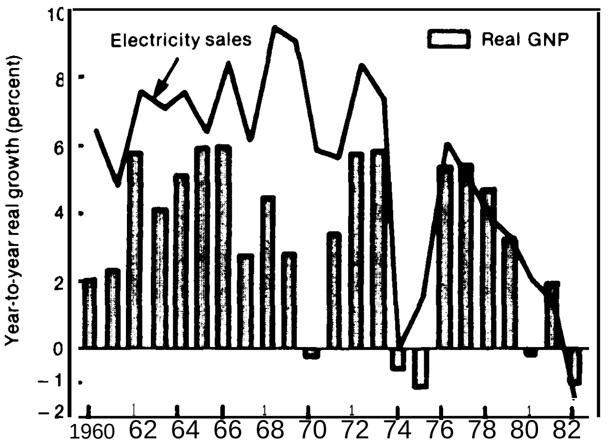
One of the reasons for this range is different assumptions about the future growth rates in GNP. The projections of faster electricity growth assume a range of 2.5 to 3.0 percent annual GNP growth per year (51). The projections of slower electricity growth assume somewhat slower growth rate in real GNP, a range of 2.0 to 2.8 percent per year (77). In general, however, all these projections assume that the United States has a "mature" economy and increases in real GNP faster than an average of 3.0 percent per year are not likely.

The projections disagree more significantly about the likely future relationship between growth rates in GNP and growth rates in electricity demand. Projections of faster electricity growth assume that electricity will increase faster than GNP. Projections of slower electricity growth asume that electricity demand will increase significantly less fast than GNP.

The ratio between electricity growth rates and GNP growth rates has indeed dropped since the 1960's. As is shown in figure 5, electricity growth rates were about double GNP growth rates in the 1960's and approximately equal to GNP growth rates (except for recession years) in the 1970's. Those expecting fast growth rates in electricity regard the late 1970's as an anomaly and expect a resurgence of a ratio of electricity to GNP growth of more than 1.0. Those expecting slow growth rates in electricity assume that the ratio of electricity growth to GNP growth will fall still further, well below 1.0. They expect that electricity will continue to behave like other forms of energy for which ratios to GNP have dropped steadily since *1973.*

The sources of uncertainty in electricity demand forecasts are very evident from a look at

Figure 5.—A Comparison of the Growth Rates of Real GNP and Electricity Sales, 1980=82



SOURCE: Craig R. Johnson, "Why Electric Power Growth Will Not Resume, " *Public Utilities Fortnigfhtly,* **Apr. 14, 1983 from data in the EIA, Annual Report to Congress 1982 and the Edison Electric Institute,**

the uncertainty surrounding the factors underlying the forecasts. The uncertainty exists both in conventional macroeconomic approaches to forecasting which relate electricity growth to expected changes in GNP, electricity prices and the prices of competing fuels. (This is sometimes referred to as the top-down approach.) There is comparable uncertainty about the factors underlying engineering or end-use projections of electricity use. This approach (sometimes called bottom-up analysis) identifies possible technical changes in the use of electricity that are economically feasible—such as improvements in appliance and electric motor efficiency, opportunities for **fuel switching, and new electricity-using industrial technologies–and then estimates the likely market penetration of these changes.**

The Top-Down Perspective on Electricity Demand—Sources of Uncertainty

One of the advantages of top-down analysis of electricity demand is that uncertainty is confined to only a few powerful variables—future growth in GNP, changes in electricity prices, and changes in the prices of competing fuels and the responsiveness of electricity demand to each.

The Influence of Economic Growth. -Future growth of GNP is a major source of uncertainty, both because income and industrial production are assumed by economists to have major impacts on electricity demand, and because of some deep uncertainties about the future direction of the economy. Even the fairly narrow range of GNP growth rates of 2 to 3 percent that has been assumed by the major electricity demand projections implies a range of electricity demand growth rates (assuming *no* price influence) of about 2 to 3 percent over the long run if electricity demand follows the income response patterns identified in the past (79). Many observers concede the range is even wider, Those with private misgivings about the future health of the economy accept the possibility of an annual rate of GNP growth lower than 2 percent. Optimists about economic renewal and increased productivity suggest the potential for a higher rate of growth.

Regional uncertainties about economic growth are more extreme than national ones. Income and industrial output have fallen in some regions as a result of the recent recession and the extent of long-term recovery from the recession in these regions is unclear. Rapid population growth is expected to occur in the South and Southwest.

Electricity Prices.– Future electricity prices and their impacts are a second source of uncertainty about electricity demand growth. This is both because there is disagreement about future change in electricity prices and because there is uncertainty about how electricity demand responds to electricity prices.

From 1970 to 1982, average electricity prices increased in constant dollars at about 4 percent per year, reversing a 20-year trend of decreasing real prices (26). There is considerable disagreement about the future course of electricity prices even though they should be easier to project than oil or gas prices because they are largely determined by regulatory rules that are predictable. The Energy Information Administration in the Department of Energy (DOE) has consistently projected very slow increases in real electricity prices of less than 0.5 percent per year until 1985 and 1.4 percent per year after that (27). The Office of Policy Planning and Analysis, also of DOE, projected somewhat more rapidly increasing electricity prices, at 2.4 percent per year until 1995 with level prices after that (20). Finally, Data Resources Inc. (DRI) has projected sharply increasing electricity prices for both industrial and residential users of 3.7 percent per year until the mid-1 980's, slower increases until 1990 and less than 0.5 percent per year from 1990 to 2000 (18).

Forecasts of electricity prices disagree principally about the future cost of coal for electricity, the future construction cost of nuclear and coal powerplants and the future rate regulation policies of Public Utility Commissions. Stabilizing of electricity prices in the 1990's is expected to occur because of a growing share of partially depreciated plants in the rate base and little new *con*struction. (See the discussion of these factors in later sections of this chapter.)

Response of Electricity Demand to Electricity Prices.—There is generally less agreement about the impact of electricity prices on electricity demand than there is about the impact of changes in GNP. Most analysts agree that the short-run response of electricity demand to an increase in electricity prices is very limited—l O to 20 percent of the price increase. Based on comparisons from State to State, however, analysts estimate the long-run response to be much greater–50 to 100 percent of the price increase. (The response to a price increase is always a decrease in demand.) For example, an increase of 2 percent in electricity prices would be expected to result in a short-run decrease in electricity demand of 0.2 to 0.4 percent (from what it would have been otherwise), but a long-run decrease in electricity demand of 1 to 2 percent.

Prices of Competing Fuels.–Very few analysts have attempted to estimate the long-run response of electricity demand to changes in the prices of other (and competing) forms of energy of which the principal competitor is natural gas. Of these attempts, the consensus is that electricity demand would be expected to increase (over the long run) about 0.2 percent for every 1 percent increase in natural gas prices.

The Energy Information Administration projects that natural gas prices will increase at more than 10 percent a year (in constant dollars) until 1985 and more slowly, at 5 percent per year after that until 1990 (27). DRI, on the other hand, projects somewhat slower increases of about 3 percent per year through the 1980's and 1990's (18).

In some areas, especially New England, oil is the chief competitor to electricity and the chief source of uncertainty. Oil prices are now higher than natural gas prices and are projected to increase but more slowly than natural gas prices.

The Impact of Prices on Demand .–The combined effect of uncertainty about future electricity and natural gas (and oil) prices and uncertainty about how electricity demand responds to changes in electricity prices is enough to explain a range of uncertainty in electricity demand from very slow growth to quite rapid growth. This is illustrated in table 3. If GNP is projected to grow at 2.5 percent (the midpoint of the range assumed in current forecasts) and the long-run response to increases in income is assumed to be 100 percent, the effect of price and price response assumptions is to produce a projection of 1.1 percent annual increase in electricity demand, at the low end, and of 4 percent at the high end. It would be possible, for example, for electricity demand to grow at 4 percent per year, if electricity prices increase at no more than 1 percent per year (in constant dollars) while natural gas prices increase at 10 percent per year, and there is a relatively small long-run decrease in demand in response to an electricity price increase (defined as a long-run elasticity of – 0.5).

Timing of Response to Prices.–Unfortunately no analyses have been published of the long-run

Table 3.—Growth Rates in Electricity Demand Given Different Price Responses[a]

Rates of electricity and gas price increase	Annual increase in electricity demand given: Low long-run price response	High long-run price response
1. High electricity prices (2%/yr) Moderate gas prices (3%/yr)	2.1%/yr	1.1%/yr
2. Low electricity prices (1'\O/yr) Moderate gas prices (3%/yr)	2.6%/yr	2.1%/yr
3. Low electricity prices (1%/yr) High gas prices (5%/yr).	3.0%/yr	2.5%/yr
4. Very high gas prices (10%/yr) Low electricity prices (1%/yr).	4.0%/yr	3.5%/yr

[a]Also called price elasticities. See *Assumptions*.

Assumptions: GNP increases at 2.5 percent par year; Income elasticity of electricity demand - 1.0; response of electricity demand to gas price (cross-elasticity) - 0.2; response of electricity demand to electricity price (own-elasticity): a) low = 0.5, b) high = –1.0.

SOURCE: Off Ice of Technology Assessment based on a presentation by James Sweeney to an OTA workshop.

response of electricity demand to electricity prices in the crucial decade since the 1973 oil embargo. The estimates mentioned above were all based on data up to 1972. The chief reason is because this analysis cannot be done without consideration of the timing of the long-run response. Not only have electricity prices (in constant dollars) changed from decreasing to increasing, but competing fuel prices (which also affect electricity demand) changed from decreasing to increasing even more dramatically.

The length of time it takes for the long-run price response to be felt is crucial to making any estimate of this response. If the "long run" is 3 to 4 years, we have already seen much of the response to the price increases of the 1970's. If the "long run" is 10 years or longer, we are just now beginning to witness the effects of actions taken in response to those price increases.

This lack of understanding of how long it takes for the full long-term response to increases in electricity prices makes it difficult to predict what still remains of consumer and industrial responses to the increasing electricity prices of the last decade. If the response takes 10 years or longer, the effects will last until the early 1990's.

Electricity Rate Structure.-The uncertainty of price impacts is further complicated because forecasts of average electricity price do not fully capture the potential price changes that will influence electricity demand. Decisions of industry and consumers are also influenced by the price of an additional unit of electricity, that is the *marginal price* of electricity. Utilities have recently begun to shift from "declining block rate" structures (in which each additional block of units of electricity costs less than previous blocks) to increasing block rate structures (in which each additional block costs more than previous blocks). There is no current survey of data on utility rate structures, but a crude estimate can be made that as many as one-fifth of all utilities may have increasing block rates for households. The number of such utilities is likely to continue to grow.

Regional Differences in Demand Response to Price Increases for Individual Utilities. -Another source of uncertainty is that individual utilities will have very different experience in electricity prices from the national average. A recent regional analysis of projected changes in electricity prices shows a mixture of declining electricity prices in some regions and increasing electricity prices in others **(48).** Real electricity prices in the Mountain region are forecast to drop by an average of more than 3 percent per year (in constant dollars) until 1987 and then stay nearly stable until 2000. Meanwhile, in the West South Central region electricity prices are projected to increase by an average of 4.6 percent per year until 1991 and then taper off slowly until the year 2000. Price changes as different as these will inevitably induce a wide regional variation in demand growth rates. Declining rates in the Mountain region should eventually stimulate increases in electricity demand while the opposite occurs in the West South Central region. This regional variation in both present and projected electricity prices will complicate and perhaps delay industry's investments to improve efficiency.

The Bottom-Up Perspective on Electricity Demand—Sources of Uncertainty

Within an overall framework of economic growth rates and changes in relative energy prices, bottom-up or end-use analysis offers a closer look at how electricity customers might actually change their patterns of electricity use in response to prices and income changes. Industrial customers purchase the most electricity, about 38 percent of the approximately 2.1 billion kwh sold in 1981. * Residential customers are close behind with **34** percent of all sales in 1981. Commercial customers and other customers purchased **24** and 4 percent, respectively.

Given a range of plausible assumptions about how customers are likely to change their patterns of electricity use over the next two decades, growth rates in electricity demand that range from 1 percent per year to as high as 4 percent per year are possible.

From a close look at each sector it is clear that a few variables are far more important than

*** 1981 data are used because industrial purchases had fallen to 35 percent of the total in 1982 as a result of the economic recession.**

others. Industrial electricity sales will be strongly influenced by the output experience of several key industries such as steel and aluminum, by the market penetration of greater efficiency in the use of electric motors, and by the success of several important new electrotechnologies for replacing oil and natural gas sources of industrial process heat.

The future rate of household formation will also strongly influence residential sales. How fast the use of electric heat and central air-conditioning spreads into new and existing housing units is also important, as is the success of high-efficiency appliances, air-conditioners, and heat pumps.

For future commercial sales of electricity the important future influences will be: the rate of construction of new commercial buildings; the prospects for significantly more efficient air-conditioning and lighting; and the potential for significant increase in electricity used for computers and other automation.

Utilities, in fact, are beginning to monitor such variables more closely in the effort to reduce some of the uncertainty about future growth rates in electricity. Utilities are increasingly turning to end-use modeling of future demand. This is in part because such models can be used to assess the impact of utility conservation and load management programs, but it is also possible to monitor important indicators of future customer behavior. Some utilities and State governments are indeed undertaking load management and conservation programs in order to directly influence customer behavior and reduce future uncertainty.

There is general acceptance that the high and low end of the bottom-up range is influenced by the key variables of price and income (GNP) used in top-down analysis. Slow increase in electricity prices is a weak stimulus to improvements in the efficiency of electricity use even if they are technically feasible, while rapid electricity price increases are a strong stimulus to efficiency improvements. Similarly, rapid increases in natural gas prices relative to electricity prices will stimulate the adoption of new electrotechnologies that substitute for natural gas. Less rapid price increases will provide less stimulus.

Industrial Demand for Electricity .-The electric-intensity of U.S. industry (electricity used per unit of output) has held steady since 1974. This is despite a steady decrease for more than two decades in the overall use of energy per unit of industrial output. The steady relationship of electricity to industrial output is the product of two opposing trends: a steady increase in electricity-use in industries which are heavy users of electricity, and a steady **decrease in the proportion of output from those same industries relative to total U.S. industrial output (58). Looking ahead, there is considerable uncertainty about both these trends.**

Electricity use in industry is concentrated. Just 13 specific industrial sectors* consume half of all industrial electricity. These are: primary aluminum, blast furnaces, industrial inorganic and organic chemicals not elsewhere classified, petroleum refining, papermills, miscellaneous plastic products, industrial gases, plastics materials and resins, paperboard mills, motor vehicle parts, alkalis and chlorine, and hydraulic cement.

Future rates of output growth in several of these industries are highly uncertain. For example, the industrial output of primary metals, which includes both aluminum and steel, decreased by about 1.0 percent per year between 1972-74 and 1978-80 (57). Capacity expansion plans for both steel and aluminum are down about two-thirds from their level a decade ago (50).

Within the chemicals industry, electricity is used heavily in the production of several basic chemicals such as oxygen (where it is used for refrigeration), and chlorine (where it is used for electrochemical separation). Although the chemicals industry as a whole grew by an average of 4.5 percent per year from 1974 to 1980, the production of these basic electrically produced chemicals grew only 1 to 2 percent per year (oxygen and chlorine) or actually decreased (acetylene and phosphorus) (1 1). Observers of the chemical industry expect this trend to continue as demand for basic chemicals becomes saturated and some production moves overseas. The U.S.

***As identified by four-digit Standard Industrial Classification (SIC) codes.**

chemical industry is expected to concentrate increasingly on small volume specialty chemicals, which use relatively little electricity for production.

Since chemicals, iron and steel and primary aluminum alone account for more than a third of electricity use in industry, a 2 percent lag in growth of these electricity-using industries behind general industrial output would alone cause a lag of about 0.5 percent in electricity demand behind overall growth in industrial output.

In addition to being concentrated by type of industry, electricity use in industry is also concentrated by function. Uncertainty about the direction of trends in electricity use in electric-intensive industries comes about because electricity use will probably become more efficient in two of the functions (electric motors and electrolysis) and is likely to expand into significant new uses in the third function (electricity to supply or substitute for process heat).

About half of all electricity use in industry is used for electric motors, including compressors, fans and blowers, and pumps (3). Improvements in the efficiency of electric motors are likely to be continuous for 10 to 15 years through improvements in the motors themselves and through improved efficiency of use which takes advantage of new semiconductor and control technology. Thus, electricity use per unit of output for these purposes could decrease by 5 percent (if there is little price stimulus) or up to 20 percent (if there is significant price stimulus). Some of this improved efficiency should come about as a result of past price increases, as capital stock turns over. impetus for the rest will depend on future electricity price increases, and the cost of installing the control technologies.

Another 15 to 20 percent of all industrial electricity is used for electrolysis of aluminum and chlorine (3,81). Aluminum electrolysis is more likely to decrease than increase as a fraction of industrial use, because efficiency improvements of 20 to 30 percent are technically possible from several technologies and are probably necessary (given sharply increasing prices for electricity in the Northwest, Texas, and Louisiana where plants have been located) to keep aluminum production in the United States competitive with aluminum production overseas (81).

Electric process heating in industry accounts for only about 10 percent of current uses of electricity but has great potential to become much more important as new electric process heating techniques are developed that make better use of electricity's precision and ability to produce very high temperatures. In some important high temperature industries such as cement, iron and steel, and glassmaking, electricity makes up 20 to 35 percent of all energy use and could as much as double its share.

Some techniques being developed could have very large impacts on electricity demand. These include plasma reduction and melting processes for primary metals production, and induction heating for shaping and forging. Other techniques such as lasers and robotics, however, are likely to have small impacts on electricity demand because only small amounts of electricity are used for each application. The biggest lasers, for example use only about 1 to 2 kW. Most use under 100 W. Table 4 shows an assessment of the relative impact likely from each of the newer techniques (81).

Great uncertainty surrounds the contribution to industrial electricity demand from the most important new electrotechnologies. The iron and steel industry could experience the greatest increase in electricity demand. Production and profit levels, however, in that industry are uncertain. Overall growth in the steel industry is projected to be only about 1.5 percent per year to 2000 (81). The contribution of electric arc steelmaking from scrap iron is expected to increase from approximately one-fourth to at least one-third of the total, but the potential for plasma reduction and melting is more uncertain partly because there may be too little capital to take advantage of technological advances (81). If new technologies penetrate slowly, the impact on electricity demand could be minimal until the late 1990's. It is conceivable, however, that rapid penetration could occur with a few very successful new techniques which in turn may increase the U.S. steel industry's competitive position and prospects for growth. In such circumstances,

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Table 4.—Estimated Impact of Industrial Electrotechnologies in the Year 2000

	Rough estimates of GW of capacity				
	1983	2000	Change to 2010ᵃ	Load factor	Level of uncertainty
Arc furnace steelmaking.	3.5-4.5	5-7	+	High	Low
Plasma metals reduction	0	2-4	+	High	High
3. Plasma chemicals production . . .	0	3-5	+	High	High
4. High-temperature electrolysis (aluminum and magnesium)	8-9	9-12	O or –	High	Low
5. Induction melting (casting)	3-4	4-5	o	Low and off peak	Moderate
6. Plasma melting	0.05	?[b]	+	High	Very high
7. Induction heating (forging)	5-7	8-10	o	Moderate	Moderate
8. Electro slag remelting.	0.075	0.15	+	Moderate	Moderate
9. Laser materials processing	0.0005-0.001	0.001-0.002	+	Moderate	Moderate
10. Electron-beam heating	0.006-0.008	0.015-0.02	+	Moderate	Moderate
11. Resistance heating and melting	0.3-0.5	0.4-0.6	O or –	High	Low
12. Heat pumps	0.1	1-3	+	High	Moderate
“ 13. Electrochemical synthesis, electrolytic separation, chlorine/caustic soda	4-5	4-5	o	High	Low
14. Microwave and radiofrequency heating	0.5	7	+	Moderate	High
15. Ultraviolet/electron-beam coating	0.01-0.02	0.5-1	+	Moderate	Moderate
16. Infrared drying and curing	0.4-0.5	0.5-1	o	Moderate	Low
17. Electrically assisted machining and forming.	<0.001	<0.001	—	—	—
18. Low-temperature plasma processing	<0.001	<0.001	—	—	—
19. Laser chemical processing	0	<.5GW[c]	—	—	—
20. Robotics	<0.001	<0.001	—	—	

[a]Explanation: “ + “ = Increase to 2010; “0” = stable to 2010; “ – “ = decrease to 2010,
[b]Any capacity in plasma melting directly competes with electric arc furnace steelmaking.
[c]This will probably only be used in U.S. Government-owned facilities for Uranium isotope Separation.

SOURCE: Table prepared by Philip Schmidt, based on research for a report publicized by EPRI in early 19S4, *Electricity and Industrial Productivity: A Technical and Economic Perspective* (81).

there could be a substantial impact on electricity demand by the early 1990’s.

The role of cogeneration* in satisfying future industrial electricity demand is a final source of uncertainty. (Cogeneration is discussed further in the section on utility strategies and was a subject of a recent OTA report *Industrial and Commercial Cogeneration (72).)* A recent study by DOE estimated that cost-effective opportunities existed in industry for about 20 GW of self-contained cogeneration without sales to the outside electrical grid, a potential increase of slightly more than the current installed capacity of about 14 GW with about 3 GW additional capacity in the planning stage (72). if fully realized, an increase in cogeneration of this magnitude would reduce the growth rate of purchased electricity by about 0.5 percent per year. Cogeneration is being adapted more slowly than the market potential indicated earlier partly because the success of industrial energy conservation programs has reduced industrial requirements for steam.

For the 1980’s, the highest growth rate in industrial electricity demand is likely to be no more than equal to industrial output, and growth rates could fall as low as 2 percentage points below industrial output growth. For the 1990’s, it is quite possible that electricity demand could grow faster than industrial output (20). The reasons for possible faster growth in industrial electricity demand in the 1990’s than in the 1980’s should be clear from the above discussion. The output of such electricity-using industries as steel and aluminum

*The combined production of electricity and useful steam (or hot water) in one process.

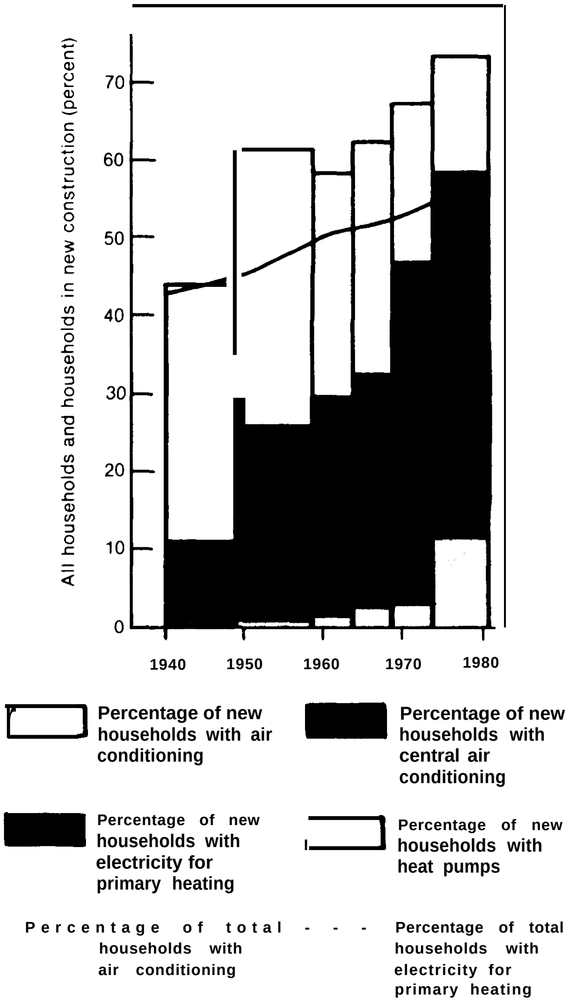
is likely to continue to grow very slowly during the 1980's, but may grow more rapidly in the 1990's. Technologies for improving the efficiency of use of electric motors are also likely to have the greatest impact in the 1980's, while new electrotechnologies for substituting electricity for process heat are not likely to have a big impact in the 1980's because they are now a small share of total electricity use. Even if they grow rapidly, they cannot have a major impact on overall industrial electricity demand until they are a larger fraction of the whole, sometime in the 1990's.

Residential Demand for Electricity.—From a bottom-up perspective, what happens to future electricity demand from households depends both on how fast the total number of households increases and on what happens to electricity use per household.

There is uncertainty, first of all, about the rate of household formation. Over the decade from 1970 to 1980, the U.S. population formed households at a rate much faster than population growth. In current census projections, this trend is expected to continue through the 1980's, resulting in a fairly rapid rate of household formation of 2.2 percent per year and a further drop in household size from about 3.2 people per household in 1970 to 2.8 people in 1980 to 2.5 people per household in 1990. On the other hand, were the U.S. taste for living in smaller and smaller households to become less important, the growth rate in household formation could fall to 1 percent per year or less.

The potential for increased use of electricity per household largely comes about because the number of households with air-conditioning and electric heating is still increasing. This is shown in figure 6. As of 1979 only 16 percent of all households had electric heat, but about half of new dwelling units were heated electrically. As new dwelling units replace existing ones, the percent of total dwelling units with electric heat could double or triple. A doubling of the share of all households heated electrically (assuming no increase in the efficiency of space heat) would add about 0.7 percent per year to household growth in electricity demand. The potential for increased use of electric space heating, however, will be influenced by the relative cost of electric heat

Figure 6.—Penetration of Air-Conditioning and Electric Heating in Residential Sector



SOURCE: Department of Energy, *The future of Electric Power in America. Economic Supply for Economic Growth,* Report of the Electricity Policy Project, June 1983, This graph was prepared from data in the EIA residential energy consumption surveys

which will in turn be reduced by increases in electric heating efficiency. About 70 percent of new households have air-conditioning compared to about 55 percent of existing households, so modest increases in electricity use from air-conditioning are also likely.

The use of electricity to heat water may expand beyond the 30 percent of households that now use it and could as much as double if there is a big decrease in the relative cost of electric and gas-heated hot water. The demand for other electric appliances is considered largely saturated and unlikely to expand substantially beyond the demand caused by increases in new households. Most (98 percent) of all households have refrigerators, 45 percent have freezers, and sO percent have electric ranges (10).

What makes projecting household electricity use highly uncertain is the difficulty of knowing how much electricity use per household will be reduced because of increases in appliance and lighting efficiency. From a comparison of the most energy-efficient appliances and lighting available in 1982 with the more typical appliances and lighting available (table s), it is clear that efficiency increases of more than **so percent can be achieved for all types of appliances, except freezers for which efficiency improvements since 1973 have already increased almost 50 percent (42). Some of these highly efficient appliances cost up to 100 percent** more than the typical appliance, but the extra cost would normally be paid back in electricity savings in **4 to 8 years.**

Continued increases in electricity prices will increase the demand for these high-efficiency products. Since some regions will have much larger electricity price increases than others, these may well create a large enough market to bring the prices of the high-efficiency products down. In some regions, market incentives will be augmented by local utility programs: rebates to purchasers of energy-efficient appliances (e.g., Gulf Power Co. in Florida) or rebates and bonuses to dealers who sell them (e.g., Georgia Power Co.) (42). Most observers agree that some improvement in appliance efficiency will occur. With modest increases in electricity prices, refrigerators are expected to reduce their average per unit electricity use by 10 percent. With stronger price incentives and perhaps utility market inducements electricity for refrigerator use may decrease by so percent both because of greater efficiency and smaller volume refrigerated. There is a similar range of possibilities for other appliances.

Commercial Demand for Electricity .-The commercial sector is the smallest of the three but is growing the fastest in electricity use. Sales of electricity to the commercial sector increased 3.9 percent per year over the decade from 1972 to 1982, faster than sales to either the industrial or residential sector, although less than half the rate of increase in commercial-sector sales of the previous decade **(26).**

One of the reasons for uncertainty in projecting future commercial demand for electricity is that there is no reliable source of data on how fast the commercial building stock is increasing. From the one available source (a 1979 survey of nonresidential building energy consumption (33)), it appears from the number of recently built buildings that commercial building square footage increased by about 2.7 percent per year from 1974 to 1979, somewhat slower than GNP growth of 3.8 percent per year over the same period. Over the same period, electricity sales increased about 4.2 percent per year, a rate faster than GNP and much faster than the increase in building square footage. If the same trends con-

Table 5.-Efficiency Improvement Potential From Typical to Best 1982 Model: Household Appliances

	Typical 1982 model	Most efficient 1982 model	Percent increase in efficiency
Heat pump: C. O.P.[a]	1.7	2.6	+ 53
Electric hot water heater: C. O.P.[a]	0.78	2.2	+ 182
Room air-conditioner: EER[b]	7.0	11.0	+ 57
Central air-conditioner: SEER[c]	7.6	14.0	+84
No-frost refrigerator-freezer: energy factor[d]	5.6	8.7	+55
Chest freezer: energy factor[d]	10.8	13.5	+25
Bulb producing 1,700 lumens: efficacy (lumens/watt)[e]	17	40	+ 135

[a]C.O.P. is the coefficient of performance, kWh of thermal output divided by kWh of electrical input.
[b]EER is the energy efficient ratio obtained by dividing Btu/hr of cooling Power by watts Of electrical power input.
[c]SEER is a seasonal energy-efficient ratio standardized in a DOE test procedure.
[d]Energy factor is the corrected volume divided by daily electricity consumption, where corrected volume is the refrigerated space plus 1.63 times the freezer space for refrigerator/freezers and 1.73 times the freezer space for freezers.
[e]1,700 lumens is the output of a 100-watt incandescent bulb.

SOURCE: Derived from Howard S. Geller, *Efficient Residential Appliances " Overview of* Performance *and Policy Issues,* American Council for an Energy Efficient Economy, July 1983.

tinue, and commercial square footage continues to grow more slowly than GNP, commercial electricity use will only increase as fast or faster than GNP as long as electricity use per square foot continues to increase.

Electricity use per square foot in commercial buildings may continue to increase for several reasons. Only **24 percent of existing commercial building square footage but almost half (48** percent) of the new building square footage is electrically heated (33). If these trends continue the share of buildings that are electrically heated could double.

Air-conditioning in commercial buildings is probably saturated. About 80 percent of all buildings have some air-conditioning. Small increases in electricity use per square foot can come about by air-conditioning more of the building and by replacing window air-conditioners with central or package air-conditioners. Window air-conditioners cool 20 percent of the existing building stock, but only 9 percent of the newest buildings (33).

Greater use of office machines and automation might increase electricity use both to power the machines and to cool them in office buildings, stores, hospitals, and schools. Machines, however, are less likely in churches, hotels, and other categories of commercial buildings.

The potential for increased efficiency of electricity use in commercial buildings is less well known than for residential buildings because commercial buildings are very diverse and the potential for increased efficiency depends partly on success in balancing and integrating the various energy loads: lighting, cooling, heating, refrigeration, and machines. OTA analyzed the theoretical potential for reductions in electricity and fuel use in commercial buildings in a recent report, Energy Efficiency *of Buildings in* **Cities (71),** and found that electricity use for lighting and air-conditioning in commercial buildings can be reduced by a third to a half. Heating requirements also can be reduced substantially by recycling heat generated by lighting, people, and office machines from the building core to the periphery. There is still very little verified documentation of energy savings in commercial buildings, however, and therefore, considerable uncertainty remains about the potential.

The results of the bottom-up analysis for the commercial sector indicate a demand for electricity that will increase for a few years at about the rate of increase of GNP but with wide ranges of uncertainty. It could be higher as a result of faster penetration of electric space heating and more air-conditioning and big loads from office machines, or lower as a result of big improvements in the efficiency of commercial building electricity use. By the 1990's, however, when the demand for electric heat in commercial buildings will be largely saturated, the trend rate of growth in electricity demand is likely to settle to the growth in commercial square footage, somewhat less than the growth rate of GNP.

Conclusion

Utility executives contemplating the construction of long leadtime powerplants must contend with considerable uncertainty about the probable future growth rates in electricity demand, The range of possible growth rates encompasses low average growth rates of 1 or 2 percent per year, which would justify very few new large powerplants, up to fairly high growth rates of 3.5 to 4 percent per year, for which the pressure to build several hundred gigawatts of new large powerplants is great, as will be clear from the discussion in the next section.

The sources of uncertainty are many. Future trends in electricity prices are viewed differently by different forecasters, because there is disagreement about future capital costs of generating capacity, future rates of return to capital and future prices of coal and natural gas for electricity. There also is uncertainty about how consumers and industry will respond to higher prices, given many technical opportunities for improved efficiency in appliance use and industrial electricity use and increasing numbers of promising new electrotechnologies that could substitute for the use of oil and natural gas for industrial process heat. Several of the industries, such as iron and steel, however, where the new electrotechnologies could have the greatest impact, face an uncertain future.

At present, utility strategy for supplying adequate electricity is influenced heavily both by the recognition of uncertainty about future growth in electricity demand and by recent financial difficulties and regulatory disincentives for large capital projects. The influence of utility rate regulation and current utility strategies are discussed later in the chapter.

RESERVE MARGINS, RETIREMENTS, AND THE NEED FOR NEW PLANTS

Powerplants are planned and ordered many years in advance of when they are needed. in order to produce power for sale by 2000, nuclear powerplants on a typical schedule would have to be ordered by 1988, **or 1990 at the latest, and coal plants or nuclear plants on an accelerated schedule, must be ordered by 1992 or 1993. Sources of generating capacity with** shorter leadtimes, such as gas turbines or coal conversion, need not be ordered before 1996 or 1997.

There is considerable disagreement about how many new powerplants will be needed by 2000. Those who believe that large numbers of new powerplants will be needed (several hundred GWs) anticipate rapid growth of electricity demand (3 or 4 percent per year), expect that large numbers of existing plants will be replaced because of deterioration in performance or retirement due to age and economic obsolescence, and expect only modest contributions from small power production (20,83).

On the other hand, some believe that no new powerplants or very few (a few dozen GW) will be needed before 2000 because they anticipate only slowly growing electricity demand (1 or 2 percent per year), expect little or no need to replace existing generating capacity, and expect substantial contributions to generating capacity from small sources of power such as cogeneration, geothermal, and small-scale hydropower (83).

This section lays out the range of possibilities from no new powerplants to several hundred gigawatts of new powerplants arising out of different combinations of growth in electric demand and varying utility decisions about powerplant retirements and use of small power sources.

The electric utility industry currently projects average growth in peak summer demand of 3.0 percent per year between 1982 and 1991 (68). * The industry has also planned for an increase in electric-generating resources of 158 GW by 1991 bringing the total generating capability up to 740 GW (68). Only 13 GW of scheduled retirements have been included in the 1991 estimate (69). At the same time the current reserve margin** of 33 percent is forecast to fall to 20 percent. As a rule, utilities like to maintain a reserve margin of 20 percent to allow for scheduled maintenance and repair and unscheduled outages. Individual regions may require higher reserve margins if they are poorly connected to other regions, if they are dependent on a small number of very large plants or if they are dependent for a large share of generating capacity on older plants or plants that burn expensive oil and natural gas.

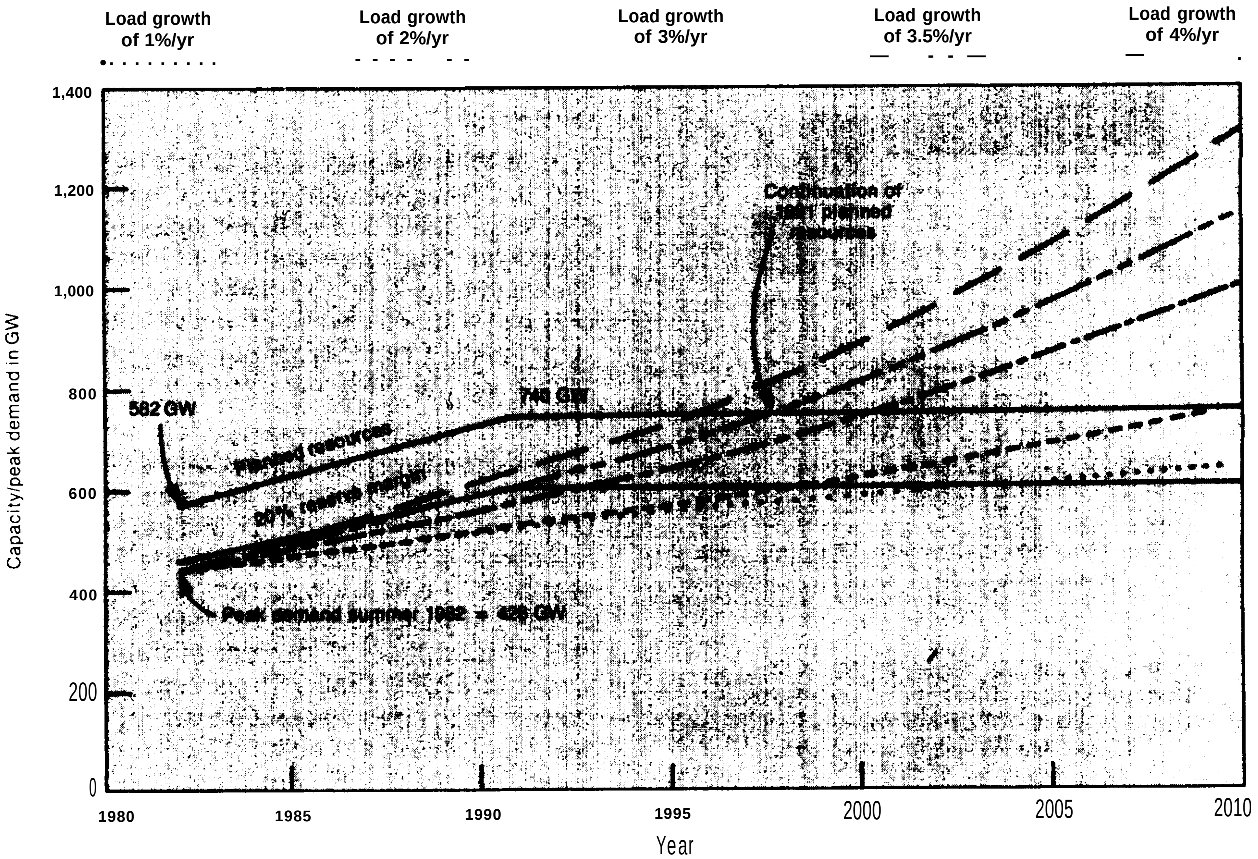
As shown in figure 7, the planned resources of 740 GW scheduled for 1991 would allow a reserve margin of 20 percent to be maintained until 1996 if electricity peak demand grows only at 2 percent per year, or until 2000 if electricity demand grows only at **1** percent per year. On the other hand, the average reserve margin will fall below 20 percent by 1987 if electricity demand increases at 4 percent per year.

However, the number of new powerplants that must be built to maintain a given reserve margin does not depend only on the rate of increase in

*This had dropped to 2.9 percent per year for 1983 to 1992 in the 1983 **North American Electric Reliability Council Forecast of Electric Power Supply and Demand (70).**

****'' Reserve margin" is defined as the percent excess of "planned resources" over "peak demand" where "planned resources" includes: 1) installed generating capacity, plus 2) scheduled power purchases less sales.**

Figure 7.—Projected Generating Capacity and Alternative Projections of Peak Demand



NOTE. "Planned resources" IS defined by NERC to include: 1) Installed generating capacity, existing, under construction or in various stages of planning; 2) plus scheduled capacity purchases less capacity sales; 3) less total generating capacity out of service in deactivated shutdown status.
"Reserve margin" given here IS the percent excess of "planned resources" over "projected peak demand. "

SOURCE" North American Electric Reliability Council, Electric *Power Supply and Demand 1982-1997,* August 1982 and Off Ice of Technology Assessment

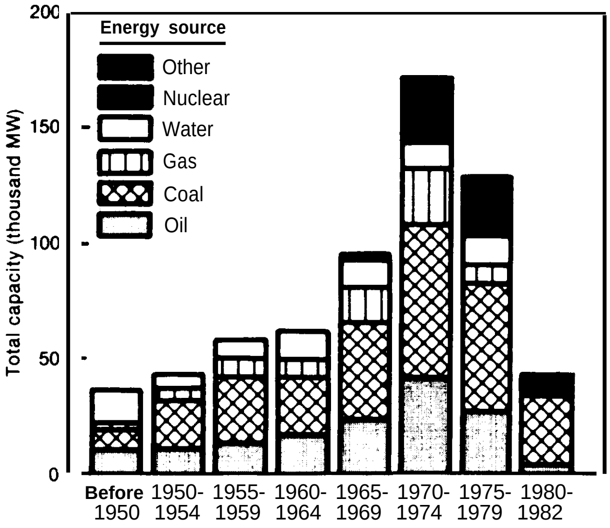
electric peak demand. It also depends on how much existing generating capacity must be replaced because powerplants are retired, due to age or to economic obsolescence, or because existing powerplants must be derated to lower electricity outputs.

Retirements Due to Age.–The "book lifetime" of a powerplant, used for accounting purposes, is usually 30 to 40 years. Over this period the plant is gradually depreciated and reduced as a recorded asset on the utility's books until, at the end of the period, it has no more book value and produces no return on capital. However, in practice powerplants may continue to operate for 50 years or more. As of 1982 there were about 10 GW of generating capacity that were more than 40 years old, more than a quarter of the total generating capacity that was in service 40 years ago.

In fact, the bulk of the current generating capacity of the United States is comparatively new. Over half has been built since 1970, as shown in figure 8. The number of plants that would be retired by 2000 varies greatly with the assumed plant life. In the unlikely event that a 30-year life would be used, over 200 GW would be retired by 2000 (see table 6). A 50-year schedule would retire only 20 GW.

Economic Obsolescence. -From 1965 **to 1979 a large number of steam-generating plants using oil or natural gas were built (see** fig. 8). They were

Figure 8.–The Energy Source and Age of Existing Electricity Generating Capacity



SOURCE: Energy Information Administration. Inventory of Power *Plants in* the *Ufnited States,* 1981 Data from the 'Generating Units Reference File:

Table 6.—Possible Needs for New Electric. Generating Capability to Replace Retired Powerplants, Loss of Powerplant Availability, and Oil and Gas Steam Powerplants

	Cumulative replacement capacity (GW) needed by:			
	1995	2000	2005	2010
If **existing powerplants are retired after:**				
30 years.	**155**	**230**	**395**	**510**
40 years.	**55**	**105**	**155**	**230**
50 years.	—	20	55	105
If all 011 and gas steam capability is *retired* **as follows:**				
All	**152**	**152**	**152**	**152**
Half	**76**	**76**	**76**	**76**
All oil and gas capacity above 20 percent of region (3 regions)	**55**	**55**	**55**	**55**
If average coal and nuclear availability slips from 700/0 to:				
About 65%	21	**21**	**21**	**21**
About 600/0	**42**	*42*	*42*	*42*

SOURCE: Office of Technology Assessment.

ordered before the 1973 oil embargo. Under current price forecasts, oil prices are expected to remain fairly stable until the late 1980's or early 1990's and then increase substantially (by about 60 percent) from 1990 to 2000 (27). The price of natural gas to utilities is expected to increase steadily through the 1980's as the long-term contracts for natural gas sold at relatively low prices expire and are replaced by contracts for more expensive gas.

As of 1981, there were 152 GW of oil and natural gas steam-generating capacity. Together they totaled 27 percent of all generating capacity but produced only 22 percent of all electricity. As shown in table 7, oil-fired steam plants produced only half as much electricity relative to their share of generating capacity. Natural gas-fired steam plants, on the other hand, produced a greater share.

Even though oil and natural gas will be expensive, plants burning these fuels can be used as part of the reserve margin. Oil and gas are, in fact, just about 20 percent of two regions, the Southeast (SERC)* and the West (WSCC). The fraction of oil- and gas-generating capacity, however, is much larger than 20 percent in three regions: Texas (ERCOT) about 72 percent, Southwest Power Pool (SPP) about 56 percent, and the Northeast Power Coordinating Council (NPCC) about 51 percent (68). If oil and gas steam plants were retired continuously in these regions until they formed no more than 20 percent of total generating capacity, the total retired would be about 55 GW.

Loss of Availability of Generating Capacity.– The percent of time that nuclear and fossil baseload plants were available to generate electricity averaged around 70 percent** over the decade of the 1970's (67). If there were a reduction from 70 to 65 percent in the average availability of nuclear and coal powerplants this would be the equivalent of a loss of 21 GW out of a total current coal and nuclear-generating capacity of **294 GW (see table 6).**

A recent study for DOE assesses the prospects for changes in average availability **(82). Statistical**

*These are the regions of the Northeast Electric Reliability Council (NERC).

**The availability figure used here is *equivalent* availability and includes service hours plus reserve hours less equivalent hours of partial outages. (66) From 1971-80, nuclear plants and coal plants over 575 MW averaged 67.8 percent in equivalent availability and coal plants from 200-574 MW averaged 74.3 percent in equivalent availability.

Table 7.—installed Capacity and Net Electricity Generation by Type of Generating Capacity, 1981-82

	Installed generating capability, summer 1981 (GW)	Percent of total	Net electrical energy generation, 1981-82 (billion kWh)	Percent of total
Steam — coal	243	42	1,177	52
Steam — oil	89	16	190	8
Steam — gas	63	11	320	14
Nuclear power	51	9	274	12
Hydro electric	66	12	261	12
Combustion turbine — oil	34	6	3	—
Combustion turbine — gas	6	1	7	—
Combined cycle oil	3	—	2	.
Other	17	3	26	1
Total	572	100	2,260	100

SOURCE **North American Electric Reliability Council,** *Electric Power Supply and Demand 1982-1991,* **August 1982.**

evidence from the past two decades would support an estimate of a loss of 3 to 5 percentage points of average availability for every 5-year increase **in average age of coal plants. Looking ahead, there could also be losses in availability of several percentage points** due to emission controls and requirements for low sulfur coal that is at the same time of lower combustion quality.

Offsetting these tendencies to reduced availability, however, there are also forces that might increase average availability. The utility industry has completed a period of construction of coal plants with poor availability, and the newest plants (from the late 1970's and early 1980's) should have substantially higher average availability. If this were to continue, overall availability could increase. If utilities invest in higher availabilities (e. g., by converting forced draft boilers to balanced draft), this will also increase availability (82). It is clear that attention to fuel quality and good management also can raise availabilities. Some Public Service Commissions (e.g., Michigan) are including incentives to improve availabilities in utilities' rate of return formulas.

On balance, it is unlikely that availability will increase or decrease dramatically. If a change in availability should occur, however, it would have a noticeable impact on the need for new capacity. A 10-percentage-point **change could imply an increased (or reduced) need for powerplants of** more than 40 GW by 2000.

Summary-The Need for New Powerplants.– the need for new powerplants depends on both the growth rates in electricity demand and on the need for replacement of existing generating capacity. Table 8 summarizes most of the range of disagreement and its implications for new powerplants. Estimates of growth in electricity demand range from 1 to 4 percent per year. (The table shows the implications of electricity demand growth rates of 1.5 to 3.5 percent.)

judgments about replacement of existing plants can, somewhat arbitrarily, be divided into high, medium, and low replacement. A high-level replacement of about 200 GW by 2000 would be necessary to: offset a slippage of about 5 percentage points in availability, meet a schedule of 40-year life expectancy for all powerplants, and retire about half the oil and gas capacity in this country (see table 6). A low-level replacement of 50 GW would meet a 50-year schedule, retire a little oil and gas capacity and would assume no slippage or an actual increase in average availability.

If these alternative replacement assumptions are combined with alternative growth rate assumptions (table 8), they lead to a wide range of needs for new plants. About 454 GW of new capacity would be needed, for example, by 2000 (beyond NERC's planned resources for 1991) to meet a 3.5 percent per year increase in peak demand for electricity **and** the high replacement re-

Table 8.—Numbers of 1,000 MW Powerplants Needed in the Year 2000 (beyond current utility plans for 1991)

Levels of replacement of existing plants	Electricity demand growth 1.5%/yr	2.5%/yr	3.5%/yr
Low: 50 GW; Replace all plants over 50 years old . .	9	144	303
Moderate: 125 GW; Replace all plants over 40 years old; plus 20 GW of oil and gas capacity	84	219	379
High: 200 GW; Replace plants over 40 years plus **95 GW of** oil and gas capacity	159	294	454

NOTES: 1. Planned generating capacity for 1991 is 740 GW, 158 GW more than 1982 generating sources of 582 GW. Starting point for demand calculations is 1982 summer peak demand of 428 GW.
2. The calculations assume a 20- percent reserve margin, excess of planned generating resources over peak demand.

SOURCE. Office of Technology Assessment.

quirements, as is pointed out in recent work at the Electric Power Research Institute (83). On the other hand, a low replacement requirement combined with only 1.S percent demand growth per year would require almost no new capacity.

This then is the dilemma for utility strategists. A shift of only 2 percentage points in demand growth combined with a more stretched out retirement schedule can reduce the requirement for new powerplants from hundreds of gigawatts (a number requiring a capital outlay of $0.5 trillion to $1 trillion 1982 dollars) to almost nothing. Some of the factors affecting utility choice of strategy, given this situation, are discussed in the next sections.

RATE REGULATION AND POWERPLANT FINANCE

Although the national average reserve margin will not dip below safe limits until well into the next decade, individual utilities may consider ordering powerplants before 1990 for any of three reasons: to replace expensive oil or natural gas generating capacity, to anticipate growth in their region, or to start a long leadtime plant well before it may be needed in the 1990's. This section describes the framework of rate regulation within which such a decision is made. The next section explores the broader strategic options for utilities.

Utilities' Current Financial Situation

Although the financial situation of utilities is improving slowly, they are still in a greatly weakened financial condition compared to their situation in 1970. The series of figures 9 through 14 prepared for the Department of Energy shows the origins of the financial difficulties of the 1970's until the relative improvement of 1982 (described below).

Utilities raised enormous amounts of capital in external financing in the 8 years from 1973-81, more than double the requirements of the telephone industry-the next most capital-intensive industry (fig. 9). In the process, more and more of utility assets became tied up in construction of new generating capacity (fig. 10), which equaled a quarter of all utility assets as of 1981. At the same time, even with high rates of inflation the nominal return on equity was kept constant. Thus the real value of utilities' return on equity declined sharply (fig. 11).

As a consequence of high inflation, enormous amounts of investment and large fractions of assets under construction, there was weakening of many indicators of financial health that are watched closely by investors. The amount of earnings paid out as dividends increased, leaving less for retained earnings to finance future projects. The ratio of operating income to interest on debt—pretax interest coverage—fell to disturbingly low levels. The cost of capital from issues of new stock and bond sales rose accordingly. After 1973, far more utility bonds were downgraded than upgraded; the number of utility bonds rated only "medium grade" BBB, increased from 10 to 43 (fig. 12). A lower rating usually means that investors require a higher yield in order to purchase the bond, and institutional investors may not be willing to purchase the bond at all (45). Similarly, the average market value of utility stock fell steadily from its high of about 2½ times book value in 1965, to a level equal to book value in 1970 **to less than** book value in 1974 (fig. 13). When stock sells below book value, there are two consequences. The utility must issue more stock, (and pay out more dividends) to raise each new unit of capital than the value of each existing unit of capital, and the value of stock for the existing stockholders is diluted. (See box A for a discussion of market-to-book ratio and stock dilution.)

One of the most serious problems for utilities has been a steady squeeze on cash flow. As shown in fig. 14, almost 50 percent of utilities' nominal return on equity was paper earnings in the form of allowance for funds used during construction (AFUDC). (See box B.) One result is that utilities have retained less and less of their earnings. The share of earnings paid to stockholders as dividends—the dividend payout ratio—increased from 68 percent in 1970 to 77 percent in 1981, For some companies it was above 100 percent, which means they paid out more than they earned (45).

In 1982 and 1983, there was some improvement in utility financial health. As of December 1983, market-to-book ratios were up to an average 0.98, and 51 out of 103 utilities had market-to-book ratios of more than 1.0 (59). Although more bonds are being downgraded than up-

Box A.—Market-To-Book Ratio and Dilution of Stock Value

When the stock of a utility is selling below its original selling price, the market-to-book ratio of the stock is below 1.0. This situation means that any sale of new stock at this lower-than-book price will dilute the value of the existing stock. This will be true even after the new asset begins earning at a full rate. The example that follows illustrates what happens when a utility's stock sells at half of book value, at book value, and at twice book value.

A utility goes into business by selling 1,000 shares at $10 each. The State regulatory agency allows the company to earn a 10 percent return. Ten percent on $10,000 is a $1,000 profit, which equals $1 a share. Now, let us say that the company has to raise $10,000 to build another powerplant and that the regulatory agency will let the utility earn another $1,000 (10 percent of $10,000) as soon as the plant is completed. Depending on the price at which the company sells new stock, the new financing reduces (dilutes), leaves unchanged, or increases earning per share. In the following table, we show what happens when new stock is sold at $5, $10, or $20.

	Market to Book Ratio		
	0.5	*1.0*	*2.0*
Sale price	$5	$10	$20
Net income before completion of new powerplant	$1,000	$1,000	$1,000
Net income earned on new powerplant	1,000	1,000	1,000
Total new income	$2,000	$2,000	$2,000
New shares sold to raise $10,000	2,000	1,000	500
Old shares	1,000	1,000	1,000
Shares outstanding after the offering	3,000	2,000	1,500
Earnings per share	$0.67	$1.00	$1.33

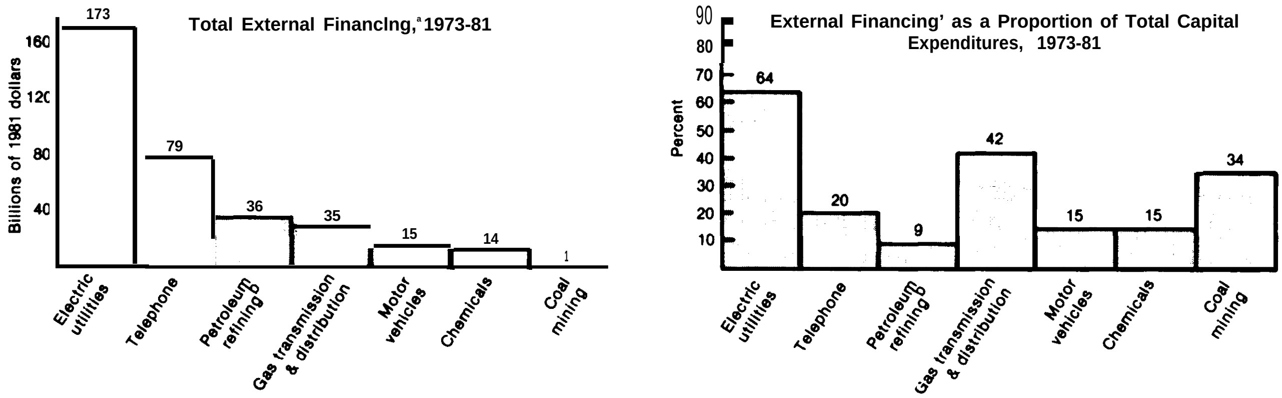
Note that when the stock has to be sold at a low price ($5), earnings per share fall from $1.00 to $0.67 after the offering, despite the rise from $1,000 to $2,000 in the utility's income after the new plant goes into service. In the second example, earnings per share are not diluted by the offering. In the third, they are actually improved.

Electric utility companies often need to sell stock to finance their capital expenditures. When shares are to be sold at low prices, such as those that currently prevail, financing is diluting. Thus, large capital expenditures at a time of low stock prices may be detrimental to current shareholders. That is one reason why many financial experts view a slowdown in utility spending as favorable for shareholders.

SOURCE: Adapted from a description in Hyman and Kelley, *The Financial Aspects of Nuclear Power: Capital, Credit, Demand and Risk*, American Nuclear Society, Dec. 3, 1981 (47).

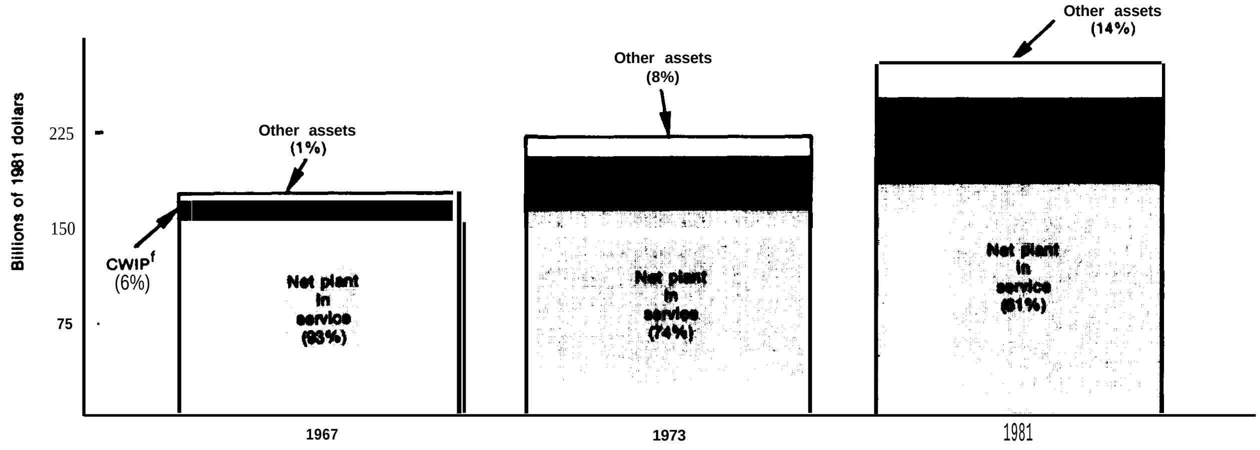
The History of the Deterioration in the Financial Health of Electric Utilities, 1960=82

Figure 9.—The Electric Utility Industry is Dependent on Externally Generated Funds to a Greater Extent Than Other Large Capital Users



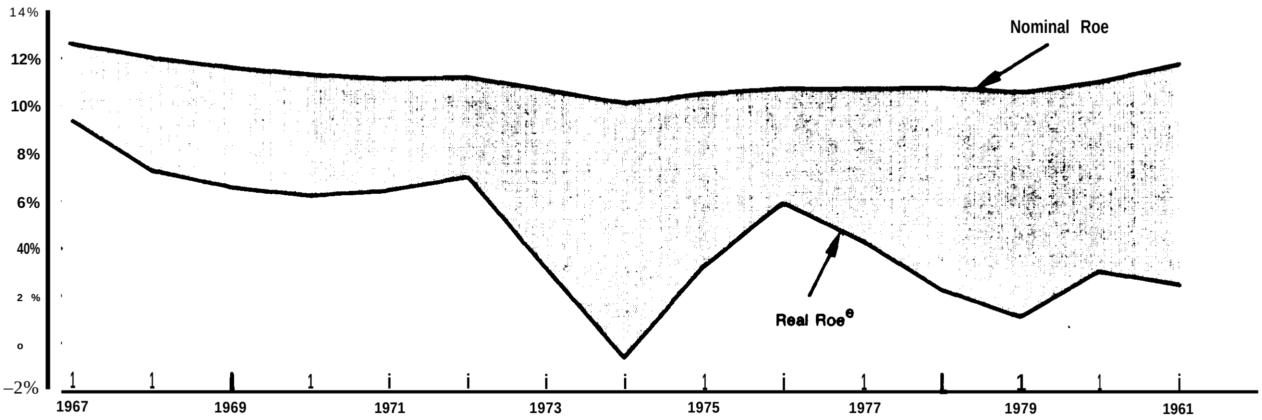
[a]Net of debt retirements.
[b]Includes exploration and production by companies primarily involved in refining.

Figure 10.–Since 1967, the Fraction of Utility Assets Tied Up in "Construction Work in Progress" Has Steadily increased



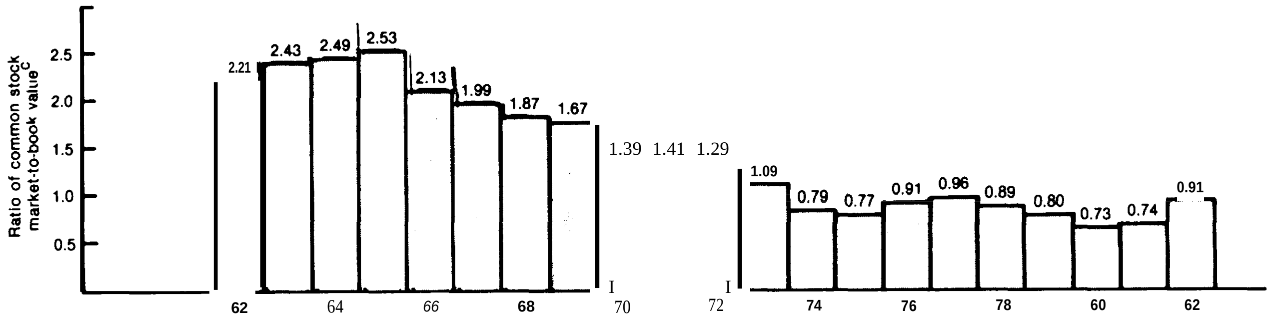
[f]Construction work in progress (CWIP) refers to plant being built, but not Yet in service.

Figure 11.— Beginning in 1972, the Utilities' Real Return on Equity Has Been Eroded by Inflation (utility Industry annual average return on common equity (end of year))



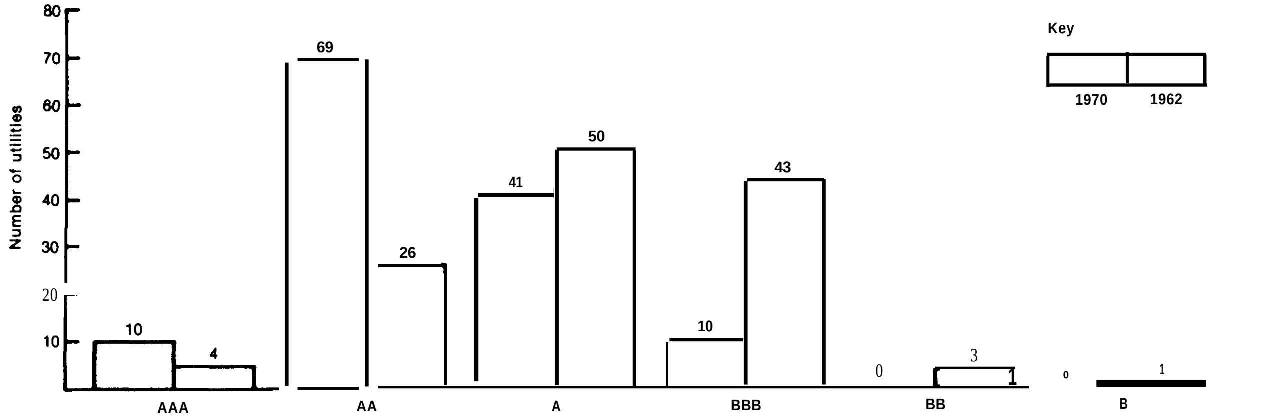
[e]Nominal Roe deflated by GNP implicit price deflator (measured at fourth quarter annually).

Figure 12.—Since 1973, the Average Utility Stock has Sold Below its Book Value[a]



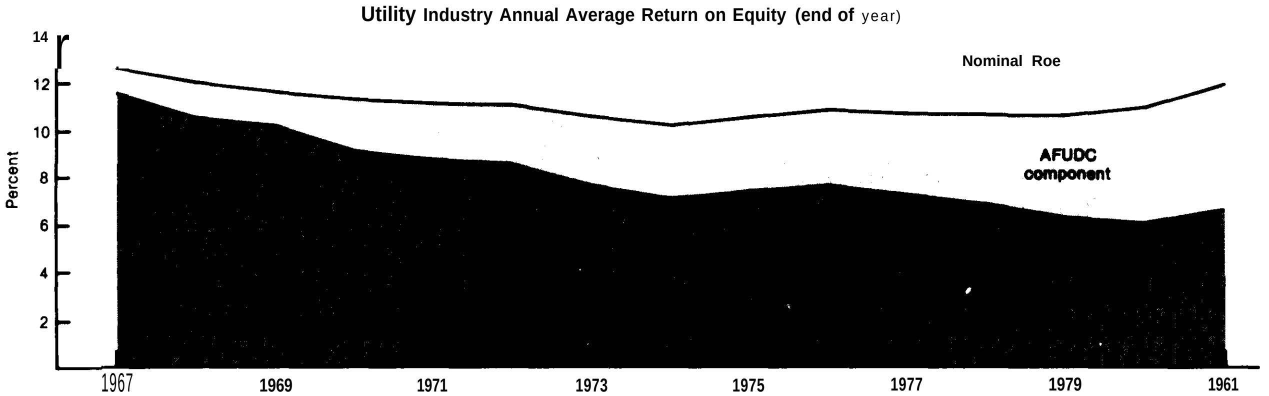
[c]Average of high and low value for the Year.
'August 1962.

Figure 13.—In 1970, A Majority of Utilities Were Rated AA or Better in 1982, a Majority Are Rated A or Worse



[a]See box A for an explanation of the implications of stock selling below book value.

Figure 14.-Over Time, the Share of AFUDC in Total Earnings Has Increased and the Share of Cash Has Fallen



SOURCE: Booz-Allen & Hamilton Inc., *The Financial Health of the Electrlc Utility Industry,* prepared for the Department of Energy October 1962, using data from Utility Compustat; U.S. Department of Commerce, *Survey of Current Business;* Edison Electric Institute, Statistical *Yearbook of the Utility Industry;* Standard and Poor's Bond Guide; Energy Information Administration, *Statistics of Privately Owned Utilities.*

[illegible]

graded, the number of net downgradings has been reduced sharply. By late 1983, the average earned return on common equity for the 100 largest electric utilities was up to 14.1 percent, more than 200 basis points higher than the earned return in 1980 (59).

Implications of Utilities' Financial Situation

There are two ways of looking at the current financial situation of the utilities and the incentives to build more plants. From one perspective the electric utilities have shared in general economic problems and have not fared as badly as some industries. The market-to-book ratios of all industrial stocks fell over the 1970's, although on average the industrial stocks stayed well above a market-to-book ratio of 1.0. For the first part of 1982, the return on investment of the electric utilities ranked 14th out of 39 industries, well above the average for such industries as chemicals, appliances and paper (41).

From this point of view, there is no need for further concern about near-term utility solvency. The worst of the utilities' problems are coming to an end, and their financial situation should improve gradually. Public utility commissions (PUCs) have responded by increasing the allowed rate of return to utilities, and the Federal Government has provided additional relief from cash flow shortages in the 1981 Economic Recovery Tax Act through liberalized depreciation allowances. The tax law further mandates that these must be "normalized" (retained by the utility) rather than "flowed through" to the consumer in lower electricity rates. Further relief for those utilities, with problems selling their stock to finance large construction programs, has also been available from the 1981 Tax Act benefits for reinvestment of dividends in purchases of new utility stock. Over the next few years, external financing needs should diminish gradually, as total construction expenditures decrease slightly and internal funding–from retained earnings, depreciation and deferred Federal taxes–increases.

From another perspective, however, there is still cause for concern. Inflation has brought about several distortions in the ratemaking process that may need to be corrected before the next round of orders for new generating capacity. From this point of view, the issue is not whether utilities need rate relief to keep from going bankrupt, but whether the treatment of capital in rate regulation needs to be adjusted for the impact of inflation in order to prevent allocation of utility resources away from capital-intensive electricity-generating processes—beyond the point where **it** would be beneficial to the ratepayer.

It is not enough, from this perspective, for utilities to recover their financial strength during the coming decade of slowed construction programs. In the 1990's, **when the utilities need capital again** for construction, investment advisors will have models that predict a deterioration in financial health associated with a large construction program unless rate regulation can be expected to give an adequate return on capital right through the construction period.

The concern that electricity rate regulation needs to be adjusted for the impact of inflation can be summed up in several points. The first problem is erosion in the definition of cost of capital. Back in 1962, electricity demand was growing rapidly. There was relatively little inflation, and unit costs of generating electricity were decreasing. Utilities were allowed an average 11.1 percent return on equity and actually earned slightly more than that—about 11.3 percent—right in line with the average of Standard & Poor's 400 industrial stocks (45).

By 1973, this situation had changed. Demand for electricity was growing more slowly, inflation had increased greatly, and the unit costs of producing electricity had begun to increase. From 1973 to 1981, the return on equity earned by utilities (10.9 percent) fell substantially below the return on equity allowed by State PUCs (1 3.3 percent). Although the allowed return came close to the return on equity earned by the 400 industrials (14.3 percent), the earned return fell well below. If the return on equity is designed to exclude AFUDC-deferred paper earnings, it fell far below the return on industrials (see fig. 14).

For utilities to earn a return on equity significantly below that earned by industrial stocks represents a change from past regulatory practice. The basis for determining rate of return has its legal foundation in two cases–the 1923 *Bluefield Water Works** case and the 1944 Hope *Natural Gas Co.* case.** These cases established three principles:

1. the utility can charge rates sufficiently high to maintain its financial integrity;
2. the utility's rates may cover all legitimate expenses including the cost of capital; and
3. the utility should be able to earn return at a rate that is comparable to companies of comparable risk.

Although in principle PUCs allowed rates of return on equity comparable to companies of comparable risk, in practice they failed to adapt rate regulation practices to accommodate inflation. The practice of using an historical test year rather than a future year to determine income and expenses is one example. Politically, it often was difficult for PUCs to grant full rate increases requested by utilities when inflation caused them to return year after year. As precedents accumulated in each State it became harder for individual Commissioners to argue for a restoration to the full Hope/Bluefield definition of cost of capital. * * *

● ***Blue field Water Works and Improvement Co. v. West** Virginia Public* ***Service Commission, 262*** **'US 679, 692** PUR **1923D** 11.

*****Federal Power Commission*** v. ***Hope Natural Gas Co. (1944), 320*** **US 591, 60351** PUR **NS 193.**

*****It is in this context that one Wall Street participant in an OTA workshop recommended a high-level commission of rate regulators, utility executives, and investment advisors to reexamine the** Hope/Bluefield **principles, determine the problems of implementing the principles in times of inflation, and make recommendations that take into account the political realities of a Federal system.**

A second problem, exacerbating the first, is that of "rate shock" which arises from the front-end loading of rate requirements for large capital investments. This phenomenon (explained in box C) is noticeable at low rates of inflation and is striking at high rates of inflation. Assuming 7 percent inflation, for example, the cost of electricity in constant dollars from Nuclear Plant X shown in box C would be 9.5¢/kWh the first year and only 1.5¢/kWh the 20th year. For large plants entering the rate base of small utilities, the increase can be 20 to 30 percent the first year. This problem is exacerbated the more AFUDC (see box B) is included in the cost of the plant as it enters the rate base. (AFUDC is described further in the next section on the risks of constructing nuclear plants because the impact of AFUDC is largest for plants with the high capital cost and long duration of nuclear plants.)

The combination of the very high rate requirements in early years and low rate requirements in subsequent years discourages multidecade planning of generating capacity. While short-term rate increases must be tolerated to realize long-term reductions in real electricity rates, there are intense political pressures on public utility commissioners to hold down these short-term rates (88).

A final cause for distortion in utility rate regulation is the generally practiced fuel pass-through which allows utilities to pass changes in fuel prices onto consumers without going back to the PUC for an increase in rates. This has been a useful device for avoiding damage to utility cash flow from the volatile changes in fuel (oil and natural gas) prices in the 1970's but it has had the inadvertent effect of shielding utilities from the effects of inflation in fuel costs while they have not been shielded from increases in the cost of capital. For a utility faced with capital expenditures to avoid fuel costs—through rehabilitating a plant, building a new one, or investing in load management—there is a theoretical incentive to stick with the fuel-burning plant as long as fuel costs are recovered immediately and capital costs are recovered late and not fully.

Many utilities continue to base their generating capacity decisions on what will minimize lifetime costs to ratepayers. However, some utilities are beginning to say openly (seethe later discussion of utility strategies) that they are attempting to minimize capital requirements rather than total revenue requirements, to protect the interests of their stockholders to the possible long-term detriment of the ratepayers.

Possible Changes in Rate Regulation

There have been many specific proposals for utility rate regulation. Some are designed to encourage conservation, load management, or the rehabilitation of existing powerplants. Others are designed to encourage the construction of new powerplants, especially when they are intended to displace powerplants now burning oil or natural gas.

This assessment does not deal with the complex subject of rate regulation reform in any detail. However, it is useful to describe briefly some of those reform proposals that are specifically intended to offset those aspects of rate regulation that discourage capital-intensive or risky projects. These reform proposals would be most likely to improve the prospects for more orders of nuclear powerplants.

Construction Work in Progress (CWIP).–The simplest of the proposed changes in rate regulation is to allow a large fraction or all of a utility's CWIP in the rate base. CWIP is advocated because it reduces or eliminates AFUDC. This in turn increases utility cash flow and the quality of earnings and reduces the likelihood of rate shock because the rate base of the new plant includes little or no AFUDC.

One argument for including CWIP in the rate base is that electricity rates come closer to reflecting the true cost of incremental electricity demand, providing a more accurate incentive for conservation. Opponents of CWIP in the rate base, however, fear that utilities will lose the incentive to keep plant costs down and to finish them on time. Furthermore, opponents claim, utilities may return to overbuilding. Many PUCs have responded to these concerns by including only a portion of CWIP in the rate base (62).

Phased-in Rate Requirements. -At least six States have developed methods of phasing in the rate requirements for large new nuclear power-

Box C.—Utility Accounting and the Origins of "The Money-Saving Rate Increase"[1]

The conventions of utility accounting have created a dilemma that affects all investment choices between a capital-intensive plant (e.g., a nuclear or baseload coal plant) and a fuel-intensive plant (e.g., a combustion turbine or an oil or gas steam plant}. if two plants (one of each type) have equal levelized annual cost, and equal lifecycle cost, the capital-intensive plant will cost consumers far more in early years and the fuel-intensive plant will cost far more in later years. This situation causes a dilemma for oil- and gas-using utilities who wish to substitute coal or nuclear plants for their oil or gas plants. When their analysis convinces them that the lifecycle cost of the coal or nuclear plant will be less, they still must face a "money-saving rate increase" to cover the early years extra cost of the capital-intensive plant.

An Example. The dilemma is illustrated by a specific example in table Cl. A nuclear plant called Nuclear Plant X has been constructed for $2 billion (including accumulated AFUDC) and is about to be placed in service to replace an oil plant that produces the same amount of electricity. The oil plant is old and fully depreciated and earns no return to capital. When the nuclear plant goes into service there will be a net fuel saving the first year of $263 million, which equals the value of oil saved less the cost of nuclear fuel for the nuclear plant. At the same time, accounting and ratemaking conventions dictate that the first-year capital charge for the nuclear plant will be $471 million, or $208 million more than the fuel savings. In the fifth year the capital charge has dropped to $364 million, less than the fuel savings for the first time (if the cost of fuel escalates at 9 percent per year), and by the eighth year the cumulative capital charge of the nuclear plant will be less than the cumulative savings resulting from lower fuel costs. In the 15th year, the nuclear plant costs only $268 million in rate requirements and saves $878 million in fuel costs.

If fuel costs escalate more slowly (at only 5 percent per year), the results are shown in the right-hand columns in table Cl. Annual capital charges for Nuclear Plant X drop below annual fuel savings during the sixth year and Nuclear Plant X breaks even on a cumulative basis by the 12th year. In both cases, Nuclear Plant X will cost less over the 30-year life of the plant (if a discount rate of 12 percent is used). In the first case (with 9 percent fuel escalation), Nuclear Plant X will cost about $3.1 billion in lifetime discounted rate requirements and will save $5 billion. In the second case (with 5 percent annual fuel cost escalation), Nuclear Plant X will save $3.5 billion. In both cases the electricity ratepayers would be better off with Nuclear Plant X over the long run. However, consumers would be worse off in the short run, because of the high capital charges at the beginning of plant operation, which translate into high electricity rates.

Two Other Examples. To take another example of this phenomenon, which is sometimes referred to as "front-end loading" of capital costs, suppose another Nuclear Plant Y, with identical construction cost (in 1982 dollars) as Nuclear Plant X had been placed in the rate base 8 years before, in 1974. By 1982, the capital charge for Plant Y in the eighth year of operation would have diminished so much (using the same schedule of capital charges) that it would cost $0.03/kWh while the first-year capital charge for Nuclear Plant X, put in service in 1982, would be $0.09/kWh. Part of the reason for the difference is that the book value (see explanation below of Plant Y is only $1.1 billion, the equivalent in 1982 dollars to the $2 billion cost of Nuclear Plant X. The rest of the difference is that the capital charge for the eighth year is only 0.15 of the original cost; compared to 0.24 in the first year.

In still another example, if Nuclear Plant X is replaced in its 30th year of operation by another identical plant, the first-year capital charge for that plant will& $3.6 billion, more than 20 times the capital charge of $170 million in the 30th year of Nuclear Plant X.

Why Utility Accounting Practice Produces This Result. T he main reason for this result is that the value of a plant is carried at original cost (book value) not at replacement cost (market value) on a utility's books. The annual capital charge used in computing rate requirements has a series of components,

[1]The analysis in this box is based on two articles by Sally Hunt Waiter, "Trending the Rate Base," *Public Utilities Fortnightly,* May 13, 1982, and "Avoiding the Money Saving Rate Increase," *Public Utilities Fortnightly,* June 24, 1962.

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all of which require multiplying some percent times original cost. These components include: return on equity investment (a percent return times the book value of equity investment), debt service (percent of book value borrowed), depreciation (a percent each year times the book value of the asset), and property tax (a percent times book value). Furthermore, as the plant is depreciated, the book value of the plant is reduced by the amount of the depreciation. A simplified example is illustrated in figure C1. The original (book value) rate base of $1,000 is reduced each year by the amount of depreciation and drops to zero in the 20th year. The current earnings are calculated at 0.12 times the depreciated rate base, and they are reduced as the rate base is reduced.

Alternative Accounting Practices. In its simplest form, the chief proposal for alleviating the distortions in decisionmaking caused by the phenomenon of front-end loading of capital charges, is to replace the use of original cost (book value) in the calculating of capital charges, with a calculation closer to replacement cost. The conceptually simplest of these calculation methods is called "trended original cost" because it increases the value of the rate base (asset) in keeping with the trend in general prices, and does not require a calculation of the market value of the asset. With a trended original cost rate base, the method for calculating the rate of return changes. Because inflation is taken care of in the reevaluation of the rate base, inflation is removed from the rate of return, and the real rate of return is used instead of the nominal rate. Depreciation charges are also changed. They are set to increase with the nominal interest rate. These changes ensure that the discounted lifecycle revenues of both methods are the same.

A specific example is illustrated in figure C2. The original rate base of $1,000 is increased each year by 0.07, the assumed rate of inflation. Then the year's depreciation charge is subtracted. The rate base gradually increases (in current dollars) until the ninth year and then it starts to drop until it reaches zero in the 20th year. Current earnings are calculated at 0.05 of the rate base, and are much lower in the early years under this method than under original cost accounting. Depreciation starts lower but eventually reaches a substantial sum in the 20th year, providing cash flow at the point when the plant should be replaced. As is clear from figure C2, the total revenue requirements for the nuclear plant increase in keeping with the general increase in prices. The present value of both revenue streams and therefore consumer payments is exactly the same at a discount rate equal to the nominal interest rate.

Table C1.—Revenue Requirements and Fuel Savings for Nuclear Plant X

Year from entry in service	Revenue requirements for nuclear plant	Fuel savings at $35/bbl oil with 9% escalation			Fuel savings at $35/bbl oil with 5% escalation		
		Fuel savings	Net savings (2) – (1)	Cumulative savings	Fuel savings	Net savings (5) – (1)	Cumulative savings
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				(millions of dollars)			
1	471	263	–208	–208	263	–208	–208
2	425	288	–139	–347	276	–149	–357
3	403	312	–91	–437	290	–113	–470
4	383	340	–43	–480	304	–79	–549
5	364	371	7	–473	319	–45	–594
6	348	404	56	–417	335	–13	–608
7	333	441	108	–309	352	19	–587
8	320	480	160	–149	370	50	–537
9	309	524	215	66	388	79	–458
10	299	571	272	338	408	109	–349
11	291	622	331	669	428	137	–212
12	286	678	392	1,061	449	163	-49
13	280	739	459	1,520	472	192	143
15	268	878	610	2,662	520	252	617
20	288	1,351	1,063	7,018	664	376	2,263
25	231	2,079	1,848	14,583	848	617	4,846
30	174	3,199	3,025	27,141	1,082	908	8,779

ASSUMPTIONS: Revenue requirements for each of 30 years based on: return on common equity = 14%; debt cost = 11%; insurance, property taxes, and replacement = 1.95%; normalized investment tax credit and accelerated depreciation and 10-year ADR life, with a 30-year life.

Figure Cl.—Rate Base and Revenue Requirements Under Original Cost Accounting

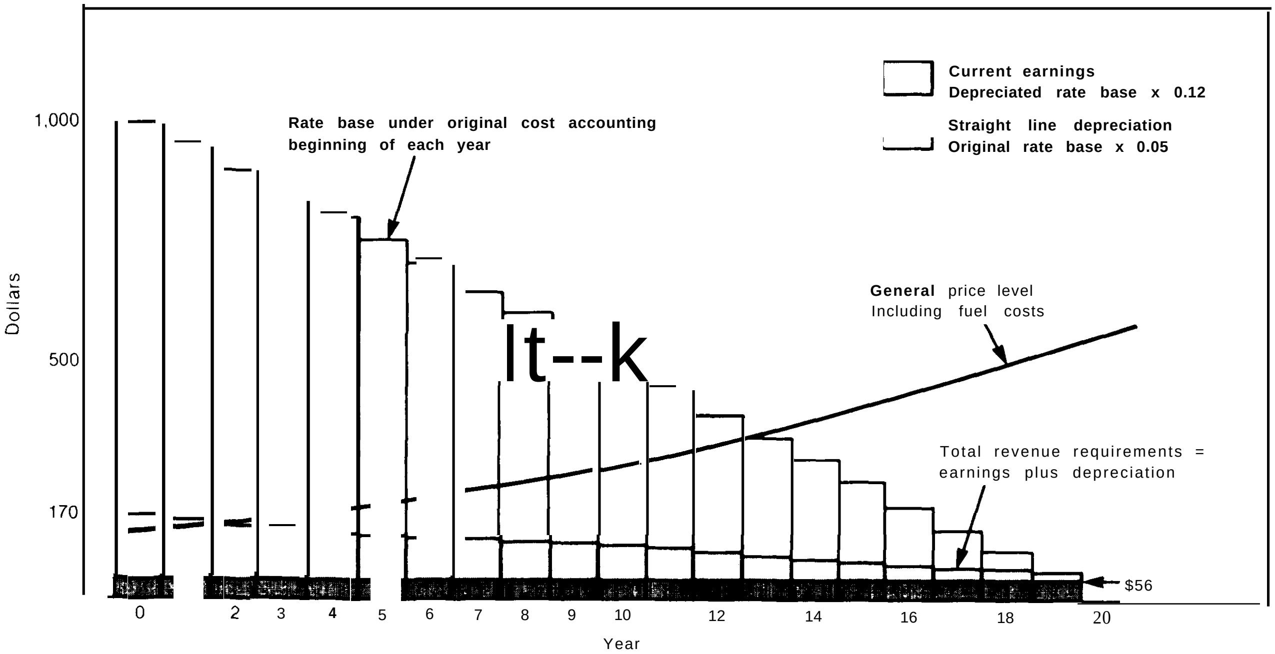
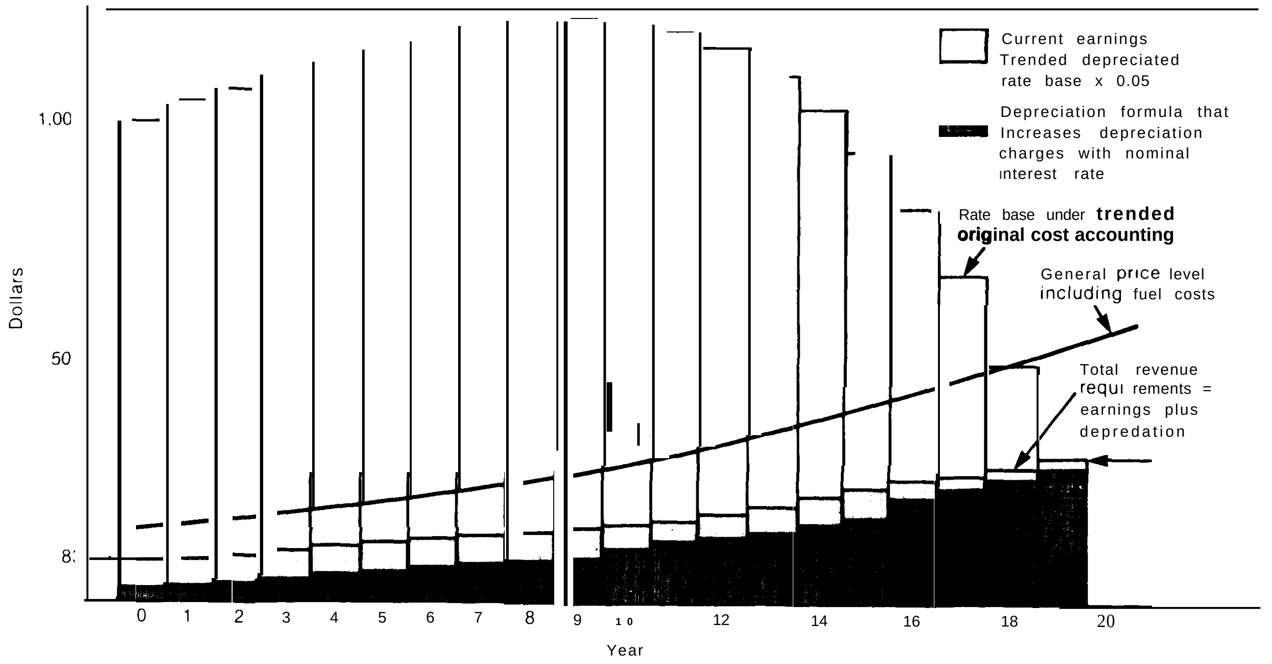


Figure C2.-Rate Base and Revenue Requirements Under Trended Original Cost Accounting



plants which would cause significant early year rate increases under conventional rate treatments **(75). Two of these (New York and Illinois) have developed plans for "negative CWIP." Under these schemes, some** CWIP is allowed in the rate base for several years before a plant comes on-line and then an equal amount is subtracted from the rate base for the first few years after the plant comes online. After the first few years the rate base returns to what it would have been in the absence of any **CWIP.**

Pay-As-You-Go for Inflation Schemes.—Recently, a series of proposals have been made to adapt the sequence of rate requirements for a capital-intensive plant, (e.g., a nuclear plant) more explicitly to inflation **(54,88).** In effect, these proposals would eliminate the front-end loading of capital return for capital-intensive plants in time of inflation and replace the "downward slope" of annual rate requirements in constant dollars (shown in fig. Cl in box C) with a horizontal or gentle upward slope more like the sequence of annual rate requirements for an oil plant (shown in fig. **C2** in box C).

Some of these proposals would do this directly by using a rate of return net of inflation and adjusting the rate base for inflation (this is called "trended original cost" ratemaking in contrast to "original cost" ratemaking), Others would do it indirectly by deferring certain operating or depreciation expenditures until later so as to approximate an upward slope of rate requirements.

The Obstacles to a Long-Term Commission Perspective.– In principle, these latter proposals would all make it easier for **PUCs** to increase the authorized real return on equity because rate increases for new powerplants are less likely. Increasing the authorized return should in turn improve the incentives for constructing new powerplants when it is in the long-term interests of the ratepayers. All these proposals, however, rely on an implicit agreement between investors and **PUCs** that a particular way of determining revenues will be maintained over decades. Under Trended Original Cost schemes, utility investors accept a lower rate of return in early years with the promise that the rate base will be fully adjusted for inflation. Under indexed rate of return schemes, investors accept a somewhat lower than market rate of return as interest rates are going up, in return for enjoying a somewhat-higher-than-market rate of return as interest rates are coming back down.

It is just this implicit agreement that seems to be missing from today's rate regulation procedures. in some cases, the PUC may be willing to work out a sensible approach to rate determination over the long term, but is blocked by the State legislature. The Indiana PUC, for example, introduced a graduated rate increase incorporating trended original cost principles to bring Marble Hill, a large nuclear plant, into the rate base of Indiana Public Service. The plan was explicitly blocked by the State legislature. Eight States, by vote of the State legislature or by referendum, have banned CWIP inclusions in utility rate bases for just the reasons described above (41).

Furthermore, commissioners may lack the time or motivation to grasp the long-term view. Pennsylvania is one of the few States with 1()-year terms for its appointed commissioners. Many States have reduced PUC terms of 6 or longer to 4 or 5 years. An increasing number of States have elected rather than appointed commissioners. For most commissioners, electric utility rate cases are only a few among hundreds or thousands of cases from local as well as statewide utilities, that provide water, sewer, telephone, and gas as well as electricity. Often, electric utilities and their consumers must take time to educate commissioners about the issues surrounding electricity supply, demand and rates over the long term.

It is interesting to note (see ch. 7) that the United States is the only one of all the major developed countries with a Federal system in which retail electricity rates are regulated at the State level. In many countries, electricity rates are unregulated. In West Germany, State electric authorities set their own rates subject to Federal approval. In the United States, State regulation leads to the result that the cost of utility capital (return on equity) varies among the different States from 12 to 17 percent, even though the market for capital generally is recognized as national. Because of the strong U.S. Federal tradition, however, any proposals for regional or Federal determination of the cost of capital or other regulation on State regulation must be developed in the context of longstanding legal traditions about the Federal regulation of commerce.

The Impact of Changes in Rate Regulation in Electricity Prices.–Changes in rate regulation to increase the return to capital, utility cash flow, and/or quality of earnings, in turn would increase electricity rates. How much rates would increase is important to know for two reasons. **It** would help to weigh current consumer interests against future consumer interests. It would help also to identify the likely future course of electricity prices and the resulting impact on electricity demand. Uncertainty about future electricity price increases is a key source of uncertainty about how much electricity demand will increase.

Most of the attempts to estimate the impact of changes in rate regulation on electricity rates have focused on regions (48,85). There appears to be minimal impact on average regional electricity prices from increasing the return to capital and including CWIP in the rate base—an increase in average regional electricity prices of 2 to 3 percent. Regional analysis of rate impacts, however, combine the experiences of quite different utilities.

For two individual utilities, examined as case studies in a recent analysis, the impacts of rate regulation changes would be significant but fairly short-lived (2). Increasing the average rate of return in 1982 from 12 to 16 percent, for example, would have caused a 1 -year increase of 3.3 percent in the rates of a Southeastern utility and a 6.2-percent increase in rates for a Midwestern utility. Rates would have stabilized in the following years.

The impact of CWIP on rates is estimated to be greater but also fairly short-lived. Including CWIP in rate base in 1982 would have increased rates 5 percent for the Southeastern utility and **14.2** percent for the Midwestern utility. Eight years later, however, in 1990, the rates would be only 0.4 percent higher than without CWIP for the Southeastern utility and would actually be lower for the Midwestern utility. Although short-lived, the increase in rates is large enough that there would be a substantial impact on electricity demand, spread out, to be sure, over a number of years.

Before PUCs can tackle fully the long-term implications of possible rate regulatory changes, it would be useful to have a more complete understanding of the impacts on rates and potential demand responses.

Conclusion.– Because of the financial deterioration experienced in the 1970's, utilities do not have the financial reserves that they had in the late 1960's and must therefore pay more attention to the impact of their future construction programs on their future financial health. Although their finances are improving, utilities are likely again to find themselves in weakened condition similar to that experienced in the 1970's if they embark on another round of large-scale construction later this century. This is especially true if inflation increases again and exacerbates the impact of AFUDC and the front-end loading of rate requirements for such capital-intensive projects as nuclear plants.

The last section of the chapter discusses utility strategies. One element of choice for both utilities and PUCs is the tradeoff between short-term price increases from rate regulation policies designed to be more attractive to capital and longer term price decreases projected to come about from construction of central station powerplants (including nuclear) which are expected to be the lowest cost source of baseload power over their lifetimes.

THE COST OF BUILDING AND OPERATING NUCLEAR POWERPLANTS

In addition to the bias against capital-intensive generation caused by current ratemaking practice, investors and utility executives cite several major financial reasons to be wary of investing in nuclear powerplants. First, the cost of building a nuclear powerplant has increased rapidly over the **past** decade. The estimated cost of the average nuclear plant now being completed is so high that the average coal plant, in most cases, would produce electricity more cheaply over a lifetime (although in most regions the lowest cost nuclear plants are still competitive with coal plants). Second, the average construction time* of a nuclear plant has increased much faster than the average leadtimes for a coal plant, and this makes it harder for nuclear plants than coal plants to match demand. Third, since the Three Mile Island accident, it has been widely recognized that a major accident can disable an entire plant for an extended period of time and require more than $1 billion in cleanup costs, as well as other expenses to restart the plant and pay for replacement power. Major disabling accidents at coal plants are both less likely and less costly to cleanup and repair. Finally, the current political climate for nuclear (described in ch. 8) is a major source of financial risk. The output of a several billion dollar investment in a plant could be lost for a year or more if regulatory commissions refuse to put it in the rate base, or if a statewide anti-nuclear referendum passes and the plant is shut down. Nuclear accidents or near-accidents in plants owned by other utilities can lead to a new series of safety regulations (discussed further in ch. 6) requiring backfits that may cost a sizable fraction of the original cost of the plant.

The Rapid Increase in Nuclear Plant Cost

In the early 1970's, nuclear powerplants were completed for a total cost of about $150 to $300/kW. ** As of 1983, seven nuclear powerplants almost complete and ready to come online will cost from $1,000 to $3,000/kW, an increase of 550 to 900 percent. General inflation alone would account only for an increase of 115 percent from 1971 to 1983. Inflation in components of (labor and materials) used to build nuclear powerplants*** would account for a further increase of about 20 percent.

*Defined as follows: *for nuc/carp/ants,* issue of construction permit to commercial operation; *for coal plants,* order of boiler to commercial operation.

**In "mixed" dollars, see explanation below.

***As measured *by the* Handy-Whitman index. See below.

Several attempts have been made to document and understand the increase in cost of nuclear power over the past decade (6,7,1 7,37,55,61 ,76). The task is difficult because the cost data cited above cannot be used for comparing plants over time. The above estimates are composites of construction expenses paid in different years with different dollar values, referred to as "mixed" dollars. Most also include some interest that has been deferred during construction, capitalized, and added to the total capital cost (see box B in the previous section on CWIP and AFUDC). The amount of interest that is capitalized varies from State to State and interest rates vary from year to year.

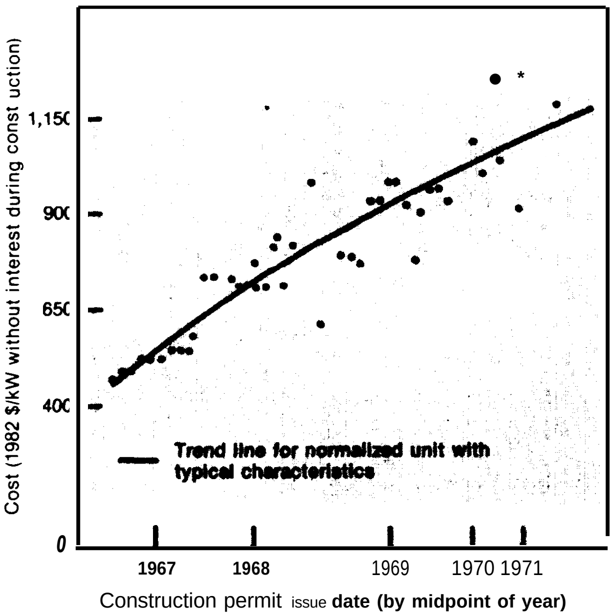
The increase in costs of nuclear powerplants through the 1970's was analyzed in a carefully documented study by Charles Komanoff (55). The costs exclude interest during construction and were adjusted for inflation, permitting comparisons from year to year. * Figure 15 is a plot of the costs per kW (expressed in 1982 dollars) of individual powerplants with construction permits issued from 1967 to 1971. (It is more accurate to group the different generations of nuclear powerplants by start date than by completion date. Later completion dates, by definition, will have a disproportionate share of the delayed, and therefore probably more expensive, plants.)

For plants with construction permits issued around 1967 (and generally completed in 1972-74), the direct costs in 1982 dollars ranged from $400 to $500/kW. For plants with construction permits issued 3 years later, in 1970-71 (and completed in 1976-78) the direct cost in 1982 dollars had more than doubled to $900 to $1,300/kW.

A comparable analysis by Komanoff of the costs of plants currently under construction has been completed but will not be published until early 1984 (56). Preliminary results show that the cost of a typical plant continued to increase, and the range of cost experiences also has increased since the early 1970's. Figure 16 compares "typical" plants completed in 1971 and 1978 (these are

*As described in Komanoff's *Powerplant Cost Escalation (55)* app. C, a standard pattern of cash payments was assumed for each plant and then deflated using the Handy-Whitman index developed to make inflation estimates of components used in powerplants.

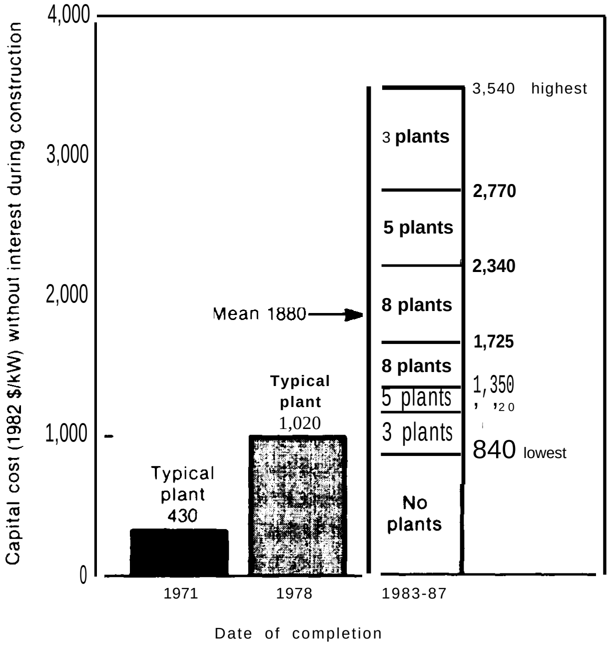
Figure 15.–Costs of Nuclear Units With Construction Permits Issued, 1966-71 (without interest during construction)



NOTE: Plant costs in mid-1979 dollars were escalated to mid-1962 dollars using the Handy-Whitman index for nuclear plant components (multiplying by a factor of 1.276).

SOURCE: Updated by OTA from data In Charles Komanoff, *Power Plant Cost Escalation,* Komanoff Energy Associates 1961, republished by Van Nostrand Reinhold, 1962.

Figure 16.—Total Capital Costs for Nuclear Plants Completed in 1971, 1978, and 1983=87 (estimated) in 1982 Dollars Without Interest During Construction



NOTES: "Plant" is defined as a single nuclear site or station with one or more reactors, The plant costs in-mid-1979 dollars from Komanoff's book *for* 1971 and 1978 plants were stripped of interest and escalated to mid-1962 dollars using the Handy-Whitman index for nuclear plant components (multiplying by a factor of 1.276). The costs for the plants to be completed in 1963-87 are based on mid-1963 utility estimates for a group of 32 sites (stations) with a total of 50 reactors and excludes: Marble Hill, Waterford 3, Susquehanna and all Washington Public Power System (WPPS) plants except WPPS 2.

SOURCE: Charles Komanoff, *Power Plant Cost Escalation,* Komanoff Energy Associates, 1981, republished by Van Nostrand Reinhold 1982; unpublished analysis from forthcoming report by Charles Komanoff and Irving C. Bupp to be published in the winter of 1984, and the Off Ice of Technology Assessment.

constructed from a composite of characteristics associated with average and not high or low costs) with the full range of costs estimated for a group of 32 plants under construction for completion in the 1980's. The cost (in 1982 dollars) of a typical plant increased from about $430/kW in 1971 to $1,020/kW in 1978, to a range of $840 to $3,540/kW for plants under construction in 1983. The median plant of this group is expected to cost $1,725/kW and the average cost is somewhat higher ($1,880/kW) reflecting the wide variation in costs at the upper end of this wide range.

The same increase also is evident in pairs of plants built by the same company and intended to be identical except for regulatory changes and some construction management improvements. The cost of Florida Power & Light's St. Lucie 2 when completed in 1983 ($1,700/kW in 1982 dollars) was about 50 percent more than that of St. Lucie 1 completed in 1976. Commonwealth Edison's Byron 1 and 2, to be completed in 1984 and 1985 at an estimated cost of $1,100 to $1,150/kW (in 1982 dollars) will cost about 90 percent more than the company's Zion 1 and 2, completed in 1973 and 1974.

Until the early 1980's, nuclear plant costs increased steadily with each generation of plants (55,61,75). However, Komanoff's analysis shows no tendency for plants scheduled for completion later in the 1980's to have significantly greater expected costs than plants being completed in 1983-84. In part, this may be due to underestimation of costs for plants still far from completion, but it also is probable that factors other than time now are more influential on powerplant cost. (A complete list of the mixed-dollar cost for plants in various stages of completion is given in app. table 3A.)

The variation from lowest to highest cost nuclear powerplants in the current generation is striking. Construction costs per kilowatt are expected to be over four times higher (in 1982 dollars) for Long Island Lighting Co.'s Shoreham at $3,500/kW than they are for Duke Power's McGuire 1 and 2 at $840/kW. For the current generation of plants, Komanoff found some variables that explain much of this large variation (56). For example, estimated plant cost decreases about 15 percent for every doubling of the number of megawatts at a single site. Estimated plant cost also decreases 8 to 10 percent for each previous plant site built by the same utility. Based on these results, a utility that had built on 5 previous plant sites should be able to construct its next plant site for 30 to 40 percent less than a utility with no experience. Plant cost also varies by manufacturer (as much as 15 percent) and is significantly higher (30 to 40 percent) for plants located in the Northeast region due primarily to higher labor cost and shorter construction seasons.

The importance of utility experience and site-related experience for this latest group of plants is evidence of the impact of some of the utility managerial experience described in chapter 5. There seems to be a site-specific and company-specific learning-curve for bringing plant costs down.

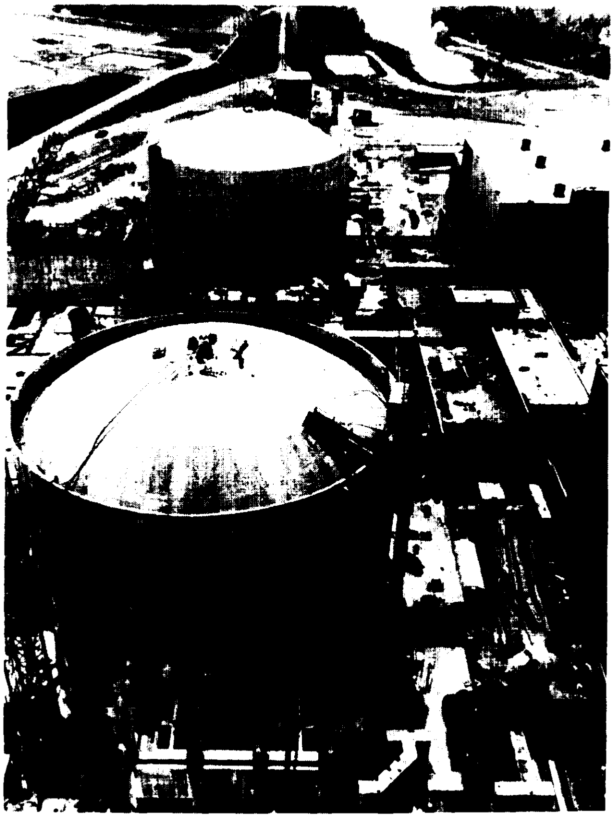


Photo credit: Duke Power Co.

Capital costs per kilowatt of identical plants at a single site are usually lower than average. This photo shows Catawba nuclear station, owned by Duke Power Co., which is expected to produce among the lowest cost electricity of any plant in its timeframe when it comes online in 1985

Reasons for Increased Construction Cost

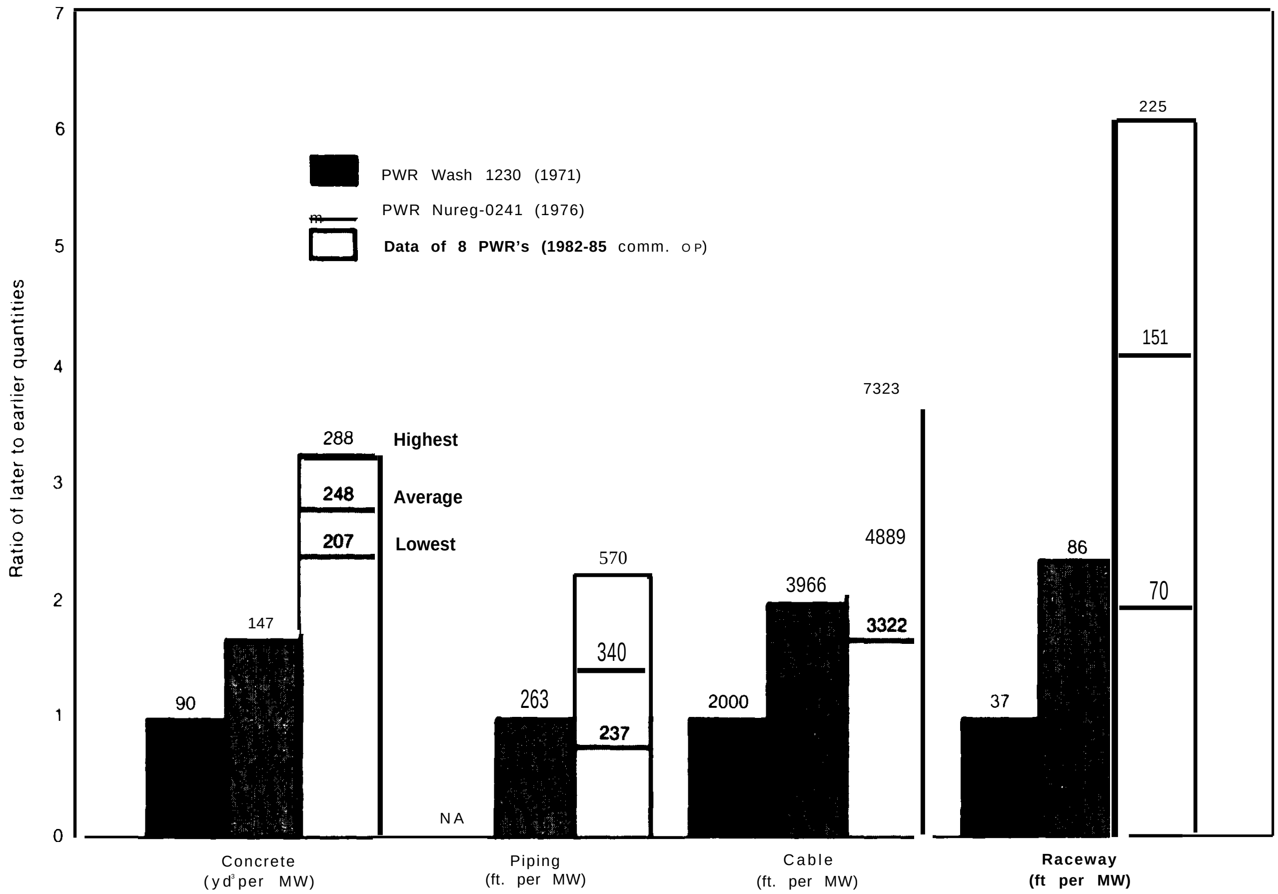
Several different kinds of increase contributed to the dramatic increase in average cost described above. To begin with, these comparative cost estimates exclude the influence of nuclear-component inflation that compares the cost of equal-quality nuclear components and materials over time. Nuclear component prices increased 1 or 2 percentage points faster than inflation. *

Several changes account for the increase in constant dollar cost. According to several related DOE studies, materials used in nuclear plants have increased, e.g., from an estimated 2,000 ft/MW of cable for a typical plant to be constructed in 1971 to about 5,000 ft/MW of cable for the average of eight plants under construction in 1982-85. Figure 17 shows similar increases in the use of concrete, piping and cable raceway (supports for electric cable) (17). Increased material requirements are due both to direct increases in structural and electrical complexity and to the increased rework necessary to meet more stringent quality-control requirements.

Materials also have become more complex. A whole set of seismic requirements to restrain piping systems during earthquakes was introduced in the late 1970's. Simple cast or machined pipe supports (costing several hundred dollars) have been replaced with very sophisticated restraints called "snub bers," with shock-absorbers, costing many thousands of dollars. Pipe supports have become more massive and have had to be fitted

*This is measured by the Handy-Whitman nuclear index (55).

Figure 17.—Trends in Material Requirements in Estimates of PWR Construction Cost



NOTE The first two columns come from engineering estimates prepared for the NRC (formerly the AEC) based on construction data from plants under construction or complete at that time The last column comes from a survey of eight plants under construction See source article for references and more description

SOURCE John H. Crowley and Jerry D. Griffith, "'U S Construction Cost Rise Threatens Nuclear Option " Nuclear *Engineering International,* June 1982

with much tighter tolerances to the pipes they support.

Quality-control procedures and paperwork have added to the cost of materials and components. Although there has been no comprehensive study, there are individual examples and anecdotes to illustrate the claim that quality control represents a bigger and bigger share of nuclear materials cost. In one such example (86) structural steel supports now required for nuclear plants cost between two and three times the cost of the same quality steel supports that are still used for general construction projects and that were permitted on nuclear projects until 1975. Of this amount, the quality control procedures account for virtually all the increased cost.

Finally, there has been a steady increase in the amount of labor required per kW, both manual (craft) and nonmanual. For a series of typical plants costed out over 15 years in a study for DOE, craft labor requirements increased from 3.5 workhours/kW for **a** plant starting construction in 1967 to **21.6** workhours/kW for the average of 16 plants under construction for completion in 1982-85 (17). Nonmanual field and engineering services also have increased dramatically. For a slightly different series of typical plants, estimates of field and engineering services increased from 1.3 workhours/kW in 1967 to 9.2 workhours/kW in 1980 (16).

The increase in labor per kilowatt of capacity is the result of complex interactions resulting from increasingly demanding regulations, quality-assurance requirements and the subsequent utility management response to these. These are described in more detail in chapters 4 and 5 and in several case studies (92).

There is large variation in material and labor requirements from plant to plant, just as there is large variation in overall capital cost. For a group of 16 plants scheduled to be completed in 1982-86, craft labor varied from a low of 15 workhours/kW to a high of 33 workhours/kW. Similarly, for a group of eight plants, linear feet of cable varied from a low of about 3,300 ft/MW to a high of about 7,300 ft/MW (see fig. 17).

The Increase in Nuclear Construction Leadtimes

Nuclear construction leadtimes also increased over the decade, making it increasingly difficult to match nuclear plants to demand, adding to interest and escalation costs, and exacerbating problems with cash flow. At the same time, leadtimes for coal plants increased very little (from an average of 58 to about 60 months) (1).

Documenting the increase in leadtimes for nuclear plants is made difficult by the fact that some plants have been delayed deliberately by their utilities because of slow growth in electricity demand and financing difficulties. There also appears to be important differences in the regulatory environments for different generations of plants that must also be taken into account.

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A recent study of leadtimes for EPRI took both deliberate delays and regulatory stage into account* (1). The study identified from published sources those plants that had been delayed deliberately more than a year by their utilities and analyzed their leadtimes in a separate group. In a more detailed case study of 26 of these plants EPRI found that 8 had been delayed significantly (averaging 27 months) while 22 had only been delayed an average of 2.5 months.

Grouped by date of permit, it is plausible to identify three generations of nuclear plants. For the first generation, for which construction permits were issued from 1966 to 1971, leadtimes** increased steadily from about 60 to 80 months. This appears to reflect an increase in the designed complexity of nuclear powerplants and possibly the strains of rapid growth as well.

A second group of plants had their construction permits issued from **1971** to **1974.** Leadtimes for that group were much higher than the first, averaging 120 months and ranging from 100 to 160 months. Leadtimes for plants without significant deliberate delays averaged about 10 months less than those with significant deliberate delays. It appears that this group of plants suffered a major increase in regulatory complexity (including the 1974 Calvert Cliffs decision, the regulations following the 1976 Browns Ferry fire and the 1979 accident at Three Mile Island) without the opportunity to develop construction and regulatory planning techniques to handle the increased complexity. They may have suffered as well from some of the effects of rapid growth in the industry, such as incomplete designs and inexperienced supervisors.

Although the data are sketchy, it is possible that a third generation of nuclear plants is now emerg-

***The study grouped the plants by date of construction permit to avoid the obvious problem that later completion dates, by definition, include a larger proportion of long-leadtime plants.**

****Leadtimes for this analysis are defined as time from date of construction permit to commercial operation.**

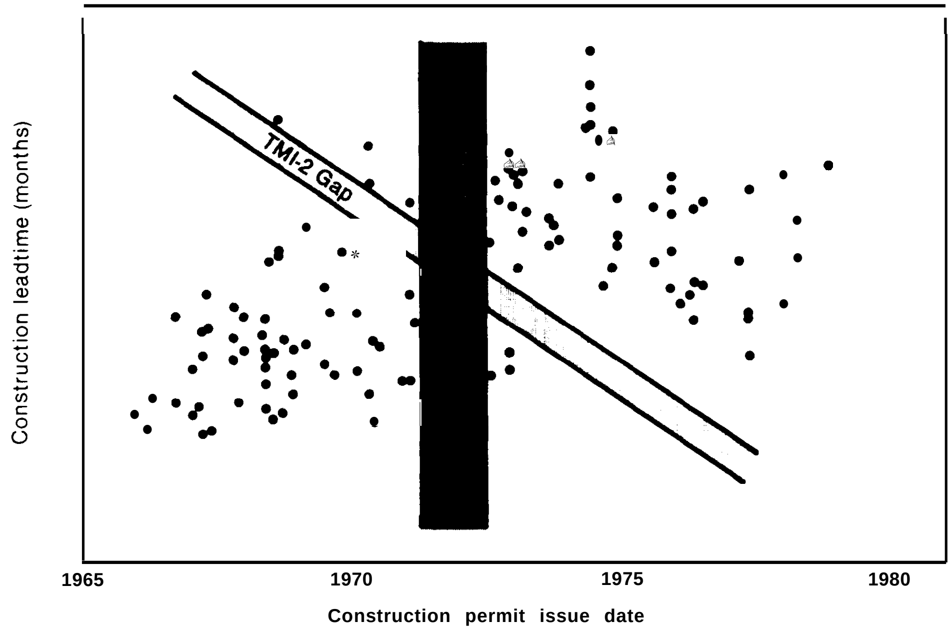
ing, with construction permits issued later, in 1975-77. After adjusting for deliberate delays and excess optimism in time estimates, EPRI found that this latest group of plants appears to have somewhat shorter leadtimes than the 1971-74 group. Leadtimes for all plants in the group average about 100 months and range from 65 to 120 months. Plants without significant announced deliberate delays average 10 to 15 months less than the average. The plants with shortest leadtimes in this group are already in operation and were completed faster than the shortest leadtime plants in the earlier group (see fig. 18). The numbers are so small, however, that it is too early to tell if these plants are anything but anomalies. Those plants with longer leadtimes in this latest group still may experience significant delays beyond the adjusted estimates calculated by EPRI. At the same time there is some case study evidence that the plants that were started later were able to compensate for increased regulatory complexity in the plant design and construction management and were also able to plan systematically their dealings with the NRC. (Case Study 2 in ch. 6.)

The Impact of Delay on Cost

In a period of substantial general inflation characteristic of the last 5 years, a delay in nuclear plant construction can cause an alarming increase in the current dollar cost of the plant. Increases in the current dollar cost, however, must be distinguished carefully from increases in the real or constant dollar cost of the plant (after the impact of general inflation has been eliminated). These in turn must be distinguished from increases due to changes in regulations or other external influence during the period of delay.

For a hypothetical plant that has been expected to be completed in 8 years but instead has been delayed to 12 years, with no increase in complexity or scope, there are two sources of increases **in total capital cost in constant dollars. One is that nuclear components, materials and labor may**

Figure 18.—Construction Leadtimes for Nuclear Powerplants



NOTES. The leadtimes are based on estimated times to commercial operation for those plants not yet in service. The gaps correspond to periods of licensing inactivity in the industry Leadtimes are calculated from construction permit issue date-to-date of commercial operation

SOURCE Applied Decision Analysis, Inc *An Analysis of Power Plant Construction Lead Times, Volume 1: Analysis and Results,* EPRI-EA-2880 February 1983 Graph based on Nuclear Regulatory Commission data.

have increased 1 or 2 percent faster than general inflation (escalation). The second is real interest during construction* that is capitalized and added to general total plant cost as AFUDC (Allowance for Funds Used During Construction). (See box B above.)

Table 9 shows the increases in constant dollars and in current dollars of several different cases: 5, 7, and 9 percent general inflation with no real escalation in nuclear components and with 2 percent real escalation and real interest rates of 3 percent and 5 percent above general inflation (1 3). Several of the examples in table 9 can serve as illustrations of the difference between increases in current and constant dollars. For example, in case 3, if a plant takes 12 years to build during a period of general inflation of 7 percent, escalation of nuclear components of 9 percent (2 percentage points faster than general inflation) and an interest rate of 12 percent (a rather high real interest rate of 5 percent), the "mixed current dollar cost" of the plant will be 233 percent higher than its overnight construction cost. Two-thirds of the increase, however, is general inflation. The real constant dollar increase in the plant cost is only 48 percent. Construction of the same plant in *8* years time would cause a current dollar increase of only 123 percent and a constant dollar increase of 30 percent. For this case, shortening the plant's leadtime would save about a third of its current dollar cost but only about 12 percent of its constant dollar cost. *

*Real **interest is the nominal rate of interest less the rate of general inflation, e.g., real interest is 5 percent for nominal interest rates of 12 percent when general inflation is 7 percent.**

***In this case 2.23 (8 years) is about 67 percent of 3.33 (12 years) and 1.30 (8 years) is about 88 percent of 1.48 (12 years).**

The Cost of Electricity From Coal and Nuclear Plants

The steadily increasing capital costs of nuclear power (including the increasing costs brought about by increasing leadtimes) leads to a crucial question: at what point does the increasing capital cost of nuclear plants make nuclear power a more expensive source of electricity compared to alternative generating sources, especially coal? As long as it is likely that utilities will avoid the use of oil and gas for base load electricity generation, the chief competitor to nuclear is coal.

Initially (for most nuclear plants completed by the early or mid-1970's) there was no doubt that electricity generated from these plants was substantially cheaper than coal-generated electricity. Because of the way capital charges are recovered in the rate base (see box **C** above), the cost of electricity from these plants has become steadily cheaper relative to electricity from coal plants built at the same time. As the capital cost of nuclear plants has risen, however, the relative ad-

Table 9.—Additions to Overnight Construction Cost Due to Inflation, Escalation and Interest During Construction (in constant and current dollars)

	Percent increase in constant dollars		Percent increase in current dollars	
	8-year leadtime	12-year leadtime	8-year leadtime	12-year leadtime
Case 1: 7% general inflation, 0 escalation, 100/0 interest rate	+ 12	+ 19	+92	+ 167
Case 2: 7% general inflation, 0 escalation, 12% interest rate	+21	+33	+ 107	+ 200
Case 3: 7% inflation, 2% escalation, 12% interest rate.	+30	+48	+ 123	+ 233
Case 4: 5% inflation, O escalation, 100/0 interest rate.	—	+34	—	+ 140
Case *5:* 90/0 inflation, O escalation, 14% interest rate.	—	+33	—	+ 273

NOTE: "Escalation" is defined as the increase in the unit costs of labor and components used in nuclear plants (with no change in quality) above the rate of general inflation. For inflation of 7 percent, an interest rate of 10 percent corresponds to a real interest rate of 3 percent, an interest rate of 12 percent corresponds to a real interest rate of 5 percent.

SOURCE: For the calculation, Wilfred H. Comtois, "Escalation Interest During Construction and Power Plant Schedules," Westinghouse Power Systems Marketing, September 1975.

vantage of nuclear power has diminished. For plants presently under construction, the average capital cost is now so high that the typical nuclear plant probably would produce more expensive electricity over its life time than the typical coal plant. Only electricity from the least expensive nuclear plants still may be competitive with average cost coal-generated electricity. Average cost nuclear plants, however, still can compete with more expensive coal plants.

Comparing the costs of nuclear and coal-fired electricity is made difficult by the different impact of fuel and capital cost components for each type of plant. Capital cost is a far more important component of nuclear-generated electricity than for coal plants. While the levelized cost of fuel (uranium ore, enrichment, storage shipment and disposal) and operations and maintenance each run about $0.0075/kWh, the capital charge (levelized charge* over the life of the plant) per kWh for new plants may range from as little as $0.01/kWh for older reactors to $0.10/kWh or even more for the most expensive of today's reactors. The capital charge per kWh increases with higher total construction cost (including the impact of longer leadtimes), with higher interest rates, and with a shorter capital recovery period. The capital charge (as well as operations and maintenance) per kWh also increases as the plant capacity factor** is reduced because there is less output among which to apportion the annual capital cost. Since the earliest nuclear plants were built, there have been significant increases in all the categories that increase annual capital charges. The capacity factors of nuclear plants also have been less than expected. (See ch. 5 for more discussion of nuclear capacity factors.)

For coal-fired electricity, on the other hand, the cost of the fuel is at least as important as the capital cost in determining the price of electricity over the life of the plant. Operations and maintenance of coal plants cost somewhat less than for nuclear plants. Fuel cost, however, may range from less than $0.01/kWh in regions where plants can be built near the coal mine to almost four times that in regions located far from coal fields (assuming rapid increases in coal prices). The rate at which coal prices are likely to escalate over several decades has a significant influence on the forecast average cost of electricity from the plant over its lifetime. Levelized electricity prices will be about $0.015/kWh (in constant dollars), higher, on average, if coal prices escalate at a real annual rate of 4 percent than if they don't escalate at all in real terms (36).

Unfortunately, there is no study of recent plants using actual reported capital cost of coal plants. In a DOE study (36) using coal and nuclear plant model data on capital cost, the cost of electricity is about equal in five of the ten DOE regions, slightly lower for nuclear in two of the regions and considerably lower for coal in two of the regions. **There is reason to believe, however that nuclear capital costs are higher and coal capital costs may be lower than the study results.** Capital costs of the typical nuclear plant reported in the study are about 15 percent lower than the average (in constant dollars) of the plants now under construction. On the other hand, the capital cost of the typical coal plant reported in the DOE study is more than 40 percent higher than the capital cost of the typical 1978 coal plant (including a flue-gas desulphurization scrubber) in the 1981 Komanoff study updated to constant 1982 dollars. While it is possible that the capital cost of coal plants may have increased 40 percent since 1978, several factors make it unlikely. Coal plant construction leadtimes (unlike nuclear plant leadtimes) have not increased since 1978. Since the cost of scrubbers already is included in the 1978 typical coal plant capital cost, it is unlikely that further pollution control improvements and design improvements would add more than 20 percent. If, indeed, actual nuclear construction costs are higher and actual coal plant construction costs are lower than the plant model results, the typical nuclear plant would be expected to produce more expensive electricity in all regions.

Low-cost nuclear plants, however, still would be competitive with the average coal plant. Com-

***Various techniques are used to "levelize" costs over a plant's lifetime. One simple method,** used **in the EIA study of coal and nuclear costs, is to take the present discounted value of the stream of costs and divide it by the number of years to get an annual levelized cost (36).**

****Capacity factor equals the number of hours of actual operation divided by the hours in the year.**

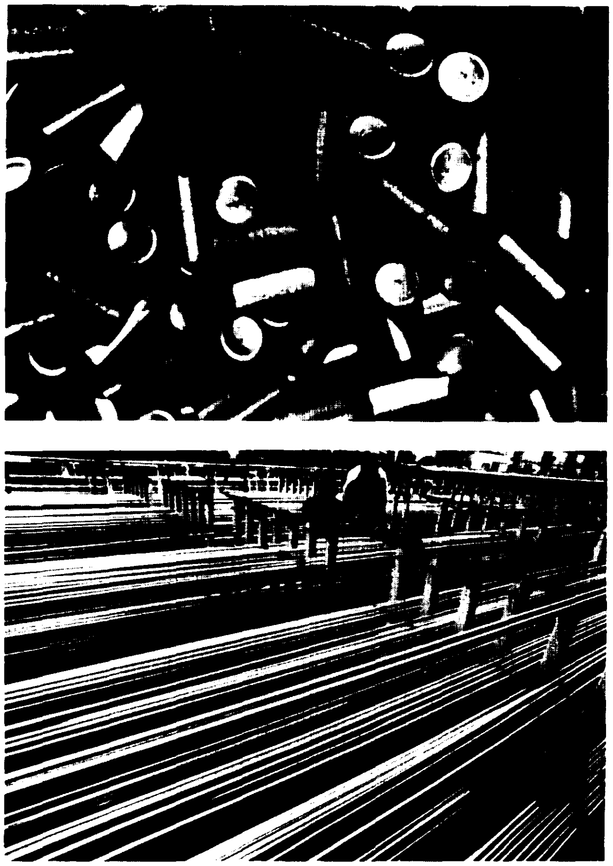


Photo credits: Atomic Industrial Forum

Nuclear fuel comes in pellets and is assembled into fuel rods and then into fuel assemblies. Fuel for a nuclear powerplant is compact and only transported every 12 to 18 months. It is inexpensive compared to the cost of alternative fuels such **as coal, natural gas, and oil. Each Vi-inch-long pellet of enriched uranium shown** here can generate approximately the same amount of electricity as 1 ton of coal

monwealth Edison Byron plants are expected to cost $1,100 to $1, 150/kW in 1982 dollars (without interest during construction)* and Duke Power's McGuire and Catawba plants are expected to cost $900 to $1,200/kW in 1982 dollars. When the construction cost of a nuclear plant is no more than 20 to 40 percent above that of a coal plant, it can be expected to produce electricity more cheaply, sometimes substantially, over the plant's lifetime.

However, there is a further element of the competition between the costs of electricity from nuclear and from coal. The pattern of costs over the life of the plants are substantially different. Under current accounting rules capital charges are highest in the early years and decrease as depreciation charges are deducted from the asset base. Coal costs on the other hand will increase at, or faster than, the rate of general inflation over the life of the plant. Thus for plants with the same levelized cost of electricity, electricity from the nuclear plant will cost more in the early years and electricity from the coal plant will cost more in later years (see box C above). The higher cost of nuclear plants in the early years could be discouraging to an electric utility that had faced much opposition to rate increases.

Future Construction Costs of Nuclear Powerplants

It is very unlikely that there will be any future for nuclear plants of current average capital cost. Nuclear plants, on average, are now so costly that they are no longer likely to produce electricity more cheaply than coal over their lifetimes. Given the pattern of front-end loading of capital costs, even with equal lifetime costs, nuclear-generated electricity would not be cheaper than coal-generated electricity for 10 to 15 years. For this reason, utilities are not likely to order more nuclear plants if the capital cost of newly ordered plants is expected to repeat that of the current average plant.

There is considerable evidence that, with effort, the cost of an average nuclear plant can be reduced substantially from the current level. The lowest cost nuclear plants already cost substantially less than the average. Within the present framework of regulatory requirements for plant design and quality control, a few utilities have built enough plants to take advantage of a construction learning curve and have developed techniques for minimizing delays, rework, and worker idleness. These techniques are described in more detail in chapter 5. They involve careful and complete engineering, careful and thorough planning and project management (including the use of sophisticated computerized tracking and

*Costs of the **Byron plants may go up, however, following a January 1984 NRC decision to deny the plants an operating license.**

inventory planning), and attention to motivation for productivity and cooperation. If a separate company is used to manage the project, there must be explicit incentives to complete projects on time and at budgeted cost. A reasonable goal for such efforts could be to equal the capital cost of Commonwealth Edison's Byron and Braidwood plants and Duke Power's McGuire/Catawba plants of $1,100/kW (1982 dollars) direct construction cost plus another $200 to $250/kW for interest during construction.

Looking overseas, there is evidence that a different approach to certain aspects of safety regulation and quality control could bring construction costs down still further. Constructing a French plant requires about half as many workhours/kW as constructing an American plant (86). As is described in more detail in chapter 7, the French have standardized their plants and have built two basic types of reactors (925 MW and 1,300 MW). This avoids much of the rework that occurs in American plants because the engineering is essentially complete before each plant is started, and because the first plant of each type functions as a full-scale model to help avoid piping and cable interferences and other problems of two dimensional design. Within a far more centralized and controlled approach to safety regulation (see ch. 7) the French have also taken an approach to earthquake protection that minimizes the impact on construction. They also have a different approach to quality control that minimizes delays during construction (described in chs. 4 and 5).

A specific estimate of possible reductions in average plant cost was made in a recent study of the U.S. nuclear industry viability (87). According to this estimate, typical plant costs (including interest during construction) could be reduced from about $2,220/kW (in 1982 dollars) to $1,700 to $1,800/kW (20 to 25 percent less). This estimate assumes that the United States can go only part way towards constructing plants with as few workhours as is now done in France. The French regulatory environment, and utility management, and construction tradition are sufficiently different that much is unlikely to be duplicated in the United States. The proposed steps to bring construction costs down would include:

- **Reduction in Construction Workhours.** A fully standardized pre-certified design and emphasis on multi-unit sites could reduce construction workhours from 14 million to 12 million per 1,300-MW plant, a number which is still about 25 percent higher than estimated construction workhours for a comparable French plant. This would come about through progress up a learning curve of construction management techniques.
- **Reduction in Engineering Workhours.** Standardization and regulatory predictability also could cut engineering workhours per plant roughly in half from about 9 million to about 4.5 million, by reducing construction engineering support by more than 80 percent and quality assurance workhours similarly. Engineering workhours would still be about 60 percent higher than those in France, reflecting the differences in U.S. construction project organization.
- **Eight-Year Project Schedule.** Reducing average project schedules from 11 to 8 years would reduce interest and real escalation costs. Total construction cost in constant dollars would be reduced by 7 to 15 percent (see table 9).

The desirability of standardization in nuclear plant design and construction is a complex question that would affect far more than the capital cost of nuclear plants. It was the subject of a previous OTA report, *Nuclear Powerplant Standardization* (April 1981) and is discussed further in chapter 4. One issue is whether standardization can be achieved without sacrificing the adaptability of nuclear technology to new information about designs that would benefit nuclear plant safety or operation. A second issue is the institutional obstacles to standardization in an industry with more than 60 nuclear utilities, 4 reactor vendors, and more than 10 AE firms.

While opportunities exist for reducing nuclear construction costs, it should be recognized that costs might also increase. Further serious accidents could lead to a new round of major changes in regulation. There are still important unresolved safety issues (discussed in ch. 4) that could lead to costly new regulations. utility executives are well aware of this possibility.

The Financial Risk of Operating a Nuclear Powerplant

The Risk of Property Damage.–The accident at Three Mile Island was a watershed in U.S. nuclear power history because it proved that serious accidents could indeed occur and cause enormous property losses even without causing any offsite damage. The total cost of the cleanup is estimated at $1 billion, not counting the carrying costs and amortization of the original capital used in building the plant nor the cost of restarting the plant. Of this $1 billion, $300 million was covered by insurance from the insurance pool (see table 10 for explanations). General public Utilities (GPU) is now in the process of negotiating the financing of the rest from various sources including the utility industry through the Edison Electric Institute, the rate payers as approved by the Pennsylvania and New Jersey PUCs, the States of Pennsylvania and New Jersey and the Federal Government.

Since Three Mile Island, property insurance coverage for nuclear plants has increased to $1 billion, about half in primary insurance and the rest in excess insurance (once a **$500 million ac**cident cost has been reached). Some of the primary insurance and most of the excess insurance have been provided by two new mutual insurance companies formed by groups of utilities, Nuclear Mutual Ltd. (NML) and Nuclear Electric Insurance Ltd. (NEIL) –(see table 10). NEIL also provides almost $200 million in insurance for purchases of replacement power while a plant is disabled.

Despite this threefold increase in insurance, however, some of the expenses incurred in the Three Mile Island accident still have not been insured; namely, maintenance of the disabled plant and carrying costs and amortization of the capital tied up in the disabled plant. For the moment these are being paid by GPU stockholders who have not received a dividend since the accident (44).

Table 10.—Nuclear Plant Property and Liability Insurance

Description	Coverage
ANI-MAERP:	
Commercial insurance consortium of about 140 investor-owned companies (American Nuclear Insurers - ANI) and 120 mutual companies (Mutual Atomic Energy Reinsurance Pool — MAERP)	Reactors at 34 sites. "Primary" insurance (responds initially to a loss) $500 million/site $68 million excess
NML:	
Nuclear Mutual Limited is a mutual insurance company created by several investor-owned utilities and located in Bermuda	Reactors at 27 sites, $500 million primary insurance/site
NEIL-I:	
Nuclear Electric Insurance Limited — extra expense insurance to pay for replacement power from an accident covered in primary insurance	Reactors at 36 sites, $2.3 million/ week 1st year; $1.15 million/week 2nd year up to $195 million
NEIL-II:	
Nuclear Electric Insurance Limited — property damage excess damage above limit of primary insurance	Reactors at 32 sites. "Excess" insurance (covers damage above limit of primary insurance) $415 million/site
Liability *insurance:*	
ANI-MAERP:	
Liability insurance required by Price-Anderson	All reactors. $160 million available from premiums, plus $400 million/ accident available from retroactive assessments of $5 million/reactor/ accident

SOURCE: **John D. Long, Nuclear** *Property Insurance: Status and Outlook,* **report for the U.S. Nuclear Regulatory Commission, NUREG-0891, May 1982; papers presented at Atomic Industrial Forum Conference on Nuclear Insurance, Feb. 14-16, 1983.**

Further increases in insurance capacity are desirable, given the increasing replacement value of plants. However, they are limited by the assets of the insurance companies and the utilities in this country and by the reluctance of reinsurers, such as individual syndicators in Lloyd's of London, to assume any more American nuclear risk.

The adequacy of current insurance is threatened further by several other issues. Under public pressure, Congress could stipulate that all property insurance be used first to pay cleanup costs and only then to pay carrying costs and the costs of restarting the plant. This would mean that the utility would have to turn to the PUC to obtain higher electricity rates to cover all the other costs of an accident or obtain the funds by withholding dividends from shareholders. Another source of uncertainty is the heavy reliance of the utility-run mutual insurance systems on retroactive assessments. These are premiums that the utility commits itself to pay in the event of an accident. NML, for example, may call on retroactive payments up to 14 times annual premiums in the event of a serious accident that depletes existing insurance reserves. The willingness and ability of utilities to pay these assessments has not yet been tested. Some observers have expressed the fear that PUCs may balk at allowing utility insurance expenses "to pay for the other guy's accident" (57).

The Risk of public Liability .–Since 1957, the Price-Anderson Act has limited public liability, in the event of a serious accident, to $560 million. Pressure to increase this limit has been mounting. Inflation alone would justify raising the limit to about $1.9 billion assuming $560 million was an appropriate figure in 1957. Pressure, however, to go beyond keeping up with inflation, or even to eliminate the limit altogether, arises from several studies published over the last 10 years, the Rasmussen Report (WASH-1900) in 1974 and the 1982 Sandia siting study. Both analyze the consequences from low probability accidents and are described more fully in chapter 8. Part of the Price-Anderson Act is due to expire in 1987. The first round of debate in Congress on this issue may begin soon, stimulated by the recent publication of an NRC report on public liability.

Ironically, this pressure to increase the limit for public liability comes just as the private insurance resources of the industry have increased enough to *cover* the current statutory limit fully. About $160 million is available from the insurance pools, and the rest (about $400 million) is available from a $5 million per reactor retroactive assessment required in the Price-Anderson Act. Under current law, the Federal Government has guaranteed to provide any liability damages beyond the nuclear industry's resources and up to the statutory limit. Currently, because of the availability of private insurance funds and the increase in the number of plants available to pay the $5 million assessment, the Federal Government has no liability. if the limit were raised or eliminated, there would be pressure for the Federal Government to again assume the excess liability.

From the standpoint of the insurance industry, the most serious issue is the growing pressure from citizen's groups to allow damage from nuclear accidents to be covered in homeowners' policies. Currently, by consensus of all insurers, all homeowners' insurance policies specifically exclude a nuclear accident as an insurable risk. Homeowners, in effect, may make claims only against the responsible utility and be paid from the utility's *own* insurance resources. For insurers, this characteristic of nuclear insurance channels the risk into a single category which can be identified and assessed. Since the potential damages are both large and of unknown probability, insurers are much more willing to provide fairly large sums if the structure of risk is simple because a given accident will result only in a claim from a single utility, and not in hundreds of individual homeowner claims through multiple insurance companies. Were the homeowner's insurance exclusion to be removed by law, one probable result would be a reduction in total private insurance resources available for a single accident. This is because the resulting multiple sources of liability (from millions of homeowner policies) increases the perceived risk to the insurers, who in turn respond by reducing the total amount available.

Another financial risk of unknown size is the possibility that workers exposed to radiation may

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file occupational health suits in future years, based on a statistical link between low-level radiation exposures and various diseases, such as cancer, with long periods of development. In some respects the nuclear power industry is better prepared for such suits than industry has been for comparable suits arising from exposure to asbestos because detailed records are kept on every worker's exposure to radiation. Currently, any court settlements due to workers' exposure to radiation would be paid out of ANI-MAERP pool insurance. If the size of such settlements becomes at all substantial, however, utilities and their insurers may move to establish a fixed compensation program, comparable to the basic workman's compensation program, which pays fixed sums for each type of injury. Since injury in this case is based on a probability link to levels of radiation exposure the level of probability would be included in the program, much as has been proposed for compensation for victims of nuclear weapons testing.

Photo credit: Westinghouse

One source of uncertainty about the future cost of nuclear power is the possibility that workers exposed to radiation may sue the nuclear plant owners to recover damages from health effects of radiation exposure

Impact of Risk on the Cost of Capital

As previously noted, from an investor's point of view there are several reasons to be wary of utilities with substantial nuclear operations:

- since nuclear-generating plants take longer to build, it is more likely that they will be poorly matched to actual demand;
- the cost of constructing them is harder to estimate and control than it is for coal plants; and
- there is a small but finite risk of a major disabling accident. Under current insurance coverage and PUC rate decisions, a large fraction of the many costs of such an accident would have to be borne by the stockholder.

A few attempts have been made to estimate the impact of these three elements of risk on the cost of capital to nuclear-owning utilities but the results are not clear-cut. As of 1981, the highest bond ratings belonged to utilities operating nuclear plants, although the lowest bond ratings belonged to utilities with nuclear plants under construction. After Three Mile Island, there was an immediate effect on the relative stock market prices of nuclear and non-nuclear utility stocks. The price of non-nuclear stock increased over 50 cents a share relative to nuclear stock. The effect persisted for at least 2 years (46). Financial experts and utility executives agree, however, that another serious accident could have very serious financial consequences.

In the year following the Three Mile Island incident, a study of investor attitudes towards nuclear utilities (1 1,46) showed that investors ranked the risks associated with nuclear power as a serious problem but less than problems caused by regulation, high interest rates and inflation. Twenty-five percent of institutional investors said the Three Mile Island accident had a negative impact on the weighting of electric utilities

in their investment portfolios. I n general, portfolio managers showed increased concern if utilities had a high dependence *on* nuclear, but over 82 percent said they recommend companies with some nuclear component in their fuel mix. It would seem that investors are more concerned currently about the risk of construction cost overruns and delays and the financial strains of plant construction than they are about the financial risk of a disabling accident (47). The recent indications that several nuclear plants such as Zimmer, Midlands, and Marble Hill may never be completed and licensed to operate has caused another round of investor concern. * Between October and late November 1983, stock prices dropped in 36 out of 50 companies with nuclear plants under construction.

In summary, utilities assume greater risks when they build nuclear plants than when they build coal plants. Even if, due to standardization and careful construction, the cost of nuclear power over 30 years is estimated to be substantially less than coal-fired electricity, utilities still might hesitate to order more nuclear plants unless they are compensated in some way for the additional risks.

***See** *Nuclear phobia,* **a research report by Merrill Lynch, Pierce, Fenner & Smith, Dec. 15, 1983.**

NUCLEAR POWER IN THE CONTEXT OF UTILITY STRATEGIES

The decision to order a nuclear powerplant is only one of many choices utility executives can make given their companies' load forecasts and present and future financial situations. They could instead order one or more coal plants; convert an oil or gas plant to coal; build a transmission line to facilitate purchase of bulk power from Canada or from elsewhere in the United States; develop small hydroelectric sources, wind sources, or other small-scale sources of power; or start a load-management, cogeneration, or energy conservation program (or some combination of all of these).

What utility executives choose depends on the reliability of their load forecasts, the options for retiring oil and natural gas plants, the availability of reliable sources of purchased power, the nature of rate regulation in the State in which they operate, and their companies' abilities to manage large construction projects on the one hand or successful load management and conservation programs on the other.

From a recent survey of utility executives (90) and the results of two OTA workshops, it is clear that utility executives are now considering a much wider variety of alternatives to construction of new large generating plants. Although utilities do not seem to be avoiding capital investment at the risk of providing inadequate electric supplies, nonetheless they are taking financial considerations heavily into account, especially the ability to earn a return on CWIP. Some executives say their companies have deliberate policies of providing generating capacity with either minimum capital cost or short leadtimes or both.

One possible option is to delay any powerplant construction as long as possible and then meet any need for new capacity with combustion turbines which can be constructed in 3 to 4 years and cost only $200 to $300/kW (in 1982 dollars). Such a choice is now less risky for future electricity rates because of apparent softening of natural gas markets. Combustion turbines cost so little that they could in theory be written off quickly and replaced by longer leadtime plants if electricity demand were increasing enough to warrant longer leadtime generating capacity with lower fuel costs.

In a recent study six utilities described two alternative sets of construction plans: one plan that they would follow under financially generous rate regulation and the other under financially constrained rate regulation (64). There is a somewhat exaggerated difference between the two sets of circumstances*–but they do illustrate the range of utility choice.

Under financially constrained circumstances, the six utilities expect to rely on more use of purchased power. One will invest in more transmission lines. The utilities also expect to keep old plants on line and will defer the retiring of oil and natural gas plants. It is interesting that none expect to build combustion turbines to catch up to demand growth.**

The preferred generating choice of the six utilities under financially generous circumstances is medium-sized coal units of **500 to 600** MW which the six utilities plan to build in substantial numbers, over 17 GW by the year 2000. Although several utilities expect to finish nuclear powerplants under construction, only one of the six expects to start a new nuclear plant. Utility executives at the OTA workshops and in the survey now perceive nuclear power to be too risky to include in future construction projects even under a less financially constrained future. Even for those utilities that have experience in keeping construction costs under control, there are important perceived risks from lack of public acceptance and the possibility of one or more Three Mile Island types of accidents. Utility executives said they expect to make use of "cookie-cutter" coal plants because of the greater predictability of their operating and construction costs.

It is conceivable that other types of nuclear plants than those currently available in the United States would be more attractive to utility executives, Executives reported in an EPRI survey of utility executives' attitudes towards nuclear power that smaller nuclear plants would be desirable because they would require a smaller total capital commitment and could more easily be fit to uncertain load growth (22).

Some executives also believe that significant safety improvements would make nuclear plants less vulnerable to changes in regulation and adverse public reactions and thus more attractive. Several utilities are members of a gas-cooled reactor council that supports research and development of high temperature gas-cooled reactors (HTGR) (described inch. 4). One executive testified for Florida Power & Light Co. (FP&L) in March 1983 that for FP&L's crowded site in Dade County, an HTGR is the only option. Shallow water and delicate ecology hinder coal transportation and the closeness of the City of Miami and problems with raising the water temperature rule out a light water reactor. FP&L does not want all the possible headaches of building the lead HTGR but might be willing to build the second plant (91).

If utilities wish to avoid building powerplants altogether they have several options (14). One of these, featured in several of the six utility strategies described in table 11, is to make better use of existing powerplants. Ironically, the financial weakness and excess capacity that had led utilities to cancel new construction has also fostered neglect of maintenance of existing powerplants. In one recent survey of 80 GW of coal powerplants there had been a decline of more than 12 percent in availability from 1970 to 1981 (1 5). Pennsylvania is one of several States investigating changes in regulatory policies that would encourage more efficient use of existing powerplants **(78).**

Major investment may be needed to extend the life of an existing plant well beyond the normal retirement **age of 30 to 35** years. A **plant that** has **been operating** effectively for 40 to 50 years may not have any of the same components as the original plant. Nonetheless, substantial investment to upgrade an existing plant will in almost all cases cost far less than building an entirely new plant of the same capacity.

Utilities can also substitute programs to reduce peak demand for building new capacity. A recent EPRI survey identified over 200 utilities that were working with their customers on conservation and load management programs (23). While some of the programs were demonstrations, others represented major corporate commitments to load control. For example, the New England Electric System's successful experiments with on-

***For example, the cost of capital is assumed to differ by 300 basis points between the generously treated case which results in an AAA bond rating and the constrained case which results in a BBB bond rating.**

*** * Building a combustion turbine for use more than 1,500 hours a year is still prohibited under the Fuel Use Act. In practice, however, an increasing number of exemptions are being allowed.**

Table 11.—Six Sets of Alternative Utility Construction Plans

Utility and type (timeframe of plan)	Projected growth in load (%/yr.)	Plan A capital discouraging	Plan B capital attraction
Utility A. Coal conversion (1982-2000)	1.5	Cost $4.1 billion • Sell part of share of nuclear plant • Convert 200 MW oil to coal • Reduce sales to outside customers • Purchase 175MW • Retire no old plants	Cost $9.9 billion • Finish nuclear plant on schedule • Convert oil plant to coal (800 MW) • Build four 600 MW coal plants (two-thirds ownership)
Utility B. Coal/nuclear (1982-2005)	2.0	Cost $23.9 billion • Delay two-thirds of a new nuclear plant for 4 years • Double the amount of purchased power • Consume more oil and gas • No existing plants retired	Cost $40.6 billion • Complete several nuclear plants without delay • Build four 500 MW coal plants in 1990's • 75 % share in two 1,100 MW nuclear units in 2000 • All plants retired on schedule • Intermediate load coal plant
Utility C. Gas/coal (1982-2000)	4.0	Cost $64.8 billion • 3,000 MW coal capacity 1982-97 • 6,000 MW coal capacity 1998-2009 • Reserve margins 13% 1990; 9.6% in 2000	Cost $62.8 billion • 5,000 MW new coal capacity in 600 MW increments 1982-97 • 5,000 MW more coal 1998-2009 • Reserve margin over 20%
Utility D. Gas displacement (1982-2001)	3.0	Cost $8.9 billion • Finish large nuclear plants near completion • No plants retired • Meet incremental demand through purchased power	Cost $30.5 billion • 2,500 MW of coal capacity 1988-97 to displace gas • Three large coal plants in mid-1990's to meet additional load • Oil and gas capacity retired on schedule • Finish large nuclear plants near completion
Utility E. Oil displacement (1982-2000)	1.5	Cost $12.9 billion • No construction projects • Defer 2,000 MW of natural gas and oil capacity	Cost $22.1 billion • Purchase share in large coal project under construction • Joint owner of coal plant online early 1990's • Build transmission lines to purchase power
Utility F. Purchase/coal (1982-2001)	3.0	Cost $4.8 billion • No construction • Increase purchased power to 36% of total • Spend $1 billion on transmission lines to wheel in power	Cost $7.6 billion • Four new coal units of 500 MW 1988-97 • Purchased power shrinks to 7 % of total capacity

SOURCE Peter Navarro. Long Term Impacts of Electricity Rate *Regulatory Policies* for DOE Electricity Policy Project, February 1983

site thermal storage of electric heat and home energy conservation led it to develop a 15-year plan aimed at reducing peak demand by over 500 MW and average demand by another 300 MW over the 1980-95 period. The plan is expected to save utility customers about $1.2 billion over that period (65).

Utilities have successfully used a wide variety of techniques to encourage investment in load management and energy conservation by their customers. As described in the EPRI report and others (14,23,42), these include programs to provide rebates for the purchase of energy-efficient refrigerators, air-conditioners, or heat pumps, low interest or interest-free loans and energy indexing programs. For a utility interested in conserving capital, some utility-controlled load management technologies offer strikingly low capital cost ($110 to $200/kW). It takes thousands of installations of such devices in buildings owned by hundreds of different customers to equal one 100 MW powerplant (see table 12).

Utility executives interviewed for the Theodore Barry survey cited above report that they are relying more and more on non-powerplant options to meet the needs of future growth but they still have concern about their long-term effectiveness (90). Without extensive metering of components of individual buildings, and extensive data collection on occupancy and patterns of use, it is difficult to determine how much of a given building's change in electricity use is due to load management devices and how much is due to other reasons that may be short-lived or unpredictable.

Utilities seeking to avoid costly capacity additions might also work to encourage power production by cogenerators and other small power producers in their service territories. (The potential for cogeneration to reduce electricity demand was discussed above in the section on electricity demand.)

However, current estimates of market potential for small power producers are several times higher than estimates of the central generating capacity that could be displaced by small producion. This is because utilities can use small power production to displace additional central station generating capacity only if it can be counted on to occur at times of peak demand. A recent CRS study estimates the total capacity displacement potential from cogeneration, wind, and small hydroelectric as ranging from about 5 GW to about 22 GW, even though the market potential for cogeneration and wind totals about 63 GW and the technical potential for small hydroelectric is estimated at over 45 GW (14). OTA recently estimated the full technical potential for cogeneration as even higher, 200 GW (72).

It is worthy of note that the estimated market potential for cogeneration alone of about 42 GW is one measure of the market for using HTGRs for cogeneration. As is discussed further in chapter 4, HTGRs operate at far higher temperatures than do light water reactors and can be used to supply steam and pressurized hot water. The resulting high efficiency of operation and production of both electricity and steam for sale can offset their somewhat higher capital cost.

Implications for Federal Policies

As long as electric utilities are regulated there is great potential to influence the strategic choices they make by adjusting the way expenses and investments are handled in electricity rate determination. This report does not analyze all the possible ways in which utility strategies other than central station powerplant construction can be influenced, but it should be recognized that Federal and State regulation can be structured to encourage cogeneration, conservation and load management, and upgrading of central station powerplants.

Utilities have several reasons to wait before ordering more powerplants. The current high reserve margins are one reason, and uncertainty about the future growth of the economy and

Table 12.-Cost and Volume of Various Load Management Devices (controlled by utilities)

Device	Estimated number of installations to equal 100 MW reduction in peak demand	Cost/ installation	Approximate cost/kW
Water heater time switch , ...	91,000	$130-$240	$118-$218
Radio and ripple control (cycles water heater, air-conditioners)	71,000 (water heaters)	Radio $95-$108	$67-$107
	93,000 (air-conditioners)	Ripple $100-$115	

SOURCE: Table published in OTA study *Energy Efficiency of Buildings in Cities;* based on John Schaefer, *Equipment for Load Management 1979;* and other sources in contract report to the Office of Technology Assessment by Temple Barker & Sloane.

its impact on electricity demand is another. Although electricity demand forecasting is a tricky business at best, there is reason to believe, from both a "top-down" and a "bottom-up" approach to demand forecasting, that electricity demand growth will be slower in the 1980's than it will in the 1990's.

Each of the utilities, influenced by its State PUC will make decisions about the proper rate and type of generating capacity to add. What these individual decisions add up to in terms of a national electric grid depends on the balance among individual utility construction decisions. For example, if all utilities choose to minimize capital requirements and depend on purchase power arrangements, the national reserve margin would drop dangerously low and there could be a scramble to build plants quickly. There could be a short period of unreliable electricity supply. On the other hand, if all utilities chose to build long leadtime generating capacity to meet forecasts of rapid growth in electricity demand, and demand growth failed to increase as forecast, the current high reserve margins might reappear. From a national point of view, it might be best if the different States and utilities adopted a mixture of these approaches.

From a perspective of long-range industrial policy, there may be reason for the Federal Government to encourage steps that make electricity rate regulatory policies handle inflation better, and insure stable electricity prices over the long term (see box C). Although average electricity rates are forecast to increase smoothly and slowly over the next one or two decades, this masks a set of offsetting roller coaster rides for individual utilities, that is reflected clearly in the differences among forecasts of regional electricity rates (mentioned in the section on electricity demand above). In times of high inflation, utilities bringing new powerplants online have rapidly increasing rates for several years and then slowly decreasing rates. The increasing rate phase may discourage the location of industries, which might benefit over the long run from the declining rate phase.

At the moment, if rate regulatory policies across the country were to shift to favoring longer leadtime, capital-intensive technologies, coal-fired generation would be encouraged far more than nuclear powerplants because utility executives seem to prefer the smaller size, shorter leadtimes, lower financial risk, and greater public acceptance of coal. The implications for the nuclear industry are bleak, and read as such by the industry (87). Only a handful of orders for central station powerplants of any kind is likely before 1990. After that, if a modest number of powerplants are needed, 10 to 15 GW/yr, coal may seem adequate (unless there is a dramatic change in attitudes and public policy about the impacts of coal-burning on acid rain and carbon dioxide buildup, and no significant improvement in coal-burning technology).

If the amount of new capacity needed is much larger, however (up to 30 GW/yr), utilities may look to nuclear again as a way of diversifying their dependence on a single technology (coal). In addition, now that natural gas shortages appear less likely over the next decade, it is also possible that combustion turbines, particularly high-efficiency combined cycle plants will seem to be acceptable sources of diversity. For those reluctant to continue such reliance very long, or to depend heavily on so-called new technology there could be renewed interest in new nuclear plants beginning in the 1990's. By that time if the construction and operating risks of nuclear are significantly better than they seem to utilities now, or if alternatives, namely coal, are significantly worse, utilities may place orders for more nuclear plants. In particular, if nuclear plants can "match the market more" (in the words of one OTA workshop participant) and come in smaller sizes, with shorter leadtimes and predictable costs, they might be a competitive option again for supplying electric-generating capacity.

Appendix Table 3A.–Estimated Costs of Nuclear Plants Under Active Construction in the United States[a]

A. 95°/0 or more complete:
- Diablo Canyon 1, 1,064 MW, Pacific Gas & Electric . .$1,700/kW
- Shoreham, 819 MW, Long Island Lighting Co[b]. . . .$4,500 +/kW
- Wm. H. Zimmer, 810 MW, Cincinatti E & G $3,900/kW
- Grand Gulf 1, 1250 MW, Mississippi P&L $2,300/kW
- Palo Verde 1, 1270 MW, Arizona PS Co. $2,300/kW
- McGuire 2, 1160 MW, Duke Power Co. $830/kW

B .90-95 °/0 complete:
- Waterford 3, 1,104 MW, Louisiana P&L. $2,400kW
- Diablo Canyon 1, 1,106 MW, Pacific Gas & Electric . . $1,700/kW
- Limerick 1, 1,1055 MW, Philadelphia Electric Co. $2,900/kW
- La Salle 2, 1,078 MW, Commonwealth Edison $1,100/kW
- Catawba 1, 1,145 MW, Duke Power Co. , ... $1,700/kW
- WPPSS 2, 1,100 MW, WPPSS $2,900/kW
- Comanche Peak 1, 1,150 MW, Texas Utilities (Dallas) .$1,700/kW
- San Onofre 3, 1,100 MW, Southern California Edison .$1,900/kW
- Fermi 2, 1,100 MW, Detroit Edison $2,800/kW

C. 80410°A complete:
- Clinton, 950 MW, Illinois Power Co. $3,000/kW
- Byron 1, 1,120 MW, Commonwealth Edison[b] . . . . . .$1,500+/kW
- Watts Bar 1, 1,177 MW, TVA $1,500/kW
- Palo Verde 2, 1,270 MW, Arizona OS Co. $2,300/kw
- Callaway, 1,150 MW, Union Electric of Missouri $2,500/kW
- Bellefonte 1, 1,213 MW, TVA $2,300/kW
- Wolf Creek, 1,150 MW, Kansas G& E/K.C. P&L $2,300/kW
- Perry 1, 1,250 MW, CAPCO Group (Ohio) $2,200/kW
- Midland 1, 522 MW, Consumers Power, Michigan . . .$2,700/kw

D .50-600/' complete:
- Midland 2, 811 MW, Consumers Power[b]. . . . .$2,700 +/kW
- Bellefonte 1, 1,213 MW, TVA $2,300/kW
- Byron 2, 1,120 MW, Commonwealth Edison[b]. . . . . .$1,500+/kW
- Seabrook 1, 1,500 MW, P.S. Company of New Hampshire. $2,800/kW
- Watts Bar 1, 1,177 MW, TVA $1,500/kW
- Braidwood 1, 1,177 MW, TVA. $1,500/kW
- Comanche Peak 2, 1,150 MW, Texas Utilities. $1,050/kW
- Harris 1, 900 MW, Carolina P&L $2,500/kW
- Beaver Valley 2 MW, 644 MW, Duquesne Lighting Co. (Pa.) $3,700/kW
- Susquehanna 2, 1,050 MW, PA Power & Light Co. . . .$1,900/kW
- Nine Mile Pt. Pt. 2, 1,065 MW, Niagara Mohawk $1,900/kW
- Hope Creek 1, 1,67 MW, Public Service E&G (N.J.) . . .$3,600/kW
- Braidwood 2, 1,120 MW, Gulf States Utilities. $1,400/kW
- River Bend 1, 934 MW, Gulf States Utilities 3,700/kW
- Millstone 3, 1,150 MW, Northeast Utilities $3,000/kW

E. 49-59°10 complete:
- South Texas 1, 1,1250 completed $3,000/kW
- Marble Hill 1, 1,130 MW, PS Co. of Indiana[b]... ... .$3,100 +/kW
- Palo Verde 3, 1,270 MW, Arizona P.S Co. $2,300/kW
- Perry 2, 1,250 MW, CAPCO Group (Ohio) $2,200/kW
- Catawba 2, 1,145 MW, Duke Power Co. $1,700/kW
- Vogtle 1, 1,150 MW, Georgia Power Co. $2,700/kW

F. Around 20°/0 complete:
- Marble Hill 2, 1,130 MW, P.S. Co. of Indiana[b]... .. .$3,100 + /kW
- South Texas 2, 1,250 MW, Houston L&P. $3,100t/kW
- Vogtle 2, 1,150 MW, Georgia Power Co. $2,700/kW

[a]Cost data as of December 1983, in mixed current dollars. Construction completion as of October 1982.
[b]" +" is added where costs are likely to go higher than utility estimates.
[c]Physically 95% complete, but potentiality subject to major rework.

SOURCE: Data compiled by Charles Komanoff for a paper by 1. C. BUDD and Charles Komanoff. The source of data is utility estimates of cost of complete nuclear plants. The costs are in "mixed current dollars," the sum of dollars spent in each year plus applicable capitalized interest. They are not mutually comparable due to different accounting conventions for items such ss "construction work in progress" and interest capitalization and different time periods. See ch. 3 for a discussion of comparable costs of these Plants. Fully comparable data will be published in early 1984 by Komanoff Energy Associates.

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Chapter 4

Alternative Reactor Systems

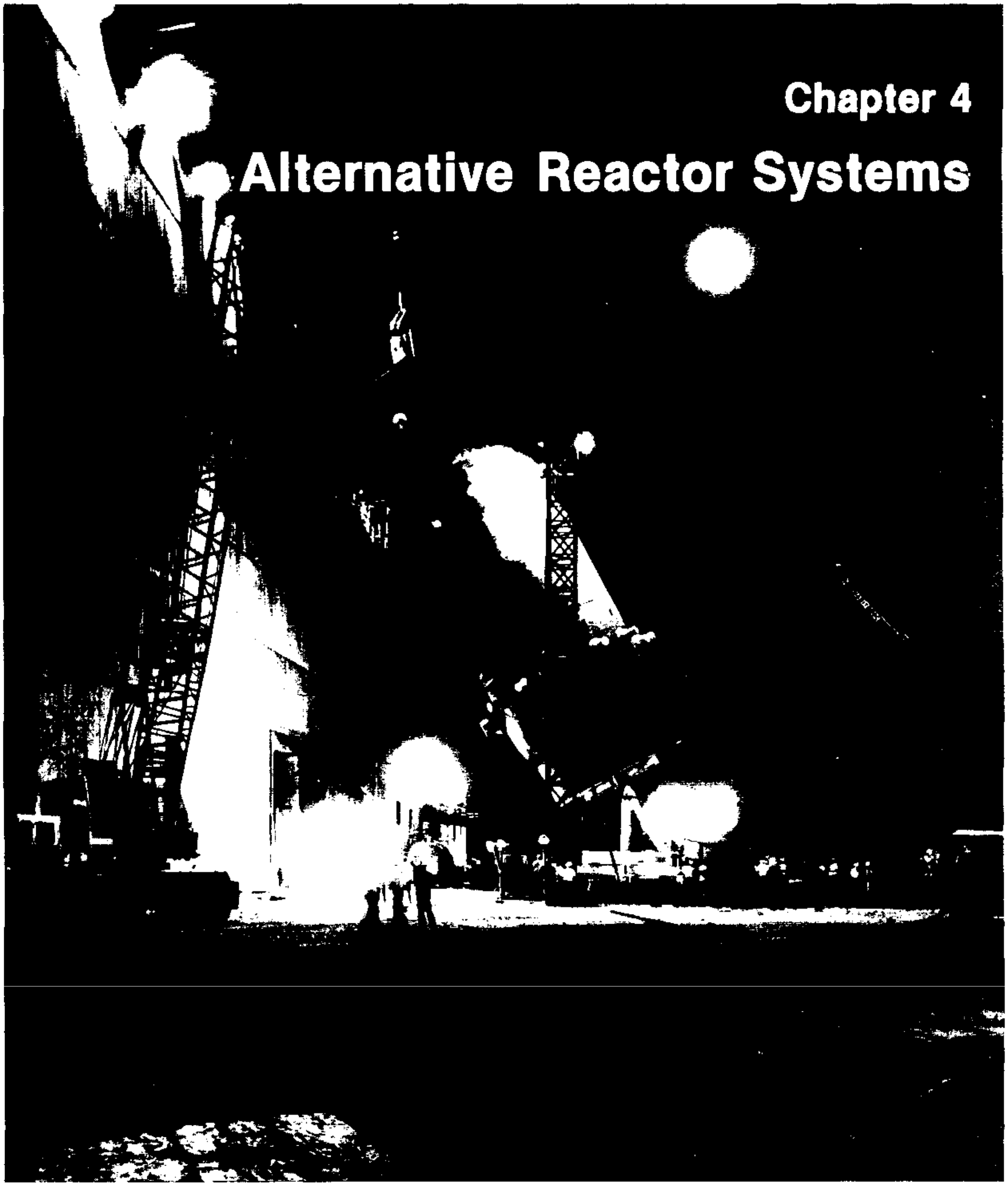

*Photo credit: Tennessee **Valley** Authority*

Boiling water reactor vessel being hoisted into a containment building at Browns Ferry nuclear plant

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Chapter 4
Alternative Reactor Systems

INTRODUCTION

Nuclear power in the United States achieved some remarkable successes in its early years and experienced dramatic growth in the late 1960's and early 1970's. While this rapid growth was seen as a measure of the success of the technology, in retrospect it may have been detrimental. As discussed in chapter **5,** the size and complexity of reactors increased rapidly and there was little opportunity to apply the experience gained from older plants to the design of newer ones. In addition, the regulatory framework was incomplete when many of the plants were designed. As new regulations were formulated, the designs had to be adjusted retroactively to accommodate to changing criteria. With the rush of construction in the mid-l 970's, it was difficult to fully integrate these new requirements into the original designs; hence some portions of the reactor designs emerged as a patchwork of nonintegrated and often ill-understood pieces.

Several changes in design requirements have had far-reaching effects in today's reactors, even though they were not originally expected to have such an impact. For example, new criteria on fire protection in nuclear powerplants have spawned new features and systems to prevent, contain, and mitigate fires. This led to greater separation of safety systems, changes in cable-tray design, requirements for more fire-resistant materials, and changes in civil structures to prevent the spread of fires. Clearly, these modifications can have ramifications for other plant systems. Other regulatory actions concerning seismic design, decay heat removal systems, and protection of safety systems from other equipment failures have also had extensive impacts.

A fresh look at the design of light water reactors (LWRs) could be useful if it more fully integrated the cumulative changes of the past and reexamined the criteria that stimulated those changes. In addition, a new design could incorporate analytical techniques and knowledge that have been acquired since the original designs first were formulated. In fact, it could be beneficial to investigate designs of alternative reactors that have different and potentially desirable characteristics. It is possible that a new design could improve safety and reliability at an acceptable cost and within a reasonable timeframe.

This provides the basic technical reason for reevaluating current nuclear technology as embodied in LWRs. It is important to question, however, the justification for actual changes to the current system. Are there any indications that the current generation of LWR is less than adequately safe or reliable? The public appears to be increasingly skeptical that nuclear reactors are good neighbors. As discussed in chapter 8, more than half of those polled expressed the belief that reactors are dangerous. The same percentage of the public opposes the construction of new plants. While this is not an absolute measure of the adequacy of today's reactors, it does reflect a growing concern for their safety.

The nuclear utilities also have assessed the current reactors in view of their special needs and interests. While they do not believe that LWRs are seriously flawed, the utilities have expressed a desire for changes that would make plants easier to operate and maintain and less susceptible to economically damaging accidents (1 3). Some movement has already been initiated within the nuclear industry in response to utility needs. Most of these efforts focus on evolutionary changes to the current designs and thus represent normal development of LWR technology.

The increasing levels of concern for safety among the public and the utilities has contributed to an interest in safety features that are inherent to the design of the reactor rather than systems which rely on equipment and operators to function properly. The emphasis on inherent safety is reflected to some extent in evolutionary designs for **LWRs, and to a much greater degree** in innovative designs of alternative reactors. In this chapter, LWRs as well as several proposed alternatives will be examined and their relative advantages and disadvantages assessed.

SOME BASICS IN NUCLEAR POWERPLANT DESIGN

To assess the safety and reliability of current reactors and compare them with alternative designs, it is important to understand the basic principles involved in generating power with nuclear technology. At the center of every nuclear reactor is the core, which is composed of nuclear fuel. Only a few materials, such as uranium and plutonium, are suitable fuels. When a neutron strikes an atom of fuel, it can be absorbed. This could cause the nucleus of the heavy atom to become unstable and split into two lighter atoms known as fission products. When this occurs, energy in the form of heat is released along with two or three neutrons. The neutrons then strike other atoms of fuel and cause additional fissions. With careful design, the fissioning can be made to continue in a process known as a chain reaction.

A chain reaction can be sustained best in uranium fuels if the neutrons are slowed before they strike the fissionable materials. This is done by surrounding the fuel with a material known as a moderator that absorbs some of the energy of the neutrons as they are released from the fission process. Several different materials are suitable as moderators, including ordinary water, heavy water, * and graphite.

The heat from the fission process is removed from the core by a continuous stream of fluid called the primary coolant. The reactors examined in this chapter use water or helium as the coolant, although other fluids have been considered. The heat in the coolant can be used directly to produce electricity by driving a turbine-generator, or it can be transferred to another fluid medium and then to a turbine-generator. Both methods have been used effectively in U.S. nuclear powerplants.

There are many possible combinations of fuel, coolant, and moderator that can be used in the design of nuclear reactors. There are advantages and disadvantages associated with the various materials, and no single combination has emerged as being clearly superior to the others.

Several designs have been developed for producing electricity commercially. The most common reactors are known as light water reactors, which use ordinary water as both coolant and moderator. LWR fuel is slightly enriched uranium, in which the percentage of fissionable material has been increased from its naturally occurring value of **0.7 percent to about 3 or 4 percent. After enrichment,** the fuel is shaped into ceramic pellets of uranium dioxide and encased in long, thin fuel rods made of a zirconium alloy.

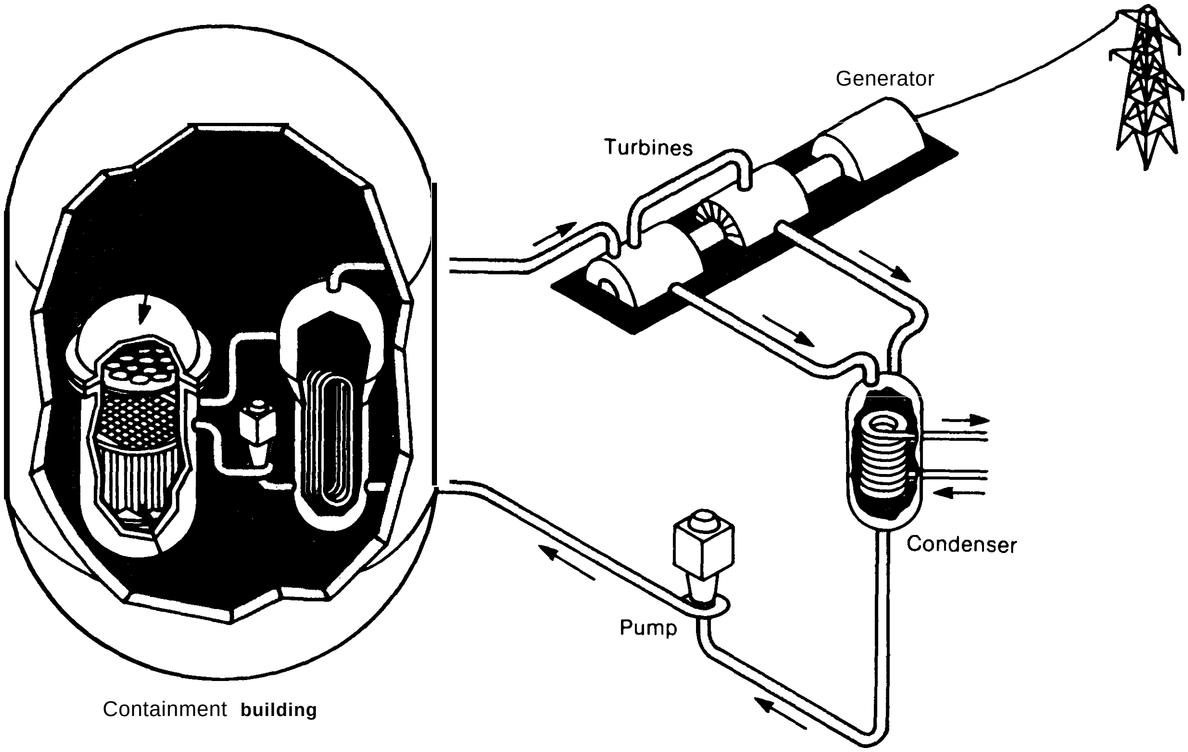
Another commercially feasible reactor is the heavy water reactor (HWR), which is moderated by heavy water and cooled by ordinary water. The fuel in an HWR is similar in form and composition to LWR fuel, but it need not be enriched to sustain a chain reaction. Another design is the high temperature gas-cooled reactor (HTGR), which uses helium as a coolant and graphite as a moderator. The HTGR can use uranium as a fuel, but it usually is enriched to a greater concentration of fissionable material than found in LWR fuel. The fuel form is very different from LWR and HWR fuel, with the uranium shaped into small coated spheres, mixed with graphite to form fuel rods, and then inserted into hexagonal graphite blocks.

In addition to selecting a fuel, moderator, and coolant, reactor designers also must devise a means to transfer the heat from the core to the turbines. In the United States, two different steam cycles have been developed for LWRs. The pressurized water reactor (PWR) shown in figure 19 maintains its primary coolant under pressure so that it will not boil. The heat from the primary system is transferred to a secondary circuit through a steam generator, and the steam produced there is used to drive a turbine.

The second type of LWR that is in commercial use is the boiling water reactor (BWR), shown in figure 20. It eliminates the secondary coolant circuit found in a PWR. In the BWR, the heat from the core boils the coolant directly, and the steam produced in the core drives the turbine. There

***A molecule of light water is made from one atom of oxygen and two atoms of the lightest isotope of hydrogen. By contrast, a molecule of heavy water is made with the isotope of hydrogen called deuterium, which has twice the mass.**

Figure 19.—Pressurized Water Reactor



SOURCE: "Nuclear Power from Fission Reactors," U.S. Department of Energy, March 1982

is no need for a heat exchanger, such as a steam generator, or for two coolant loops. **In addition, since** more energy is carried in steam than in water, the **BWR requires less circulation than the PWR.**

The two LWRs described above can be used to illustrate another crucial part of reactor design. Since nuclear reactors produce highly radioactive materials as byproducts of the fission process, it is essential that the design incorporates enough safety features to ensure the health and safety of the public. During normal operation, the radioactive materials are safely contained within the fuel rods and pose no threat to the public. The concern is that during an accident the fuel may become overheated to the point that it melts and releases the fission products that accumulate during normal operation.

Safety is designed into a nuclear reactor on several levels. First, every effort is made to prevent minor events from developing into major problems. This is accomplished in part by incorporating inherent features into the design to ensure stable and responsive operation. For example, the physics of the core dictates that most reactors will internally slow down the fission process in response to high coolant temperatures, and thus dampen the effects of problems in removing heat from the core. Both PWRs and BWRs have been designed to respond in this way.

Other features, known as engineered safety systems, operate in parallel with, or as a backup to, the inherent physical safety features. They are designed to ensure that the chain reaction is interrupted promptly if there is a problem in the plant and to remove heat from the core even under extreme circumstances. This is necessary because radioactive decay continues to produce heat long after the reactor has been shut down. If decay heat is not removed, the core can overheat to the point of melting. In the event that the shut-

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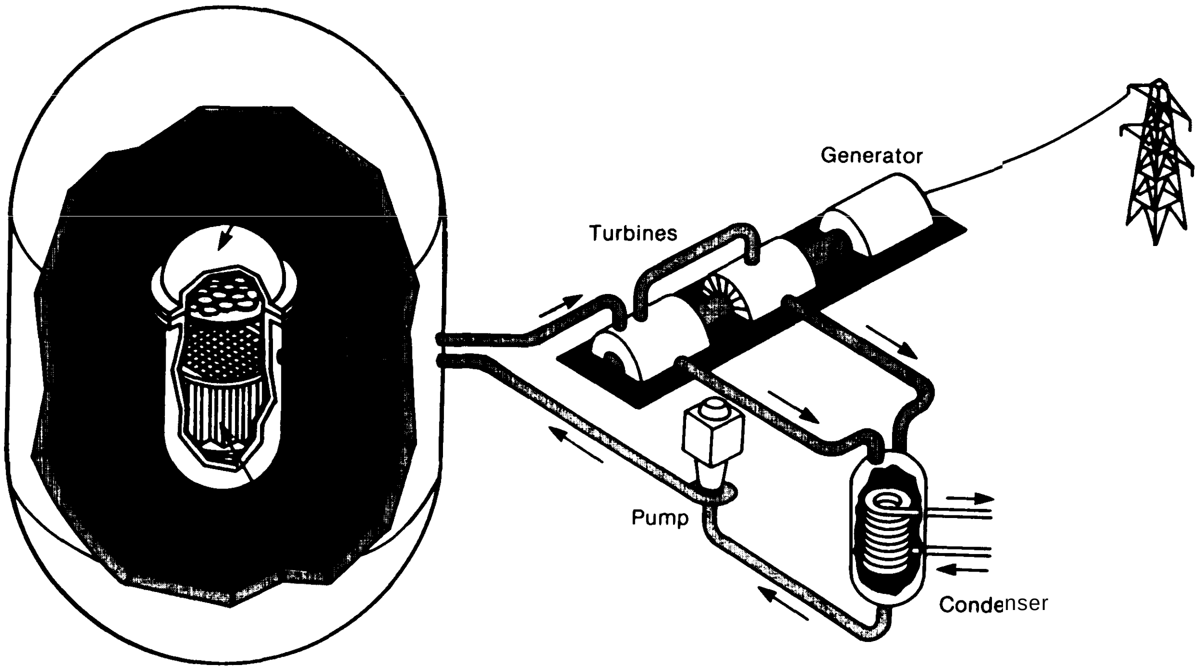
Figure 20.—Boiling Water Reactor



SOURCE: **"Nuclear Power from Fission Reactors," U S. Department of Energy, March 1982.**

down or decay heat removal systems fail, additional safety systems prevent the escape of fission products to the atmosphere.

Rapid interruption of the nuclear chain reaction is accomplished by inserting control rods which contain neutron-absorbing boron into the core. The control system is designed to shut down the reactor automatically in the event that abnormal conditions develop in the core or primary coolant system. Even after the chain reaction is interrupted, however, the coolant must continue to circulate to remove decay heat. If the coolant pressure drops in a BWR or PWR–indicating that some of the coolant has been lost from the primary system—the core is automatically flooded by an emergency core cooling system (ECCS). If the secondary cooling system fails in a PWR, an auxiliary feedwater system is designed to take over. Other backup cooling systems in these plants include high- and low-pressure injection pumps and spray systems. These safety systems are designed to operate automatically, with no requirement for action by the plant operators. They are dependent on human action only insofar as they must be designed, constructed, and maintained to function correctly.

The final step in the design for the safety of a nuclear powerplant is to incorporate features that prevent the release of fission products in the event of a fuel-melting accident. This is done using the concept of "defense in depth," that is, providing successive barriers that radioactive materials must breach before endangering the public. The barriers in LWRs are the fuel cladding, the heavy steel of the reactor pressure vessel, and the thick concrete of the containment building that encloses the pressure vessel and other components in the coolant system.

These examples necessarily oversimplify the complex designs and interactions of safety systems. Many safety systems play a role in the routine operation of the plant as well. This sampling serves as background for the subsequent discussions of safety features of LWRs and of alternative designs.

THE SAFETY AND RELIABILITY OF LIGHT WATER REACTORS

Overview of U.S. Reactors

Of the 84 nuclear reactors with operating licenses in the United States today, about two-thirds are pressurized water reactors. They are offered by three companies—Babcock & Wilcox Co., Combustion Engineering, Inc., and Westinghouse Electric Corp. The remaining reactors (with the exception of one HTGR) are boiling water reactors, sold by General Electric Co. These four companies all supply the nuclear steam supply system (NSSS), or the nuclear-related components of the reactor. The balance of the plant consists of such items as the turbine-generator, the auxiliary feedwater system, the control room, and the containment building. The balance of plant design typically is supplied by an architect-engineering (AE) firm, any one of which might team up with a vendor to provide a reactor plant that meets the needs of a particular utility at a specific site. So far, no completely standardized plant design has emerged, although some convergence has occurred among the designs of each nuclear steam system vendor. There is still a great deal of difference among the designs of similar components (e.g., steam generators) and system configurations. This is not surprising considering the various combinations of vendors and AE firms that have been involved in powerplant design. Furthermore, the **utilities themselves may customize a reactor design to meet specific site requirements.**

Even without the benefits of a standardized design, the LWRs that have operated in the United States for more than 20 years have had good safety and reliability records. There never has been an accident involving a major release of radioactivity to the environment, and the operating performance, while not spectacular, has been comparable to that of coal-fired powerplants. Still, doubts linger about both the safety and reliability of these LWRs. This section examines the reasons for such concerns, including particular features of these reactors that contribute to **concern.**

Safety Concerns

The occurrence of several widely publicized accidents such as those at Three Mile Island and Browns Ferry nuclear plants have underscored the potential for a catastrophic accident. These accidents shook some of the confidence in our understanding of nuclear reactors. For example, the scenario that unfolded at Three Mile Island had not been stressed prior to the accident: it involved the loss of coolant through a small leak in a pressure relief valve, whereas safety analysis had previously concentrated on large loss-of-coolant accidents. Most studies of these serious accidents have faulted the plant operators more than the reactor hardware (1 O), which indicates that LWR designs are not as forgiving of human error as they might be.

Safety concerns also arise because nuclear powerplants have encountered hardware malfunctions in virtually every system, including control rods, steam generators, coolant pumps, and fuel rods. The majority of these hardware problems have been resolved by retrofits, changes in methods of operation, and redesign. Some problems are expected as a new reactor matures, but many of the LWR problems have persisted. Others continue to surface, some because of the intense scrutiny of plants following the Three Mile Island accident and others because of the aging of the earlier reactors. Most of the difficulties probably have technically feasible solutions, but it is not always clear that they would be cost effective to implement. Meanwhile, the discovery of new problems and the slow resolution of old ones continues to erode confidence in the safety of LWRs.

Confidence in LWRs might be enhanced if there was an objective standard for judging the safety of these plants. As a step in this direction, the Nuclear Regulatory Commission (NRC) has proposed a set of qualitative and quantitative safety goals for nuclear powerplants on a 2-year trial basis (4). These safety goals will provide a means for answering the question, "How safe is safe enough?"

There is a fundamental problem with specifying standards for safety: there is no technique for quantifying the safety of a nuclear powerplant in an objective and unambiguous way. One attempt to define nuclear safety is probabilistic risk assessment (PRA), which outlines sequences of events that could lead to accidents and then assigns probabilities to each basic event (12). PRA is becoming a useful tool for such tasks as comparing certain design options in terms of their safety impact. However, the technique is still in its infancy and the results vary widely from one practitioner to the next. The variations occur because the users of PRA must put in their own assumptions about factors contributing to accidents and their probabilities of occurrence. More research is required to establish reasonable and standard assumptions and to refine the process of assessing risk.

Another important component of safety analysis is the consequence of an accident. This depends on the amount of radioactive material that can be released to the environment following a nuclear reactor accident, otherwise known as the nuclear source term. Recent findings indicate that the source terms now used in regulation and risk analysis may overestimate the magnitude of potential fission product releases (5). Only further analysis can tell whether reductions in the source terms can be fully justified, and, if so, the magnitude of the appropriate reduction for each fission product and for each accident scenario. Modeling and analysis programs are now being conducted by NRC and by the Electric Power Research Institute (EPRI), the American Nuclear Society, and by the Industry Degraded Core Rulemaking Program. These studies should eventually produce realistic estimates of fission product releases, but the task is complex and likely to be lengthy.

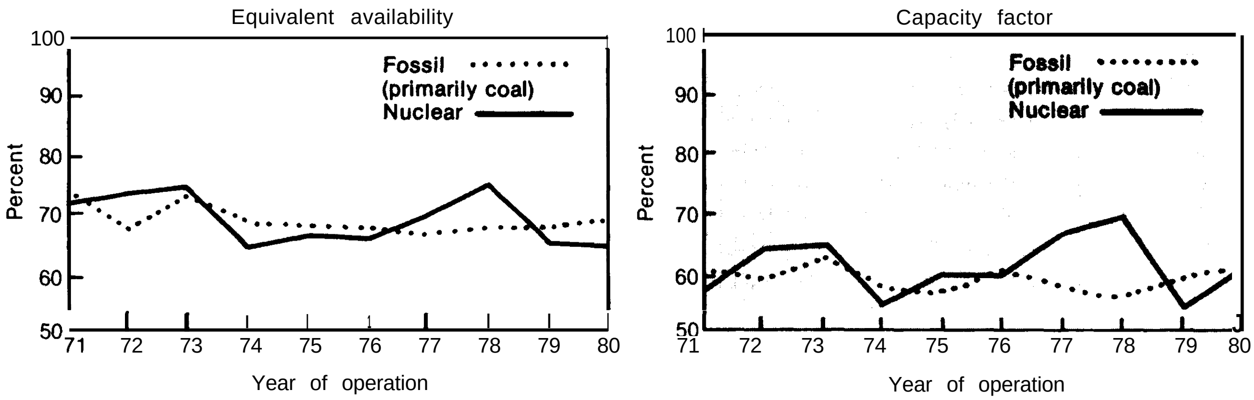
Reliability Concerns

Reliability and safety concerns are closely related, since the same factors that create concern about the safety of LWRs also raise questions about their reliability. If a safety system malfunctions or threatens to do so, the plant must be shut down for a lengthy and often expensive period of maintenance. On the other hand, chronic reliability problems are likely to indicate or contribute to fundamental difficulties that could reduce safety.

The reliability of LWRs is easily quantifiable, in contrast to the difficulties in defining safety. Detailed data on reactor performance have been collected since the beginning of the nuclear era, and they can be analyzed to determine trends. Two measures of performance are commonly used—availability and capacity factor. The availability is defined as the percentage of a time period during which the reactor was available for operation (whether or not it was actually in service). The capacity factor is the ratio of the actual amount of electric generation to the total theoretical output of the plant during the same time period. Each of these quantities has some drawbacks as a measure of plant reliability: the capacity factor is affected by the demand for electricity and the plant availability is insensitive to the capability of the plant to operate at full power. Since nuclear powerplants usually are baseloaded, the capacity factor is generally a better measure of reliability. Both capacity and availability are shown in figure 21 as a function of time for all years from 1971 through 1980 **('17). To** provide a basis for comparison, reliability records are also shown for coal-fired plants larger than 400 megawatts electrical (MWe). It can be seen that the average availability for the two types of plants has been nearly identical at about 69 percent. The average capacity factor for nuclear plants over the same time period was 60 percent, which was 3 percentage points better than for coal. Thus, nuclear plants operate reliably enough compared with their closest counterparts, even though the average performance has not been as outstanding as anticipated by the original nuclear powerplant designers.

it is instructive to reexamine performance data for groups of reactors as well as the industry as a whole. Capacity factors are shown for each reactor type and vendor in table 13 (27). When comparing the data on a lifetime or cumulative basis, it can be seen that there are only slight differences among reactor vendors or types. It also

Figure 21.—Comparison of Fossil Units (400 MWe and Above) to All Nuclear Units



Equivalent availability	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	Avg.
Fossil	72.2	67.8	73.2	68.3	67.7	67.2	66.7	67.4	68.0	69.5	68.6
Nuclear	71.6	73.7	74.4	64.0	66.7	65.6	69.8	74.3	64.8	64.5	68.9

Capacity factor	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**Avg.**
Fossil	**60.0**	**59.6**	**62.4**	**57.7**	**57.3**	**69.4**	**57.4**	**55.3**	**56.3**	**59.5**	**56.6**
Nuclear	**58.9**	**63.1**	**64.1**	**53.6**	**59.4**	**59.0**	**65.2**	**68.3**	**52.9**	**59.5**	**59.8**

SOURCE. National Electric Reliability Council, "Ten Year Review 1971-1980 Report on Equipment Availability "

Table 13.—Comparison of Lifetime Capacity Factors for U.S. Reactors

	Lifetime capacity factor
Reactor type:	
PWR	61 .OO/o
BWR	58.70/o
Reactor supplier:	
Westinghouse	62.7%
Combustion Engineering	59.70/0
Babcock & Wilcox	57.0 "/0
General Electric Co.	58.7%
All plants	60.2%

SOURCE: A. Weitzberg, et al , "Reliability of Nuclear Power Plant Hardware — Past Performance and Future Trends," NUS Corp., Jan15, 1983.

should be noted that these averages can mask substantial spreads in the performance of individual plants. As discussed in chapter 5, the cumulative capacity factors of the worst plants are as low as 40 percent while those of the best are as high as 80 percent.

The hardware problems discussed above have contributed to low availabilities in some plants. These and other hardware problems have been responsible for lengthy periods of downtime as discussed in detail in volume II. It is concluded there that most of the these problems have been or soon will be resolved (27).

Despite signs of progress, LWRs still are not operating trouble-free. The steam generators in several plants have degraded to the point that it has been necessary to replace them. This repair is estimated to cost between $60 million and $80 million in addition to the cost of purchasing replacement power. Other plants may have to undertake expensive retrofits or modify operation to mitigate concerns over pressurized thermal shock (26).

Another impediment to achieving high availability is the stream of retrofits that has followed the accident at Three Mile Island. The Three Mile Island action plan contains about 180 requirements for changes in operational plants; these changes, of course, could not be incorporated into the basic powerplant design, but had to be added to existing systems. This type of retrofitting is seen as a problem by both the nuclear industry as well as its critics since it introduces the possibility of adverse safety consequences. In fact, in some cases, new requirements might reduce rather than enhance safety. This could happen if unanticipated interactions arise or if there is an inadequate understanding of the system the requirement is intended to improve.

The revision in NRC requirements for seismic restraints on piping is often cited as an example of retrofit problems. The restraints in nuclear powerplants are designed to preserve the integrity of pipe by limiting vibrations even if an earthquake should occur. Many plant operators and designers complain that these restraints are expensive to install and that they hold the pipes too rigidly to allow for thermal expansion. Furthermore, some critics of the current seismic requirements feel that piping actually may be more prone to failure in an overconstrained system. These critics assert that today's requirements for seismic restraints result from an attempt to make it easier to analyze conditions in plants rather than from an identifiable need (l).

On the balance, retrofits probably have improved the safety of operating nuclear powerplants. in fact, one assessment of plants before and after the Three Mile Island retrofits concludes that the probability of an accident has been reduced by a factor of 6 in PWRs and by a factor of 3 in BWRs, with the core melt probability for PWRs now only slightly higher than for BWRs. These improvements are attributed primarily to higher reliability of feedwater systems and regulatory and inspection procedures that reduce the probability of human error (19).

Examples of Specific Concerns

Since 1978, NRC has been required by Congress to prepare a list of generic reactor problems. This list is revised annually to reflect new information and progress toward resolution. Each time a new safety issue is identified, NRC assesses the need for immediate action. In some cases, action such as derating (reducing the approved operating power) certain reactors, is taken to assure public health and safety. in other cases, an initial review does not identify any immediate threat to the public, and further research is conducted. Many generic safety issues have been resolved and removed from NRC's list of significant safety items (26).

Table 14 summarizes the 15 most important unresolved safety issues as determined by NRC in 1982. A few of the items on that list will be examined here as examples of the types of concerns that remain about LWRs and some of the factors preventing their resolution.

One of the most widely publicized safety problems is the potential in PWRs for fracture of the reactor vessel from pressurized thermal shock. Reactors are designed to be flooded with relatively cold water if a loss of coolant accident occurs. The sudden temperature differential causes surface strains, known as thermal shock, on the thick metal wall of the reactor vessel and imposes severe differential stress through the vessel wall. While plant designers have understood and accounted for this phenomenon for 'years, they have only recently discovered that two other factors may make the effect more acute than anticipated. One is that the emergency cooling system is likely to be actuated following a small-break accident (e.g., the one at Three Mile Island) when the reactor vessel is still highly pressurized. In such a situation, the stresses due to thermal shock would be added to those due to internal pressure. The second factor is that the weld and plate materials in some older reactor vessels are becoming brittle from neutron exposure faster than had been expected. Such embrittlement increases the vulnerability of the vessel to rupture following pressurized thermal shock. While the possibility

Table 14.—Unresolved Safety Issues

issue/Descridion	issue/DescrilMion
Water hammer: Since 1969 there have been over 150 reported incidents involving water hammer in BWRs and PWRs. The incidents have been attributed to rapid condensation of steam pockets, steam-driven slugs of water, pump startup with partially empty lines, and rapid valve motion. Most of the damage has been relatively minor.	**Containment emergency sump performance:** Following a loss of coolant accident in a PWR, water flowing from a break in the primary system would collect on the floor of containment. During the injection mode, water for core cooling and containment spray is drawn from a large supply tank. When the tank water is depleted, a recirculation mode is established by drawing water from the containment floor or sump. This program addresses the safety issue of the adequacy of the sump and suppression pool in the recirculation mode.
Steam generator tube integrity: PWR steam generators have shown evidence of corrosion-induced wastage, cracking, reduction in tube diameter, and vibration-induced fatigue cracks. The primary concern is the capability of degraded tubes to maintain their integrity during normal operation and under accident conditions with adequate safety margins.	**Station blackout:** The loss of A.C. power from both off site and onsite sources is referred to as a station blackout. In the event this occurs, the capability to cool the reactor core would be dependent on the avail ail it y of systems which do not require A.C. power supplies and the ability to restore A.C. power in a timely manner. There is a concern that a station blackout may be a relatively high probability y event and that this event may result in severe core damage.
Mark I containment long-term program: During a large-scale testing program for an advanced BWR containment system, new suppression pool loads associated with a loss of coolant accident were identified which had not been explicitly included in the original design of the Mark I containment systems. In addition, experience at operating plants has identified other loads that should be reconsidered. The results of a short-term program indicate that, for the most probable loads, the Mark I containment system would maintain its integrity and functional capability.	**Shutdown decay heat removal requirements:** Many improvements to the steam generator auxiliary feedwater system were required after the accident at Three Mile Island. However, an alternative means of decay heat removal in PWRs might substantially increase the plants' capability to deal with a broader spectrum of transients and accidents and thus reduce the overall risk to the public.
Reactor vessel material toughness: Because the possibility of pressure vessel failure is remote, no protection is provided against reactor vessel failure in the design of nuclear facilities. However, as plants accumulate service time, neutron irradiation reduces the material fracture toughness and initial safety margins. Results from reactor vessel surveillance programs indicate that up to 20 operating PWRs will have materials with only marginal toughness after comparatively short periods of operation.	**Seismic qualification of equipment in operating plants:** The design criteria and methods for the seismic qualification of equipment in nuclear plants have undergone significant change. Consequently, the margins of safety provided in existing equipment to resist seismically induced loads may vary considerably and must be reassessed.
Fracture toughness of steam generator and reactor coolant pump supports: Questions have been raised as to the potential for lamellar tearing and low fracture toughness of steam generator and reactor coolant pump support materials in the North Anna nuclear powerplants. Since similar materials and designs have been used on other plants, this issue will be reassessed for all PWRs.	**Safety implications of control systems:** It is generally believed that control system failures are not likely to result in the loss of safety functions which could lead to serious events or result in conditions that cannot be handled by safety systems. However, indepth plant-by-plant studies have not been performed to support this belief. The purpose of this program is to define generic criteria that may be used for plant-specific reviews.
Systems interactions in nuclear powerplants: There is some question regarding the interaction of various plant systems, both as to the supporting roles such systems play and as to the effect one system can have on other systems, particularly with regard to the effect on the redundancy and independence of safety systems.	**Hydrogen control measures and effects of hydrogen burns on safety equipment:** Reactor accidents which result in degraded or melted cores can generate large quantities of hydrogen and release it to the containment. Experience gained from the accident at Three Mile Island indicates that more specific design provisions for handling large quantities of hydrogen releases maybe appropriate, particularly for smaller, low-pressure containment designs.
Determination of safety relief valve pool dynamic **loads** and temperature limits for BWR containment: Operation of BWR primary system pressure relief valves can result in hydrodynamic loads on the suppression pool retaining structures or structures located within the pool.	**Pressurized thermal shock:** Neutron irradiation of reactor pressure vessel weld and plate materials decreases fracture toughness. This makes it more likely that, under certain conditions, **a crack could grow to a size that might threaten vessel integrity,**
Seismic design criteria: While many conservative factors are incorporated into the seismic design process, certain aspects of it may not be adequately conservative for all plants. Additional analysis is needed to provide assurance that the health and safety of the public is protected, and if possible, to reduce costly design conservatism.	

SOURCE: US. Nuclear Regulatory Commission, "Unresolved Safety Issues Summary," Aug. 20, 1982, of a pressure vessel failure is peculiar to only a few older reactors, it is of concern that such a potentially severe condition was not recognized sooner. Measures to mitigate the problem of pressurized thermal shock include reducing the neutron flux near the outer walls, increasing the temperature of emergency cooling water, heating the reactor vessel at very high temperatures to reduce brittleness, and derating the plant (1 5,27).

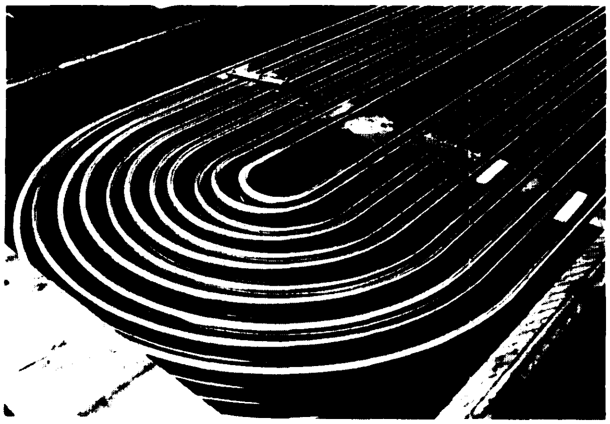
BWRs are not susceptible to pressurized thermal shock, but they have been plagued by a problem known as intergranular stress corrosion cracking. This problem, which involves defects in the reactor coolant piping, is now listed by NRC as resolved, but it continues to be the subject of extensive and costly research programs throughout the industry. Most of the service piping sensitive to such cracking has been designed out of the later BWRs, but reactors currently under construction will have recirculation loop piping with some susceptibility to this phenomenon (15,27).

Another problem on the list of unresolved safety issues deals with the corrosion or fatigue cracking of steam generator tubes (15). This is of concern because these tubes separate the primary coolant from the secondary system, and there is some question whether degraded tubes will be able to maintain their integrity under accident conditions. NRC estimates that steam generator degradation has accounted for about 23 percent of the non refueling outage time in nuclear reactors. The corrosion has been attributed to a combination of inappropriate water-chemistry treatment and poor quality materials in the steam generators. The result has been wastage, cracking, reduction in tube diameter, separation of cladding from the tube sheet, and deterioration of the metal plates that support the tubes inside the generators. The severity of the problem varies with steam generator design and water treatment methods. Much of the corrosion has been brought under control, but plant operators continue to inspect their steam generators regularly and plug the degraded tubes when necessary. Operators of several nuclear units–Surry 1 and 2 in Virginia and Turkey Point 3 and 4. in Florida—have already had to replace their steam generators. Other units may face expensive and lengthy overhauls in the future. The fatigue cracking appears to result from flow-induced vibrations, and resolution of this problem may require design modifications.

Two general safety issues deal with uncertainties over the behavior of the complex systems found in nuclear powerplants. One concern is that the interactions among the various systems are not fully understood and could contribute to an accident under some circumstances. in particular, it is possible that some system interactions

Photo credit: Atomic Industrial Forum

These four steam generators are awaiting installation in a large pressurized water reactor. In this type of reactor, water flows through the core to remove heat and then through narrow tubes in the steam generator to transfer it to a secondary coolant loop.



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could eliminate the redundancy or independence of safety systems. Another concern is that the failure of a control system might aggravate the consequences of an accident or prevent the operator from taking the proper action. These concerns relate to the need to understand the entire reactor and its interrelated systems rather than to any specific feature of its hardware. Resolving either of these concerns probably would require analysis on a plant-specific basis, but NRC is attempting to identify generic criteria. Both of these issues contribute to a larger question: are LWR designs more complex than necessary and could a simpler, but equally safe, reactor be designed?

Another safety concern is that a nuclear plant may develop a serious problem and fail to shut down automatically in an incident known as an "anticipated transient without scram." **In such a situation, the emergency cooling system would** have to remove not only the decay heat, but also the heat generated by full-power operation. NRC has removed this item from its list of generic safety issues, but many critics feel that it continues to represent a valid concern. This issue was highlighted by the discovery at the Salem plants in New Jersey that faulty circuit breakers prevented the scram systems from activating automatically (16).

The resolution of several of the unresolved issues may require adding new equipment to LWRs in operation or under construction. One of these items is the provision for an alternative means of removing decay heat. NRC is examining whether an additional system might substantially increase the capability of the reactor to deal with a broader range of accidents or malfunctions. Another issue is whether the installation of a means to control hydrogen is required to prevent the accumulation of dangerous levels of the gas in the containment vessel. These concerns are an outgrowth of lessons learned from the Three Mile Island accident. Either measure discussed above would be very costly to retrofit on existing plants but might be easily designed into a new plant.

These examples indicate that there are still unresolved generic safety questions concerning the LWR, and that the resolution of these issues will involve a complex tradeoff between cost and safety. While no single issue has been identified as a fatal flaw, neither is there a clear indication that current LWR technology is fully mature and stable.

Lessons Learned From Operating LWRs

The utilities operating LWRs have gained knowledge of both the strengths and weaknesses of their plants. A recent survey of the utilities reflects the concerns about safety and reliability mentioned above and gives specific recommendations about features that might mitigate the problems (13). The following recommendations were made:

- safety and control systems in new LWRs should be simpler and easier to operate, test, and maintain. Utility personnel expressed preferences for passive and fail-safe characteristics whenever possible;
- safety systems should be separated from nonsafety systems and dedicated to single functions. plant operators worry that overlapping functions may lead to adverse impacts in a complex accident scenario;
- the response of existing plants to abnormal occurrences should be slowed. Because of the low inventory of primary and secondary cooling water in current LWRs, the time between the start of a transient and the onset of melting in the core can be short. If all safety equipment works as designed, it is likely that transients would be brought under control quickly, regardless of the cause. If certain important safety components fail, melting could begin after 40 minutes in a PWR. The failure of all safety systems, which is not considered a plausible scenario, could cause core melting in less than 1 minute;
- containment buildings should be larger to provide adequate space for maintenance. Current structures do not allow enough room to easily handle equipment that is being disassembled for maintenance; and
- the potential for retrofits on future plants should be reduced as much as possible by taking a fresh look at the LWR. Such an effort should integrate the retrofits into a new

design rather than piece them on top of an existing one.

Both NRC's list of unresolved safety issues and the survey of utility executives provide concrete examples of reasons for concern over the safety and reliability of current plants. Existing LWRs have serious, although resolvable, problems with important hardware components; the interrelated safety and control systems hinder a deep understanding of their behavior; complexity has been increased by the large number of safety-mandated retrofits; and current reactors are somewhat unforgiving of operator errors. Despite this less-than-perfect record of the LWR, many in the industry are reluctant to abandon it. They argue that they have made appreciable progress along the learning curve that would have to be repeated with an alternative reactor concept.

ADVANCED LIGHT WATER REACTOR DESIGN CONCEPTS

Improvements could be made to the current generation of LWRs by redesigning the plants to address the safety and operability problems outlined above. Furthermore, the entire design could be integrated to better incorporate various changes made to LWRs in the past decade. If such a redesign effort were successful, LWRs would probably continue to be the preferred option in the future. LWRs have the advantage of being familiar, proven designs with a complete infrastructure to support manufacturing, construction, and operation.

Advanced LWR designs are being developed by both Westinghouse Electric Corp. and General Electric Co., and they should be available to U.S. utilities before any new reactors are ordered. General Electric is designing a new BWR that is an evolution of the most advanced plants currently under construction. The newer reactor has been modified to enhance natural circulation of the primary coolant and hence improve passive cooling. This increases the ability of the coolant system to remove decay heat in the event that the main circulation system fails. The design further provides for rapid depressurization of the primary system so that both low- and high-pressure pumps can supply water to the reactor vessel. This safety feature provides additional assurance that emergency coolant would be available in the event that primary coolant is lost (6).

Westinghouse Electric Corp. is developing an advanced version of its PWR. The company has undertaken a joint program with Mitsubishi Heavy Industries, the Westinghouse licensee in Japan. It is expected that the design development will be completed by 1984, and there are plans to initiate verification testing by 1986. Westinghouse is reviewing this design effort with NRC so that the advanced PWR could be readily licensed in the United States.

The Westinghouse design focuses on reducing risks, improving daily operations, anal controlling costs *(8,11).* It attempts to reduce economic risk to the owner and health risk to the public by incorporating several new features. The coolant piping has been reconfigured and the amount of water in the core has been increased to reduce the possibility that a pipe break could drain the primary coolant enough to uncover the core. Protection against other accidents that could uncover the core has been provided by safeguarding against valves that could fail in an open position. Additional risk reduction efforts have been focused on the response of plant operators and systems following an accident, with the goal of requiring less operator action and more automatic responses.

Improvements in normal plant operations are another important feature of the Westinghouse advanced design. The reactor has been redesigned to operate 18 to 24 months on a single batch of fuel, rather than the current 12 month cycle. The longer fuel cycle is made possible by enlarging the diameter of the reactor and reducing the power density and neutron flux. This is combined with a different way to moderate the neutrons at the beginning of the cycle so that more plutonium is produced; the extra fuel is burned at the end of the cycle when the fissionable uranium is depleted. Other efforts have been made to reduce the amount of time required to refuel and inspect the reactor when it is shut down. The combined effect of these final two features is to increase the availability of the reactor, perhaps to as much as 90 percent.

Efforts have also been directed toward increasing the reliability of the advanced PWR. For example, the steam generators have been redesigned so that there will be fewer stresses on the tubes and less potential for contaminants to collect. Other improvements have been made to increase the reliability of the nuclear fuel and its support structure.

Operational improvements have been made in the area of occupational radiation exposure. The new plants have been designed for easy access to reduce worker exposure. In addition, radiation shielding has been added to areas where high radiation fields can be expected. Finally, ease of maintenance and repair have been factored into the redesign of the steam generators; this should reduce the large occupational exposures that have resulted from steam generator maintenance in current PWRs.

An area that is closely related to both safety and operation is the effort to increase the design margins of the advanced PWR. The increased amount of coolant in the core and the reduced core power density make the reactor less sensitive to upsets. Furthermore, the physics of the design dictates that the core will be even better at slowing the fission process in response to a rapid rise in temperature.

The capital cost of the advanced PWR proposed by Westinghouse probably would be greater than that of current PWRs. An effort has been made to hold down the capital cost by simplifying fluid systems, making more use of multiplexing, and completing at least three-quarters of the design before construction is initiated. Moreover, other features of the design should compensate for the increased capital costs, resulting in lifetime costs that should be comparable to those of today's LWRs. Significant fuel savings are expected, with reductions in both uranium and enrichment requirements. This is due to the reduction in specific power, the more effective use of plutonium created within the core,

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We nghou e efe o d n ed PWR ean hee de gn ha n o po e n eg a ed fa h on man e on ea ned o da e Ea a u a on u ng p obab k a e men nd a e ha he ad an ed de gn m gh du e he p obab o a den b mo e h a facto o 0 when ompa ed w h u en WR ow m o be een h w be pe e ed b he p b d e o g o gh h g o w e w o e p o d

An intermediate step in the redesign of the PWR has been taken by the Central Electricity Generating Board (CEGB) in Great Britain (22). CEGB did not redesign the basic PWR; rather, it added safety features to the Standardized Nuclear Unit Power Plant System (SNUPPS), which was developed and marketed in the United States in the 1970's. Most of the changes increase the separation and redundancy of safety systems, such as adding a steel containment shell to the normal concrete containment structure, increasing the number and capacity of pumps in the emergency-cooling system, and increasing the number of independent diesel generators to provide electrical power if the normal supply is interrupted. These changes are likely to reduce the probability of a core meltdown, and the probability for the release of fission products is much lower still. These safety improvements will not be inexpensive; the new design is estimated to cost 25 percent more than the original SNUPPS plant.

HEAVY WATER REACTORS

If the new designs for LWRs are perceived as being less than adequate to ensure safe and reliable operation, it is possible that alternative designs will become more attractive to utilities and investors. The HWR is a potential candidate because it is the only other type of reactor that has been deployed successfully on a commercial scale. The HWR has been developed most extensively in Canada, where the CANDU (Canada deuterium uranium) reactors produce all the nuclear-generated electricity. In addition, HWRs have emerged as competitors with LWRs in several other nations, including India, Korea, and Argentina.

The interest in this type of reactor originally derived from the effective way in which heavy water moderates neutrons, with a resultant increase in fuel economy when compared to LWRs. There are also various inherent safety features of the HWR that make it an attractive alternative to the LWR. in addition, the current generation of HWRs has compiled an excellent operating record. In fact, the HWRs in operation worldwide have the most impressive reliability record of any commercial reactor type. As shown in table 15, HWRs operated at an average capacity factor of 71 percent in 1982, which far exceeds the records of either PWRs or BWRs. Moreover, in 1982, 5 of the top 10 best performers internationally were HWRs, even though this type of plant accounts for only 5 percent of the total nuclear capacity. Both lifetime and annual capacity factors for the world's best power reactors are shown in table 16.

Table 15.—World Comparison of Reactor Types (150 MWe and larger)

Type of reactor	Number of reactors	Average annual load factor (percent)
Pressurized heavy water reactor	13	71
Gas-cooled reactor[a] (Magnox)	26	57
Pressurized (light) water reactor	106	59
Boiling water reactor	57	60

aTh, natural. uranium gas-cooled reactors referenced here differ Significantly from the HTGR discussed in this report.

SOURCE: "Nuclear Station Achievement 19S3," *Nuclear Engineering International*, October 1983,

The design of an HWR is somewhat similar to a PWR in that primary coolant transfers heat from the core to a secondary coolant system via a steam generator (3,6,21). In many other ways, the design of an HWR differs significantly from that of a PWR. As implied by its name, heavy water is used to moderate the neutrons generated in the chain reaction. This is a more effective moderator than ordinary water, and so the core can be composed of less concentrated fissionable material than in a PWR. As a result, the HWR can operate with unenriched or natural uranium. Nations that have not developed enrichment technology perceive this as an advantage, but in the United States uranium enrichment is readily available. it is likely that U.S. utilities would elect to operate HWRs with uranium that is slightly enriched. On such a fuel cycle, the HWR would require only 60 percent of the uranium used in

Table 16.—World Power Reactor Performance (150 MWe and larger)

Reactor type	Unit	Nominal rating gross (MWe)	Capacity factor (percent)
Annual[a]			
PHWR	Pickering 2	542	96
PHWR	Bruce 3	826	96
PHWR	Bruce 4	826	95
PHWR	Pickering 4	542	91
BWR	Muehlberg	336	91
PWR	Turkey Point 3	728	90
PWR	Beznau 2	364	89
BWR	Garona	460	88
PWR	Grafenrheinfeld	1299	88
PHWR	Bruce 1	826	87
Cumulative[b]			
PHWR	Bruce 3	826	88
PHWR	Bruce 4	826	85
PWR	Beznau 2	364	85
PHWR	Pickering 2	542	83
GCR	Hunterston A	169	83
PWR	Stade 1	662	82
PHWR	Pickering 4	542	81
BWR	Muehlberg	336	80
PWR	Obrigheim	345	80

[a]From July 1982 through June 1983.
[b]From start of operation through June 1983

SOURCE "Nuclear Stat Ion Achievement 1983, " Nuclear *Engineering International*, October 1983

an LWR to produce the same amount of electricity.

The use of heavy water instead of ordinary water as a moderator and coolant provides a fuel-economy advantage, but it also suffers from a disadvantage. Heavy water is expensive, and the initial inventory of heavy water represents about 20 percent of the capital cost of HWRs. Total capital costs of HWRs are probably comparable to those of LWRs, but fuel cycle costs over the life of the plant should be lower.

Another feature of the HWR that distinguishes it from a PWR is the use of hundreds of small pressurized tubes instead of a single large pressure vessel. The pressure tubes in an HWR enclose the fuel assemblies and heavy water coolant which flows through the tubes. They are positioned horizontally in a large unpressurized vessel known as a calandria, as shown in figure **22.** The calandria is filled with heavy water, which acts as a moderator and is kept at low temperature and pressure. The heavy water in the calandria surrounds the coolant tubes but is isolated from the fuel.

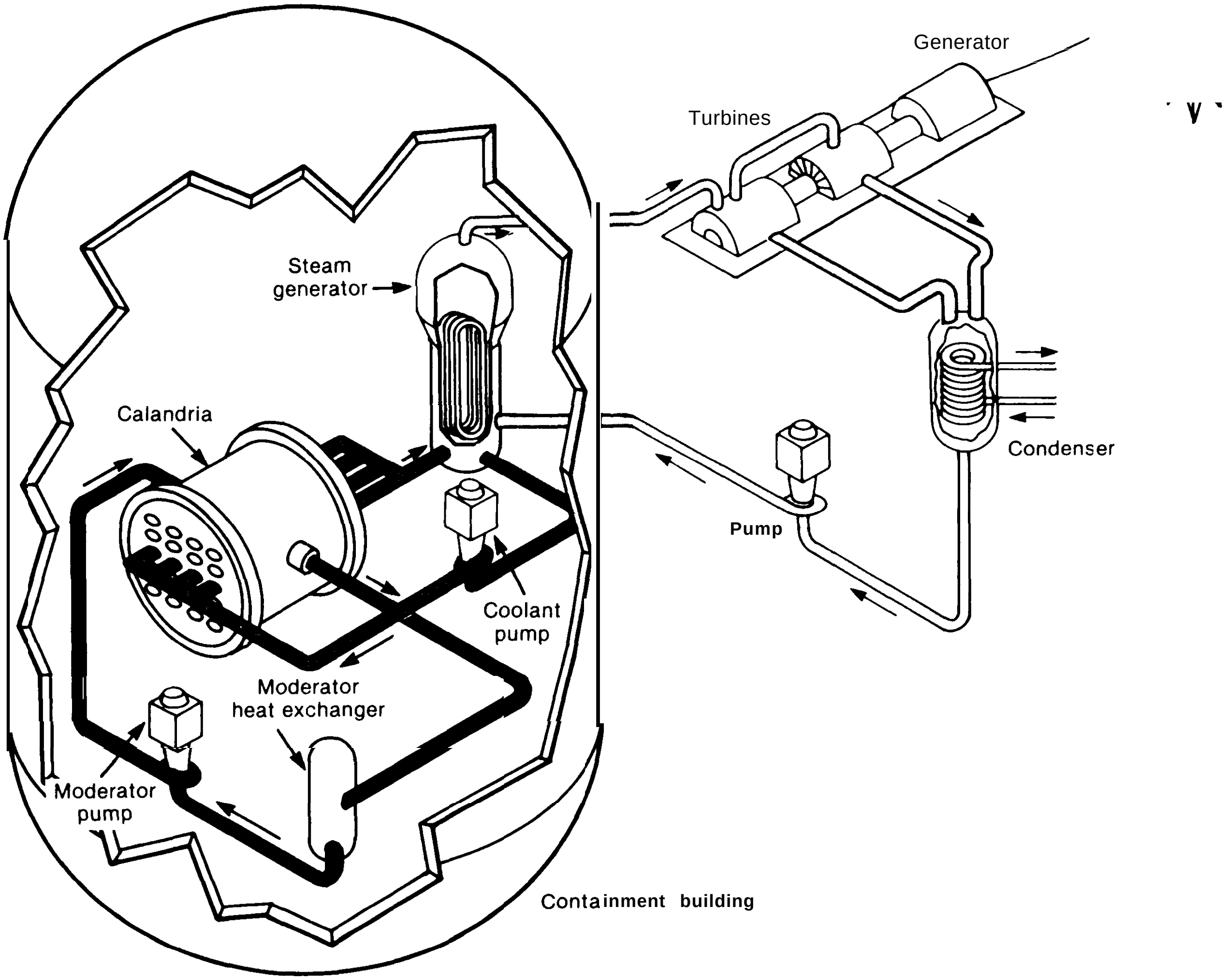
A disadvantage of the pressure tube configuration is that the thin walls of the tubes restrict the temperature of the coolant more than the heavy steel pressure vessel of an LWR. Hence, the overall efficiency of energy conversion is somewhat less in an HWR. Efficiency is further limited in the HWR by the heat that is deposited in the heavy water moderator. Current HWRs achieve an efficiency of only 29 percent, while LWRs typically achieve a 33-percent efficiency.

The pressure tube configuration has some advantages in that it separates the moderator from the coolant. The reactivity control devices and safety systems are located outside the primary coolant loop and cannot be affected by a loss of coolant accident. Moreover, the moderator acts as a backup heat sink that could cool the fuel if the primary coolant system fails. This reduces the necessity to develop elaborate systems to provide emergency core cooling and decay heat removal, which have been a primary concern in LWRs.

The HWR differs from the LWR in its method of refueling. In an LWR, the reactor must be shut down, the cover of the pressure vessel removed, and the fuel rods exchanged in an operation that lasts for several weeks. HWRs can utilize online refueling because they use pressure tubes rather than a single pressure vessel. This means that the reactor can continue to operate while depleted fuel assemblies are removed and replaced with **fresh fuel. This method of refueling contributes to the overall availability of the reactor since there is no need to shut** it down. It also enhances rapid identification and removal of fuel elements that leak radioactive materials into the cooling water.

As discussed above, the HWR appears to have certain safety and operational advantages with respect to the LWR. However, there are other factors that make it unlikely to be considered as a viable alternative to the LWR in the United States. As with all alternatives to the LWR, the heavy water reactor suffers from lack of familiarity and experience in the United States. There are no vendors in the United States which offer HWRs, and hence there is no established domestic infrastructure to build and service them. Furthermore, there are no utilities with HWR experience. These factors would not necessarily prohibit the introduction of an HWR into the United States, since the manufacturing require-

Figure 22.—Heavy Water Reactor



SOURCE: Office of Technology Assessment.

ments, design, and operational skills for the HWR and LWR are similar. However, any alternative design would have to overcome barriers before being accepted. It would have to be clearly superior to the LWR, but in some areas that have proved to be most troublesome for **LWRs** for instance, operational complexity, the HWR may actually add to the uncertainty.

In addition to lack of familiarity, the HWR offers no capital cost advantages to the LWR. Even though lifetime costs may be lower, it is unlikely that utilities would be willing to assume large capital debts without a clear demonstration of the ad-vantages of an alternative reactor.

Another issue relates to uncertainties in the licensing process. The HWR is a fully commercial and licensable reactor in Canada and other nations. In the United States, however, it would be necessary to modify the licensing procedures to match a new reactor. It also is likely that design modifications would have to be made to the **HWR in order to accommodate to the U.S. regulatory structure; there is a spectrum of opinions on how extensive these changes would be (24). Cost and availability uncertainties would be in-**

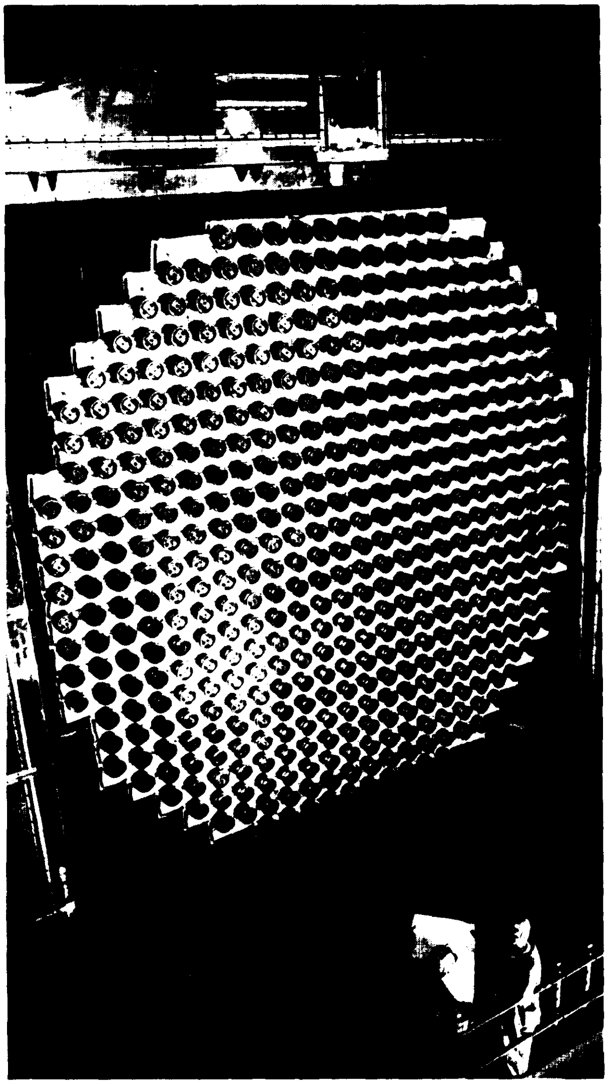


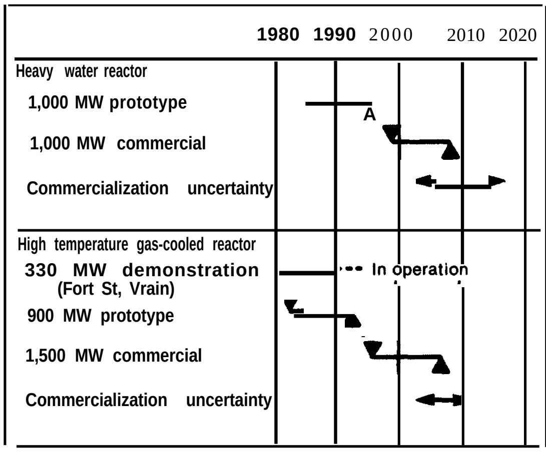
Photo credit: Ontario Hydro

In a heavy water reactor, natural uranium is **used as the fuel.** The fuel bundles are loaded horizontally, each in its own tube containing pressurized water. The pressure tubes in a heavy water reactor replace the large steel vessel in light water reactors

troduced into a system that already is less predictable than desired. Initial capital costs might be increased by design modifications to improve efficiency or meet stringent seismic requirements. The commercialization process could be extended if significant changes are required in the licensing and design of this reactor. One possible schedule for development was developed by EPRI and is shown in figure 23.

In the United States, the HWR is not perceived as offering enough advantages to abandon LWR technology. Nonetheless, the HWR, may become a source of electricity for U.S. utilities. It is possible that Canadian reactors operating near the U.S. border might significantly increase the export of power to U.S. grids if the HWRs in Canada continue to operate safely and reliably.

Figure 23.—Schedules for Alternative Reactors



▼ Preliminary safety analysis report filed

▲ Completion of construction

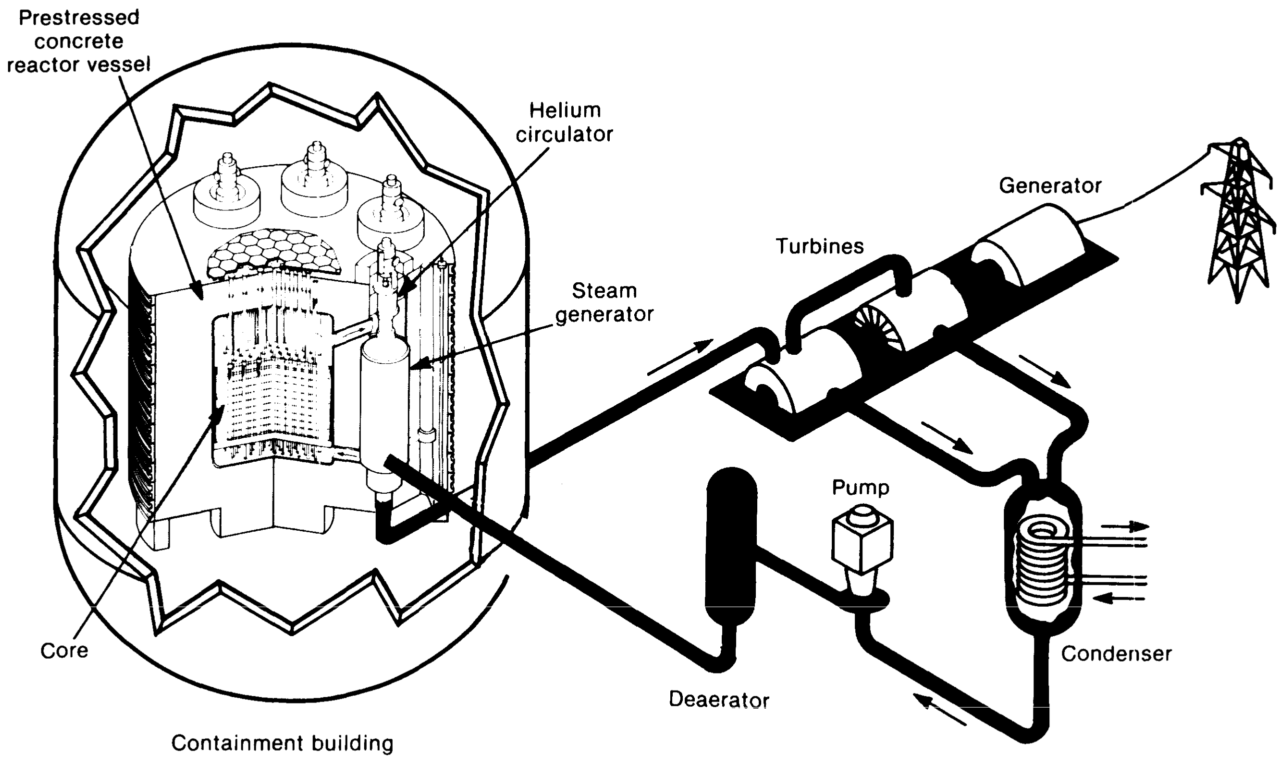
◄► Uncertainty in achieving commercialization target

SOURCE: "Alternative Nuclear Technologies, " Electric Power Research Institute, October 1981.

THE HIGH TEMPERATURE GAS-COOLED REACTOR

The HTGR is cooled by helium and moderated by graphite, and, as shown in figure 24, the entire core is housed in a prestressed concrete reactor vessel (PCRV) (2,6,25). The reactor uses enriched uranium along with thorium, which is similar to nonfissionable uranium in that it can be transformed into useful fuel when it is irradiated. Because helium is used instead of water as a coolant, the HTGR can operate at a higher temperature and a lower pressure than an LWR. This results in a higher thermal efficiency for electricity generation than can be achieved with the

Figure 24.—High Temperature Gas-Cooled Reactor



SOURCE: GA Technologies and Office of Technology Assessment.

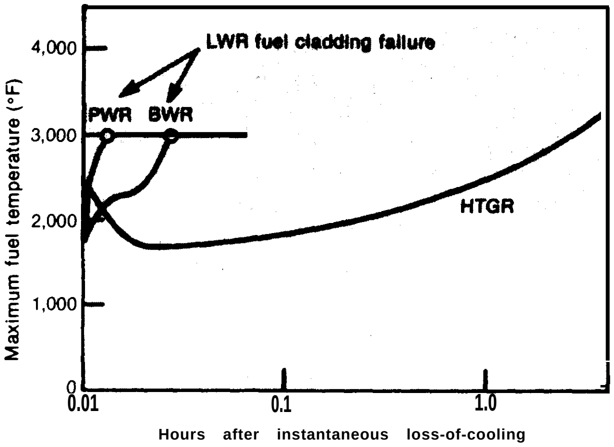
other alternative reactors discussed in this chapter; it also makes the HTGR particularly suited for the cogeneration of electricity and process steam.

The HTGR has several inherent safety characteristics that reduce its reliance on engineered devices for safe reactor operation. First, the use of helium as a primary coolant offers some advantages. Because helium is noncorrosive in the operating temperature range of the HTGR, it causes little damage to components. Furthermore, it is transparent to neutrons and remains nonradioactive as it carries heat from the core. The use of graphite as a moderator also has some advantages. It has a high heat capacity that greatly reduces the rate of temperature rise following a severe accident, and hence there is less potential for damage to the core. As a result, HTGRs do not require a containment heat removal system.

The design of the fuel and core structure for the HTGR also has inherent safety features. The core is characterized by a low power density in the fuel, only about one-tenth that of a light water reactor. As discussed above, the core has a large thermal capacitance due to the presence of graphite in the core and support structures. As a result, temperatures would rise very slowly even if the flow of coolant was interrupted, The operators of an HTGR would have a great deal of time to diagnose and correct an accident situation before the core is damaged. Figure 25 compares the 10-hour margin to fuel failure for an HTGR with conventional LWRs, in which the margins are measured in minutes.

Another safety feature of the HTGR is the PCRV, which contains the entire primary coolant system. The PCRV provides more shielding from the radioactive materials in the core than a steel vessel since the thick concrete naturally attenu-

Figure 25.—Comparative Fuel Response Times



SOURCE: Gas-Cooled Reactor Associates.

ates radiation. in addition, catastrophic failure of a PCRV is regarded to be much less likely than failure of a steel vessel. The vertical and circumferential steel tendons that are used to keep the concrete and liner in a state of compression are isolated from exposure to damaging neutron fluxes and extreme temperatures. Furthermore, they are independent of one another and can be readily inspected; it is extremely unlikely that many of the tendons would fail simultaneously.

The entire primary coolant loop, including the steam generators, helium circulators, and other auxiliary equipment, is included within cavities in the PCRV. The advantage of such a configuration is that pipe breaks within the primary loop cannot result in a rapid loss of coolant. As a result, the only engineered safety system needed to protect the core from overheating in the event the main core cooling fails is a forced circulation, decay heat removal system. In the HTGR, this is provided by a core auxiliary cooling system, which is dedicated to decay heat removal and incorporates three redundant cooling loops for high reliability. This is enhanced by a PCRV liner cooling system that provides an additional heat sink for decay heat.

Because of the high thermal efficiency of this reactor and the safety features discussed above, the HTGR has long been considered as a possible alternative to the LWR for commercial power generation. Work on the HTGR was initiated in the United States soon after the LWR was developed. The concept was successfully demonstrated in 1967 when a 40-MWe reactor was placed in commercial operation. This prototype unit, Peach Bottom 1, was constructed by Philadelphia Electric Co. and was the world's first nuclear station to produce steam at 1,000° **F.** The plant operated at an average availability of 88 percent before being decommissioned in 1974 for economic reasons.

Research and development (R&D) leading to commercial-sized systems continued after the Peach Bottom 1 demonstration. A cooperative effort of Public Service Co. of Colorado, the Atomic Energy Commission, and General Atomic Co. led to the construction of the 330-MWe Fort St. Vrain reactor in Colorado. This plant introduced several advanced features relating to the design of the fuel, steam generators, helium circulators, and PCRV. The plant first generated power in 1976 but experienced problems in its early years that contributed to a disappointing availability record. However, the majority of the systems in the Fort St. Vrain reactor have performed well. Furthermore, radiation exposures have been the lowest in the industry, even though extensive modifications were made to the primary system after the plant started operating. The Fort St. Vrain experience also demonstrates that the HTGR is manageable and predictable, even under extreme conditions. In the past 7 years, forced circulation cooling has been interrupted 17 times at the Fort St. Vrain reactor. The operators generally were able to reestablish forced circulation within 5 minutes, with the longest interruption lasting 23 minutes. Even with so many loss of flow incidents, there has been absolutely no damage to the core or any of the components.

Fort St. Vrain also experienced some unexpected technical difficulties-slow periodic fluctuations in certain core exit temperatures were observed. The fluctuations were associated with small movements of fuel in the core, caused by differential thermal expansion of fuel blocks. The problem was resolved at Fort St. Vrain by maintaining the spacing between fuel regions with core restraint devices. The next generation of reactors will avoid such problems by redesigning the fuel block.

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Photo credit: Gas-Cooled Reactor Associates (GCRA)

The high temperature gas-cooled reactor uses helium as a coolant instead of water. Helium offers some advantages since it is less corrosive than water and does not become radioactive. The helium circulator for the Fort St. Vrain reactor is shown above

Since 1977, the HTGR program has focused on the development and demonstration of a commercial-sized plant. The emphasis is currently on designing a four-loop, 2240 megawatt thermal (MWth) reactor that can generate electricity at high efficiency or be applied to the cogeneration of electricity and process steam. This design incorporates the lessons learned from the operation of Fort St. Vrain, experience from the earlier design of commercial HTGRs, and information obtained from cooperative international programs. Key design changes have been made to simplify the plant, improve its licensability and reliability, correct specific component-design deficiencies, and increase performance margins (7). The design work has been sponsored by the U.S. Department of Energy (DOE).

Another design effort is directed toward developing a much smaller gas-cooled reactor, known as the modular HTGR (14). This concept capitalizes on small size and low power density to produce a reactor that may be able to dissipate decay heat with radiative and convective cooling. In other words, it would not require emergency cooling or decay heat removal systems. Such a reactor would be inherently safe in the sense that no operator or mechanical action would be required to prevent fuel from melting after the reactor is shut down. The design for this type of reactor is still in a preliminary stage, but its potential for walk-away safety may warrant further investigation.

In addition to the domestic effort to develop the HTGR, there are also international programs to design and construct gas-cooled reactors. The Federal Republic of Germany has operated a 15-MWe prototype plant since 1967 with great success, achieving an average availability of more than 85 percent. A 300-MWe demonstration plant is scheduled for startup in 1984, and work has been initiated on the design of a 500-MWe HTGR. Japan also has been involved in the development of a very high temperature gas-cooled reactor for process heat applications. The Japanese program is directed at designing a 50-MWth reactor to begin construction in 1986.

INHERENTLY SAFE REACTOR CONCEPTS

incentives for developing a more forgiving reactor arise from several sources. As previously discussed, the design of current LWRs has developed in a patchwork fashion, and there are still a number of unresolved safety issues. The accident at Three Mile Island increased the incentive to develop a foolproof reactor when it became clear that LWRs are susceptible to serious accidents arising from human error. A more forgiving reactor design became desirable in terms of investment protection as well as public health and safety.

The modular HTGR discussed above is an example of an effort to develop an inherently safe reactor. Another example of a reactor that attempts to improve safety dramatically is based on LWR technology. [t is known as the Process Inherent Ultimately Safe (PIUS) reactor, and it is being developed by the Swedish nuclear firm ASEA-ATOM (6,9,23). The design goal is to ensure safety, even if the reactor is subjected to human error, equipment failure, or natural disaster. In the PIUS reactor, this goal was translated into two primary design objectives: first, to ensure safe shutdown and adequate decay heat removal under any credible circumstances; and second, to use the construction and operating experience of current LWRs as a basis for development. This eliminates some of the uncertainties associated with a *new* design.

The safety goal was paramount in the design of the PIUS reactor concept. The nuclear island was designed to ensure that the fuel would never melt, even if equipment failure were to be compounded by operator error. To accomplish this, two conditions have to be met. First, it is necessary to ensure that the core always remains covered with water. In LWRs, engineered safety systems ensure that cooling water is available to the core. However, confidence in these systems was shaken by the accident at Three Mile Island when the fuel was exposed long enough to melt.

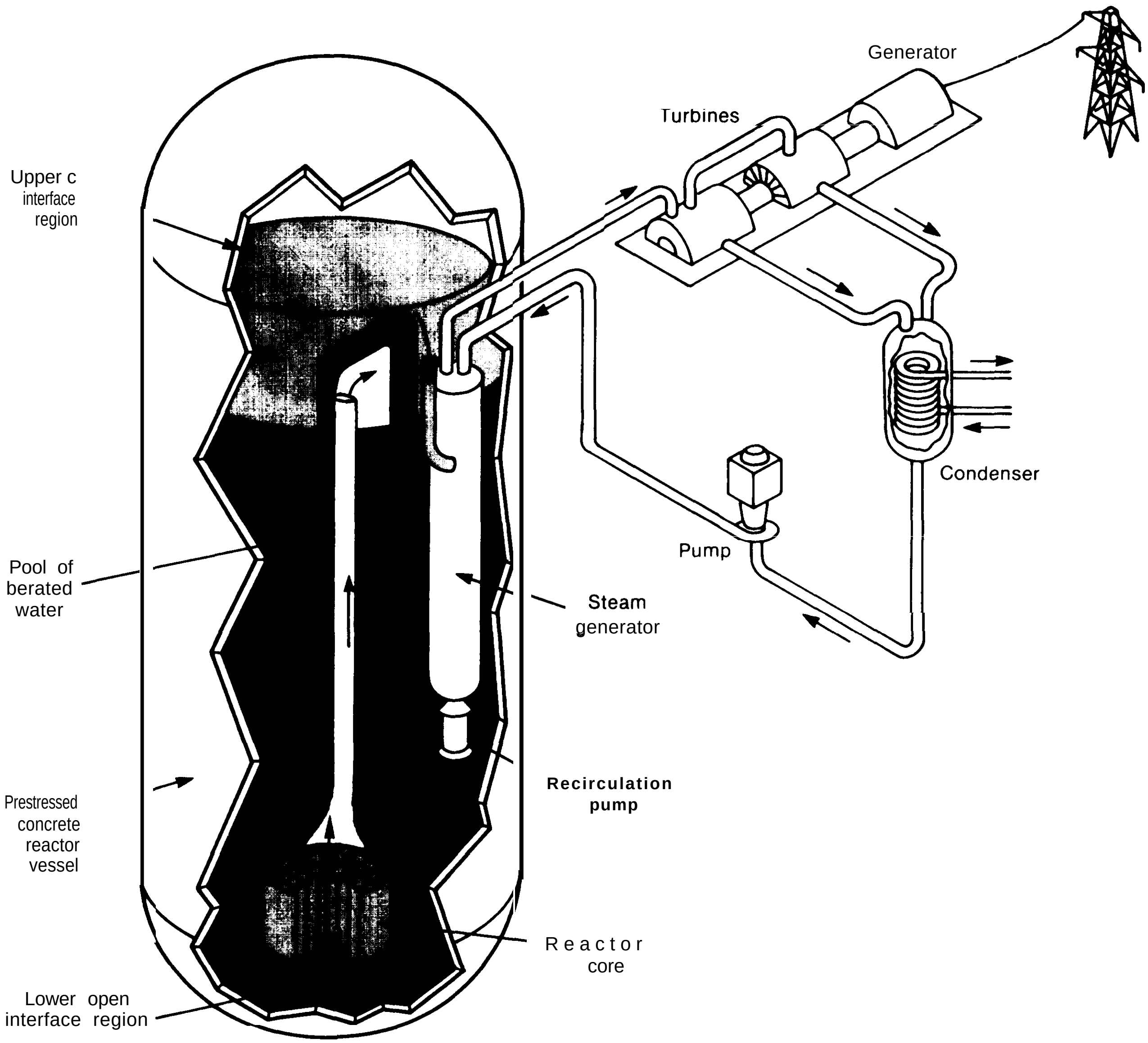
The basic configuration of the PIUS reactor is similar in many ways to that of a conventional PWR. It employs a primary loop of pressurized water that transfers heat to a secondary steam loop through a steam generator. The main differences between the two reactors are the size of the pressure vessels and the location of the primary system components. In a PWR, the fuel is surrounded by water and enclosed in a pressure vessel that is slightly larger than the core; the primary system pump, steam generator, and piping are located outside the vessel. In the PIUS reactor, the core is located at the bottom of a very large pool of water. As shown in figure 26, the pool and core are enclosed in an imposing concrete vessel (13 meters in diameter and 35 meters high) that is reinforced with steel tendons. In the PIUS reactor, the other primary components are submerged in the same pool of water that contains the fuel, and all penetrations to the PCRV are located at the top of the vessel. With such a configuration, it is impossible for any type of leak or equipment malfunction to drain off the cooling water.

During normal operation, primary coolant is pumped through the core and primary loop. At the bottom of the plenum under the reactor core there is a large open duct extending down into the pool. The pool water ordinarily is prevented from flowing into the core circuit by the difference in density between the hot water within the core and the cool pool water. At the static hot-cold interface in the duct, a honeycomb grid helps prevent turbulence and mixing between the hot and cold fluids. If for any reason the core temperature should rise to the point at which steam is formed, the pressure balance at the interface would be upset, and the pool water would automatically flow upward and flood the core. Natural thermal convection through the pool would provide enough circulation to cool the core, and the pool water would keep the core covered for about a week. This system relies completely on thermohydraulic principles and is totally independent of electrical, mechanical, or human intervention. The principal uncertainty in this reactor concept is in the stability of the pressure balance between the hot primary circuit water and the cold berated water.

The PIUS reactor is designed to automatically shut down as soon as the pool water begins to flow through the core. This is guaranteed by maintaining a high concentration of boron in the pool water; boron is a strong neutron absorber and automatically interrupts a chain reaction. This feature of the PIUS reactor is attractive because the possibility of a transient without a subsequent reactor scram is virtually eliminated.

If the PIUS reactor proves to be reliable, it might resolve some of the troublesome problems with LWRs. With inherent mechanisms for automatic shutdown, natural convective cooling, and a

Figure 26.—Process-inherent Ultimately Safe Reactor



SOURCE: ASEA-ATOM and Office of Technology Assessment

large heat removal capacity, there do not appear to be any credible mechanisms for uncovering or overheating the core of the PIUS reactor. However, the changes from the standard LWR design create new problems and uncertainties. The design of the **PIUS is different enough from current LWRs that further development will be required** for components, materials, and procedures. The design and construction of the PCRV will pose a problem, since it is larger than any other similar vessel. The steam generator in the PIUS reactor also will require additional development since it will be of a different configuration than in conventional PWRs. More importantly, maintenance may be very difficult since the components will be submerged in a pool of berated water. It is therefore essential that all primary system components perform reliably and with little maintenance. The submerged components and piping pose another problem—since the pool water will be about 380° F less than the primary system coolant, it is necessary to insulate the primary coolant loop from the borated pool water. The insulation for such an application has not yet been fully developed or tested. Another potential difficulty relates to fuel handling. Nuclear fuel assemblies are removed and exchanged routinely in current LWRs, but a similar operation in the PIUS reactor is complicated by having to work at a distance of 80 feet.

Another serious concern relates to the thermal hydraulic response of the reactor. There is considerable uncertainty about the flow patterns in the lower interface region between the pool water and the primary coolant. If the boundary is not stable, normal operations could be interrupted unnecessarily by the inflow of borated pool water through the core, shutting the reactor down. Computer simulations have been performed by ASEA-ATOM to determine the characteristics of the interface region. The Tennessee Valley Authority has supplemented this with a small-scale test to observe flow patterns. The uncertainties associated with the liquid-interface region can only be resolved with larger and more definitive experiments, such as th 3MWm test planned by ASEA-ATOM.

In many respects, the PIUS design builds on demonstrated LWR technology. The fuel for the PIUS reactor is essentially the same as for LWRs. The PIUS core is designed to use burnable poisons to maintain a constant reactivity throughout the fuel cycle. These have been used extensively in BWRs, and the experience is directly applicable to the PIUS reactor. The water chemistry and waste handling systems for the PIUS are also very similar to today's LWRs. Finally, most of the materials that would be used in the PIUS are identical to those in conventional LWRs. In fact, the temperature, pressure, and flow conditions in the PIUS reactor would be less severe than in LWRs.

Overall, the PIUS reactor represents a fairly dramatic departure from conventional LWRs. One consequence of this reconfiguration is that the economics become far less certain. Because of the requirement for a large PCRV, the nuclear island of the PIUS is likely to be significantly more expensive than that of an LWR. Furthermore, the remaining technical uncertainties relating to component and materials development could be costly to resolve. The originators of the PIUS design suggest that other plant costs might be reduced by easing or eliminating the safety qualifications for the balance of plant systems because reactor safety would not be dependent on them. I n current LWRs, safety qualification of secondary and auxiliary systems contributes significantly to the overall cost of the plant. If nuclear regulators agree to such a reorientation, it is conceivable that the overall cost of the PIUS reactor would be comparable to today's PWRs or BWRs. It should be noted, however, that many nuclear-grade systems would still be required to remove, process, and return radioactive gases and liquids from the pressure vessel.

Technical and economic uncertainties are significant factors in the decision to develop any new reactor concept. **In spite of these unknowns, further development of the PIUS reactor might be warranted** due to its potential safety advantages. These advantages might restore public confidence in the safety of nuclear power, but they must be tested further before any final judgments can be made.

Regardless of the merits of this particular design, the PIUS concept illustrates that innovative revisions of the standard LWR design can emerge if designers are not constrained in their thinking. Even if the PIUS concept itself turns out to have some insurmountable problems, exploratory research might continue concerning the basic concept of inherent safety.

THE SMALL REACTOR

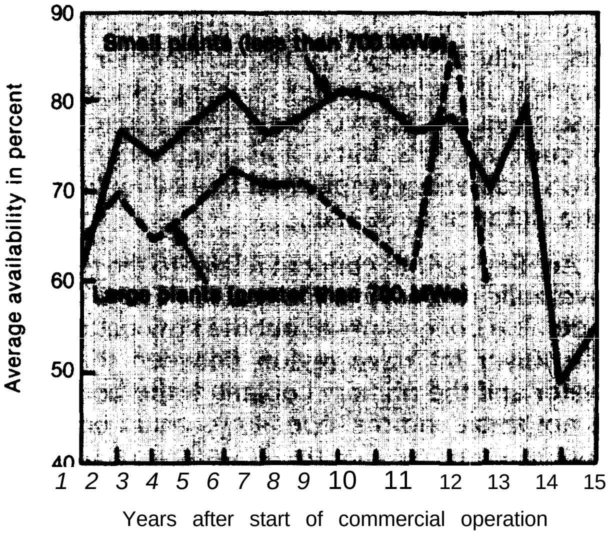
Considerable sentiment is often expressed in favor of reactors that are smaller than the 1,000- to 1,300-MWe LWRs that now represent the norm. When the current generation of reactors was being designed in the late 1960's, it seemed natural to continue scaling up the size because larger nuclear units were cheaper to build per kilowatt of capacity. Moreover, utilities were growing rapidly and needed large increments of new power. The situation is very different now. Many seem to feel that a carefully designed small reactor might be easier to understand, more manageable to construct, and safer to operate. Although many of these claims seem intuitively convincing, they are difficult, if not impossible, to substantiate. OTA sponsored a search for evidence that small plants have any advantages over large plants in terms of safety, cost, or operability (20). This search revealed no firm statistical data in support of the small reactor, although it summarized some of the arguments that make it an attractive concept (see vol. II).

Utilities may find small plants especially appealing today because they allow more flexibility in planning for the total load of the utility. In addition, the consequences of an outage would have a smaller impact on the overall grid. Furthermore, reducing the size of plants would limit the financial exposure of the utility to loss and increase overall system reliability. Initially, small plants appear to suffer a disadvantage in unit construction costs since they cannot realize the full benefits of economies-of-scale. However, more of the plant could be fabricated in the factory rather than constructed in the field, and this could result in large cost savings if the market is large enough to justify investment in new production facilities. Moreover, the construction times for small plants would probably be much less than for their larger counterparts. Overall, it is not clear that small plants would necessarily be more expensive than today's large ones.

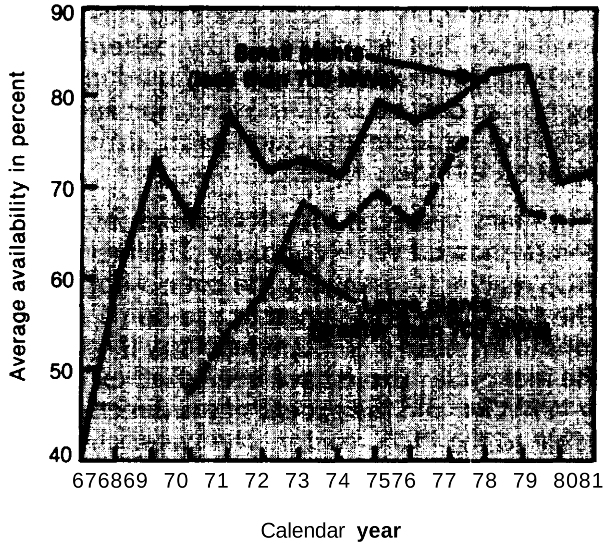
The operability of different sized plants maybe compared on the basis of availability. As shown in figure 27A & B, the availability of small plants generally exceeds that of currently operating larger plants, although only by about 5 percent. This trend surfaces both when availabilities are plotted as a function of the number of years after start of operation (which compares plants of the same age) and as a function of calendar year (which compares plants operating in the same environment). These differences could be due to either the number or duration of outages at smaller plants, which indicates that small plants

Figure 27.—Nuclear Reactor Availability

A.—As a Function of Age



B.—As a Function of Calendar Year



may be easier to control or maintain. However, this comparison is not conclusive since most of the smaller reactors were designed and built in the 1960's and have not been affected by as many design changes as the newer, larger plants.

It is difficult to compare the safety of small and large reactors, but one indication is the occurrence of events that could be precursors to severe accidents. It appears that the frequency of such events is independent of reactor size. However, the initiating events that do occur at small plants may be easier to manage than similar events at large plants. This result is based on too small a sample to be conclusive, but it may warrant further study. Another safety comparison can be made on the basis of the consequences of an accident. The worst-case accident in a small plant would be less damaging because the fission product inventory is much less in a smaller plant. This effect, however, might be offset by the larger number of small units needed to comprise the same generating capacity.

Small reactors are unlikely to be able to compete commercially with their larger counterparts unless R&D that specifically exploits the potential for modular, shop fabrication of components is sponsored. This would allow small plants to take full advantage of the increased productivity and quality of work in a factory setting.

THE STANDARDIZED REACTOR

The concept of a standardized reactor has been widely discussed for years in the industry but has yet to become a reality (18). The advantages are many: more mutual learning from experience among reactor operators, greater opportunity for indepth understanding of one reactor type, and sharing of resources for training operators or developing procedures. Since much of the concern over current reactors centers on their management rather than on their design, the opportunity to concentrate on learning the correct application of one well-understood design is appealing.

Utilities and vendors would be especially enthusiastic about standardized designs if that concept were coupled with one-step or streamlined licensing. The simplification of the licensing process might bring concomitant benefits in reduced capital costs. If the plants were smaller than those of the current generation, larger numbers of small plants would be built to meet a given demand, and this would facilitate standardization.

A major barrier to designing a standard plant is the difficulty in marketing identical reactors, given the current industry structure and regulatory climate in the United States. There are many opportunities for changes in today's plants, such as to match a particular site, to meet the needs of a specific utility, and to accommodate NRC regulations. In addition, the existing institutional structure does not lend itself easily to industry-wide standardization. There are currently five reactor suppliers and more than a dozen AE firms. While each reactor vendor is moving toward a single standardized design, balance of plant designs by the AEs continue to vary. It is unlikely that a single dominant plant design will arise out of all combinations of vendors and AEs, which implies that there may not be industrywide standardization. However, it is possible that a few prominent combinations of the more successful reactor suppliers and AEs will join forces to produce a more manageable number of standardized designs.

CONCLUSIONS

No single reactor concept emerges as clearly superior to the others since the preferred design varies with the selection criterion. If safety is of paramount concern, the reactors that incorporate many inherent safety features, such as PIUS or the modular HTGR, are very attractive. In such reactors, the critical safety functions of reactor shutdown, decay heat removal, and fission product containment are provided by simple, passive systems which do not depend on operator action or control by mechanical or electrical means. The full-scale HTGR is also attractive in terms of safety since it provides more time than any of the water-cooled concepts for the operator to respond before the core overheats. The remaining reactors appear to be roughly comparable regarding safety features. The HWR has the lowest inventory of radioactive materials, and the independent moderator loop serves as a passive, alternative decay heat removal system. In addition, the HWR has compiled a superb record in Canada. Advanced LWRs incorporate the benefits accrued from many years of extensive operational experience. Finally, small and/or standardized reactors may have operational advantages resulting from a better understanding of and control over their designs.

If the reactors were to be ranked on the basis of reliable operation and easy maintenance, a different order results. The advanced LWR is very attractive because these criteria have heavily influenced its design. Small reactors also appear high on the list because their size and shop-fabricated components may facilitate operation, maintenance, and replacements. HWRs rate high because they have performed well to date, and they do not require an annual refueling shutdown. The few HTGRs that are in operation have had mixed performance records, but the newest design addresses some of the problems that contributed to poor reliability. One factor enhancing overall performance is the ease of maintenance in an HTGR resulting from inherently low radiation levels. There are many uncertainties associated with the PIUS concept. It is likely to pose maintenance problems. It is also possible that the behavior of the PIUS will be erratic in normal transients, thus increasing the difficulty of operation. In other ways, however, the PIUS could be simpler to operate.

Any attempt to rate these reactor concepts on the basis of economics is very difficult. Experience with LWRs indicates that the price of facilities of the same design can vary by more than a factor of 2, so estimates of costs of less developed reactors are highly suspect. Only a few speculative comments can be made. Small reactors suffer a capital-cost penalty due to lost economies-of-scale, but it is possible that this could be reduced by fabricating more components in factories and keeping construction times short. HWRs are expected to have comparable capital costs, but their lifetime costs may be lower than those of LWRs since the **HWRs have lower fuel costs. Standardization of any of the reactors discussed would reduce costs, if the reactors could be licensed and constructed more quickly. The HTGR appears to be comparable in cost to LWRs, but there are greater and different uncertainties associated with it. It is premature to estimate the cost of a PIUS-type reactor for several reasons. First, it is still in the conceptual design phase, so types and amounts of materials cannot be determined precisely nor can construction practices and schedules be accurately anticipated. In addition, the PIUS designers are relying on low costs in the balance of plant to compensate for the higher costs of the nuclear island. It is not clear whether the balance of plant systems can be decoupled from their safety functions; the regulatory agencies obviously** will have a major impact on this decision, and hence the cost of a PIUS-type plant.

A final criterion applied to these reactors might be the certainty of our knowledge of them. How predictable will their performance be? The ranking here is almost the reverse of that for safety. Advanced LWRs are clearly superior in terms of familiarity because they have evolved from plants that have operated in the U.S. for more than 20 years. HWRs have also compiled a Icing record, but design modifications might have to be made before the reactor could be licensed in the United States. There is much less experience with HTGRs in the United States, with only a single facility in operation. The PIUS concept lags far behind the other reactors in terms of certainty since it has never been tested on a large scale.

This survey has examined many reactor concepts and found that none were unambiguously superior in terms of greater safety, increased reliability, and acceptable cost. Most represent a compromise among these factors. A few could not be adequately compared because so many uncertainties surround the design at this stage. The present lull in nuclear orders provides an opportune time to reduce the uncertainties and expand our knowledge of the less well-tested concepts. A demonstration of advanced LWRs may soon occur in Japan, and the results should be valuable input to future decisions on the LWR concept. If continued, the Department of Energy's development program on HTGRs will continue to provide information and experience that could make the HTGR a viable alternative to the LWR. It may also be valuable to examine the operation of Canada's HWRs to determine if any of their experience can be applied to U.S. reactors. If considerable sentiment continues to be expressed in favor of small reactors, some initial design work may be appropriate. Finally, a preliminary investigation of the PIUS reactor would teach us still more about a concept that is very promising. Work on this or another "fresh look" design would require government support since the existing reactor designers do not see a big enough market to support new research programs.

Until the results of future investigations are in, nothing on the horizon appears dramatically better than the evolutionary designs of the LWR. There is a large inertia that resists any move away from the current reactor types, in which so much time has been spent and from which so much experience has been accrued. However, if today's light water reactors continue to be plagued by operational difficulties or incidents that raise safety concerns, more interest can be expected in alternative reactors.

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Chapter 5

Management of the Nuclear Enterprise

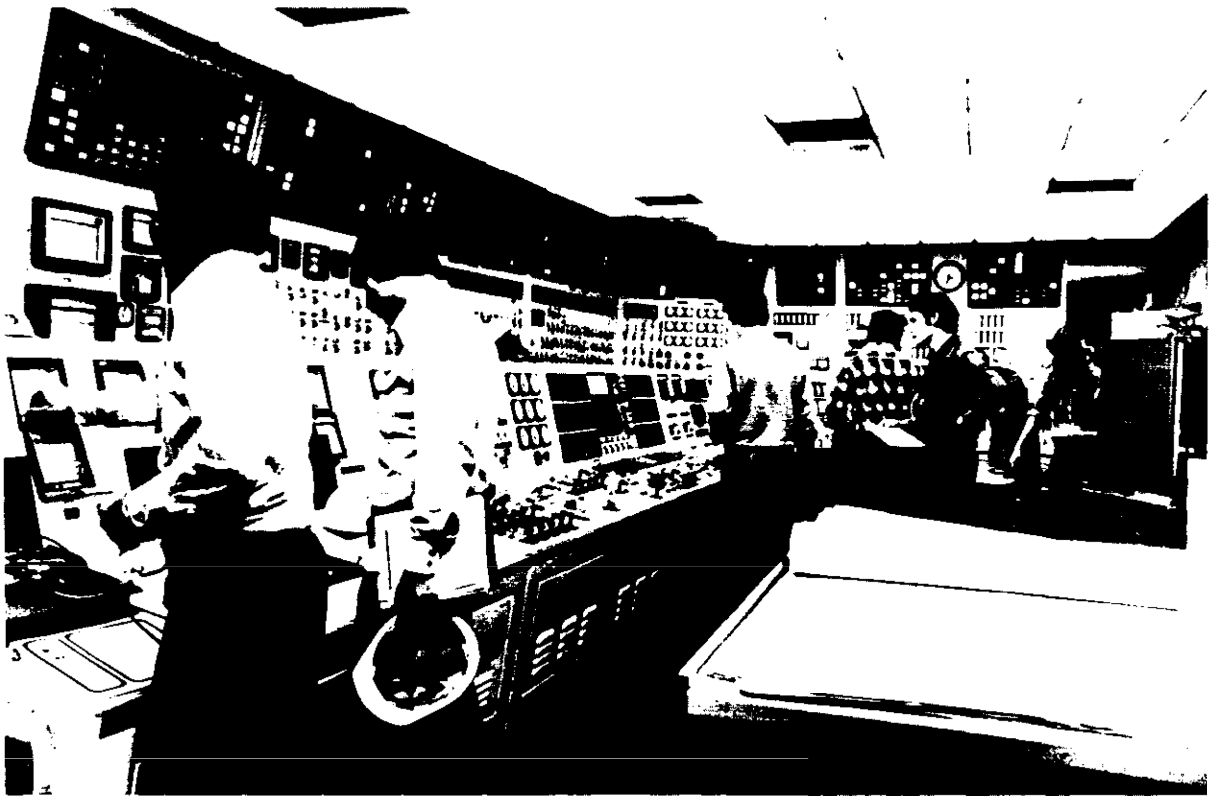

Photo credit: Atomic Industrial Forum

The control room at a typical nuclear plant

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Chapter 5
Management of the Nuclear Enterprise

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.

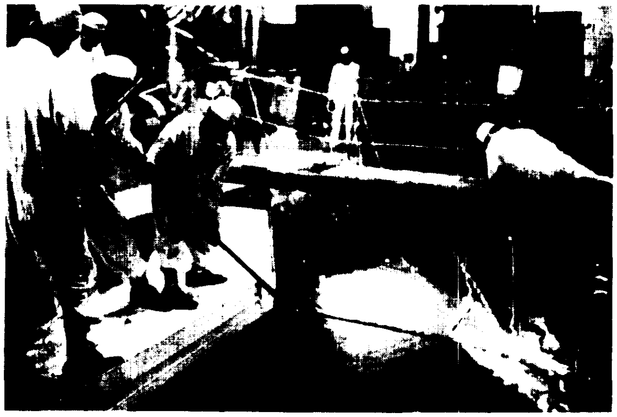


Photo credit: Atomic Industrial Forum

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

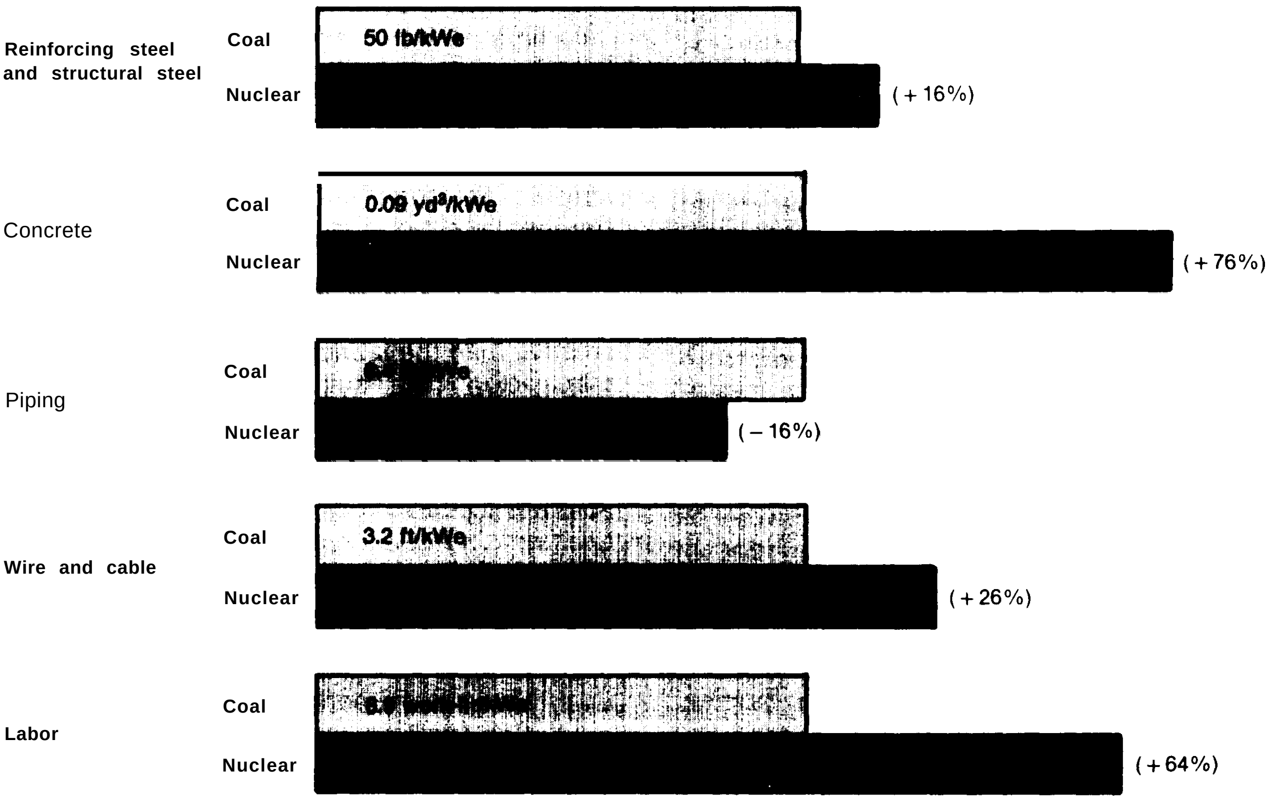
Technological Factors That Influence Construction and Operation

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 event of an accident (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 (17). 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.

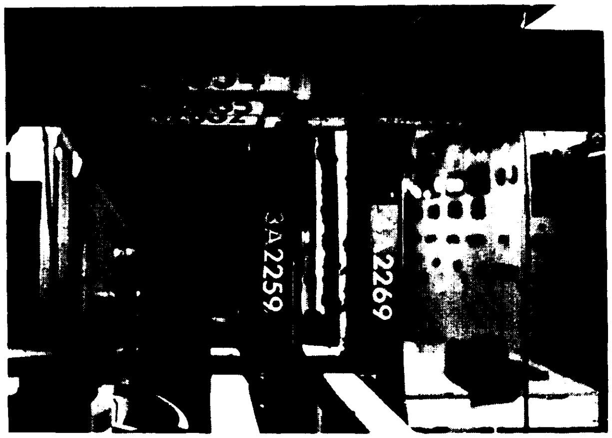


Photo credit: OTA Staff

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.

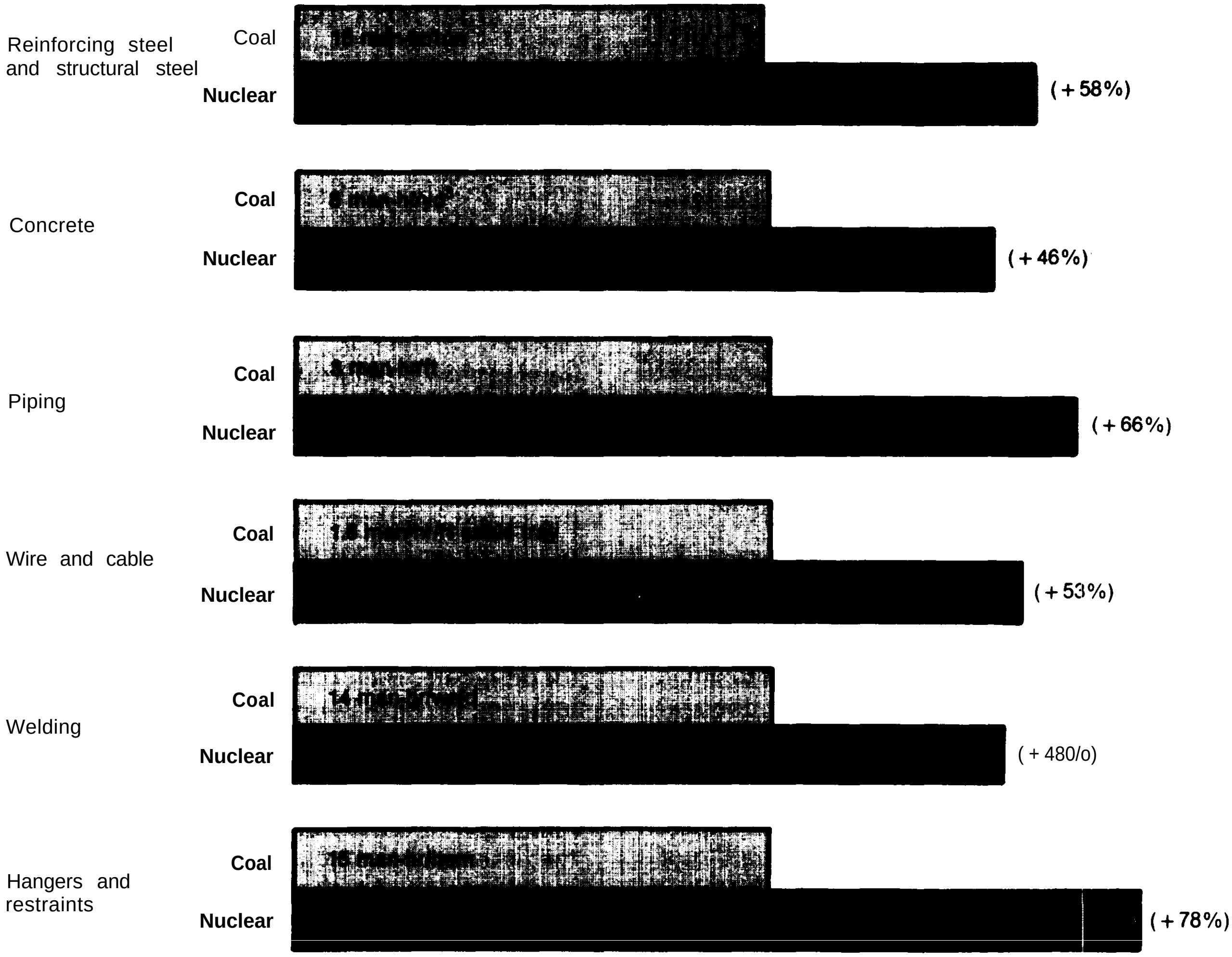
The exacting nature of nuclear technology manifests itself somewhat differently during operation. It often is necessary to maintain extremely tight control of sensitive systems to keep the plant running smoothly. For example, the water chemistry system in LWRs must be carefully monitored and adjusted 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



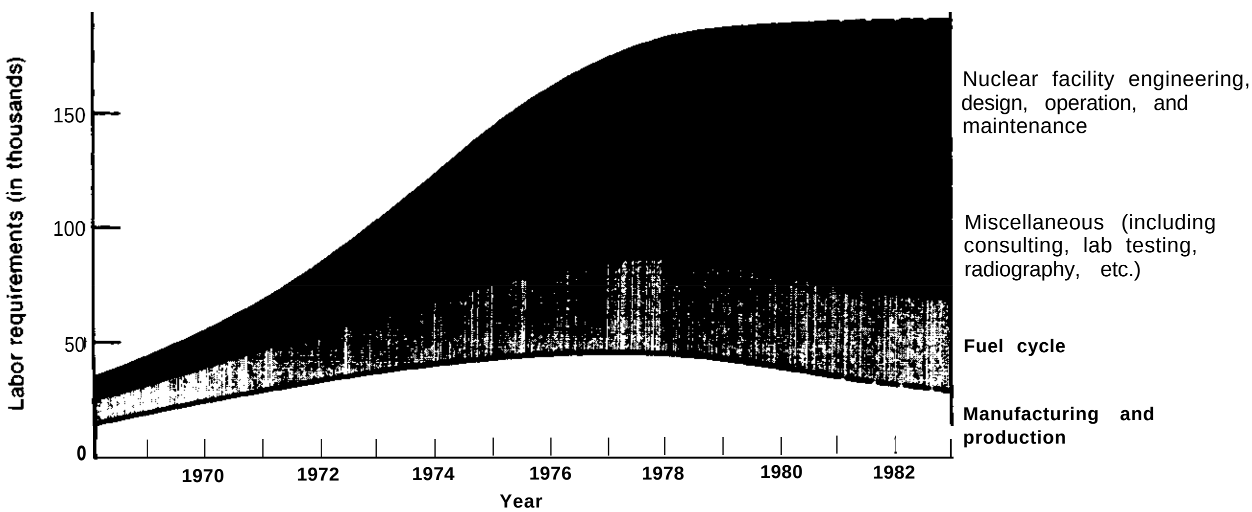
SOURCE. J D. Stevenson and F. A. Thomas, Selected Review of Foreign Licensing *Practices for Nuclear Power Plants,* **April 1982**

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.

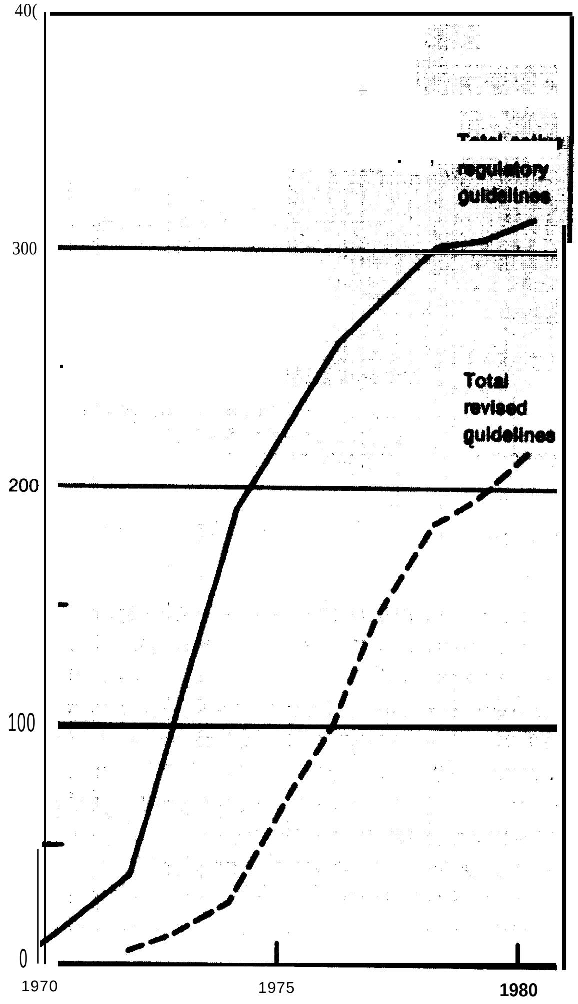
In many cases, changes in NRC regulations obviously enhance plant safety. In other cases, it is not clear that safety is increased by adding or modifying systems and components. As discussed in chapter 6, the adverse impacts of certain regulations include equipment wearout due to excessive surveillance 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



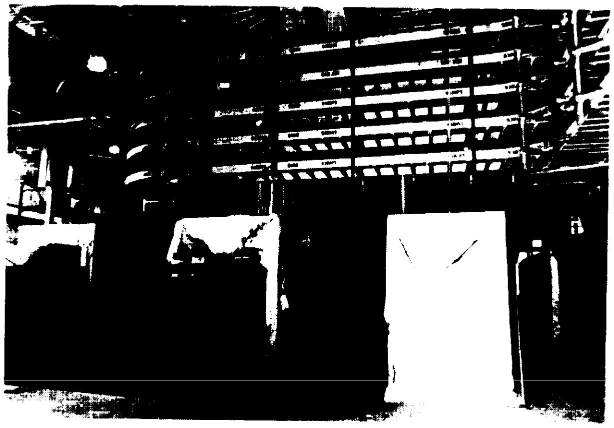


Photo credit: Atomic Industrial Forum

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-

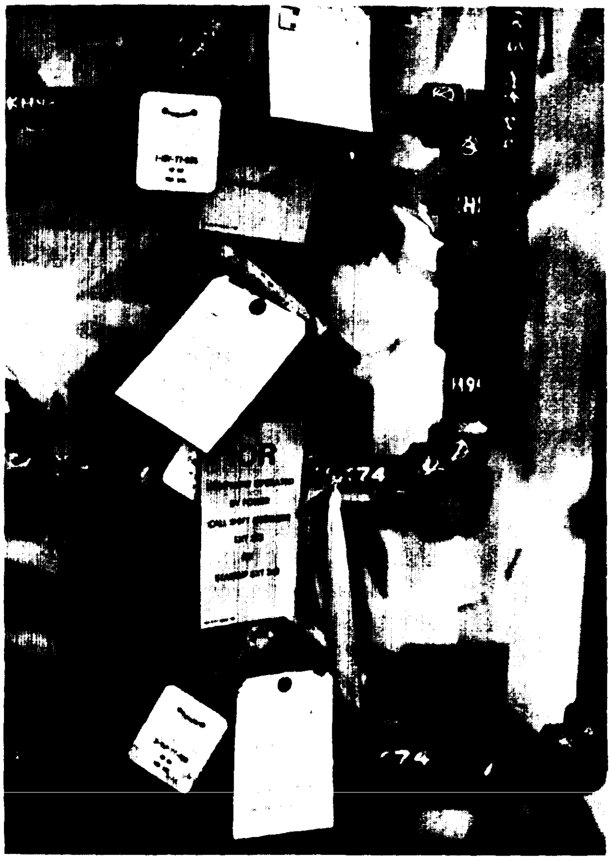


Photo credit: OTA Staff

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-

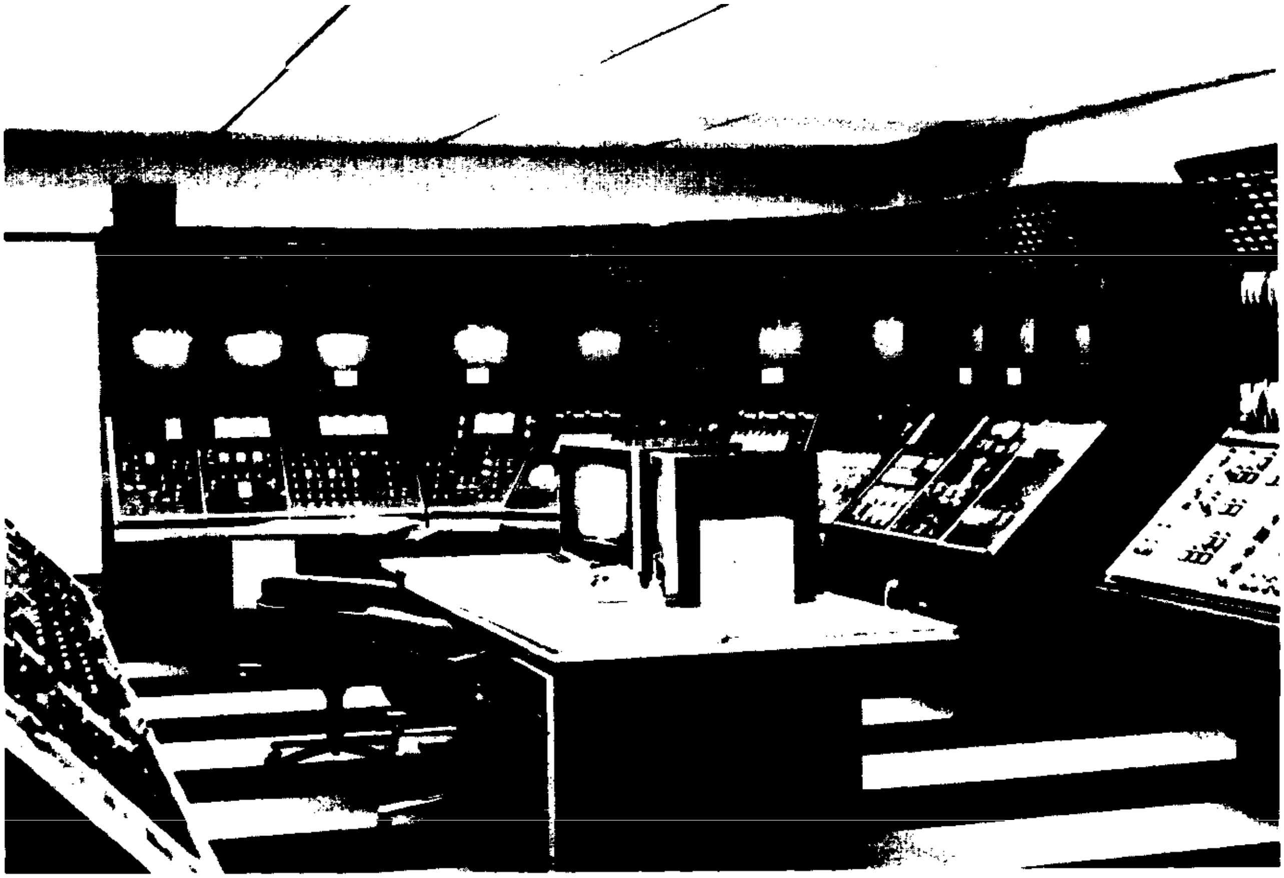


Photo credit: Pennsylvania Power & Light

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. Further-

more, 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 power-plants 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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Chapter 6

The Regulation of Nuclear Power

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Chapter 6
The Regulation of Nuclear Power

Nuclear power is one of the most intensively regulated industries in the United States, and the scope and practice of regulation are among the most volatile issues surrounding the future of nuclear power. Strong—and usually conflicting—opinions abound among the participants in the nuclear debate on whether the current regulatory system is adequate to ensure safe and reliable powerplants or is excessive, and whether it is enforced adequately or is interpreted too narrowly.

Every aspect of the nuclear industry—from the establishment of standards for exposure to radiation to the siting, design, and operation of nuclear powerplants and the transportation, use, and disposal of nuclear materials–is regulated at the Federal, State, or local level. In general, the Federal Government retains exclusive legislative and regulatory jurisdiction over the radiological health and safety and national security aspects of the construction and operation of nuclear reactors, while State and local governments share the regulation of the siting and environmental impacts of nuclear powerplants and retain their traditional responsibility to determine questions of need for power, reliability, user rates, and other related State concerns.

This chapter describes the existing regulatory process at the Federal, State, and local levels; reviews the various criticisms of that process raised by the different parties in the nuclear debate; and discusses proposals for substantive and procedural changes in nuclear power regulation. The chapter focuses on the health and safety and environmental regulation of nuclear powerplants; financial and rate regulation are discussed in chapter 3.

It should be emphasized that this chapter primarily reports on the existing regulatory process and on proposals for changes in that process. Arguments for and against the existing system and proposed changes are presented as they appear in the literature or as OTA determined them in the course of this study. Such criticisms of the regulatory system can reflect the biases and vested interests of the commentators. In light of this, it is important to examine the arguments critically from a safety and efficiency perspective. Where OTA found sufficient documentation to support a particular argument, the basis for the conclusions is identified. In instances where OTA could not make such a determination, the arguments are presented without conclusions to illustrate the scope of the controversy and the wide divergence among the parties' perceptions of the current role of regulation and of the need for changes in the regulatory system.

FEDERAL REGULATON

The primary forms of regulation under the Atomic Energy Act (see box D) are: 1) the issuance of licenses for the construction and operation of reactors and 2) inspection and enforcement to ensure that nuclear plants are built and operated in conformance with the terms of a license. This section describes the licensing process that was put in place during the 1970's when the last group of plants received construction permits. This is precisely the licensing process that has been the target of so much criticism by the nuclear industry, utilities, nuclear critics, and regulators. In addition, this section discusses the way in which this licensing process might operate in the current climate. Although the basic regulations have not changed substantially since the 1970's, the way those regulations are applied to construction permits or operating licenses might be very different if an application were filed today.

Box D.—Historical Overview of Nuclear Regulation

Federal oversight of the nuclear industry began in the early 1940's with military control of the development of nuclear fission to produce weapons-grade fuel. In 1946, Congress passed the first Atomic Energy Act, which was designed primarily to protect "atomic secrets" so that the U.S. monopoly on nuclear weapons and technology would be preserved. The act also established an Atomic Energy Commission (AEC) to provide civilian control over nuclear weapons and investigate the potential for peaceful uses of atomic energy.* The 1946 act expressly forbade private ownership of nuclear materials and established an absolute government monopoly over nuclear energy. The Joint Committee on Atomic Energy, composed of nine Senators and nine Representatives, also was formed in 1946 as the prime congressional committee responsible for nuclear energy.

In 1947, the Reactor Safeguards Committee was established within AEC to review the hazards of proposed nuclear plants. But AEC remained largely preoccupied with weapons development until the early 1950's, when the Naval Reactors Branch successfully demonstrated a pressurized water reactor, thus laying the foundation for a workable technology to generate power through nuclear fission. Spurred by this demonstration and developments abroad, by the burgeoning demand for electricity, and by reports from the Joint Committee expressing dissatisfaction with AEC's lack of progress in reactor development, the Eisenhower administration urged Congress to amend the 1946 act so that private industry could enter the nuclear energy business.

In 1954, Congress amended the Atomic Energy Act, directing AEC to promote nuclear energy and to regulate the emerging nuclear industry by issuing licenses to private companies to build and operate commercial nuclear power stations and by adopting whatever rules were deemed necessary to protect the public health and safety. In 1957, a second obstacle to the investment of private capital in nuclear industry was removed when Congress passed the Price-Anderson Act. This law limits the liability of the builders and operators of nuclear plants to the general public in the event of injuries from an "extraordinary nuclear occurrence" and established a $560 million fund from which damages would be apportioned among the victims of an accident.

In 1955 and 1956, AEC issued the first sets of "basic regulations for civilian atomic industry" under the amended Atomic Energy Act. According to then-AEC Chairman Lewis Strauss, "the AEC's objective in the formulation of the regulations was to minimize government control of competitive enterprise . . . [and] open the way to all who are interested in engaging in research and development (R&D) of commercial activities in the atomic energy field." The basic notion underlying this first regulatory scheme was to allow industry the discretion to choose plant designs and build them using its own judgment on how best to satisfy the requirement for a "reasonable assurance that the health and safety of the public will not be endangered." The assumption at that time was that the industry would be able to handle the technology well, and regulation would entail only a brief design review of safety-related components and periodic inspections. As the civilian nuclear power industry grew, it became apparent that both the industry and AEC had underestimated the complexity of ensuring safety and, therefore, the degree of regulation that would be appropriate. Regulatory activity expanded throughout the 1960's and 1970's along with an increasing appreciation for the probability and consequences of reactor accidents; this in turn contributed to increased public participation in the regulatory process. Regulatory guidelines also increased in scope and complexity with the rapid evolution of nuclear technology.

*The Energy Reorganization Act of 1974 abolished the AEC and transferred its regulatory functions to the newly created Nuclear Regulatory Commission. The R&D functions of AEC were transferred first to the Energy Research and Development Administration and evenutally to the Department of Energy.

In the 1970's, a utility would undergo an initial planning phase before it would apply to the Nuclear Regulatory Commission (NRC) for a construction permit, It would select a site in accordance with NRC (and State and local) policies and guidelines; choose an architect/engineering (AE) firm; solicit bids for the nuclear steam supply system (NSSS) and the balance of the plant; award contracts; and assemble data to be submitted to NRC with the construction permit (CP) application. During this planning phase, the utility also would ensure compliance with State and local laws and regulations, which could require a variety of permits for approval of the facility.

The utility then would file an application for a CP, as indicated in figures 32 and 33. The application would include: 1) a Preliminary Safety Analysis Report (PSAR) that presents in general terms the plant design and safety features and data relevant to safety considerations at the proposed site; 2) a comprehensive Environmental Report (ER) to provide a basis for the NRC evaluation of the environmental impacts of the proposed facility; and 3) information for use by the Attorney General and the NRC staff in determining whether the proposed license would create or maintain a situation inconsistent with the antitrust laws.

NRC regulations require the antitrust information be submitted at least 9 months but not more than 36 months prior to the other portions of the CP application. A hearing might be held at the completion of the antitrust review, but it would not be mandatory unless requested by the Attorney General or an interested party, The NRC also must make a finding on antitrust matters in each case where the issue is raised before the Commission.

Upon receipt of a CP application, the NRC staff would review it to determine if it is complete enough to allow a detailed staff review, and request additional information if necessary. The application would be formally "docketed" when it met the minimum acceptance criteria.

In the past, the PSAR included very incomplete design information (only 10 to 20 percent in some cases). Most parties in the nuclear debate agree that many of the construction problems evident in today's plants could have been prevented if more complete designs had been available during CP review. In recognition of this argument, NRC officials have indicated that they now would require an essentially complete design with a CP application, a move that has widespread support.

In the next step of the process, the NRC Office of Nuclear Reactor Regulation would compare the details of the permit application with the NRC's Standard Review Plan (SRP) and usually would submit two rounds of questions to the applicant. These questions often would result in changes in the plant design. The staff then would prepare a Safety Evaluation Report (SER) documenting the review and listing "open issues, " which are changes dictated by NRC but disputed by the applicant. Concurrent with the preparation of the SER, the Advisory Committee on Reactor Safeguards (ACRS) would review and comment on the application, and the NRC staff could issue supplements to the SER to respond to issues raised by ACRS or to add any information that may have become available since issuance of the original SER. During the 1970's, this review process culminating in SER might have taken 1 to 2 years. The review period could potentially be shortened if an application were filed now with essentially complete design information or a standardized design. Detailed design information would be likely to meet the minimum criteria for acceptance of the application with little delay. A standardized design could indirectly accelerate the process even more because it is unlikely that many new questions would be raised by the ACRS or about the SRP after approval of the first plant using that design.

During this period, the NRC staff also would be reviewing the proposed plant's environmental impacts and preparing a draft Environmental Impact Statement (E IS) to be issued for review by the relevant Federal, State, and local agencies and by interested members of the public. After comments on the draft EIS were received and any questions resolved, the staff would issue a final EIS.

Soon after a CP application was docketed, NRC would issue a notice indicating that it would hold

Figure 32.-NRC Responsibilities in Nuclear Powerplant Licensing

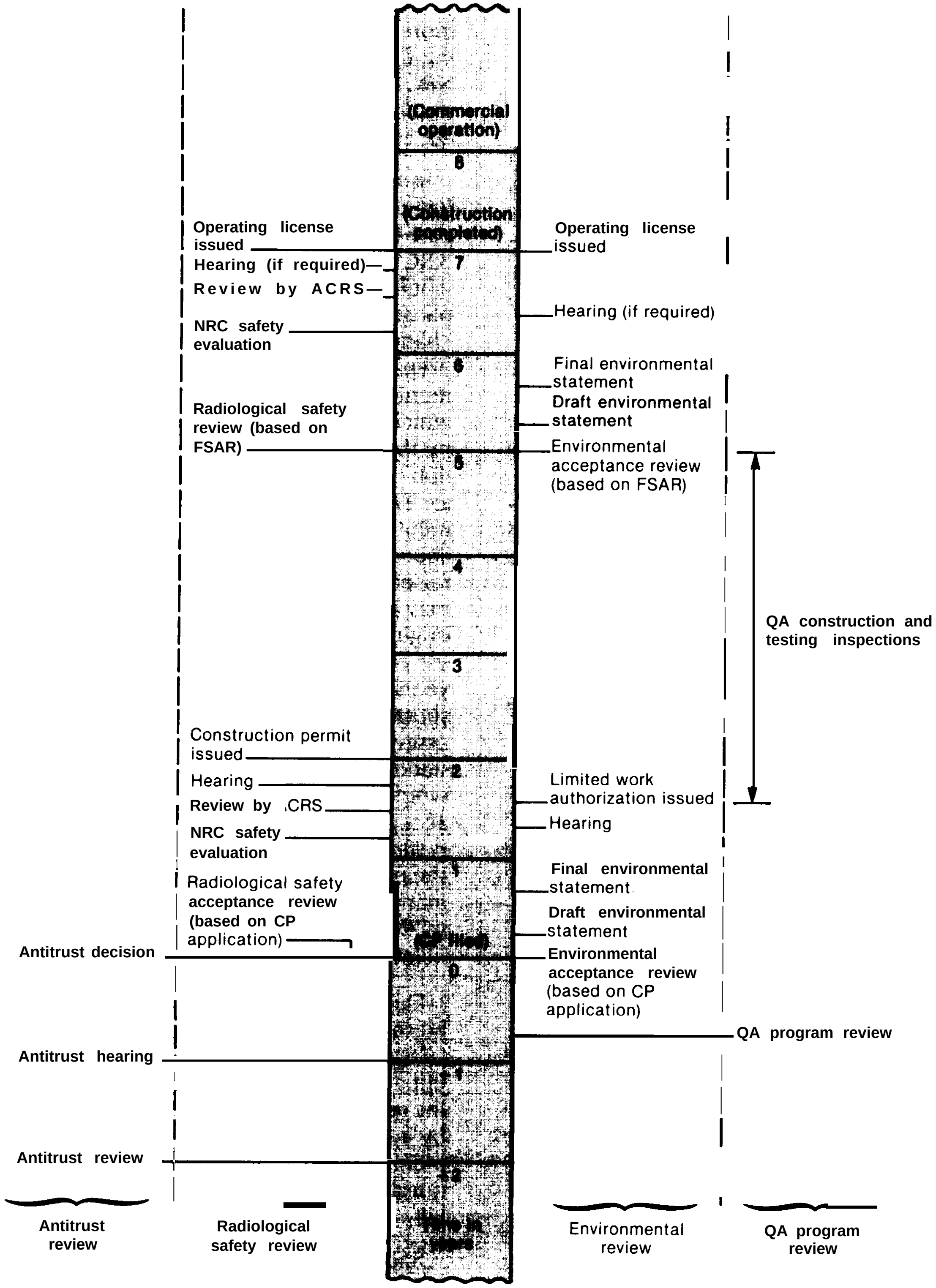
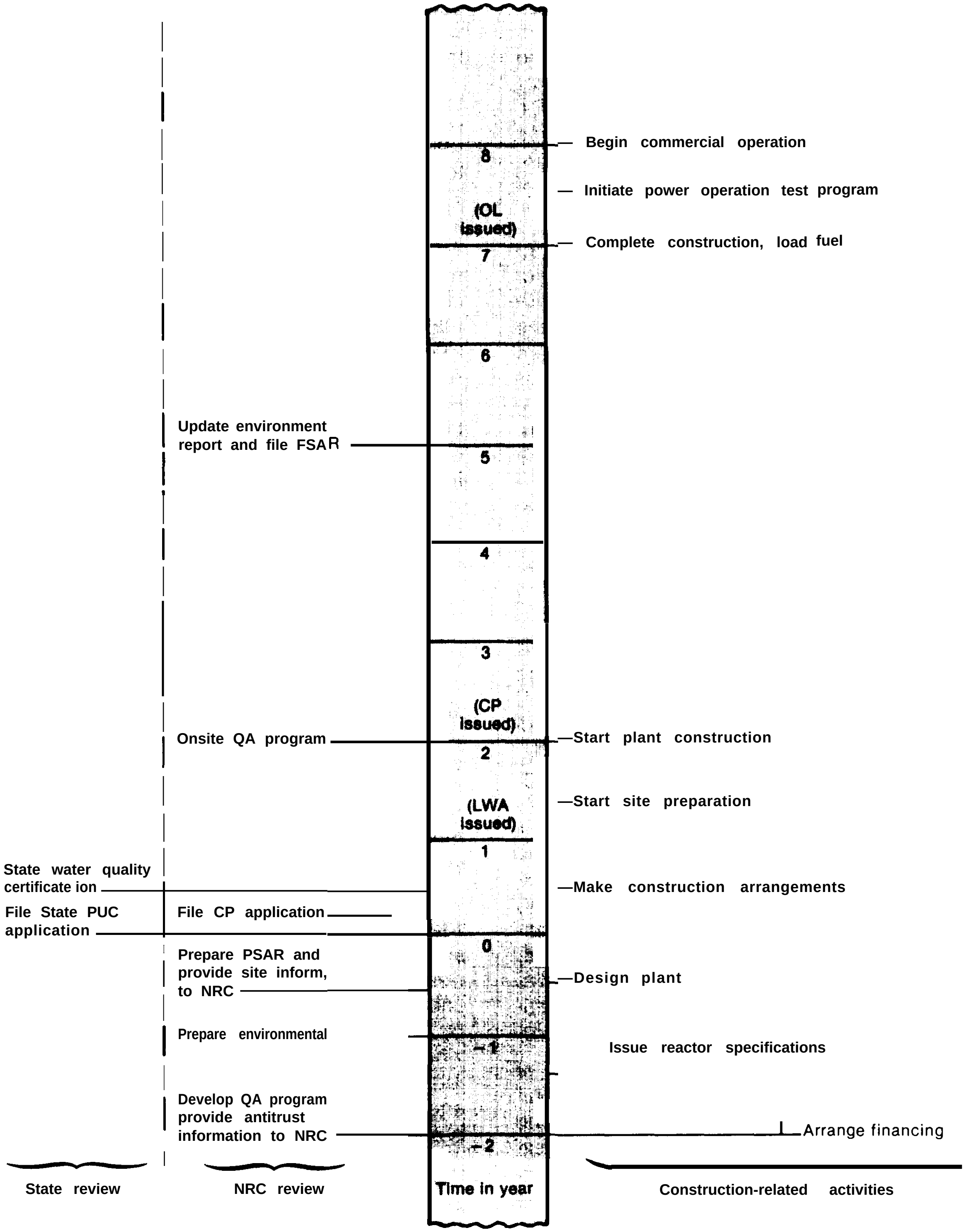


Figure 33.—Utility Responsibilities in Nuclear Powerplant Licensing and Construction



a hearing on safety and environmental issues raised by the application. Interested parties could provide written or oral statements to the three-member Atomic Safety and Licensing Board (ASLB) as limited participants in the hearings, or they could petition for leave to intervene as full participants, including the right to cross-examine all direct testimony in the proceeding and to submit proposed findings of fact and conclusions of law to the hearing board.

NRC regulations provide an opportunity at an early stage in the review process for potential intervenors to be invited to meet informally with the NRC staff to discuss their concerns about the proposed facility. This provision has not been commonly used; as a result, the safety concerns of the critics have not been considered seriously and formally until the hearings. The problem with this timing is that it places the critics in the position of attempting to change or modify a decision that already has been made rather than influencing its formulation.

The environmental hearings could be conducted separately to facilitate a decision on a Limited Work Authorization (LWA) or could be combined with the safety hearing. The SER and any supplements to it plus the final EIS would be the major pieces of evidence offered by the NRC staff at the hearing. The ASLB would consider all the evidence presented by the applicant, the staff, and interveners, together with proposed findings of fact and conclusions of law filed by the parties, and issue an initial decision on the CP. ASLB's initial decision would be reviewed by the Atomic Safety and Licensing Appeal Board (ALAB) on exceptions filed by any party to the proceeding or, if no exceptions were filed, on ALAB's own initiative ("sua sponte"). Since Three Mile Island, all ASLB decisions must be approved by NRC before they take effect. NRC also considers petitions for review of appeals from A LAB decisions.

NRC regulations provide that the Director of the NRC Office of Nuclear Reactor Regulation may issue an LWA after ASLB has made all of the environmental findings required under NRC regulations for the issuance of a CP and has reasonable assurance that the proposed site is a suitable location from a radiological health and safety standpoint, and after Commission approval. A licensing board may begin hearings on an LWA within a maximum of 30 days after issuance of the final EIS.

When construction of a plant had progressed to the point where final design information* and plans for operation were ready, an application for an **operating license (OL)** would be prepared. The OL process has been very similar to that for a CP. The applicant would submit a Final Safety Analysis Report (FSAR), which sets forth the pertinent details on the final design of the facility, including a description of the containment, the nuclear core, and the waste-handling system. The FSAR also would supply information concerning plant operation, including managerial and administrative controls to be used to ensure safe operation; plans for preoperational testing and initial operations; plans for normal operations, including maintenance, surveillance, and periodic testing of structures, systems, and components; and plans for coping with emergencies. The applicant also would provide an updated ER. Amendments to the application and reports could be submitted from time to time. The staff would prepare another SER and EIS and, as at the CP stage, ACRS would make an independent evaluation and present its advice to NRC by letter. The ASLB would also review the OL application and issue a decision. Until recently, the ASLB has granted all requests for OLS. However, in January 1984 the ASLB refused to grant an OL to Commonwealth Edison Co. for the two-unit Byron station. As in the procedure for a CP, this decision will be reviewed by the ALAB and the Commission.

A public hearing is not mandatory prior to issuance of an OL. However, soon after acceptance of the OL application, NRC would publish notice that it was considering issuing a license, and any person whose interest would be affected by the proceeding could petition NRC to hold a hearing. The hearing would apply the same adjudicatory procedures (e.g., admission of parties and evidence, cross-examination) and decision process that pertain to a CP.

***The final design illustrates how the plant has been built and thus reflects all amendments and variances issued and backfits ordered by NRC since the CP.**

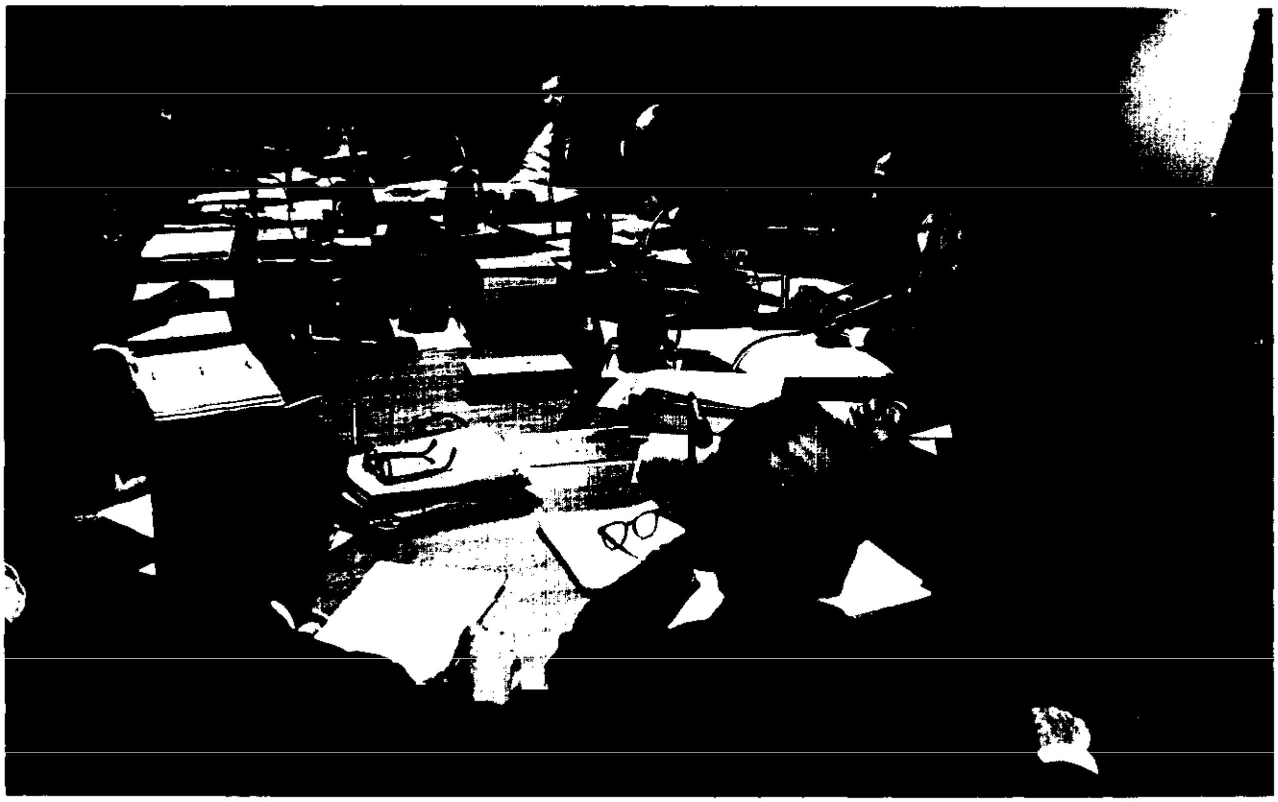


Photo credit: Nuclear Regulatory Commission

The members of the Nuclear Regulatory Commission are **meeting with the licensing staff of the** NRC to **review an upcoming operating license.** The Commission's meetings are open to the public

A stated goal of NRC (under normal circumstances and barring any important new safety issues) is to conclude ACRS and Office of Nuclear Reactor Regulation reviews and the hearing process before the utility completes construction of the plant. Current NRC regulations authorize the staff to issue an OL restricted to 5-percent power operation; full power operation must be approved by the Commissioners themselves. Upon receipt of the low-power OL, the utility could begin fuel loading and initial startup. The plant then would have to undergo extensive testing before it could begin commercial operation. Through its inspection and enforcement program, NRC maintains surveillance over construction and operation of a plant throughout its service life. As discussed in chapter 5, this surveillance is intended to assure compliance with NRC regulations designed to protect the public health and safety and the environment.

Other Federal agencies with statutory or regulatory authority over some aspects of the construction and operation of nuclear powerplants include: Environmental Protection Agency, U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration, Department of Energy, Department of the Interior, U.S. Geological Survey, Department of Agriculture, Department of Housing and Urban Development, Advisory Council on Historic Preservation, Department of Transportation, Federal Aviation Agency, Department of Defense, Council on Environmental Quality, River Basin Commissions, and Great Lakes Basin Commission. These agencies review, comment on, and administer specific issues under their jurisdiction.

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The Role of Emergency Planning

NRC requires license applicants and licensees to specify their plans for coping with emergencies. NRC regulations established in 1980 specify minimum requirements for emergency plans for use in attaining "an acceptable state of emergency preparedness", including information about the emergency response roles of supporting organizations and offsite agencies (16). For plants just starting construction, these plans have to be stated in general terms in the PSAR and submitted in final form as part of the FSAR. Detailed procedures for emergency plans would have to be submitted to NRC no less than 180 days prior to the scheduled issuance of an OL. Licensees with operating plants in 1980 were also required to submit detailed emergency plans to comply with post-TMl regulations.

NRC regulations specify a broad range of information that must be included in emergency plans. Utilities must develop an organizational structure for coping with radiological emergencies and define the authority, responsibilities, and duties of individuals within that structure as well as the means of notifying them of the emergency. Second, the utility must specify the criteria on which they determine the magnitude of an emergency and the need to notify or activate progressively larger segments of the emergency organization (including NRC, other Federal agencies, and State and local governments). Third, the utility has to reach agreements with State and local agencies and officials on procedures for notifying the public of emergencies for public evacuation or other protective measures and for annual dissemination of basic emergency planning information to the public. Fourth, programs must be established to train employees and other persons to cope with emergencies, to hold periodic drills, and to ensure that the emergency plan and its implementing procedures, equipment, and supplies are kept up to date. Finally, the utility must develop preliminary criteria for determining when, following an accident, reentry of the facility would be appropriate and when operation could be resumed.

The role of emergency planning has become increasingly controversial since the accident at Three Mile Island. Local governments must participate in the preparation of the emergency plan and reach agreements with the utility on public notification, evacuation, and other procedures, and they may intervene in the hearings on the plan. This is the principal leverage a local government has over the operation of a nuclear plant, and it can hold up the issuance of an OL. For example, at the Shoreham nuclear powerplant, significant differences in scope between the emergency plan proposed by the utility and that developed by the county are the primary issue that must be resolved before the utility can obtain an OL. There is a possibility that those differences might not be resolved. The adequacy of the utility's emergency planning also has become an issue at the Indian Point Station due to its proximity to densely populated New York City.

Such situations are of great concern to nuclear utilities, their investors, and the surrounding communities. If emergency plans are not developed in a timely and satisfactory fashion, the plant owners will not be granted a license to operate their plant. Moreover, emergency planning problems are difficult to anticipate, and their resolution is not necessarily assured by prudent management. Thus, they tend to increase the uncertainties associated with nuclear plant schedules. This source of uncertainty might be eliminated if final approval of emergency plans were required much earlier in the licensing process or even as a condition of State issuance of a Certificate of Public Convenience for a nuclear plant.

STATE AND LOCAL REGULATION

A wide range of State and local legislation, regulations, and programs affect the licensing, construction, and operation of nuclear powerplants. During the last decade, more and more States moved to a more thorough consideration of need for power and choice of technologies, environmental policy, and energy facility siting. Table 22 identifies the various State authorities in these areas. In most cases, NRC requires State approvals to be obtained before the Commission will take any action *on* a CP or OL application.

Several States (e.g., California, Oregon, Vermont, Wisconsin) also have enacted special restrictions on the construction of nuclear powerplants on the basis of economic, environmental, or waste-disposal considerations. The U.S. Supreme Court recently upheld State authority to restrict nuclear power development when it ruled in favor of California's siting law, which bans new nuclear powerplants pending a method to dispose of nuclear waste. The Court held that the Atomic Energy Act does not expressly require the States to construct or authorize nuclear powerplants or prohibit the States from deciding, as an absolute or conditional matter, not to permit the construction of any further reactors.

The State regulation of environmental and siting issues discussed below adds to the complexity and uncertainty in planning and licensing nuclear powerplants. In a State with multiple layers of review within numerous agencies, dozens or even hundreds of State approval steps may be involved. However, the State regulatory process generally has been far less difficult to manage than the Federal regulatory aspects related specifically to nuclear health and safety.

Need for Power

Primary responsibility for regulating electric utilities has been vested for many decades in State public utility commissions (PUCs). PUCs set rate schedules designed to meet the cost of service and to earn the utility stockholders an appropriate return on investment, as discussed in chapter 3. Many PUCs also approve financing for new facilities deemed necessary to supply service and issue Certificates of Public Convenience and Necessity (CPCN), which certify that when the facility goes into service the capitalized cost will be added to the rate base.

Although the procedures for determining need for power and issuing a CPCN vary from State to State, no utility will proceed beyond engineering to construction without a CPCN or an equivalent guarantee that it will be allowed to earn a return on its investment. Furthermore, it is unlikely that a utility would apply to NRC for a CP without already having obtained a CPCN or at least being confident of receiving it.

Environmental Policy

Several Federal statutes, including the National Environmental Policy Act (N EPA), the Clean Air Act (CAA), the Clean Water Act (CWA), and the Housing and Urban Development (HUD) 701 Comprehensive Planning Assistance program, emphasize the State role in regard to environmental issues. Moreover, many States have enacted their own environmental legislation. Thus, the same environmental aspects of a proposed nuclear powerplant often are reviewed by both the State and the NRC, and in some cases, joint NRC-State hearings may be held on matters of concurrent jurisdiction.

Traditionally the States have been responsible for land use, and many States have comprehensive land-use planning programs. Energy facility siting also can be affected by States, local governments, or regional organizations through comprehensive planning activities under federally approved coastal-zone management programs and under the HUD program.

State water management agencies must approve a proposed nuclear powerplant, examining issues related to both the quality and quantity of water supply and to effluent discharge limitations. The States have programs to review water withdrawals from streams and structures placed in water, and they issue Water Quality Certificates under CWA, which include any effluent limitations, monitoring, or other requirements necessary to assure that the plant will comply with applicable Federal and State water-quality standards. These conditions become part of the NRC permit or license. In addition, if a nuclear facility will discharge into navigable waters, it must obtain a National Pollutant Discharge Elimination System (NPDES) permit. CWA establishes special procedures for NPDES permits dealing with thermal discharges.

Nuclear plants can have air-quality impacts from cooling tower plumes, but neither the States

Table 22.—State Siting Laws

State	Lead agency PUC[a]	Lead agency Ind.[b]	Forecasting plans required[d] (years) Env.[c]	Forecasting plans required[d] (years) Utility	Forecasting plans required[d] (years) State	One-stop licensing	Statutory decision time (months)	Preemption authority	Need for power determination	Legislation adopted Original	Legislation adopted Amended	Title of legislation or agency created
Arizona		x		10		No	—	No	Yes	71		Power Plant Siting Committee
Arkansas	x			2		No	—	Yes	Yes	73		Utility Facility Environmental Protection Act (two stop)
California		x			5-10-20	Yes	25-36[e]	No	Yes	74		Energy Resources Conservation and Development Commission
Connecticut		x		0		Yes	10	Yes	Yes	71	73	Public Utilities Environmental Standards Act (Power Facility Evaluation Council
Florida			x	10		No	14	No	Yes	73	75	Electric Power Plant Siting Act (1973)
Iowa		x		None		No	—[f]	No	Yes	76		State Commerce Commisson
Kansas		x		None		No	—	Yes	Yes	76		Corporation Commission
Kentucky	x			None		No	—	No	Yes	74		Power Plant Siting Act
Maine						No	—		Yes			
Maryland	x				10	No	—	Yes	Yes	71		Power Plant Siting Act
Massachusetts		x			10	Yes	6[h]	Yes	Yes	73	75	Energy Facilities and Siting Council (1975)
Minnesota			x	15		No	—[i]	Yes	Yes	73		Power Plant Siting Act
Montana	x			10		No	—	No	Yes	73		Utility Siting Act
Nevada	x			None		Yes	—	No	Yes	71		Public Service Commission
New Hampshire	x			10-15		Yes	14[j]	Yes	Yes	71		Electric Power Plant Siting Act
New Jersey			x		4	No	—	N/A	N/A	73		Coastal Area Facility Review Act
New Mexico	x			None		No	—	No	No	71		Public Utilities Commission
New York		x			15	Yes	—	Yes	Yes	72	75	Board of Electric Generation Siting and the Environment
North Dakota	x				10	Yes	—	No	Yes	75		Energy Conversion and Transmission Facilities Siting Act
Ohio		x			10	Yes	—	Yes	Yes	72		Power Siting Commission
Oregon		x		10		Yes	24[k]	Yes	Yes	71	75	Energy Facility Siting Council (1975)
South Carolina		x		10		No	—	Yes	Yes	71		Public Service Commission
Vermont		x		None		Yes	—[m]	Yes	Yes	75		Public Service Board
Washington		x		10		Yes	12[h]	Yes	Yes	70	76	Energy Facility Site Evaluation Council (1976)
Wisconsin		x		0		No	18	Yes	Yes	75		Public Service Commission (two stop)
Wyoming		x		5		yes	—	No	Yes	75		Industrial Development and Siting Act

[a]Public Utility Commission
[b]Independent.
[c]Environmental.
[d]Indicates the period of time which utility or state prepared forecasts must cover (e.g., Arizona utilities are required to submit a 10-year forecast).
[e]California allows extended time upon mutual agreement by Commission and applicant.
[f]Statute specifies that "the Commission shall expeditiously render a written decision with complete determination . . ."
[g]Only available information is given.
[h]A 1976 amendment provides for the time period to be nonbinding if "compliance with said requirements will prevent the Council from rendering a decision upon the application . . ."
[i]The Minnesota statute contains an emergency certification provision for "demonstrable emergency." The provision authorizes certification "no later than 195 days "following acceptance of an application."
[j]A 1976 amendment allows the state legislature opportunity to disaffirm findings by the siting council 45 days after council certification of nuclear power facility.
[k]Nine months for combustion and/or geothermal generation.
[m]Certification of nuclear power facilities is contingent upon approval by the Vermont General Assembly.
[n]Allows for extended time upon mutual agreement by the Energy Facility Site Evaluation Council and applicant. A 1977 amendment also provides for "expedited processing" of an application upon request by "any person."

SOURCE: U.S. Nuclear Regulatory Commission, *Improving Regulatory Effectiveness in Federal/State Siting Actions*, NUREG-0195, Washington, D.C., May 1977; J. Williams, Nuclear Siting and Licensing Act of 1978, *Hearings*, U.S. Congress, Serial No. 95-187, Washington, D.C., July 1978.

nor the Federal Government have standards governing such emissions. Rather, the primary effects of CAA and State air-quality programs under that act are through restrictions on the siting of and emissions from fossil-fueled plants, which may increase the attractiveness of the nuclear option for electric utilities.

State Siting Activities

Twenty-five States currently have siting laws. These include "multistop" regulation by a variety of State agencies, each concerned with a separate aspect of the construction or operation of a plant; State licensing through a "one-stop" agency charged with determining the suitability of all aspects of a particular site on behalf of all State regulatory bodies; or State ownership of the site, with a single agency empowered to administer the terms of a lease with the utility or consortium that owns the plant.

ISSUES SURROUNDING NUCLEAR PLANT REGULATION

For the last decade, nuclear plant regulation has been slow, unpredictable, expensive, and frustrating for many involved in licensing. Moreover, it has failed to prevent accidents such as those at Three Mile island and Browns Ferry as well as construction problems like those experienced at Diablo Canyon and Zimmer. Even in the case of the Byron plants where the OL was denied by the ASLB, the problems were not acted on until the two plants were nearly complete. The frustrations, costs, and uncertainties have resulted in extensive criticisms of the regulatory process and a variety of proposals for changes in that process. The focal points for such criticisms are backfitting, * hearings and other NRC procedures, the current two-step licensing process, NRC responsibilities not directly related to safety, the use of rulemaking, and safety goals.

The principal concerns about nuclear plant regulation expressed by utilities and the industry are that neither the criteria nor the schedules for siting, designing, building, and operating nuclear plants are predictable under the current licensing scheme. The industry and some regulators also complain about the extensive opportunities for public participation in licensing, arguing that such participation prolongs hearings unnecessarily without adding to safety. They believe that these factors have contributed to higher costs and longer construction times and may have reduced safety by requiring the applicant and the regulators to focus more of their efforts on the procedural aspects of licensing to the detriment of substance.

Nuclear critics, on the other hand, argue that the lack of predictability and construction difficulties were due to the immaturity of the technology and a "design-as-you-go" approach. The critics feel that many of their safety concerns would not have arisen had it not been for the rapid escalation in plant size and number of orders that occurred in the 1960's and 1970's, utility and constructor inattention to quality assurance, and inconsistent interpretation and enforcement of regulations within NRC. While some critics say that nuclear plants will never be safe enough, others believe that the current regulatory process could ensure safety if it were interpreted consistently and enforced adequately. Most critics agree that limiting the opportunities for interested members of the public to participate in licensing will detract from safety.

This section will describe in detail the various parties' views (as determined by OTA) on NRC regulation—what they believe works, what they believe doesn't, and why they hold their views–and how they think the regulatory process could be improved. These views were solicited by OTA

*Although "backfitting" technically refers only to design or regulatory changes ordered by NRC during plant construction, and "ratcheting" to changes imposed after a plant goes on line, "backfitting" usually is used in the literature to refer to both types of changes. Modifications requested by the permit or license holder are termed "amendments" or "variances."

at workshops and panels involving a broad spectrum of interested parties, including nuclear critics and representatives from utilities, vendors, and AEs. These meetings were supplemented by a survey conducted for OTA in which a small sample of qualified individuals responded to an extensive questionnaire(l 5). Suggestions for revisions to current NRC regulations and procedures have been made by a number of interested parties. They will be presented in the following text as originally proposed and then evaluated on the basis of the information available to OTA. The discussion of regulatory revisions will focus on two legislative packages currently before Congress: The Nuclear Powerplant Licensing Reform Act of 1983, submitted by NRC (23), and the Nuclear Licensing and Regulatory Reform Act of 1983, proffered by the U.S. Department of Energy (DOE) (21).

The evaluation of proposals for changes in NRC regulation must depend first on an assessment of the goals to be served by regulation and by the individual changes. The primary goal of NRC regulation as defined in the Atomic Energy Act is to ensure that the utilization or production of special nuclear material will be in accord with the common defense and security and will provide adequate protection to the health and safety of the public. Therefore, in analyzing proposals for changes in licensing, the first consideration must be whether they are necessary to further the fulfillment of this goal. If changes would further this health and safety goal–or at least not detract from it–then secondary policy goals might be:

- to provide a more predictable and efficient licensing process in order to assure license applicants that a plant, once approved, can be built and operated as planned;
- to increase the effectiveness of public participation in licensing; and
- to improve the quality of NRC decisions in order to increase public confidence in plant safety.

Achieving these secondary policy goals probably is a necessary condition in ensuring (whether for national security, economic, or other reasons) that nuclear power remains a viable option for utilities in choosing their mix of generating technologies. However, it should be emphasized that these goals cannot be accomplished through licensing changes alone. Rather, they also will require a commitment to excellence by all parties in the management of plant licensing, construction, and operation, as well as a commitment to resolving outstanding safety and reliability issues.

Another consideration in evaluating proposals for change in the licensing process is whether amendment of the Atomic Energy Act is necessary to accomplish a particular change, or whether it can be accomplished through rulemaking or even simply more effective implementation of the existing regulations.

BACKFITTING

The utilities' and the nuclear industry's complaints about lack of predictability in reactor regulation focus principally on the potential for changes in regulatory and design requirements during plant construction and operation ("backfitting").

The present NRC regulations define backfitting as" . . . the addition, elimination or modification of structures, systems or components of the facility after the construction permit has been issued" (16). Under the present regulations, the standard NRC may use (the language in the regulations is discretionary) in ordering a backfit is whether it will "provide substantial additional protection which is required for the public health and safety or the common defense and security."

NRC never has invoked the backfit definition formally to amend a permit, license, rule, regulation, or order. Rather, it has changed its requirements through a variety of less formal procedures, such as bulletins, circulars, regulatory guides, and informal meetings. While NRC has justified the changes on a safety basis, the decisionmaking process has not been as transparent nor as predictable as desired by the industry or its critics. The industry would like to have the backfit rule rewritten and the procedure for invoking it revised so that it would provide greater certainty and stability **in terms of costs and** schedules and greater flexibility in implementation. The critics would like to see NRC follow an established and documented procedure in ordering backfits to facilitate evaluation of safety considerations.

Specific Concerns

Until recently, NRC's Office of Nuclear Reactor Regulation has been responsible for reviewing and coordinating backfit proposals. The nuclear industry has perceived that review to be unsystematic, haphazard, and without reference to any regulatory standard. The industry does not believe that all of the changes made to plants over the years have contributed significantly to safety. In fact, it considers some of these changes to have made plant design and operations more complicated, less predictable, and possibly less safe (8). Moreover, these changes have absorbed a large share of the utilities' financial and technical resources. For example, after a decade of operation, there were still hundreds of people working to make changes at the Browns Ferry nuclear plants (5). At another utility, the backfits in 1980 alone required $26 million and 10 to 12 staff-years of engineering. In addition, the long-term expenditures associated with Three Mile island backfits are estimated to cost $74 million at the same plant (26). Thus, there are powerful incentives for the nuclear industry to try to have the backfit rule and its implementation changed.

Nuclear critics counter that the rule would be adequate if it were implemented consistently and understandably. They contend that backfits serve an important safety function, since many problems arise only after construction or operation has been initiated. The critics, however, agree with the industry that it would be more appropriate to allocate resources to the design phase rather than using them to satisfy safety concerns with backfits. Unfortunately, this is not an option for existing plants, but can be applied only to the next generation of nuclear reactors.

To review these claims about backfitting, OTA undertook a survey of people of all viewpoints connected with nuclear power, including industry representatives, regulators, and critics. The results of this survey form the basis for the analysis presented here.

There are certain ways in which backfits have the potential to adversely affect the safety of nuclear plants. First, additional equipment can impair normal operations or safety functions; backfits related to seismic protection often are cited as examples of these problems. As discussed in chapter 4, requirements for additional pipe hangers and restraints increasingly have constrained the layout of the piping systems in nuclear powerplants. This could contribute to thermal stresses in normal operation and make the system more prone to failure in accident situations. Another adverse consequence associated with seismic backfits is that they can lead to overcrowding, making some equipment virtually inaccessible for inspection or maintenance.

Backfits also can affect safety by disrupting normal plant operations while new equipment is being installed. While this potential problem is less a result of NRC's management of backfits than of utility planning and expertise, it is important to recognize that there are safety implications associated with installation. Such an incident occurred at the Crystal River plant in 1980 when the utility attempted to install a subcooling monitor while the unit was still operating. This action triggered a series of unplanned events, eventually followed by safe shutdown of the plant.

It should be noted that while examples can be found in which backfits have adversely affected safety, this does not imply that the overall impact has been negative. In fact, one recent study indicates that modifications made to plants after Three Mile Island may have reduced the probability of a large-scale accident by as much as a factor of six at some plants (1 3). However, the overall gain or loss in safety due to backfits has not been analyzed in any comprehensive fashion.

OTA concludes that, while most backfits represent safety improvements, they can have a negative impact when deployed in a manner

that does not allow for sufficient analysis of the consequences of installing or modifying equipment and its interaction with other systems. A more rational and less hurried approach could improve this situation for current plants. if the next generation of reactors is an evolutionary development of today's light-water reactors (LWRs), new plants should be even less troubled by backfits. New LWR designs will incorporate the lessons learned from Three Mile Island and the accumulated experience of current reactors, and they will address unresolved safety issues with state-of-the-art technology. However, if an alternative reactor design is selected for commercial deployment, it maybe impossible to avoid extensive backfitting until the technology is fully mat ure.

NRC backfit requirements also have been criticized by the nuclear industry as being overly prescriptive to the point of being incompatible with practical design, construction, or operating techniques. Rather than establishing general guidelines or safety criteria and allowing individual utilities some flexibility in applying them, NRC generally issues detailed and specific requirements. Nuclear powerplant designers must conform to the regulations and appendices in 10 CFR Part 50 as well as 10 other major parts to title 10, over 150 regulatory guides, three volumes of branch technical positions, numerous inspection and enforcement circulars and bulletins, proposed rules, and over 5,000 other voluntary codes and standards that may be invoked at any time by regulatory interpretation. During construction, these standards and codes often are interpreted in the strictest sense possible, with no allowances for engineering judgment. For example, the fillet weld, which is commonly used in field construction, varies in width along the length of the weld. Plant designers recognize that some variation will occur and set the design requirements according to an average width. An inspector, by strict interpretation of an industry code, may not look at the average width, but reject an otherwise acceptable weld if it is slightly less in width than called for by the designer at any point along the length of the weld. Constructors compensate for such anomalies by overwelding, which entails considerable time and expense (19).

It is OTA's conclusion that the requirements associated with the design, construction, and operation of nuclear powerplants are prescriptive and, in some cases, internally inconsistent or in conflict with other good practices. However, while the inconsistencies and contradictions are problematic, **the prescriptive nature of the rules should not pose insurmountable difficulties for plant owners and designers.** Some utilities have been able to accommodate to the same prescriptive requirements that govern all nuclear construction and still complete their plants efficiently and with few regulatory difficulties. Moreover, NRC is not wholly responsible for prescriptive regulation. The nuclear industry has developed a large and growing set of voluntary standards to provide guidance in interpreting NRC criteria. These standards were expanded greatly in the mid-1970's to match the growth in NRC requirements and often were written with little consideration of their impact. In addition, many of the early standards were written too rapidly to reflect field experience and a convergence of accepted practices. NRC magnified these problems by invoking the standards precisely as written rather than allowing them to evolve gradually (19).

Another concern about backfitting is that there are no clear and consistent priorities. Permit and license holders argue that they have not always been given consistent and stable criteria by which to construct and operate a plant and, as a result, some less important backfits have been imposed before more critical ones. The prime example of this cited by utilities and the industry is the Three Mile Island action plan, in which the NRC gave the utilities no guidance on the relative priorities among approximately 180 requirements of varying importance. The action plan was developed with little comprehensive analysis. As discussed above, if the next generation of plants incorporates a clean-sheet design based on past experience with LWRs, backfits should not be as serious a problem as they have in the past. While a lack of priorities has been troublesome for plants currently under construction or in operation, it is unlikely that future LWRs will experience the same degree of difficulty.

A final concern about backfitting is its potential contribution to increases in construction leadtimes and plant costs, These issues are discussed in greater detail in chapters 3, 4, and 5 and are only summarized here. The most recent plants to obtain CPs from NRC required 30 to 40 months after docketing (i.e., not including the preliminary utility planning phase) to obtain their permits, compared to 10 to 20 months between 1960-70. Similarly, construction (the time between issuance of the construction permit and the operating license) typically takes 100 to 115 months, up from the 32 to 43 months in 1960-70 (18). Backfitting has been suggested as one of the sources of delay, along with deliberate delays due to a decrease in the need for power and difficulties in financing construction.

In order to examine the impact of regulation on nuclear powerplant construction leadtimes, OTA analyzed case studies of the licensing process, which are detailed in volume 2 of this report (1). Because it is difficult to separate the effects of backfitting from other regulatory activities, they were considered in the context of the entire licensing process. Based on these case studies, on published analyses of the causes of increases in nuclear plant construction leadtimes, and on extensive discussions with parties from all sides of the nuclear debate, OTA has concluded that **the regulatory process per se was not the primary source of delay in nuclear plant construction.** Rather, during the 1970's (when leadtimes escalated the most), utilities delayed some plants deliberately because of slow demand growth and financial problems, Plant size was being scaled up very rapidly and construction was begun with incomplete design information. The increasingly complex plant designs meant that more materials—concrete, piping, electrical cable—were required, and constructors often experienced delays in delivery of equipment and materials. At the same time, worker productivity declined substantially, at least in part because plants were more complicated and thus more difficult for the utilities to manage and build (3).

Backfits did lead to delays in some plants, especially those subject to the extensive regulatory changes that followed the accidents at Browns **Ferry and Three Mile Island, but in others the effects of regulatory changes were moderated** through strong management. All plants had to accommodate to some backfits that resulted from the immaturity of the technology and the overly rapid scale-up of plant size. In these cases, regulatory delays must be considered positive. Moreover, in some plants that have experienced regulatory delays, such as Cincinnati Gas & Electric Co.'s Zimmer plant, regulatory actions were an appropriate response to evidence of improper construction practices(9). NRC should not be arbitrarily limited from imposing backfit requirements that lead to long delays in such cases, since interest in the public health and safety should supercede concern for minimizing leadtime and cost .

In general, OTA concludes that, as in other aspects of quality control, **skillful management by the utility, its contractors, and NRC is the key to avoiding delays that otherwise might result from the licensing process.** Thus, licensing is most likely to proceed without hitches with experienced, committed utility and contractor management personnel; a clear need for power from the plant; and a constant and open dialogue among NRC staff, nuclear critics, and utility and construction managers. Since skillful management has not been a hallmark of NRC administration, changes to make the organization more responsive and efficient should enhance the licensing process and reduce unnecessary delays. However, such changes cannot substitute for good utility management and a commitment to safety in construction and operation.

Proposals for Change and Evaluation

In 1981, NRC created the Committee for Review of Generic Requirements (CRGR) to respond to some of industry's concerns and to reduce some of the burdens that the utilities felt backfitting had imposed on them. The CRGR review should guide the industry in assigning priorities, even if it does not solve some of the more fundamental problems with backfitting. The NRC and **DOE** proposals for reform attempt to address the larger issues,

In evaluating the proposals outlined below, it is important to recognize that backfitting cannot be eliminated entirely, but will continue to be applied to plants under construction or in operation as long as there are outstanding generic safety questions. As discussed in chapter 4, the current generation of LWRs still is troubled by a number of potentially serious safety issues even though they have been studied extensively by NRC and industry groups. Nuclear critics are concerned that the resolution of problems such as steam-generator degradation and cracking in primary system components might be compromised in the interest of limiting backfits. Therefore, they are skeptical about proposals that would restrict NRC's freedom to impose legitimate backfit requirements or emphasize cost and efficiency at the expense of safety.

The debate about backfitting centers on four main considerations of the backfitting rule: 1) whether the current definition and standard need to be revised or simply invoked and enforced; 2) if they do need to be changed, how should the new definition and standard be phrased, 3) what criteria should be applied by NRC in ordering a backfit; and 4) whether any changes that may be needed should be made legislatively or through rulemaking. As discussed in the previous section, some change in the manner in which backfits are managed and enforced within NRC probably is necessary so that the primary regulatory goal of ensuring safety is achieved. Moreover, to provide license applicants with more stability and certainty, and to increase the effectiveness of public participation in licensing, the backfit procedures and criteria at least must be made more explicit.

Definition

The present definition of a backfit in the NRC rules includes any design or technological change ordered after issuance of the CP. In doing so, it ignores the reality that much design information is not available when the CP is issued, and not all evaluations and modifications of designs should be considered backfits merely because they are postpermitting. From another perspective, however, the present definition may be too narrow in that it focuses only on changes in "structures, systems, or components of the facility," and thus excludes important institutional and management changes.

One alternative definition has been put forward by the NRC Regulatory Reform Task Force (RRTF) in its proposed revisions to the NRC rules: "the imposition of new regulatory requirements, or the modification of previous regulatory requirements applicable to the facility, after the construction permit has been issued" (23). Prior to the invocation of a backfit, NRC would set approved design and acceptance criteria for the protection of public health and safety and national security. Once a licensee embarked on the design, construction, or operation of the reactor and had committed substantial resources to and was acting in accordance with the NRC criteria, then, according to the definition above, any proposed change in those criteria should be considered a backfit and should trigger a special decisionmaking process.

A second definition (proposed in the DOE legislative package) is "an addition, deletion, or modification to those aspects of the engineering, construction or operation of a . . . facility upon which a permit, license or approval was issued" (21). This definition may be slightly narrower than the RRTF definition in that it applies backfit criteria only to the conditions in a license rather than to the full range of regulatory requirements applicable to a facility.

The most important attributes of any NRC requirement are explicit criteria and consistent application of these criteria by NRC management. Thus, either NRC or DOE proposed definitions would be preferable to the current one, under which it is unclear when a change ordered by NRC should be considered a backfit, provided that the application of the definition by NRC is consistent and clear to all interested parties. Such a change should contribute to more predictability about backfits.

The definition of a backfit would be particularly important if it were coupled with a threshold standard for triggering it. One approach would require a backfit to result in a substantial increase in public protection, with benefits from the increased protection exceeding both the direct and indirect costs of the backfit. **While such a cost-benefit standard would presumably assure consistency, OTA concludes that the available methodologies are inadequate to fully quantify improvements in safety.** Thus it is likely that a cost-benefit standard alone (or the use of quantitative safety goals to justify backfits, as discussed in detail below) would be unworkable until such methodologies are developed further. Rather, some combination of engineering judgment coupled with cost-benefit analysis, as has been used in the past, will be necessary.

Within this context, however, NRC could improve the process of evaluating and imposing backfits by making its standards more explicit and by specifying the relative consideration to be given to factors such as the effects for ordering backfits on public and occupational exposures to radioactivity; the impact on safety given overall plant system interactions, changes in complexity, and relationship to other regulatory requirements; the cost of implementing the backfit, including plant downtime; the resource burden imposed on NRC; and, for backfits applicable to multiple plants, the differences in plant vintage and design. While these factors probably are considered in some form in NRC's current deliberations, the decisionmaking process is frequently inscrutable.

Other changes could be made in the backfit review process to ensure that criteria and standards are applied consistently. A centralized group such as CRGR or ACRS could review backfits routinely and judge them according to standards established by NRC. Alternatively, an independent panel of experienced engineers drawn from utilities, the public, and industry (but not from the organization that did the design) could be set up for centralized review.

General Procedures

Changes in overall procedures and guidelines for backfitting also have been proposed. The DOE bill would shift the burden of proof from industry to NRC by requiring NRC to demonstrate that a backfit is cost effective. Moreover, the DOE bill would restrict the information that NRC can require from licensees. In addition, it implicity directs NRC to employ a lower standard of safety for older plants with shorter remaining operating lives, even though these are often the plants most in need of upgrading. Further, the DOE bill would apply to breeder reactors and reprocessing plants where backfitting is likely to lead to significant improvements in safety.

These procedural changes in the DOE bill would have the effect of making it more difficult for NRC to order safety-related improvements after a construction permit has been issued. Such changes will be controversial without other assurances—absent in the DOE bill—that safety can be assured.

A more general and fundamental change has been proposed by the nuclear industry, which would like to see NRC's prescriptive rules replaced with a few general criteria. In such a system, each utility could determine how it might best satisfy NRC's criteria, subject to concurrence by NRC. OTA finds that the latter proposal has some merit in that it might encourage innovative approaches among the more capable utilities and vendors. Treating the problems generically rather than prescriptively also might reinforce the use of owners' groups and data pooling. However, it should be noted that such an approach also could pose severe resource problems for NRC. If NRC staff had to review numerous different proposals for changes rather than devise a single solution of its own, it would severely tax a system that already has difficulty with coordination and organization.

It generally is agreed that the key to a shift to performance standards is to make the industry (including utilities, vendors, and AEs) accept full responsibility for safety and to design and build plants according to a consistent regulatory philosophy rather than making numerous modifications as problems rise. Acceptance of this responsibility could be demonstrated in part by industrywide improvements in management practices, quality control, performance records, and event-free operations. If the evidence indicates that the industry has matured sufficiently to be able to construct and operate plants safely and reliably, NRC may be able to allow more flexibility in the interpretation of its guidelines. **However, as long as**

any industry participants demonstrate an inability to guarantee safe operations, OTA believes that the current level of detail in the backfit regulation probably is necessary to fulfill NRC's primary legislative mandate of protecting public health and safety.

Legislation

OTA found that congressional action is not necessary to change the backfit rule. Changes that would contribute to reactor safety, and lend stability and certainty to, and increase the effectiveness of public participation in this aspect of regulation can be accomplished better administratively, through rulemaking. This would allow greater flexibility in adjusting to changing construction and operating experience and in applying risk assessment and cost-benefit analysis than a backfitting standard rigidly determined by legislative action. Because of the extensive public comment process associated with rulemaking, it also might permit greater participation in development of a backfit rule by all parties. This was the rationale followed by NRC in drafting its legislative regulatory reform proposal, which did not include provisions related to backfitting. NRC personnel reportedly are working on a draft revision of the current rule, which will appear as a notice of proposed rulemaking.

HEARINGS AND OTHER NRC PROCEDURES

Hearings and other procedural aspects of NRC licensing and safety regulation, including the conduct of safety reviews, management problems within NRC, the use of rulemaking, and some aspects of enforcement, are highly controversial. The industry and the utilities perceive the hearings and other procedures as contributing minimally, if at all, to plant safety, but requiring overwhelming amounts of paperwork and management resources. Nuclear critics, on the other hand, see these procedures as their only means of raising safety concerns, and they strongly object to any attempts to limit the process and their participation.

Hearings

The current licensing process includes adjudicatory hearings, * with public participation, before a CP is issued and optional hearings (generally requested) at the OL stage. Formal adjudicatory hearings probably are not required under the Atomic Energy Act, which does not specify the type of hearing that the Commission must hold. However, they have been granted for so long that it would be difficult, if not impossible, to interpret the act as allowing anything less than a formal adjudicatory hearing. Furthermore, trial-type hearings are required under the principles of administrative law to the extent that the examination of evidence is necessary to resolve questions of fact, as opposed to issues of law or policy, which can be resolved in legislative-type hearings.

Part of the debate concerning hearings has focused on the appropriateness of using an adjudication process to resolve technical issues. Industry and utility representatives claim that the current system leads to unnecessary delays and inefficient allocation of resources. On the other hand, nuclear critics view the hearing process as an opportunity to examine NRC records and raise issues that might have been overlooked. In this sense, the adjudicatory hearings are appropriate for NRC licensing because they are designed, legally, to illuminate the contested issues of fact and cause the utility and NRC to justify their technical decisions more thoroughly than they might in a legislative-type hearing.

Closely associated with the issue of appropriateness is the efficiency argument. The industry claims that hearings have been too long (spread out over a year or more in extreme cases) and costly due to the highly technical and complex nature of the subject matter and the inclusion of

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*A formal adjudicatory hearing is similar to a trial, in that the parties present evidence subject to cross-examination and rebuttal, and the tribunal or hearing officer/board makes a determination on the record. The key ingredient is the opportunity of each party to know and meet the evidence and the arguments on the other side; this is what is meant by "on the record."

issues not directly germane to safety, such as need for power and alternative means of generating that power, It is possible that changes could be made to the hearing process to reduce inefficiencies while preserving the right of the critics to participate effectively. As discussed below, legislative action would not necessarily be required, since most of the problems could be ameliorated by strict conformance to the NRC rules of administrative procedure.

A final important consideration is the degree to which critics participate in the decisionmaking process and their effectiveness in raising safety concerns. Timing is a central issue concerning participation. In the past, plant designs have been so incomplete at the CP hearing stage that it has been virtually impossible to make constructive criticisms about them. But by the time the OL hearings are held, the final design is complete, it has been reviewed and approved by the NRC staff, and the plant is built. Therefore, any concerns the critics raise are directed toward a group that has already decided upon the plant's safety.

Another issue related to participation is the effectiveness of the interaction between critics and the NRC staff. Industry representatives interact with the staff prior to hearings and reach agreements on the major safety issues. When the critics question these resolutions at the hearings, they feel that the staff does not give adequate attention to their complaints. Furthermore, the critics feel that they have even less influence with the staff when they are not in an adjudicatory setting. The critics cite occasions on which they were ignored by the NRC staff when they informally raised issues such as emergency core cooling, environmental qualification, and fire protection. These issues later proved to be major concerns.

Proposals for Change in the Hearing Process and Evaluation

There have been several proposals to address the industry's and critics' complaints about the NRC hearing process, including changing the format of the hearings, improving management of the hearings and other procedures, and changing the structure of licensing so that safety issues are addressed in a public forum before the CP or OL hearing.

The industry and some regulators would like to see the hearings restructured to a hybrid format that would combine some of the elements of adjudication and legislative-type hearings. In a hybrid hearing, all testimony and evidence would be presented first in written form, as in a legislative hearing. Adjudicatory hearings would be granted on issues that present genuine and substantial factual disputes that only could be resolved with sufficient accuracy by the introduction of evidence in a trial-like setting.

Both the NRC and DOE legislative packages would amend the Atomic Energy Act to provide for hybrid hearings. Under the NRC proposal, hearings on CPS would be optional rather than mandatory, and the Commission could substitute hybrid hearings for adjudication, after providing the parties an opportunity to present their views, including oral argument on matters determined by the Commission to be in controversy. Such arguments would be preceded by discovery, and each party, including the NRC staff, would submit a written summary of the facts, data, and arguments to be relied on in the proceeding. The hearing board then would designate disputed questions of fact for resolution in an adjudicatory hearing based on the standard described above and on whether the decision of the Commission is likely to depend in whole or in part on the resolution of a dispute.

The hearings as proposed by NRC and DOE would be limited to matters that were not and could not have been considered and decided in prior proceedings involving that plant, site, or design unless there was a substantial evidentiary showing that the issue should be reconsidered based on significant new information, The NRC bill defines "substantial evidentiary showing" as one sufficent to justify a conclusion that the plant no longer would comply with the Atomic Energy Act, other Federal law, or NRC regulations (23).

The DOE bill would require hybrid hearings to be substituted for adjudication. This maybe contracted with the NRC bill, in which the shift to a hybrid hearing would be discretionary. The DOE bill would allow anyone to introduce written submissions into the record. Interested parties could petition the hearing board for oral arguments, which would be granted on contentions that had been backed up with reasonable specificity. As in the NRC bill, oral argument would be preceded by discovery and submission of written facts and arguments. After oral argument, each party could file proposed findings that set forth the issues believed to require formal hearings. Under the DOE bill, the hearing board's decision as to which issues required adjudication would be reviewed by the Commission.

The DOE bill specifies that issues raised and resolved by NRC in other licensing proceedings could not be heard again unless "significant, new information has been introduced and admitted which raises a prima facie showing that action is needed to substantially enhance the public health and safety or the common defense and security." New issues would not be admitted unless they were "significant, relevant, material and concerned the overall effect of the plant" on health, safety, or security (21).

Efficiency improvements

Hybrid hearings are intended to increase the efficiency of the hearing process and to improve the effectiveness of public participation in that process. In terms of efficiency, proposals for hybrid hearings are directed toward complaints that hearings are too long and costly and tie up too much of staff and industry resources without contributing to plant safety. Although it is true that the hearings can be unduly long and expensive, OTA found, based on extensive discussions with utility and industry representatives, regulators, and nuclear critics and public interest groups, that **if management of the hearings were tighter, either through enforcement of the existing regulations or through changes in those regulations, a formal shift to hybrid hearings would be unnecessary.** Most of the problems cited by the industry that contribute to unnecessarily long hearings can be remedied through better management control by the utilities and NRC to ensure that safety issues are resolved early in the licensing process and through tighter management of the hearings by the licensing boards or hearing officers without making fundamental and highly controversial changes in the structure and scope of the hearings themselves. Furthermore, because proposals for a shift to hybrid hearings include more opportunities for requesting hearings than under the present licensing process, and more administrative decisions subject to appeal, it is likely that these proposals actually would increase the amount of time taken up by hearings.

Other changes in NRC regulations or in management of the hearings could contribute to more efficient hearings. Such changes include: vigorously enforcing existing NRC regulations that impose time limits in hearings; excluding issues not raised in a timely manner without a showing of good cause; requiring all parties to specify the factual basis for contentions; resolving generic issues through rulemaking once they have been litigated in a licensing proceeding; using summary disposition procedures for issues not controverted by other parties; excluding issues that were raised and resolved in earlier proceedings unless a showing of significant new information can be made; and eliminating consideration of issues not germane to safety that are best considered in other forums. Only the last of these changes would require legislative action.

improvements in Public Participation

The hybid hearings proposed by NRC and DOE also can be assessed in terms of the effectiveness of public participation. DOE and the industry argue that these proposals would provide more opportunities for critics to influence the decision process. As stated by Secretary of Energy Donald Hodel:

> After a plant is essentially complete, with many hundreds **of millions–or billions–of dollars already spent, the view of the public cannot, as a practical matter, be considered as effectively as it could be at the beginning of the licensing process. Therefore, [DOE is] proposing a system with multiple opportunities for public participation early in the process, before firm decisions are made by the Commission and the applicant (6).**

Under the DOE bill, these opportunities would occur if and when standardized plants are considered for approval, when the specific site is considered for approval, and when the issuance of a combined CP/OL is being considered. The NRC bill would allow hearings at these points as well as on construction permits, operating licenses, and preoperational reviews for plants with CP/OLs.

In analyzing whether hybrid hearings would improve the effectiveness of public participation in licensing, it is important to distinguish the timing and number of hearings from the scope of those hearings. To the extent that the NRC and DOE bills would increase the number of opportunities for public involvement in nuclear plant licensing before final decisions have been made, they would improve the effectiveness of public participation in the hearing process. **However,** if those opportunities are not provided when design decisions are being made and safety issues are being raised and resolved—all of which currently occurs in industry-staff interactions from which members of the public are excluded—then the public's ability to have its safety concerns heard will not be improved, and the critics still will feel that decisions will have been made prior to the hearings.

Nuclear critics contend that the means proposed by DOE and NRC to increase the efficiency of the hearings would serve to undercut the effectiveness of public participation by severely limiting the scope of that participation. They note that both bills would weaken the rights of the public to cross-examine NRC and utility witnesses, which they argue is often the only way to uncover safety problems and uncertainties that could not be revealed through examination of written testimony. Furthermore, the critics feel that both bills (but especially the DOE bill) may make it more difficult for members of the public to raise serious safety issues by raising the standards for admission of evidence.

Nuclear critics also point out that, under the bills' provisions for hybrid hearings, the hearing board would have to decide in each case which evidence is subject to cross-examination—a decision that often would be appealed, thus lengthening the process rather than shortening it. Under the DOE bill, the Commission itself would have to review the hearing board's decision, plus the written submissions and oral presentations, and affirm or reverse the board's designation on each issue. The critics are especially cautious about NRC dictating to the hearing boards which issues to consider. They cite quality assurance at Zimmer and the steam generators at Three Mile Island as issues NRC previously has taken away from hearing boards on the grounds that the staff was working on them. In the critics' view, all of the points listed above are serious defects that would seriously erode public confidence in the effectiveness of NRC safety regulation.

OTA concludes that the effectiveness of public participation in licensing can be improved without causing the hearing process to negatively affect costs or construction schedules. First, the proposals for early design and site approvals would permit extensive public participation in hearings on safety issues prior to the start of construction of any particular plant. Then, when a utility applied for a CP based on an approved design and site, the only questions that would remain to be heard in the CP hearings would be the combination of the site and the design, plus any safety issues that were not resolved in the design approval. This might alleviate the critics' concern that design-related safety issues are resolved in private industry-staff interactions. Allowing public involvement early and often in utility planning for nuclear power also would enhance the effectiveness of public participation in the licensing process.

Second, a funding mechanism for public participation in licensing would ensure that the critics could make a substantive contribution to design and safety issues by enabling them to devote more resources to the identification and analysis of reactor engineering and safety. This would respond to the industry's complaint that the critics are not sufficiently knowledgeable about reactor engineering and safety, as well as to the critics' view that the utility, and to a lesser extent the NRC staff, can devote extensive resources to defending design decisions.

Funding of public participation has been a part of the rulemaking proceedings in the Federal Trade Commission, the National Highway Traffic Safety Administration, DOE, and the Environmental Protection Agency, and of both rulemaking and public hearings in the National Oceanic and Atmospheric Administration and the Consumer Product Safety Commission. In the mid-1970's, NRC considered an intervener funding program but did not implement one, arguing that NRC adequately represents the public interest in reactor safety and that the present method of funding through citizen contributions is a more democratic measure of public confidence in how well NRC does its job. Given the extent of the criticism of NRC management and expertise expressed to OTA by all parties, any policy package intended to revitalize the nuclear option should include reconsideration of an intervener funding program and alternatives such as an office of public counsel within NRC.

Changes in the Role of the NRC Staff

The NRC staff currently participates as an advocate of the license application in the hearings. This role is a consequence of the detailed involvement of the staff in licensing issues and the resolution of most issues to the satisfaction of the staff and the applicant prior to the hearings. The disadvantage of this situation is that the staff may be perceived as being less effective in resolving safety problems than it might be. This concern could be addressed by limiting the staff's participation in contested initial licensing proceedings to those issues on which it disagrees with the applicant's technical basis, rationale, or conclusions. The staff then would not be perceived as defending a particular plant in a hearing and might be more effective in aiding ASLB.

A related issue is the ex parte rule. Like a court trial, an agency adjudication is supposed to be decided solely on the basis of the record so that a participant in an adjudicatory hearing will know what evidence may be used and will be able to contest it. These rights can be nullified if agency decisionmakers are free to consider facts outside the record without notice or opportunity to respond.

The most common problem of extrarecord evidence occurs when there are ex parte contacts–communications between any interested party and an agency decisionmaker that take place outside the hearing and off the record. The Administrative Procedures Act (APA) prohibits such communications once a notice of hearing has been published for a particular proceeding. When an improper off-the-record contact does occur, the A PA requires that it be placed on the public record; if it was an oral communication, a memorandum summarizing the contact must be prepared and incorporated into the record.

Strict interpretation of the ex parte rule effectively cuts off communication between the Commissioners and some parts of NRC during a licensing determination or requires that the communication be made public. The Rogovin Report recommended more active involvement by the Commissioners in individual licensing determinations, but implementation of this recommendation is constrained by the ex parte rule (14). In its rulemaking options, NRC's RRTF argued that the Commissioners should be allowed to talk to staff supervisory personnel who are not participating directly in a particular hearing. The ex parte rule could be interpreted more liberally to allow such Commission/staff interaction—especially if the role of the staff in hearings is limited—as long as true ex parte communications continue to be made public.

Other NRC Procedural Issues

Additional issues related to NRC procedures include the role of ACRS in the conduct of safety reviews; management problems within NRC and other aspects of safety reviews; the use of rulemaking; and NRC enforcement methods.

Advisory Committee on Reactor Safeguards

The Atomic Energy Act requires ACRS to review each license application referred to it, at both the CP and OL stages, even if the Committee does not judge the review to be merited. Many observers consider ACRS to be particularly adept at revealing previously unrecognized safety problems, but because its members devote only part of their time to ACRS activities, it has few resources to pursue such problems in depth. Both the Rogovin Report and the President's Commission report on

Three Mile Island recommended that ACRS be relieved of its mandatory review responsibilities and be allowed to participate in hearings (7,14). A 1977 NRC review of the licensing process also recommended that the ACRS be given discretionary authority to decide which license applications merit its review (22).

The DOE bill would make ACRS discretion very broad; it would amend the Atomic Energy Act to make ACRS review of applications to grant, amend, or renew a CP, OL, combined construction and operating license (COL), or site permit discretionary unless the Commission specifically requested a review. Only ACRS review of design approvals or amendments and renewals would be mandatory under the DOE bill. Further, the DOE proposal specifies that neither the ACRS decision to review nor the NRC decision to refer an issue to ACRS would be subject to judicial review. Under the NRC legislative proposal, ACRS review of CPS, OLs, site permits, design approvals, and amendments to any of these would continue to be mandatory.

OTA concludes that the ACRS review of designs should be mandatory to ensure that safety problems are identified early in the licensing process. If proapproval of standardized designs were implemented, only discretionary ACRS review of a CP application should be required because it would be based on a thoroughly studied design, Similarly, if site-banking were implemented, ACRS reviews of sites also could be discretionary. Another mandatory ACRS review might be appropriate before granting an OL or deciding to allow a plant to begin operation under a COL, since at this stage significant safety issues can arise about compliance with the original design.

Management Control

According to the industry, the primary problem with NRC procedures is lack of management control within NRC, as reflected in uneven safety and other reviews, in a lack of priorities, and in the problems with backfitting discussed previously. There does not appear to be any true decisionmaking process; rather, NRC appears to react to immediate, pressing problems. As a result, small problems can be given proportionately more attention than is warranted. Furthermore, the decision path within NRC is virtually untraceable, making it difficult to knowledgeably critique the staff's analysis and resolution of safety concerns.

Another concern that is shared by the NRC staff and the industry is that the regulatory process is too cumbersome and legalistic in an area that is primarily technical. This produces requirements for an inordinate amount of paperwork and may divert attention away from the primary mission of ensuring plant safety. For example, the Sholly Rule (which requires that a notice be put in the Federal Register before any change—no matter how trivial–is made in a plant's technical specifications) requires extensive staff attention and resources, but produces little accompanying benefit to the public. Similarly, the industry thinks it has to report too much to NRC, and that significant safety issues may get lost in the resulting paperwork.

Another problem concerns consistency of reviews; the SRP helps to even out reviews, but it is limited by the resources of the NRC staff. This review is, of necessity, an audit review, with the ratio of hours spent on the design to those spent in review on the order of 10,000 to 1. Consistency will be increasingly difficult to guarantee as more review functions are shifted to the NRC regional offices.

It is unclear how to address these concerns. Good management cannot be legislated. Adding more technically qualified staff probably would improve the quality of substantive reviews but would not necessarily improve management. Further, it is generally agreed that the ultimate responsibility for safety rests with the utilities and the industry. Even the most competent and effective NRC could not make an incompetent or unwilling utility operate safely short of shutting down a plant if the utility did not accept this responsibility. Financial sanctions other than fines, such as might be imposed through insurers or financiers, may be the most effective in this regard.

As noted above in the discussion of backfitting, it is important that NRC procedures be explicit,

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workable, and applied consistently, but even the best written regulations or legislation cannot achieve this if there is not a firm commitment by top NRC management to ensure that the regulations are implemented properly. For example, the current NRC rules of administrative procedure, for the most part, are adequate to increase the effectiveness of the hearing process but are not enforced by NRC.

The Use of Rulemaking

In other agencies, increasing the use of rulemaking, as opposed to bulletins, circulars, notices, and regulatory guides, has improved the quality of management decisions due to the extensive opportunities for external review and comment by all interested parties. However, NRC is not perceived as being particularly good at rulemaking. Many NRC rules are considered incomprehensible due to the poor wording that results from the cumbersome internal review process: a rule drafted by the technical staff is revised by numerous others culminating with the legal staff-by which time it may be unrecognizable—but the technical staff is reluctant to change the wording lest it has to start the review process all over again. Thus, the staff tends to avoid rulemaking because fulfilling the review requirements is likely to make the final product look much different than the initial intention.

If NRC could streamline its rulemaking procedure, it might be particularly useful in resolving generic issues–those common to more than one plant. As discussed earlier, one of the factors that can contribute to inefficiency in the regulatory process is the consideration of generic questions during the licensing or oversight of a particular plant. The Rogovin Report and the President's Commission on the Accident at Three Mile Island recommended the increased use of administrative rulemaking procedures to resolve issues that affect several licensees or plants, as opposed to considering such issues during the licensing or oversight of individual plants (7,14). NRC has been heading in this direction over the past decade with its rulings on emergency core cooling systems and its environmental statement on mixed oxides. However, considerably more progress could be made in resolving generic issues through rulemaking.

OTA concludes that resolution of generic questions through administrative rulemaking would remove a source of regulatory inefficiency if the rulemaking procedure were improved. Moreover, it also would improve the effectiveness of participation by the public (including the industry, nuclear critics, and other interested parties) on these issues because of the opportunities for review and comment through publication in the Federal Register and, often, for public hearings on a proposed rule. Furthermore, a rule is an enforceable regulation, and thus is a stricter means of instituting requirements than notices, circulars, regulatory guides, or bulletins. Also, as discussed previously, generic treatment of safety concerns would facilitate industry use of owners' groups and other management tools.

NRC is not particularly adept at rulemaking, producing poorly worded regulations that are difficult to interpret by those who must implement and enforce them. But, because of the regulatory and enforcement problems posed by the use of alternatives to rulemaking for generic issues, NRC would be better off to improve its ability to write comprehensible rules than to continue to develop solutions to generic problems through licensing or notices on individual plants.

RRTF suggested that a generic question be heard once in a license proceeding and then be published as a proposed regulation within 45 days after resolution in that proceeding. If the regulation were adopted by NRC following the requisite public comment period, it could not be relitigated in subsequent licensing proceedings unless "special circumstances" were shown. If the "hearing" of the initial rulemaking were in an adjudicatory setting, then this proposal would provide for comprehensive discussion of generic issues for all parties. However, if the hearing were limited to a legislative-type proceeding, critics of the regulation may not feel that they really have been heard.

If the RRTF suggestion is not implemented, some other means of involving as many parties as possible in the development of rules—before they are published in the Federal Register for cement—should be devised. NRC is involving the industry in the development of the generic rule for radiation protection but not the critics. As a result, when the draft rule is published, the critics may view it with skepticism and distrust of the process. Their only recourse would be the public comment process and, ultimately, a petition to change the rule after it has been finalized.

In addition to the concern for rulemaking procedures, there is another issue relating to content of NRC rules. The current NRC technical regulations have evolved over a 25-year period with each new rule devised on a largely ad hoc basis. The relative contribution of each of the numerous regulations to safety is undetermined, although it is likely to be highly variable. As one utility representative expressed it:

> **Many codes and standards were contrived and written by well-qualified, well-meaning individuals projecting ideal situations. They never had any idea that in this day and age of rigid quality assurance and quality control, the codes and standards would be enforced to the letter (1 2).**

Some industry representatives and regulators argue that it is now time for a wholesale revamping of NRC's technical regulations to reflect the current state-of-the-art and the accumulated operating experience. Before such a radical step, however, what is needed is a detailed analysis of the existing technical rules. A possible starting point would be to initiate a thorough revision of the technical regulations related to licensing. Any such effort also should examine the relative advantages and disadvantages of a shift away from hardware-based (prescriptive) standards and toward performance criteria, the role of safety goals and PRA, and the source-term work.

Enforcement

With regard to enforcement, nearly all parties to the nuclear debate agree that the procedures could be improved. First, there are some 80 or more means by which NRC can transmit information to a utility or the industry, but only two, orders and rules, are mandatory in the sense that the recipient would be subject to fines or other enforcement action if he did not respond. Although many observers would prefer to see a greater use of rules to change requirements, NRC's current problems with wording could lead to enforcement problems. inspectors in the field have to enforce a rule based on what was written, which may differ from what was meant. Individual judgment on the inspectors' part as to whether the intent of a rule is being met is discouraged to prevent the matter from ending up in court. Yet, inspection and enforcement staff rarely are asked to participate in the formulation of regulations, and thus have little contribution to their enforceability.

Second, there is general agreement that the current system of fining utilities for violations does not work, although the range of opinions about why it doesn't work is quite broad. The utilities contend that they are less inclined to identify safety concerns when they know that a fine is likely to follow. Further, they state that the present system of fines does not distinguish between a one-time simple human failure and continual inattention to problems or negligence. Utilities would prefer to see a system in which they could begin by informally negotiating solutions to safety concerns with NRC. If the problem is not remedied immediately, the Commission then could resort to fines and press releases. This procedure currently is followed by some NRC Regional Administrators.

Nuclear critics agree that the present system of fines is inadequate, but they cite different reasons. They point out that a large fine ($500,000) is equivalent to a single day's outage cost for a major utility and, in some cases, can be passed on to the ratepayers. They would like to see NRC change its enforcement policy to include the option of shutting down a plant or denying an OL and making it clear that those options will be invoked. The current perception that NRC does not enforce the regulations already in place does not bode well for convincing the critics or the industry that strong enforcement is a real threat. The recent ASLB action in denying an OL for the Byron plants may contribute to a change in the perception of NRC's willingness to enforce its regulations.

THE TWO-STEP LICENSING PROCESS

The current two-step licensing process (CP and OL) was instituted before the nuclear industry was fully mature. There were many first-time license applicants, designers, and constructors with unproven and incomplete design concepts; at that time, plant designs needed a final evaluation prior to operation. Now, reactor engineering may have matured to the point where final designs for most plants can be described at the CP stage. Therefore, the industry argues that a two-step licensing process no longer is necessary.

The utilities and the nuclear industry contend that the two-step procedure exacerbates construction scheduling problems because the plant design, regulatory design review, and hearings all occur during construction. They would like to change this to a one-step process that would place all three activities before construction begins. They believe this would improve the predictability and efficiency of the licensing process by making scheduling more certain. Also, an OL is perceived in many cases to be pro forma, but it still requires a full EIS and optional but usually requested hearings. * They suggest that a one-step procedure might encourage earlier identification and resolution of licensing issues while continuing to accommodate participation by interest groups and State and local governments.

There are two ways to achieve the equivalent of a one-step NRC licensing process: by combining the CP and OL, and by banking reactor designs and sites. The NRC and DOE legislative packages include proposals for both of these measures. it should be noted that neither the DOE nor the NRC bills is tied to the use of standardized designs, either in the provisions for combined CP/OLs or for design banking. However, in the following discussion of these proposals, it is assumed that plants will be much less customized, relying on only a few standardized and complete designs. An earlier OTA study, ***Nuclear Powerplant Standardization,*** found that standardization of designs and construction, operation, and licensing practices could alleviate many of the nuclear industry's difficulties in verifying the safety of individual plants. In addition, standardization could facilitate the transfer of safety lessons from one reactor to another and could help reduce the rate of cost and leadtime escalations (1 O). As discussed in detail in chapter 4, it is likely that any new plants would try to maximize these advantages by standardizing designs to the greatest extent possible.

***The ASLB refusal to authorize an OL for Commonwealth Edison Co.'s Bryon plants may indicate a change in approach at NRC. Even if the decision is overturned by the ALAB, it is unlikely that utilities will ever again consider the OL to be a formality.**

The NRC legislative proposal specifies that to get a COL, an application must contain "sufficient information to support the issuance of both the construction permit and the operating license. " The NRC staff analysis of the proposal interprets this to mean that the application must include an essentially complete design. Under the NRC bill, an optional hybrid hearing could be requested before the COL is issued and again before the plant goes into operation for matters that were not considered in the first hearing. The final review before a plant goes on line would end with NRC issuing an "operation authorization" that would be the regulatory equivalent of a license for purposes of inspection and judicial review (23).

This proposal would eliminate the duplication of detailed environmental and safety reviews that are currently needed for an OL; otherwise, it is the equivalent of the present two-step process with a new name. It is likely that hearings would still be held before construction and again before operation. Moreover, if the plant were a unique rather than standardized design, this procedure could take even more time than the current two-step process.

In the DOE legislative proposal, NRC would provide an expedited procedure for COL holders to start operation by allowing the licensee to certify safety when the plant is virtually complete. NRC would publish notice of the certification with a 30-day comment period, and the staff would have 45 days from the date of that notice to review the plant for safety, consider the public comments, and recommend action to NRC. There would then be an additional 30-day period in which NRC could take action to prohibit or limit operation if the certification was found to be incorrect. If NRC did not prohibit operation during that period, the plant could goon line. The only opportunity for public hearings would be at the issuance of the initial COL.

The COL proposal is controversial because of uncertainty about the level of design detail that would be required to obtain a combined license, since this is left up to NRC to specify through rulemaking. In addition, neither bill directs NRC to resolve all outstanding safety issues prior to licensing. Nuclear critics argue that the number of design changes still being made between a CP and an OL and the critical safety issues still being uncovered at the OL stage indicate that the industry and NRC are not yet ready for one-step licensing. Such a procedure could reduce attention to unresolved safety issues raised at the CP stage and could be used to restrict NRC's ability to order backfits. Regulators and critics especially object to the DOE bill because it allows the licensees themselves to certify safety, with a limited time for the NRC staff to verify that certification, and no real opportunities for citizen participation.

Some utilities are not convinced that a one-step process would be any more predictable than the current two-step process in terms of requirements for a license and backfits. Furthermore, it is possible that the proposed COL procedure, when coupled with hybrid hearings, would take longer than the current CP and OL process. Using procedural changes to improve the management of the hearings and implementing site- and design-banking, which together would serve as a surrogate for one-step licensing, probably would do more to increase the efficiency and predictability of licensing than a switch to a COL.

Current NRC regulations allow for design review prior to the filing of the CP application, but the results of the review are not binding upon the CP determination. Alternatively, reactor vendors can submit generic designs for approval through rulemaking. Many industry analysts argue that reactor engineering has matured sufficiently to allow proapproval of standardized plant designs, or of major system or subsystem designs, and both the NRC and the DOE bills include provisions for "design-banking." Debate continues, however, on the degree of specificity that should be required for proapproval of designs and whether such approval would act as a disincentive to the continued improvement of designs.

Under the NRC legislative proposal, a binding design approval valid for 10 years could be granted without reference to a particular site and could be renewed for 5 to 10 years unless NRC found that significant new safety information relevant to the design had become available. The public would have an opportunity to request hybrid hearings *on* the design before NRC granted approval. Issues related to the design could not be raised in a subsequent CP, OL, or COL hearings unless the combination of a design with a particular site resulted in new issues that had not been addressed in the design approval or there was convincing evidence that reconsideration of design issues was necessary.

The DOE bill also would allow utilities to choose a preapproved plant or major subsystem design as an alternative to selecting a unique plant design. Design approvals would be subject to hybrid hearings. Once approved, a design would be valid for 10 years and then could be renewed for 10 years but would be subject to the same backfitting requirements as normal plants under the DOE bill. Preapproved designs would be incorporated into a CP or COL application, and the review of design issues in the hearings would be strictly limited. The DOE bill would require NRC to define the level of detail necessary for design approvals through the normal rulemaking process.

Proapproval of standard designs might make a substantial contribution to a more efficient and predictable licensing process by removing most design questions from the licensing of a particular plant, but it is likely to be as controversial as the proposal for a COL. Issues include the degree of specificity required for design approval, the conditions and procedures under which the utility or its contractors could deviate from a preapproved design once construction has begun, and the ability of NRC to order backfits on approved designs.

Nuclear critics are concerned that discussion of new or previously unresolved safety issues would be foreclosed in the CP or COL hearings on preapproved standardized designs, especially in light of the provisions that prohibit the raising of generic safety issues in the licensing of particular plants and of the provisions that shift the burden of proof to the public to show that a preapproved design does not meet current safety standards. Proponents of this change argue that proapproval of designs could improve the effectiveness of public participation in that it would allow earlier and more detailed discussion of design issues in hearings without the time constraints imposed by the licensing of a particular plant.

The critics also object to the length of time for which a design approval would be valid, given the frequency with which design changes have been instituted in the past, and to the subsidy granted by deferral of the application fee until the design is used. Furthermore, there is concern that once a design has been approved, the vested interest in it would remove any incentives to improve it. However, as discussed in chapter 7, the industry argues that its need to remain competitive with foreign countries should be incentive enough.

In the present system, NRC approval of site suitability is not initiated until the CP application is docketed, which places site review on the "critical path" for reactor licensing. The existing NRC regulations permit review of site suitability prior to filing of the CP application, but the outcome of this review is not binding in the final CP decision unless a special ASLB decision is obtained. Both the NRC and the DOE legislative packages recommend a procedure for binding early site approval that would be independent of a CP application.

In the NRC legislative proposal, a site approval that does not reference a particular nuclear plant could be granted for up to 10 years, with renewal possible for 5 to 10 years. Federal, State, regional, and local agencies, as well as utilities could apply for site approvals, thus encouraging broader planning. In the NRC bill, a site approval would not preclude the use of the site for an alternative or modified type of energy facility or for any other purpose. However, other uses not considered in the original approval may invalidate the site permit, as determined by NRC. The public would have an opportunity to request hybrid hearings on the site approval, but issues related to the site would be excluded from further licensing proceedings unless matching the site with a particular plant design raised issues that were not considered at the time of the site approval.

The DOE proposal is similar to NRC's, except the site-approval procedure in the DOE bill would not allow alternative uses and would allow CP applicants to perform limited construction activities before issuance of a permit. A site approval would be valid for 10 years, with 10-year renewals. Under the DOE legislative proposal, the public could request hybrid hearings prior to NRC approval of a site.

As with design approvals, OTA concludes that site-banking could improve the efficiency and predictability of the licensing process by taking siting out of the critical path entirely. As long as the site-approval process allows adequate opportunity for public participation and ensures consideration of issues related to the combination of a particular site and design prior to issuance of a CP, binding early site approval should not be a controversial change. In fact, severing site approval from the CP could facilitate earlier and more substantive public participation. The principal objections nuclear critics have to these bills are the length of time for which approvals are valid (including renewals, 20 years in the NRC bill and an indefinite period in the DOE) and the subsidy introduced by deferring the application fee until the site actually is used or the approval expires. Furthermore, the selection of particular sites—whether they are matched with a plant or not—will remain controversial, as discussed in chapter 8.

OTHER NRC RESPONSIBILITIES

In licensing a nuclear powerplant, NRC is required to make several determinations that are not related directly to safety. These include certification of the need for power from the plant (required under NEPA) and of compliance with antitrust laws,

There is general agreement that NRC is poorly equipped to judge need for power on a local or regional basis, and therefore that it is a waste of staff resources to make such a determination. Moreover, at least 45 States already require other agencies to determine the need for power either in the certification or licensing of powerplants, in rate cases, in the approval of financing, or in an independent planning process (20). Furthermore, evaluations of the need for power and the choice of alternative types of generating technologies can take up hearing time and staff time that could be better spent in the analysis of safety and design issues.

Both the .NRC and the DOE legislative packages provide for binding NRC acceptance of a need for power determination made by a Federal, State or other agency authorized to do so. The NRC bill also provides for acceptance of other agencies' rulings on alternative sources of generating capacity. Only where no other agency is required to make such a determination would NRC perform a de novo review of the need for power. In both bills, these provisions are embedded within the section on a one-step licensing process, but they could be separated out. Because each agency is required under NEPA to make these determinations, legislative action would be required to delegate that authority to the States or other Federal agencies. it is possible that this provision would result in expanded opportunities for public participation in the discussions of the need for power and choice of technology. However, neither bill sets minimum standards for public participation in delegating this authority to the States, nor do the bills mandate consideration of the full range of alternatives, as required in NEPA.

Under current practice the Department of Justice performs a comprehensive review of license applications for compliance with antitrust laws. Although NRC weighs the opinion of the justice Department heavily in its determination, the Commission remains responsible for the final antitrust decision. As in need for power, it may not be appropriate for NRC to devote staff resources to antitrust law. One option is for NRC to adopt the Justice Department's decision on antitrust unless an affected party objects within a specified time after notice of the decision. If the objection is found to have merit, then NRC could remand to Justice for further consideration or do an independent review. Legislative action would be required to delegate this authority to the Justice Department.

The U.S. General Accounting Office (GAO) also has recommended that the NRC provide better coordination with State and local governments in NEPA reviews. At least 23 States have statutes requiring preconstruction environmental reviews similar to those required under NEPA, but NRC's NEPA regulations make no provision for coordination with the States or for eliminating duplication of efforts. GAO recommends NRC work jointly with all the States to identify common legal and procedural requirements as a first step in coordinating environmental reviews (2).

Finally, it has been suggested that introducing a little flexibility into the concept of exclusive Federal jurisdiction over reactor regulation would go a long way toward alleviating State and local concerns and improving public acceptance. For example, Oregon has a memorandum of understanding with NRC that sets forth "mutually agreeable principles of cooperation between the State and NRC in areas subject to the jurisdiction of the State or the NRC or both. " This memorandum is intended to minimize duplication of effort, avoid delays in decisionmaking, and ensure the exchange of information that is needed to make the most effective use of the resources of the State and NRC. To accomplish these ends, the memorandum provides for potential future subagreements in areas of mutual concern, including siting of nuclear facilities, water quality, nuclear plant operation, radiological and environmental monitoring, decommissioning of nuclear plants, emergency preparedness, personnel training and exchange, radioactive material transportation, and other areas. Subagreements adopted to date include a protective agreement for the exchange of information, and an agreement on resident inspectors at the Trojan plant, the only nuclear powerplant in Oregon (11).

SAFETY GOALS

One concept that has attracted much attention in discussions of backfitting and other changes in the NRC technical regulations is the use of safety goals* to establish safety requirements and gage the need for changes in those requirements.

NRC currently is developing a safety goal policy, and the DOE legislative proposal emphasizes the importance of this effort by endorsing the Commission's efforts. The DOE bill would require NRC to report to Congress within 1 year on its progress in developing and implementing a safety goal policy. The NRC proposal is described below.

NRC Safety Goal Proposal

NRC has issued a policy statement on safety goals for nuclear powerplants that is being used on an experimental basis (25). It currently plays no part in licensing decisions, and license applicants do not have to demonstrate compliance with it. If the proposed policy receives sufficiently favorable response, NRC will consider amending its regulations to include safety goals in licensing decisions.

In developing a safety goal policy, NRC considered qualitative goals that would interpret the Atomic Energy Act's standard of adequate protection of public health and safety, as well as quantitative goals that could provide a more exact standard against which risks could be measured. Qualitative goals were adopted to lend NRC safety decisions "a greater coherence and predictability than they presently appear to have," supported by numerical guidelines as goals or benchmarks (25). The NRC report notes that this approach allows it to capture the benefits of qualitative goals and quantitative guidelines in measuring performance while avoiding the vagueness of qualitative goals without numerical guidance. It does not lock NRC into quantitative goals that may not be able to yield technically supportable results given the uncertainties inherent in quantitative risk assessment.

The qualitative safety goals established in the NRC policy statement are:

> **Individual members of the public should be provided a level of protection from the consequences of nuclear powerplant accidents such that no individual bears a significant additional risk to life and health**
>
> **Societal risks to life and health from nuclear powerplant accidents should be as low as reasonably achievable and should be comparable to or less than the risks of generating electricity by viable competing technologies (25).**

The intent of the first safety goal is to require a level of safety such that individuals living or working near nuclear powerplants should be able to go about their daily lives without special concern by virtue of their proximity to such plants. The second safety goal limits the societal risks posed by reactor accidents and includes an implicit benefit-cost test for safety improvements to reduce such risks.

These goals focus on nuclear powerplant accidents that may release radioactive materials to the environment. They do not address risks from routine emissions, from other parts of the nuclear fuel cycle, from sabotage, or from diversion of nuclear material. The policy statement notes that the risks from routine emissions are addressed in current NRC practice through environmental impact assessments that include an evaluation of the radiological impacts of routine operation of the plant on the population around the plant site. For

***NRC defines a safety goal as "an explicit policy statement on safety philosophy and the role of safety-cost tradeoffs in the NRC safety decisions" (25).**

all plants licensed to operate, NRC has found that routine operations will have no measurable radiological impact on any member of the public. Therefore, the object of the experimental policy is to develop safety goals that limit to an acceptable level the additional potential radiological risk that might be imposed on the public as a result of accidents at nuclear powerplants.

In establishing the numerical guidelines to support these safety goals, NRC noted that progress in developing probabilistic risk assessment (PRA) techniques and in accumulating relevant data since the 1974 Reactor Safety Study (24) has led to recognition that it is feasible to begin to use quantitative assessments for limited purposes. However, because of the sizable uncertainties still present in the methods and the gaps in the data base–essential elements in gaging whether the guidelines have been met–NRC indicated that the quantitative guidelines should be viewed as goals or numerical benchmarks that are subject to revision as further improvements are made. Many of the participants in the Safety Goal Workshops held by NRC agreed that quantitative goals were not feasible at this time, but numerical guidelines could be used to support qualitative goals. Finally, in setting the numerical guidelines, NRC specified that no death attributable to a reactor accident ever will be "acceptable" in the sense that the Commission would regard it as a routine or permissible event. NRC intends that no such accidents occur but recognizes that the possibility cannot be eliminated entirely.

With these caveats, NRC established four experimental numerical guidelines: two for individual and societal mortality risks for prompt and delayed deaths; a benefit-cost guideline for use in decisions on safety improvements that would reduce those risks below the levels specified in accordance with the longstanding regulatory principle that risks from nuclear power should be "as low as reasonably achievable"; and a plant performance guideline that proposes a limitation on on the probability of a core melt as a provisional guideline for NRC staff use in reviewing and evaluating PRAs of nuclear powerplants. These guidelines are:

The risk to an individual or to the population in the vicinity of a nuclear powerplant site of prompt fatalities that might result from reactor accidents should not exceed 0.1 percent of the sum of prompt fatality risks resulting from other accidents to which members of the U.S population are generally exposed.

The risk to an individual or to the population in the area near a nuclear powerplant site of cancer fatalities that might result from reactor accidents should not exceed 0.1 percent of the sum of cancer fatality risks resulting from all other causes.

The benefit of an incremental reduction of risk below the numerical guidelines for societal mortality risks should be compared with the associated costs on the basis of $1 ,000/man-rem averted.

The likelihood of a nuclear reactor accident that results in a large-scale core melt should normally be less than 1 in 10,000 per year of reactor operation (25).

In its experimental safety goal proposal, NRC left open a number of questions for future consideration. These include: whether the benefit side of the tradeoffs should include the economic benefit of reducing the risk of economic loss due to plant damage and contamination outside the plant; whether a numerical guideline on availability of containment systems to mitigate the effects of a large-scale core melt should be added; and whether there should be a specific provision for risk aversion and, if so, what it should be. In addition, the proposal sought further guidance on developing a detailed approach to implementing the safety policy, including decision making under uncertainty; resolving possible conflicts among quantitative aspects of issues; the approach to be used for accident initiators that are difficult to quantify (e.g., seismic events, sabotage, human and design errors); the terms for definition of the numerical guidelines (e.g., median, mean, 90-percent confidence); and identifying the individuals to whom the numerical guidelines should be applied (e.g., the individual at greatest risk, the average risk).

Shifting from prescriptive regulation to a safety goal approach could have far-reaching consequences. Such a change might contribute to a more favorable regulatory environment for the nuclear utilities since the number and unpredictability of regulatory actions probably would be reduced. Furthermore, utilities would be allowed to select the least costly route to compliance, with resultant gains in efficiency. Another result of the safety goal approach might be to encourage diversity and innovation in developing alternatives for improving safety. Such activities, however, may not be consistent with the standardization of nuclear powerplants (4).

The proposed safety goals and numerical guidelines are not free of controversy. The proposed guidelines have been criticized as being "too remote from the nitty-gritty hardware decisions that have to be made every day by designers, builders, operators, and regulators to be of much use" (25). Most regulators and industry representatives agree that while, in principle, it would be nice to be able to use overall goals to supplant the myriad specific decisions NRC must make about the adequacy of hardware and procedures, they find the proposed goals too general and abstract to provide specific guidance for dealing with practical questions, and withhold judgment on whether they will prove useful. As one Commissioner noted, the only reliable guides to reactor safety remain time-tested engineering principles:

> redundant and diverse means of protection against core damage, sound containment, sufficient distance from populated areas, effective emergency preparedness, and, of course, careful attention to quality assurance in construction and operation. To provide guidance to the NRC technical staff and the nuclear industry, and to inform the public, the Commission should distill its experience and state clearly and succinctly that each of these [engineering] principles must be satisfied separately, and how this is to be done. Unfortunately the Commission seems to be on an opposite course (25).

The nuclear critics object more strongly to the safety goal proposal, arguing that to adopt goals with no viable means of confirming their achievement is a useless exercise. They do not believe there is any immediate prospect of PRA being developed sufficiently to provide a means of confirmation. Therefore, the critics argue that it is not feasible to use quantitative guidelines for limited purposes, and NRC only misleads the public in saying that PRA calculations will be used to support qualitative goals.

LICENSING FOR ALTERNATIVE REACTOR TYPES

Nuclear powerplant licensing experience in the United States, for the most part, is based on the LWR design concept. The exceptions are the Fort St. Vrain high-temperature gas-cooled reactor (HTGR), which achieved full power in 1981, and the Clinch River breeder reactor. Yet variations on the LWR and other reactor design concepts are attracting attention for their possible safety and reliability advantages over the LWR, as discussed in chapter 4. Given the extent of the licensing and regulation experience with LWRs, it is reasonable to question whether a shift to a different design would entail substantial changes in the regulatory process, such that the same problems encountered in the regulation of LWRs would be repeated with alternative reactors, and whether the development of a licensing process for such reactors would delay their implementation.

Small LWRs contributed greatly to the original development of commercial nuclear power in the United States. However, as operating experience grew, apparent economies of scale motivated utilities to purchase larger reactors. Today the norm is over 1,000 megawatts electric (MWe), but interest in smaller reactors is reemerging, primarily for financial and system flexibility reasons. A shift to smaller reactors could not be accomplished by replicating existing small plants because the designs of those plants do not meet all current safety requirements. NRC has established a systematic evaluation program specifically to review these older designs and improve their safety where possible. New small reactors would require new designs based on current NRC regulations, although such designs would not necessarily differ substantially from large LWRs except in the size of the core and other plant components. Thus the regulatory process probably would be similar to that for current large LWR designs, including the potential for backfits, unless small LWRs were standardized within the context of proapproval of designs.

The high temperature gas reactor has little operating experience in the United States. The primary safety concerns are quite different from the LWR and have not been studied as intensively. As a result, the potential for the emergence of significant unforeseen safety concerns probably is higher than for the LWR. On the other hand, inherent characteristics of HTGRs make them less susceptible to certain types of accidents that can progress more quickly or have more serious consequences in a LWR. This eventually may simplify the licensing process after any initial problems are resolved.

During the early 1970's, several utilities made CP applications for HTGRs. As a result, NRC made a significant effort to formalize design requirements and establish review plans for the HTGR. Nevertheless, several years would be required to make the regulatory process for this design as mature as that for LWRs. Backfitting requirements for the HTGR are uncertain but should be reduced through the operating experience of the Fort St. Vrain plant and the 900 MWe prototype that DOE is sponsoring.

The heavy water reactor, as represented by the well-proven Canadian CANDU design, has attractive safety and reliability features, but licensability is a major constraint on the adoption of this design by U.S. utilities. The NRC requirements for seismic protection and thicker pressure tube walls would require design changes in the CANDU that might reduce its efficiency and could lead to backfits until these changes were proven. NRC would have to establish new design criteria and standard review plans before a heavy water reactor could be licensed.

The Process Inherent Ultimate Safety (PIUS) reactor is the least developed of the alternative design concepts. It has readily visible safety advantages, but they might not be accounted for in the regulatory process until significant operating and construction experience is established. If PIUS is forced to include all the engineered safety features of the LWR, it is not likely to be competitive. Successful development of PIUS, therefore, depends on NRC determining what level of safety is appropriate and crediting the inherent safety features of PIUS during the design approval and licensing process.

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Chapter 7

Survival of the Nuclear Industry in the United States and Abroad

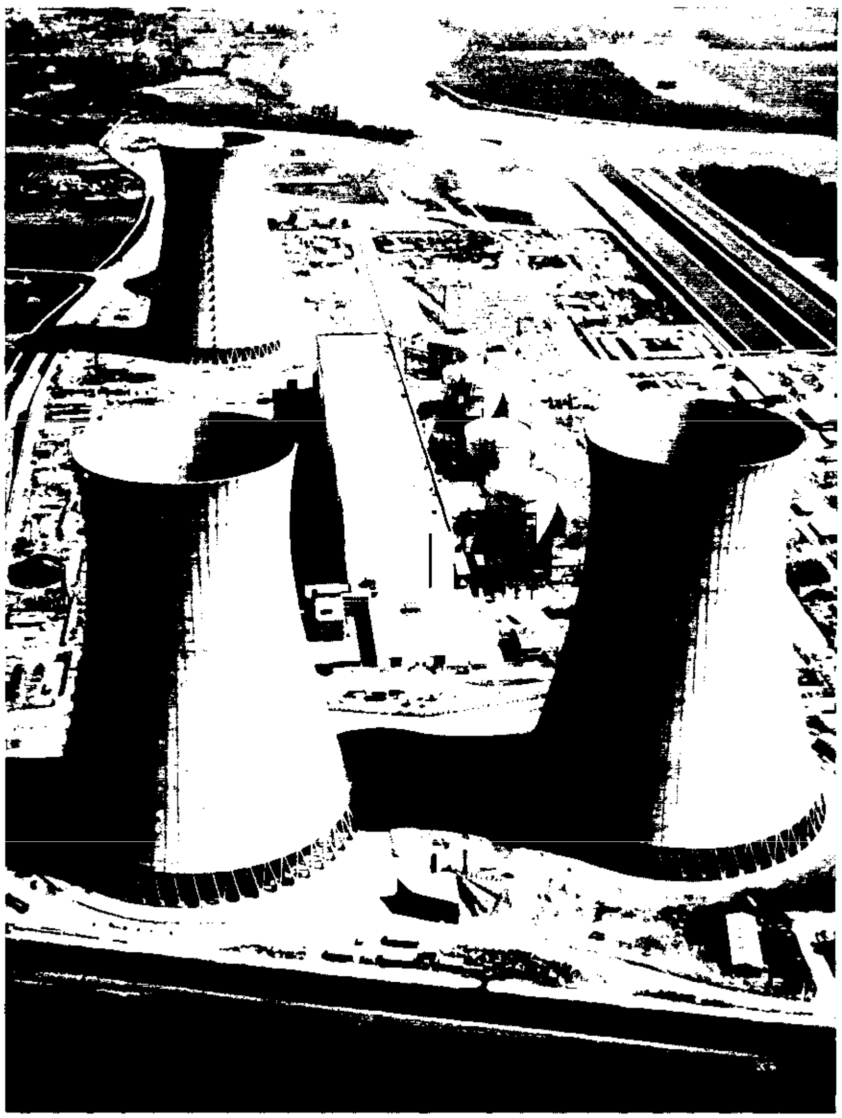

Photo credit: **Electricite** *de France*

Four nuclear units at Dampierre, France

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Chapter 7
Survival of the Nuclear Industry in the United States and Abroad

INTRODUCTION

Whether or not utility executives order more powerplants (given all the uncertainties and disincentives described in earlier chapters) has direct implications for the U.S. nuclear industry and its ability to remain viable as a source of nuclear powerplants both within the United States and abroad. This chapter examines the consequences for different parts of the U.S. industry of a long period with no orders for new plants or a period in which orders for new plants follow a long delay. The chapter then surveys the prospects for nuclear power abroad and the likelihood of U.S. exports as well as the possibility that the United States might be able to turn to foreign suppliers as future sources of the technology.

Although there are no strict parallels between the U.S. nuclear industry and that of any other country, there nonetheless is much to be learned from foreign experience. Many of the same problems faced by the U.S. industry are being faced elsewhere: public opposition to nuclear power, slow demand growth, and the difficulty of controlling cost and time overruns in nuclear plant construction. Understanding how these and other problems are being coped with in each country, provides some perspective on the U.S. situation and information on approaches that might be successful in the United States.

THE EFFECTS IN THE U.S. NUCLEAR INDUSTRY OF NO, FEW OR DELAYED NEW-PLANT ORDERS 1983 TO 1995

The nuclear industry may be portrayed as a monolith by its critics. In fact, however, it has always been a loose-knit group of several hundred businesses and organizations, given what cohesion it has by the demands of a difficult technology and the need to develop a coordinated response to critics. Today, the industry consists of the 59 public and private utilities that are the principal owners of nuclear powerplants in operation or under construction, 4 reactor manufacturers also known as nuclear steam supply systems (NSSS) vendors, 12 architect-engineering (AE) firms with a specialty in nuclear design and construction, about 400 firms in the United States and Canada qualified to supply nuclear components, and several hundred nuclear service contractors. Table 23 shows the combinations of reactor manufacturers and AE firms for plants under construction or on order as of the spring of 1981.

Of about 90,000 employees of the nuclear industry, about half operate and maintain commercial power reactors (as well as some test and research reactors), a quarter are engaged in reactor and reactor component manufacturing, and a quarter are engaged in design and engineering of nuclear facilities (other than design associated with reactor manufacture) (4).

Companies and organizations in each of these sectors must develop strategies for coping with the likelihood of no new orders for nuclear plants for 3 to 5 years and the possibility of no or very few orders for 5 or more years after that. In a comprehensive study for the U.S. Department of Energy (DOE), the S. M. Stoner Corp. (37) assessed the impact on NSSS vendors and component suppliers of three possible futures:

- a slowly increasing projection of: no orders until 1986, an average of two to three a year

Table 23.—NSSS/AE Combination of Light Water Reactors Under Construction or On Order As of 1981

	Reactor vendors			
Architect/ engineering firms	Westinghouse	General Electric	Combustion Engineering	Babcock & Wilcox
Bechtel	6	10	6	5
Burns & Roe	—	1	1	—
Black & Veatch	—	2	—	—
Brown & Root	2	—	—	—
Ebasco	4	1	4	—
Gilbert/Commonwealth	1	2	—	—
Gibbs & Hill	2	—	—	—
Gilbert Associates	—	—	—	—
Utility Owner	7	—	6	—
Fluor Power Services	—	—	—	—
Sargent & Lundy	8	7	—	—
Stone & Webster	5	6	2	2
United Engineers	2	—	—	2
Tennessee Valley Authority	3	6	2	2

SOURCE *Nuclear Powerplant Standardization* Light Water Reactors (Washington, D.C. U.S. Congress, Office of Technology Assessment, OTA-E-134, April 1981)

until 1989, and six to eight orders a year after that;

- no orders until the early 1990's; and
- no orders until 1988 or 1989 and an average of one a year for 5 years after that.

The findings of the Stoner study are echoed in the results of 35 interviews conducted by OTA with representatives of reactor vendors, nuclear suppliers, AE firms, utilities with nuclear plants, and industry analysts and regulators. Further insights are available from several assessments of personnel needs for the industry **(4,9,16,18).**

Reactor Vendors

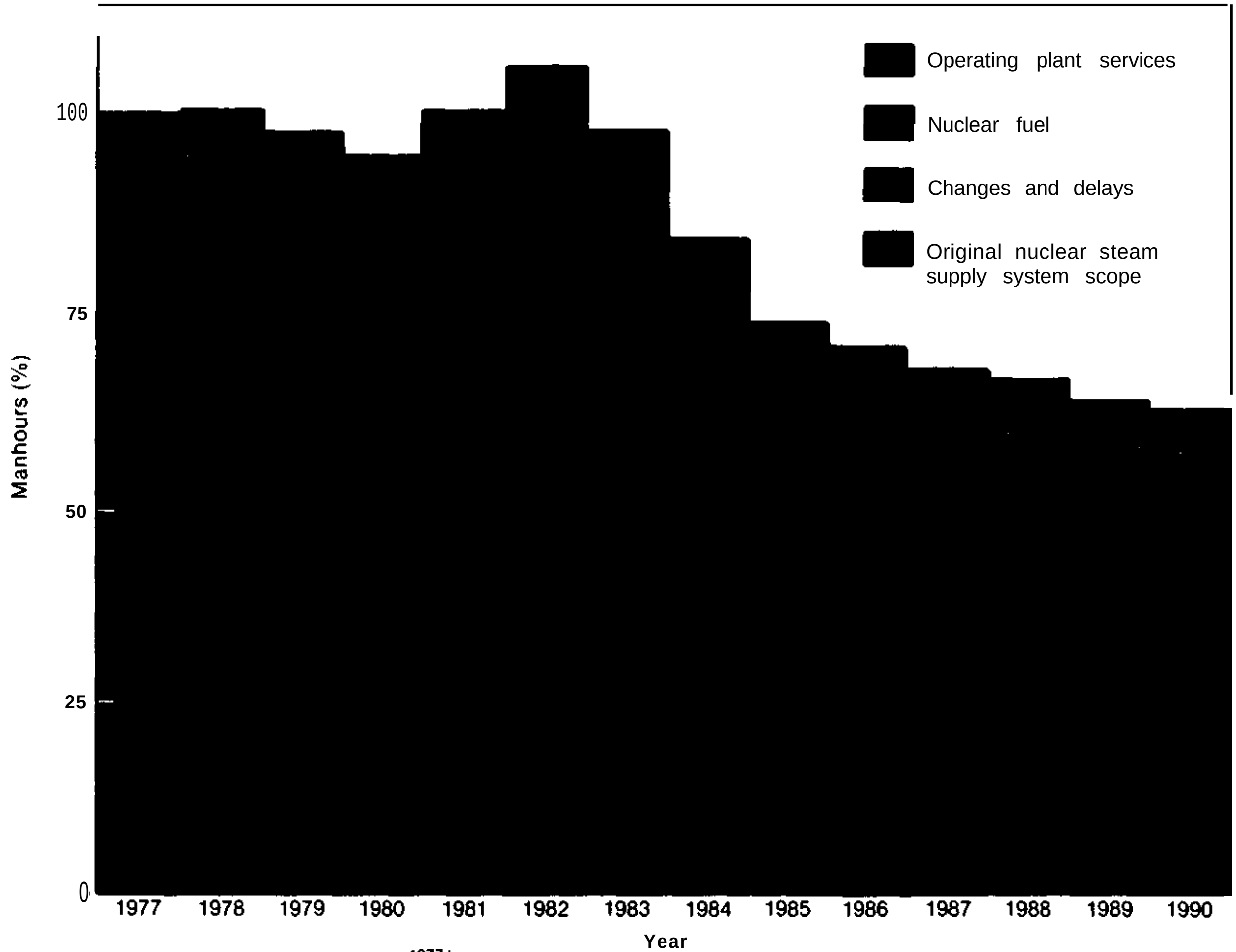
No new nuclear reactors are now being built. The nuclear business for the four reactor vendors currently consists of assembling at site, fuel loading and services, and the latter two will continue regardless of what happens to new orders. Figure 34 shows one vendor's prediction of the need for engineering manpower through the 1980's. Engineers will be needed for services to operating plants and fuel loading. Manpower to handle changes in existing plants, and rework in plants under construction, will initially increase but then diminish. The need for engineering manpower to design new NSSS will practically disappear.

Refueling, which occurs in each plant approximately every 18 months, is a demanding task requiring sophisticated skills and a sound knowledge of nuclear physics. Used fuel rods are removed and new fuel rods are inserted among partially used fuel rods, and the array of both fresh and older fuel rods is then reconfigured to provide maximum nuclear energy. Vendors expect also that spent fuel management will also be a continuing source of business.

Vendors are now competing for the nuclear service business in an arena once dominated by the nuclear service consultants. The Stoner report estimates further that backfits and rework may require 30 to 50 man-years of contracted engineering work per operating plant with a total demand of 3,000 to 6,000 technical people per year. (37) The vendors are uncertain, however, if the current level of backfits, stimulated largely by requirements following the Three Mile Island accident, will continue beyond the next few years, and, at the same time realize that over the long run the continued cost of backfits will discourage new orders.

The only current new plant design activities are joint ventures by both GE and Westinghouse with Japanese companies. The Westinghouse project is being aimed at both the domestic and export markets and is being developed in consultation with the Nuclear Regulatory Commission (NRC). (See ch. 4.) The GE project is being developed for Japan only and not for future U.S. licensing.

Figure 34.-Engineering Manpower



[a]As estimated by one NSSS supplier, (Base year is 1977.)

SOURCE A *Study of the Adequacy of Personnel for the U S Nuclear Program* (Washington, D C.: Department of Energy, November 1981)

Both companies hope that an export market will sustain some of their design and manufacturing capability. The likely export market (described later in this chapter), however, has shrunk to only a fraction of what was projected 5 years ago and is currently substantially less than what can fully use worldwide manufacturing and design capability.

For U.S. companies to compete successfully requires not only continued technical success (as is being attempted in these joint ventures) but also possible modifications in U.S. export financing and nonproliferation policies (25). There is evidence that some orders have already been lost because U.S. vendors are losing their reputation for up-to-date technology. As a Finnish source told ***Nucleonics Week:*** "Why should Westinghouse put in millions (of dollars) for R&D if they don't have business prospects. That is one reason why we are not studying their (U. S.) reactors in a [plant-purchase] feasibility study" (29).

Moreover, future export orders are likely to involve reduced U.S. manufacturing demand since many of the countries most likely to pursue nuclear programs have nuclear import policies designed to promote domestic industries. Other ad-

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vanced countries with nuclear programs, especially Japan, are also likely to bid successfully for component manufacturing business (25,37).

The current backlog of NSSS manufacturing work is scheduled for completion in 1984. All U.S. vendors have taken steps to close or mothball many of their manufacturing facilities, or to convert them for other uses. It has been estimated that announced facilities closings and consolidations have already reduced by two-thirds the U.S. capacity to supply nuclear powerplants. Some vendors are maintaining their technical capability with nuclear work for the U.S. Navy, DOE, or research and development (R&D) sponsored by the Electric Power Research Institute (EPRI) (37).

Vendors are already feeling the effects of a shrinkage in nuclear component suppliers on which they base future standardized NSSS designs. Currently, each vendor purchases components from about 200 qualified nuclear suppliers. Several vendors estimate that the number of suppliers will drop by two-thirds in 3 tos years, leaving the vendors dealing with a much higher proportion of sole source suppliers (37). Vendors faced with this situation are considering various responses, such as manufacturing their own components, encouraging less qualified suppliers to upgrade their products and get them certified, and developing new sources of foreign supply.

Nuclear Component Suppliers

The impact of the shrinkage in new orders is most dramatic on component suppliers. Some companies supply components used both for new plants and for backfit and spare parts for plants in operation. These companies expect to keep their businesses going. Many companies, however, supply only components for new plants. Some of these produce nuclear components that are identical or very similar to non-nuclear components except for quality-control documentation. These companies can be expected to maintain their nuclear supply lines. Others, however, produce very specialized nuclear components that require separate testing and manufacturing facilities. Many of these facilities are now closed or mothballed (37).

At present the number of component suppliers appears to be declining slowly. One clear sign is the decision by suppliers not to renew the "N-stamp," a certificate issued by the American Society of Mechanical Engineers (ASME) for the manufacturer of nuclear plant components. N-stamps are not specifically required by the NRC for the manufacture of safety-related nuclear-plant components. However, they are required by some States, and their use certifies that certain NRC quality-assurance requirements have been met.

The number of domestic firms holding N-stamps has dropped by about 15 to 20 percent since 1979, the year of the accident at Three Mile Island, and the drop would probably be greater if the renewal were annual instead of triennial **(21). By contrast, foreign N-stamp registration has held steady. By** the end of 1982, some 400 companies in the United States and Canada held about 900 N-stamps, according to ASME. An additional 50 companies held about 100 certificates for Q-system accreditation on nuclear-grade materials. Overseas, about 70 companies held about 100 N-stamps, and about 20 companies held about so Q-system certificates (21).

Maintaining an N-stamp requires both personnel and money. Thus, in the absence of new nuclear business, many smaller companies have decided they cannot justify the costs. In addition to the $5,000 to $10,000 that must be spent for ASME certification (renewable at the same cost every 3 years), there is also the need to dedicate part of the plant and at least one or two employees to the intricate paperwork that accompanies each N-stamp component. In total, cost estimates for maintaining a stamp range from $25,000 to $150,000 a year (21). Suppliers say that no other work, including contracts for the National Aeronautics and Space Administration (NASA) and the U.S. Navy nuclear program, requires such a detailed paper trail. "1 make a valve that sells for about $300" one supplier said. "If it has an N-stamp I have to charge $4,000 for the same valve. And with low volume, I suppose I should charge even more" (21).

So far, the reduction in N-stamps has not been as rapid as the lack of new orders might suggest. Part of the reason may be a habit of looking to the future that has been characteristic of the nuclear industry since the beginning. Some suppliers evidently believe that the N-stamp imparts a certain status to a nuclear supplier's operations, and those who must consider letting their certification expire say they would do so reluctantly. "It's a nice marketing tool," one supplier said, "even when you're selling non-nuclear items. And it's good discipline for a company to have it" (21). Some suppliers and utilities report that they must persuade their subcontractors to keep the stamp. "We're giving companies [with N-stamps] our nonnuclear business, just to help them along, " one utility executive said. Another challenge is to prevent market entry by foreign companies. "If equipment from overseas becomes standard," one supplier said, "we'll never get that business back" (21).

For many suppliers it will be almost impossible to obtain nuclear qualification for new product lines. For some product lines, 1 to 5 years would be needed to carry out the necessary tests. Maintaining an older nuclear-qualified product line alongside a newer nonnuclear product line will be difficult for those suppliers with a preponderance of nonnuclear business. Since nonnuclear business is likely to respond more quickly to an increase in general business investment of the recession than is nuclear business, there may be pressure to drop the nuclear product lines. The existence of nuclear components in 35 gigawatts (GW)* of partially completed but canceled nuclear plants is viewed as a further damper on the nuclear component business even though only some of this equipment is expected to be sufficiently maintained and documented enough to be usable (see advertisement). For all these reasons, there may be a far more rapid decrease in suppliers over the next 3 to 5 years than over the past 3 years, possibly down to a third of the present number (37).

Architect= Engineering Firms

AE firms have substantial work for the next few years finishing the plants under construction, installing backfits and dealing with special problems such as steam generators. One promising concept for interim survival involves "recommissioning" nuclear stations—installing some new components to extend their operating lives by 10 to 20 years. Like the reactor vendors, AE firms complain of reduced sources of supply for nuclear-grade components and materials. And, like the reactor vendors, they are moving outside their specialties to bid on nuclear services (e. g., emergency planning) and rework proposals.

Most AE firms also have large amounts of business stemming from major construction projects other than nuclear: cogeneration, geothermal, and coal technologies; petrochemical plants; industrial process heat applications; and conventional fossil powerplants. During the 1981-83 recession, business in these areas was no more robust than the firms' nuclear work. One AE executive said, "As it is now, we can't move our nuclear people to nonnuclear projects just to keep them in-house. There isn't much nonnuclear work around either" (21). Several firms reported they expected their nonnuclear work to pick up long before their nuclear work (21).

Much of the project management and construction skills used on other types of large construction projects are also required for nuclear projects. These skills will be available as long as the AE firms have experience in major construction projects. The design and project management skills unique to nuclear projects area small proportion of the total work force.

Some firms are taking losses to keep their skilled nuclear people employed because they estimate that retraining would ultimately cost more. Architects are working as draftsmen, for example, and skilled machinists are cutting and stacking sheet metal. Layoffs have not been necessary, one AE executive said, because employees are retiring early or quitting to move to fields with more growth potential and less regulation, such as military R&D (21).

The Impact on Nuclear Plant Operation

The halt in nuclear plant orders and uncertain prospects for new orders have had discernible

*One GW = 1 GWe = 1,000 MWe (1 ,000,000 kWe) or slightly less than the typical large nuclear powerplant of 1,100 to 1,300 MW.

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Photo credit: Engineering News Record

Advertisement for nuclear component auction appearing in *Engineering News Record,* Feb. 21, 1983 effects on the utilities' experience in keeping their existing nuclear plants staffed and maintained. The effects are most noticeable in two areas: obtaining component parts and services, and filling certain key jobs.

Component Costs and Delays. -With the decrease in nuclear component suppliers described above, utilities report an increase in the number of sole source suppliers and a resulting upward pressure on prices. One utility reported that sole source suppliers received 40 to 50 percent of 1982 contract dollars. A more typical range reported by utilities was 25 to 30 percent, an increase from 15 to 20 percent a decade ago (21).

In a few cases, utilities report that prices of services and components are falling because of increased competition. Generally, however, prices are expected to rise partly because of lack of competitive pressures on the increased number of sole source suppliers and partly because the fixed cost of nuclear quality assurance must be spread over dwindling sales.

Delays are also expected to be more of a problem for similar reasons. With less nuclear work to do, suppliers are more likely to arrange production schedules to use qualified craftsmen and their 'special machinery only when a number of orders are in hand, postponing work on some projects for months. Or they could require premiums for deadlines that are more convenient for the utilities. "He'd get the part for you, when you wanted it," one utility executive said of a supplier, "but you'd have to pay for a whole shift to go on overtime" (21). Suppliers report that utilities are placing more "unpriced" orders, for which the supplier alone sets the costs, and choosing other than the lowest bid to get the schedule and quality they need **(21).**

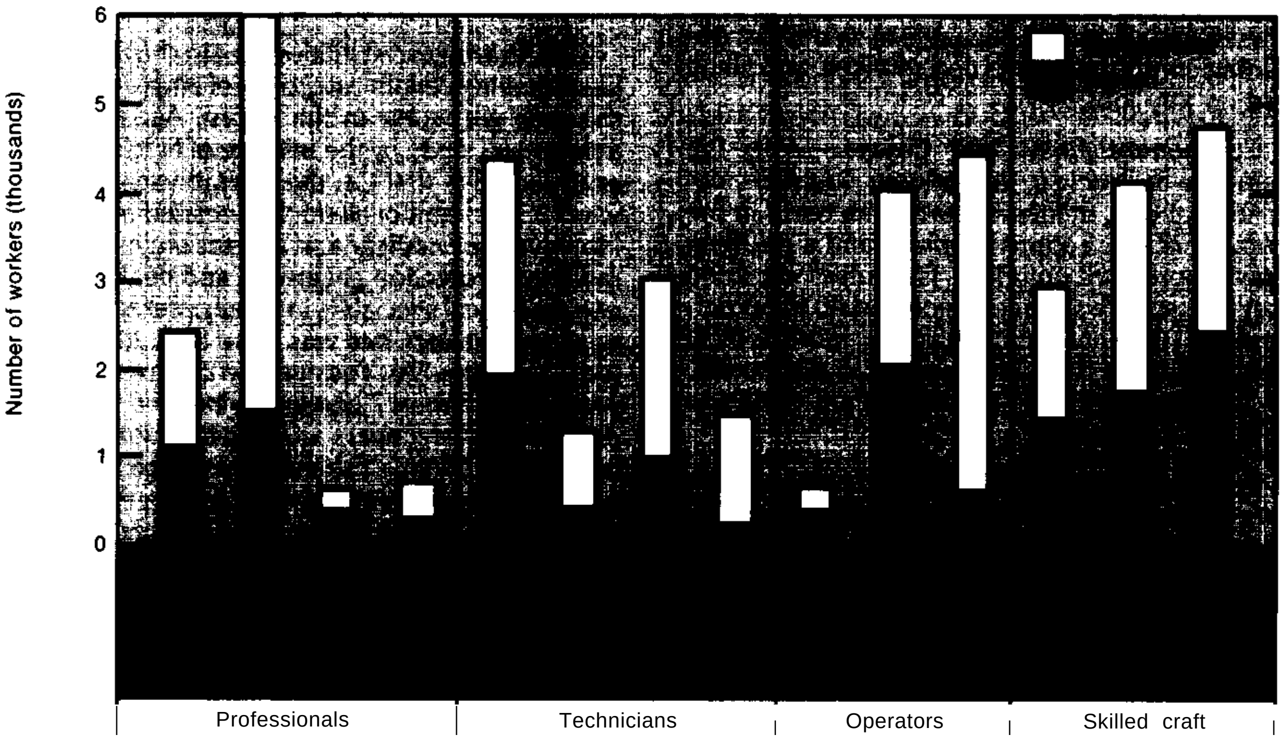
In addition to possible increased prices and delays, utilities are also experiencing some greater confusion in the bidding process for rework and nuclear services as more and more firms attempt to diversify in the face of falling profits. "Anything in an RFP [request for proposal], that's at all related to our business, we'll bid on it," one nuclear consultant said. "We've got to try for anything out there, just to survive" (2]).

Skill Shortages.– Utilities are also having trouble recruiting certain categories of employees and this may get worse in the future. According to a personnel study by the Institute of Nuclear Power Operations (INPO), the overall vacancy rate was 12.5 percent of all nuclear-related positions. However, for nuclear and reactor engineers, for radiation protection engineers, and health physicists (technical specialists in health effects of radiation), the vacancy rate was more than 20 percent (see app. table 7A). The average turnover rate for engineers is almost 7 percent a year, and, for most categories of engineers, quitting their jobs in utilities means leaving the industry altogether (16). For the nuclear utilities as a group, an estimated 6,000 additional engineers will be needed between now and 1991. Almost 5,000 of these will be needed to replace those that leave the industry (see fig. 35). About 3,000 technical level health physicists will be needed, about 2,000 of these for replacement **(18).**

Despite the availability of ample jobs for nuclear specialists, degrees and enrollment in nuclear-related fields are stable or declining (see fig. 36 for nuclear engineering degrees). There is some evidence that students are being discouraged from enrolling in programs leading to employment in nuclear power by a perception that the industry is declining and by parental concern and some peer pressure against nuclear power careers. A recent DOE study of personnel for the nuclear industry contrasted steadily increasing enrollment in medical radiation physics programs with declining enrollments in technically similar health physics and radiobiology programs aimed at work in the field of nuclear electricity generation (9).

INPO which has developed demanding training requirements for utility personnel has also taken some modest steps to help with recruiting by setting up a fund for graduate nuclear training (see ch. 5). Individual utilities have also taken steps to fund nuclear programs at local community colleges. More, however, may be needed if

Figure 35.–Estimates of Additional Manpower Requirements for the Nuclear Power Industry, 1982-91



SOURCE: Ruth C. Johnson, *Manpower Requirements in the Nuclear Power Industry, 1982-91,* **September 1982, ORAU-205.**

current turnover and recruiting trends continue, or worsen.

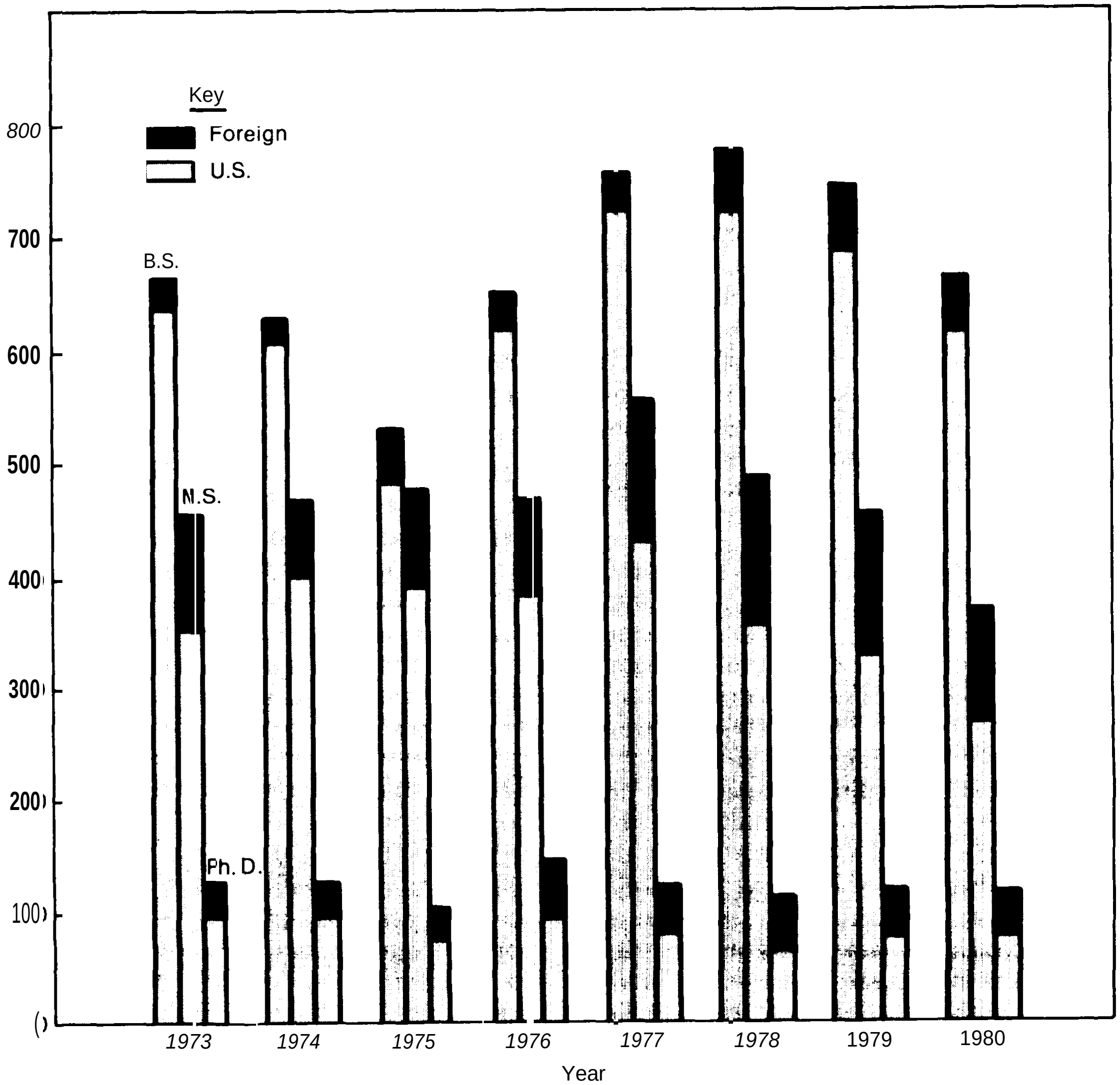
The Impact on Future New Construction of Nuclear Plants

There are several ironies in the current situation of much of the nuclear industry. Many companies are sustaining themselves on backfits and rework, which over time increases the cost of nuclear power to utilities and consumers alike and makes it less likely that utilities will place orders soon for more nuclear powerplants. Some companies are maintaining their nuclear business because the rest of their business has not yet been affected by the improvement in the economy. As business investment picks up, the rate of companies leaving the nuclear business may accelerate. The recovery is likely to create work and jobs in most other industries before utilities see their reserve margins shrinking and begin ordering again (see ch. 3). As one supplier said, "If the economy revives, I'm not sure I can wait around for the nuclear contracts to roll in. I maybe doing something else in the meantime" (21).

Some effects of a hiatus in new plant orders are inevitable even if the optimistic projection of nuclear orders after 3 to 5 years occurs. There are likely to be fewer reactor manufacturers (two or three rather than four) and some initial delays for vendors in securing all the necessary suppliers and encouraging their renewal of N-stamps. Even under this optimistic projection, foreign sources would probably be used for some specific areas of supply.

Component suppliers estimate a delay of 1 or 2 years in obtaining N-stamp qualifications and additional delays once they are operating because of unfamiliarity with support services. "Right now," one said, "my people know just who to call for an interpretation of the regulations. They know which seismic stress labs are the best. If we had to start over [several years hence], a question that takes an afternoon on the phone to answer today would take three to four months to answer" (21).

Figure 36.—Nuclear Engineer Degrees: Foreign Nationals and U.S. Citizens



SOURCE: *A Study of the Adequacy of Personnel for the* U.S. *Nuclear Industry* (Washington, D. C.: Department of Energy, November 1981).

Despite these difficulties, it is probable that even after a hiatus, a realistic 8-year project schedule (under conditions assuming no hiatus) would be delayed only about a year, and perhaps less, if utilities were to freely allow overseas purchasing. If utilities insisted on U.S. sources for all or most components, the delay could be longer (37).

With a hiatus of 10 years or longer, there will be a much bigger problem in new plant construction. Unless there have been at least some overseas orders, the reactor vendors are likely to provide designs for initial plants that were developed overseas in joint ventures with foreign countries, perhaps even as licensees of foreign companies (37). With a longer passage of time, there will be more critical areas with no qualified U.S. supplier and more dependence on overseas component suppliers. Since licensing and quality-control requirements for foreign nuclear programs are quite different it could prove time-consuming and difficult to obtain nuclear qualification and licensing for the design and components of the initial plant (37). Under these circumstances it is unlikely that there would be more than two U.S. vendors. It is also conceivable that foreign companies might bid directly for the design and supply of the initial units (37).

After a period of 10 years or more without nuclear plant construction some skills would still be available from other industries. Control and instrumentation designers and workers would probably be available from the electronics and aerospace industries. Construction contractors expect that semiskilled construction and maintenance workers would also be available. Of the construction skills, a shortage of welders with nuclear certification might pose the greatest staffing problem. But one AE executive said that the biggest difficulty "would be administrative;" learning again to control "the thousands of decisions and tasks" needed to construct and test a nuclear plant (21).

Still another possibility, a very low volume of orders beginning in the late 1980's, is the situation most likely to encourage evolution in the nuclear industry structure to permit the necessary economies of scale in design and construction management experience (37). In this situation, it is likely that utilities or others will form regional or national nuclear generating companies to obtain the economics of scale from multi-unit sites and standardized construction. This is also the situation that is likely to encourage "turnkey" construction, a practice used for the earliest plants constructed in the late ı %0's and still used for some exports of nuclear plants (e.g., a plant being constructed by Westinghouse in the Philippines). In turnkey construction, a company or consortium, often headed by an NSSS vendor, offers to construct and warranty an entire nuclear island, * or even a complete nuclear plant, for a fixed price, ready for the operating utility to "turn the key" and operate the plant. Such fixed-price agreements may be the only way for vendors to convince utilities that their costs for nuclear power are predictable. It is quite possible that foreign vendors might offer turnkey plants in the United States. It is perhaps more likely that U.S. vendors may attempt to form consortia with foreign designers and component suppliers to offer turnkey plants.

Conclusion.–As of 1983 the nuclear industry is still intact although somewhat reduced from 3 to 4 years ago. The industry probably would survive a short hiatus of 3 to 5 years in new orders with only some increase in costs and delays in obtaining some components from U.S. sources and perhaps little or no increase in costs and delays if foreign component sources are used.

Predicting the consequences of a hiatus of 10 years or more is more difficult but it is **unlikely** to mean the end of the nuclear option in the United States. If vigorous, economical, and safe nuclear programs survive in several foreign countries, they are likely to provide designs and some components for the initial plants of a new round of nuclear construction if one occurs. (The survival of foreign nuclear programs is the subject of the next section of this chapter.) Many U.S. businesses would still supply nuclear components because they supply very similar nonnuclear components. Many others probably would get recertified to supply nuclear components. U.S. vendors of NSSS will still have large nuclear service and fuel-loading businesses and probably some foreign nuclear work as well. They are likely to be active in any consortia or joint ventures involving foreign sales of nuclear powerplants in the United States.

Under some circumstances, AE firms could end up with less nuclear business after a long hiatus, depending on what restructuring might occur in the industry. A shift to turnkey construction of entire plants or the formation of a few generating companies with their own design and construction management staffs would sharply reduce the role of the architect-engineer. The number of utilities directly involved in nuclear construction would also be drastically reduced under such circumstances.

***Nuclear island refers to all the equipment that directly or indirectly affects the safety of nuclear operations. In addition to the reactor vessel itself and the primary cooling system it usually includes the secondary cooling system and the steam generators (in a pressurized water reactor).**

THE PROSPECTS FOR NUCLEAR POWER OUTSIDE THE UNITED STATES

Many of the problems that have threatened the nuclear power industry in the United States have also weakened nuclear power prospects abroad. However, a few countries–with somewhat different institutional structures for producing electricity and stronger motivation to avoid dependence on energy imports-may be able to nurture their nuclear industries to survive the 1980's in stronger condition than the U.S. industry. This section surveys the highlights of the foreign nuclear experience–economic, technical, and political–and points out a few aspects of foreign experience that provide a perspective on U.S. experience. The section also assesses the likely competitive situation of the U.S. industry vis a vis its competitors abroad.

The Economic Context for Nuclear Power

Worldwide forecasts of the future role of nuclear power have experienced the same boom and bust cycles as have U.S. forecasts. In 1975, OECD* countries forecast a total of 2,079 GW of nuclear power by the year 2000. As of 1982 the OECD countries forecast for the same year had fallen by 75 percent, to only 455 GW of nuclear power (table 24). The reasons for this drastic reduction in expected nuclear capacity are familiar to anyone acquainted with the U.S. nuclear industry: slower-than-expected electricity demand growth, high interest rates that increased the cost of capital for nuclear powerplants and stronger-than-expected public opposition in many countries.

Just as in the United States, the rate of growth of electricity demand slowed from the 1960's to the 1970's in France, West Germany, and the United Kingdom (except for demand from French households) (10) (see fig. 37).

Given the slower-than-expected growth rates in electricity demand, many countries are now lowering their forecast growth rates for 1990 and 2000 and finding themselves with adequate generating capacity, West Germany expects to need new powerplants only if oil and gas capacity is to be replaced (24). A Government commission in France estimated that completion of the present construction program should provide most of the electricity forecast to be needed before 2000. As of mid-1983, the Government had not

*OECD means Organization for Economic Cooperation and Development, a Paris-based organization of industrialized countries.

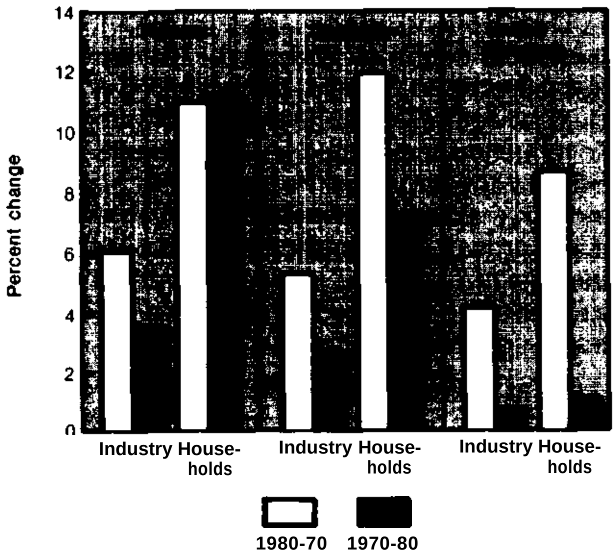
Table 24.–Forecasts of Installed Nuclear Capacity in OECD Countries (GW)

Regions and countries	Forecasts for the year 2000: OECD, 1975	INFCE, 1980[a]	OECD, 1982[a]	Nuclear capacity installed: 1980	1990[b]	Installed public generating capacity of all types: 1979[c]
Western Europe:	798	341	214	43.8	126.6	371
France	170	96	86	16.1	56.0	47
Germany.	134	63	34	8.6	23.5	66
United Kingdom.	115	33	31	6.5	11.1	69
North America:	**1,115**	**384**	**173**	**60.2**	**131.2**	**671**
Canada	115	59	22	5.2	15.0	72
United States	1,000	325	151	55.0	116.2	599
West **Pacific:**	**166**	**130**	**68**	**15.8**	**28.0**	**153**
Japan	157	130	68	15.8	28.0	126
Australia/New Zealand . . .	9	0	0	0.0	0.0	27
OECD total	2,079	855	455	119.8	285.8	1,195

[a]Figures are the averages of high and low estimates.
[b]Capacity installed or due to be commissioned by Jan 1, 1990 Source SPRU turbine generator data bank
[c]Source: United Nat Ions, 1981.

SOURCE Mans Lonnroth, "Nuclear Energy in Western Europe," a paper for the East-West Center, Honolulu Conference on Nuclear Electric Power in the Asia Pacific Region, January 1983.

Figure 37.–Average Annual increase in Electricity Demand: France, West Germany, and United Kingdom



SOURCE: OECD.

yet accepted the report because of the drastic implications for the future of the nuclear power industry.

Other conditions, familiar to observers of the U.S. nuclear industry, were described by Mans Lonnroth, and William Walker in a 1979 paper, ***The Viability of the Civil Nuclear Industry (26).*** Although the rapid increases in oil prices after 1973 made nuclear power appear relatively less expensive over the long run, it made it harder to finance in the short run because the resulting high rates of inflation increased interest rates. In those countries where the government approves electricity rates it became harder to get political support for rate increases to compensate for inflation. Inflation and the several recessions of the decade also put pressure on governments providing financing to electric utilities to restrict the extent of their support ***(26).***

Public Acceptance

In most European countries and some other countries, there has been considerable public opposition to nuclear power. This sometimes arises from specific concerns about plant siting, design and management, and sometimes from much broader philosophical concerns about the future direction of a society based on high technology which requires extensive central control (24,30).

In a few countries, public opposition to nuclear power has become directly involved in political and administrative decisions that affect the growth of nuclear power. The most dramatic of these is Sweden. in a referendum held in March 1980, 57 percent of the public voted that 3 plants under construction should be completed but the total of 12 reactors then in existence should be operated only until economical means are found to replace them and should not be replaced with more nuclear powerplants if there is any feasible alternative. Parliament subsequently adopted this position as official Government policy. A similar referendum, which halted nuclear power-

Photo credit: OTA Staff

In West Germany, construction of nuclear plants has been stopped in the courts while in France the more centralized decision-making system has kept nuclear construction going without **delays,** despite public opposition.

plant construction in Austria, was passed following a period of widely publicized debates among nuclear experts. In West Germany, citizens can sue in State courts to stop the construction of powerplants. Four plants were stopped in the mid-1970's and brought nuclear construction in Germany to a virtual halt. Subsequent extensive Parliamentary Commissions have recommended caution but not a halt. In the United Kingdom, a public inquiry was conducted throughout 1983 to consider the general adoption of a modified Westinghouse light water reactor (LWR) design. (This is the Sizewell B design, discussed in ch. 4.) This technology would be in addition to the existing series of advanced gas-cooled reactors that until now have formed the basis of the United Kingdom's nuclear technology.

In France, there have been infrequent Parliamentary discussions of policy with respect to nuclear power; otherwise decision making has been treated as a technical and administrative rather than a political matter (31). Public opposition has been expressed in anti-nuclear demonstrations, in demonstrations at particular sites, and in the formation of ecology parties which have challenged candidates in local and regional elections. None has had any substantial impact on the French nuclear program. In part, this appears to be because public opinion surveys have shown increasing support for nuclear power (36).

Foreign Technical Experience: Plant Construction and Reliability

Many foreign countries have experienced delays in building nuclear powerplants similar to those experienced in the United States, but some have built all their plants as fast or faster than any U.S. plant (see table 25). In France, the slowest plants have taken 7 or 8 years from reactor order to commercial operation, while the fastest plants take 5 to 6 years (14). In Japan, slower plants have taken 9 or 10 years while faster plants have also been built in 5 or 6 years. In Japan most of the delay occurs at the site-approval stage, prior to the start of construction. For the other countries with at least several nuclear plants the fastest construction times are comparable (6 to 8 years) with the fastest construction schedules in the United States.

Typical nuclear plants in several foreign countries can also be constructed more cheaply than typical U.S. plants. Based on information obtained in an NRC survey of foreign licensing practices, U.S. costs are comparable with those of Sweden and West Germany but about 30 percent higher than in Japan and about 80 percent higher than in France (38). *In* France, a nuclear plant can be constructed for about half the man-hours/kW required for a nuclear plant in the United States. The other three countries use about 30 percent fewer man-hours/kW than in the United States (fig. 38). Most of the savings occurs in two categories: the nuclear increment over man-hours needed for constructing a non-nuclear powerplant, and the engineering man-hours used during construction, which is almost 10 times higher in the United States than in any other country (38) (see ch. 3).

Performance of U.S. reactors falls at, or slightly below, average in cumulative load factors for world reactors* (see table 26). Several countries, such as Finland, Switzerland, Belgium, and the Netherlands, with only one to four reactors, have very high average cumulative load factors. Canada's nine heavy water CANDU reactors have the highest load factors of all, averaging over 80 percent (see ch. 4). In other countries, however, with large numbers of reactors, average reactor performance does not differ substantially from the United States. At the same time, a smaller share of U.S. reactors can be found among the top-ranking reactors. Among the top 25 percent are 96 percent of Canada's reactors, 32 percent of Sweden's reactors, 44 percent of West Germany's reactors, 16 percent of Japan's reactors, but only 10 percent of U.S. reactors. Many U.S. reactors can be found at the bottom of the list; 27 percent of U.S. reactors rank in the lowest 25 percent of world reactors.

Licensing and Quality Control

West Germany has as complex a licensing process as the United States. Licensing of nuclear plants is governed by seven State (Lander) licens-

***World reactors excluding reactors in Eastern Europe, the U. S. S. R., and several third-world countries for which cumulative load factor data is not available (see appendix table 7B for listing of nuclear capacity in all countries).**

Table 25.—Sample Construction Times for Nuclear Plants in Various Countries

	Faster		Slower	
	Date of com operation	Years Sine; reactor order	Date of com operation	Years since reactor order
France:				
St. Laurent B1, B2	1981	-	—	—
Gravelines C5	1984	5	—	—
Dampierre 2,3,4	—	—	1981	
Cattenom 2	—	—	1986	8
Germany:				
KKU, Unterweser	1978	7		—
KKI-1, Ohu	1977	6		—
KKG, Grafenrheinfeld	1981	6		—
KKK, Krummel	—	—	1983	11
KBR, Brokdorf	—	—	1987	12
Italy:				
Caorso	1978	8		—
Montalto 1	—	—	1986	12
Japan:				
Ikata 2	1982	5		—
Fukushima 11-2	1984	6		—
Fukushima 11-3	1985	5		—
Genkai 2	1981	5		—
Ohi 1,2	—	—	1979	9
Fukushima 11-1	—	—	1982	10
Sweden:				
Barseback 1	1975	6		—
Barseback 2	1977	5		—
Ringhals 3,4	—	—	1982	10
Forsmark 1	—	—	1980	9
Spain:				
Almaraz 1	1981	9		—
Valdecaballeros 2	—	—	1988	13
Lemoniz 1	—	—	1983	11
Switzerland:				
Goesgen	1979	6		—
Leibstadt	—	—	1984	14
Taiwan:				
Kuosheng 1	1981	8		—
Chin-Shan 1	1979	9		—
Maansham 2	—	—	1985	11
Canada:				
Pickering 1	1971	6	—	—
Bruce 5	1983	7		—
Gentilly 2	—	—	1983	9
Darlington 1	—	—	1989	12
United Kingdom:				
Torness 1, 2	1986	8	—	—
Heysham 3,4	1986	7		—
Dungeness B-1, B-2	—	—	1982	17
Heysham 1,2	—	—	1983	13
United States[a]:				
St. Lucie 2	1983	6		—
Hatch 2	1979	7	—	—
Diablo Canyon 1	—	—	1984	16
Midland 1	—	—	1985	13

[a]Starting time is construction permit rather then reactor order.

SOURCES: December 19S1 Atomic Industrial Forum List of Nuclear PowerPlants Outside the United States; ch. 5, table for U.S. nuclear plants.

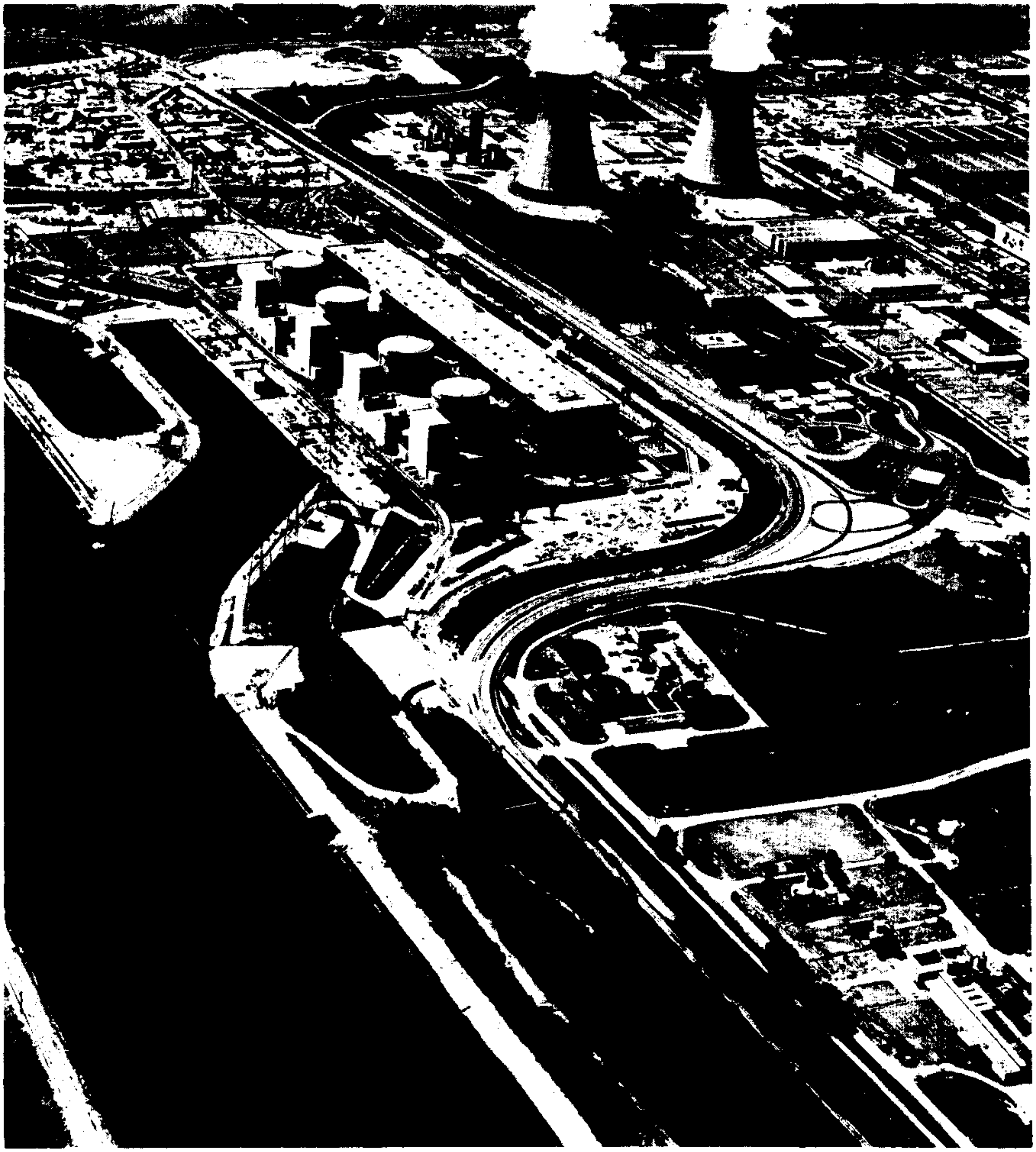
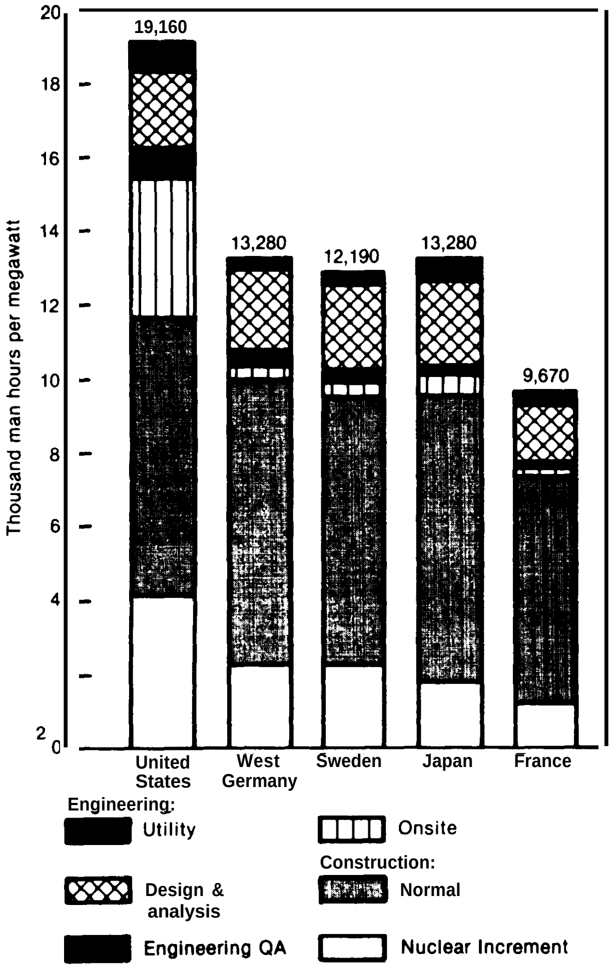


Photo credit: Electricite de France

Each of the four identical 925-MW units at Tricastin in France averaged 6.5 years construction time. Work force and engineering experience with the standard design and with the site accounted for the short construction time

Figure 38.-Engineering and Construction Man-Hours per Magawatt of Capacity (typical nuclear plants)



SOURCE: J. D. Stevenson end F. A. Thomas, *Selected Review of Foreign Licensing Practices for Nuclear Power Plants*, NUREG/CR-2664. These estimates were made from estimates of staffing patterns, project duration, end other Information obtained from Interviews with about 50 people in the United States end foreign countries. The Interviews are listed In the front of the report.

ing agencies each of which in turn depends on one of seven independent inspection agencies (TUV) for technical licensing requirements. In the 1970's, West German licensing and quality-control requirements imposed on nuclear plants increased in much the same fashion as they did in the United States (19). Engineering work tripled, quality-assurance documentation quintupled, and there was a 50-percent increase in the time required for component manufacture.

In France, Japan, and the United Kingdom, the consideration of siting and environmental issues is clearly separated from the consideration of safety issues. In all three countries the only opportunity for public intervention occurs at the earliest site-approval stage. This process can take 2 to 3 years in Japan (17). In France, the site-approval process can take place as much as 8 years before application for a construction license. In fact, sites have been approved for all nuclear construction until 1990 (36). In England, there is an option to hold a public inquiry at this early stage. The public inquiry for the Sizewell B covers a broad range of issues concerning development of pressurized water reactors (PWRs) in England (32).

Once site approval has been obtained, the licensing process in all three countries involves a technical exchange of information between licensing entity and licensee. In Japan and the United Kingdom, there is only one license (a construction license) but there is a series of technical requirements—for tests, safety analyses, and operating procedures—that must be met before the plant is allowed to operate. In practice, this amounts to a multistage licensing procedure. In France, there is an additional operating license, but the process is similar. The plant must pass a series of tests and have proposed operating procedures approved before an operating license can be issued (36).

Overall Nuclear Development

There are significant differences among countries in the probable future course of nuclear development. Table 27 classifies countries with actual or possible nuclear power programs into six categories based on the prospects for further nuclear construction.

Five countries–France, Japan, Canada, Taiwan, and Korea—have Government-supported programs of constructing and operating nuclear plants. Three—France, Japan, and Canada–have emphasized standardization to minimize construction cost and increase reliability. All three have ambitions for major export programs in the 1990's when demand picks up again, although Canada has had several setbacks in its efforts to make the CANDU heavy water reactor (HWR) a viable export, when sales failed to go forward in Mexico, Korea, and Rumania. In addition, Can-

Table 26.—Operating Performance by Country (average reactor cumulative load factor, to end of 1933)

	Reactor types									
	PWRs		BWRs		Magnoxs		Heavy water		HTRs &AGRs	
Country	Load factor, %	Number of units	Load factor, %	Number of units	Load factor, 0/0	Number of units	Load factor, %	Number of units	Load factor, %	Number of units
United States	54.8	48	56.1	23	—	—	—	—	17.9	1
Argentina	—	—	—	—	—	—	75.3	1		—
Belgium	75.6	3	—	—	—		—	—	—	—
Brazil	2.3	1	—	—	—		—		—	—
Canada	—	—	—	—	—	—	80.1	9	—	—
Finland	75.0	2	62.7	2						—
France	56.0	23	—	—	52.8	5	—	—	—	—
Germany, West	71.2	7	44.1	4						—
Great Britain	—	—	—	—	58.5	18	-	-	40.6	4
India	—	—	49.1	2	—		33.4	2		—
Italy	44.1	1	30.3	1	59.3	1	—	—	—	—
Japan	56.2	11	61.0	12	62.6	1	49.8	1	—	—
Netherlands	77.9	1	—	—	—	—	—	—		—
South Korea	55.2	1	—	—			—	—	—	—
Spain	36.8	2	62.0	1	72.0	1	–	—	—	—
Sweden	38.3	2	65.1	7	—		—	—	—	—
Switzerland	75.1	3	80.5	1	—		—	—	—	—
Taiwan	—		51.9	4	—		—	—	—	—
Yugoslavia	53.1	1	—	—	—	—		—	—	—
World	56.7	106	56.6	57	57.8	26	76.0	13	38.0	5

Notes: 1. All plants operating less than a year as of July 1983 were excluded from this calculation.
2. The USSR and several countries in Eastern Europe with substantial numbers of nuclear plants are not listed, (See appendix table 7B)
3. Graphite-water and fast breeder reactors are not included,
4. Plant load factors were weighted by plant rated capacity to get country and reactor-type averages.

SOURCE: Nuclear Engineering International, "Nuclear Station Achievement 1983," October 1983.

Table 27.—Categories of Foreign Nuclear Programs in Western Europe and the Asia-Pacific Region

	Category	Countries in category
I.	More nuclear plants planned and under-construction backed by Government policy	France, Japan, Taiwan, Canada, Korea
II.	More nuclear plants planned but may be stopped by public opposition	United Kingdom, West Germany, Italy
III.	More nuclear plants planned but delayed due to economic difficulties	Spain, Yugoslavia, Greece Portugal, Turkey
IV.	Nuclear plants in existence with de facto and de jure halt on further construction	Sweden, Switzerland
V.	Nuclear plants begun but indefinitely halted	Philippines, Indonesia
VI.	Government policy prohibits nuclear plants	Australia, Austria, Norway Ireland, Denmark

SOURCES: Off Ice of Technology Assessment categorization based on papers presented at conference on Nuclear-Electric Power in the Asia Pacific Region Jan 24-28, 1982; and Måns Lönnroth and William Walker *Nuclear Power Struggles. Industrial Competition and Proliferation Control,* George Allen and Unwin, London, 1983.

ada has entered into negotiations with U.S. utilities to build plants whose output is primarily intended for the U.S. market (20,24). Several characteristics of the nuclear industry in Canada, France, and Japan make it far easier to maintain momentum in the nuclear industry than it is in the United States. In Canada and France, the nuclear-using utilities are Government-owned (see table 28). With only one nationalized utility in France and three nuclear-owning utilities in Canada, the institutional coordination for an effective standardization program is fairly easy. In Japan, the nine utilities are investor-owned and depend on private financing. However, planning for nuclear power development takes place within the overall framework of private-public cooperation established by the Ministry of International Trade and Industry (MITI). Of these coun-

Table 28.—Structure of Electric Utility in Main Supplier Countries and the Distribution of Authority Over Key Decisions Influencing Financial Health of Utilities

Ownership of utilities	Choice of generating mix	External financing of investments	Rate regulation	Comments
United States: Large number of utilities, mainly privately owned	In principle utility, but, State governments tend de facto to influence decisions	Capital market (bonds, stocks). Bonds rated by independent rating agencies; State finance for public utilities	Public utility commissions in each State	Fragmented authority over utility financial health. Role of Federal Government very weak
France: State owned, EdF	Government, at recommendation from EdF	National budget, international capital market (e.g. US) for bonds	National Government approves rate change	National Government controls financial health
West Germany: Several utilities, the larger ones having mixed State (land) and private ownership	Utility, but regional government makes final licensing decisions	Capital market, regional government	Federal Government has to approve rate changes	Local, regional, and Federal governments all influence, and have interest in, financial health of utilities due to ownership and rating responsibilities
Canada: Mainly provincially owned (Ontario, Quebec, etc.)	Utility recommendation, provincial government final decision	Budget of provincial government, capital market (bonds)	Provincial government approves rate changes	Provincial government controls financial health
United *Kingdom:* State owned, CEGB and SSEB	National Government, after recommendation from generating boards	Budget of National Government	National Government approves rate changes	National Government controls financial health
Japan: Private investor owned (9)	Safety assessments carried out by central government, environmental assessment by local government. Final authority rests with Prime Minister	Mixed (bonds, equity ...)	Ministry of International Trade and Industry (MITI)	Financial health generally good. Utilities with nuclear investments have developed substantial in-house technical capabilities
Sweden: State owned (50)%) Privately owned (35%) Local government (15°10)	National Government final licensor after pro. posals from utilities	National budget (for State-owned utility), bonds for utilities not owned by the state	Almost none. Electricity producers allowed to compete for large-scale customers and distributors	Financial health generally good, due to large share of inflation resistant hydro. Competition between utilities said to hold rates down

SOURCE. Mans Lonnroth and William Walker, *The Viability of the Civil* Nuclear Industry, a working paper for the International Consultative Group on Nuclear Energy Published by the Rockefeller Foundation and the Royal Institute of International Affairs in 1979.

tries, France and Japan have substantial domestic markets for nuclear powerplants and are thus in stronger position to sustain nuclear industries.

The United Kingdom, West Germany, and Italy have nuclear powerplants underway, but these could still be stopped by public opposition. Further construction of LWRs in the United Kingdom will depend on the outcome of the Sizewell B Inquiry. The case for new construction is greatly weakened by the very low electricity demand growth in the United Kingdom over the decade of the 1970's (32).

in West Germany, a group, called a "convoy," of six similar nuclear powerplants was started through licensing review in the spring of 1982 (7). There are indications that political and public opposition may have peaked although there have been no changes in legal structure (24). Construction stoppage is still a possibility, however, because citizens retain the legal right to sue to stop the plants and the courts are independent.

In Italy, two nuclear plants are under construction in addition to four in operation. Local opposition to the two under construction caused extensive delays. The State electricity corporation, EN EL, will begin a vigorous campaign of local public education at each site of four plants proposed to be built by 1990. Success of such efforts in avoiding site delays is still unknown; similar site public relations efforts in France were targets of protestor bombings.

Of the countries with nuclear plants in existence and nearing completion, but with a hold on further construction, Sweden has the most explicit moratorium. Switzerland also appears to have halted further construction beyond plants scheduled to begin commercial operation in 1985. Several countries have avoided nuclear power in developing a national energy policy. Despite possessing some of the world's richest uranium supplies, Australia is dedicated to basing its electricity generation on coal. Austria and Norway have decided against building nuclear plants but are able to use abundant hydropower. New Zealand has surplus electricity from hydropower and coal; and Ireland will increase coal-fired electricity (12).

Implications for the U.S. Nuclear Industry

Implications for the U.S. industry can be drawn from the experience of other countries in developing nuclear power. Probably the most powerful lessons will come from countries more like ourselves.

The West German "Convoy" Experiment.– The German licensing system for nuclear power appears every bit as cumbersome as the U.S. system; in fact it involves even more regulatory man-years per regulated megawatt (38). With seven State licensing authorities, assisted by seven different independent engineering review organizations (TUVs), the West German system adds State-to-State inconsistency to the several stages of hearings and the independent court reviews of the U.S. system.

In an effort to halt the cycle of delays, requirements for rework, and increasing engineering manpower and paperwork, Kraftwork Union (KWU), the chief German reactor vendor, has negotiated a plan with State licensing authorities and technical agencies (TUVs) for a series of powerplants to be ordered and licensed in groups of five or six or "convoys" over the next 10 to 12 years (19). The basic process is modeled on the successful French program. Each series would have a standard design. Improvements on the design would be saved for a subsequent series.

The various parties to the construction and licensing of powerplants have agreed to several changes in procedure designed to reduce the cost and delays in plant construction. Documentation requirements have been simplified. Technical reviews of different aspects of the convoy plants have been assigned each to a separate technical review agency. KWU will make maximum use of computer-assisted design and develop a convoy management system that controls the critical features of the design of each plant.

The legal framework has not changed in West Germany in order to facilitate the convoy concept. As KWU concluded in its report on the concept, "without the broad consensus of all the parties involved (namely the customers, licensing authorities, authorized inspection agencies, and manufacturers) the concept will remain nothing more than a collection of odds and ends, with every chance of real success denied it" (19).

Although the institutions are different, the problems of getting a large number of different organizations to work together to streamline an increasingly cumbersome process is similar to what would have to be accomplished in the United States. Success of the West German effort would demonstrate that such an effort is possible.

Backfits.—In both West Germany and France there are policies that restrict backfits. In West Germany, utilities are supposed to be compensated for the costs of implementing any backfits after the State licensing authority has given its approval (38). In practice, this provision has not been carried out very often and has not prevented the escalation in required engineering man-hours described above.

In France, backfits are restricted once each standardized design has been approved. Occasionally, certain backfits (e.g., several following the Three Mile Island accident) may be judged

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important and then they are implemented on all plants of a certain design (36,6).

Standardized Training.–In West Germany there is a single institution for certifying powerplant operators. This school, called the Kraftwerkschule is owned by a joint organization of 116 utility members in six countries. Operators complete a 3-year course including supervised operation of an actual powerplant. Such training is a minimum requirement for a deputy shift supervisor. The shift supervisor must be an engineer (33).

Siting of Nuclear Powerplants.–In Japan and Italy, land is constrained, and finding sites for nuclear plants is difficult. In Japan, the most difficult part of the licensing process is the series of negotiations with local governments. MITI has in its budget about $60 million for public works grants to local governments that accept nuclear powerplants nearby. Additional funds are used to reduce electric bills of local residents (12,36,38). More funding is available if power is exported from the local area.

A similar approach is used in France where electric bills in areas surrounding nuclear plants are reduced by 15 percent, and funds to build housing, schools, and other public facilities are lent by the utility to nearby towns which repay the loan in utility property tax abatements. In Italy, there is an 18-month site review and approval process. Special public education centers are set up at each proposed site well in advance to help educate the public about the benefits and risks of nuclear power (12).

Financial Risk.—There is far less financial risk to utilities investing in nuclear power in other countries than in the United States. In West Germany, utilities set their own electric rates subject

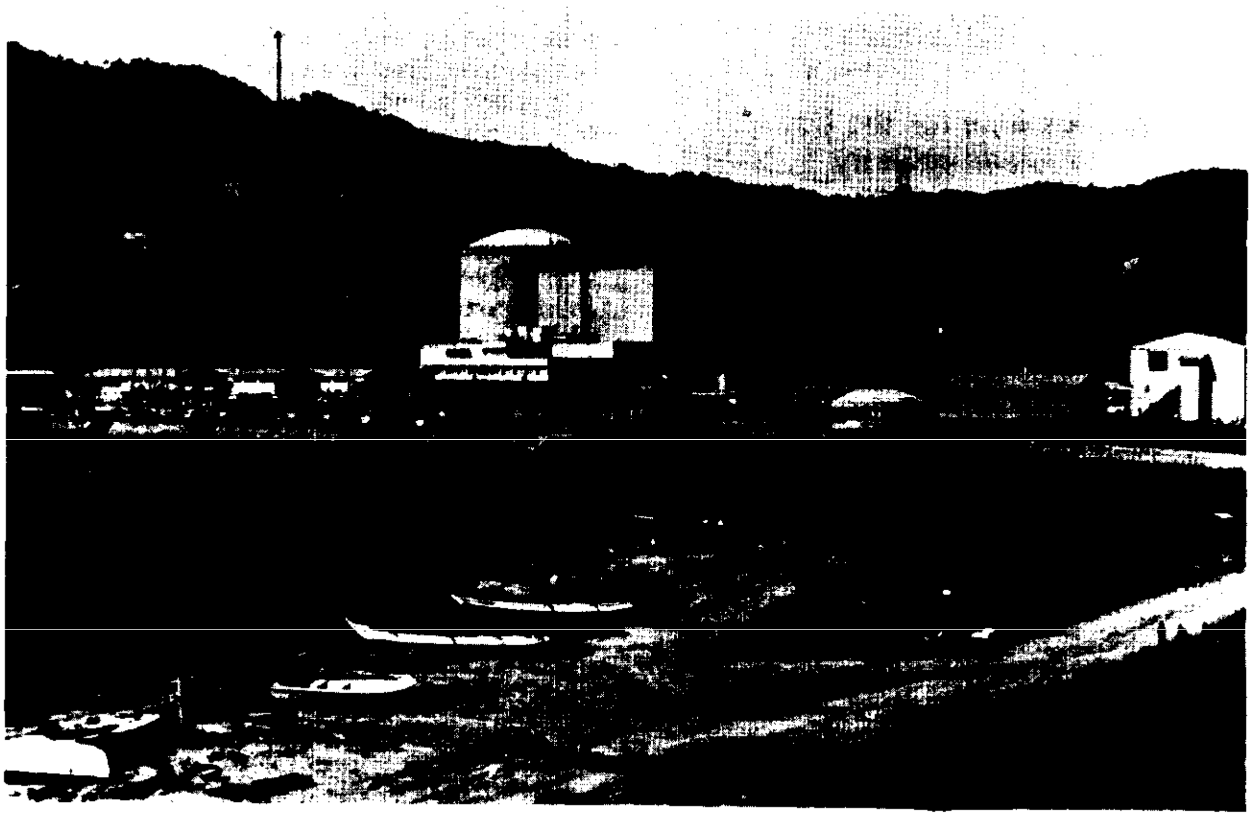

Photo credit: Atomic Industrial Forum

For citizens living near Japanese nuclear powerplants, electricity rates are reduced and grants are made available for public works

to general Federal approval for household rates and subject to antitrust provisions for industrial rates. Financing is provided not only by the private sector market but also by regional governments, which are pat-t-owners of the largest utilities. In Sweden where utilities also use private financing for investments, electric rates are generally not regulated, and utilities are in good financial shape (see table 28) (26). Similarly, in Japan, privately financed utilities are strong financially. Electric rates in Japan are the highest in the world and reflect the full costs of producing power, in order to encourage conservation (12). In France, on the other hand, the Government approves electric rates; in 1982 they were not increased enough to prevent a deficit of about $1 billion in the account of the electric utility (36).

Timing and Balance.—There are some indications that public opposition outside the United States has been intensified by very rapid development of nuclear power in Sweden and West Germany (26). At the same time, public acceptance for nuclear power in many countries seems to be more solid if nuclear power is included as part of an overall national energy plan that includes a strong emphasis on energy conservation, renewables, and other sources of electricity. Such plans have been formally announced in Japan, France, West Germany, and Italy, all countries with potentially important roles for nuclear power (12).

Shift to a New Reactor Technology.–As consideration is given in the United States (see ch. 4) to the desirability of shifting to a whole new reactor technology—heavy water reactors (HWRs), gas-cooled reactors (GCRs), or "forgiving" LWRs, several lessons can be learned from foreign experience. One is that it is quite possible to shift to a new technology. France shifted from GCRs to PWRs for plants ordered in the early 1970's. The United Kingdom is now considering the shift to PWRs in a formal public inquiry. In both cases, the shift has been towards a "standard" technology now in use in the United States and elsewhere, Clearly, this is a different situation from a shift to a relatively untested technology described as a possibility in chapter 4.

The public inquiry into the Sizewell B PWR now underway in the United Kingdom has been one of the most extensive public debates on nuclear power ever held. Beginning in January 1983, it lasted most of 1983. Much of the argument focused on the economics of the proposed project. In all but one of the five electricity demand scenarios proposed by the Central Electricity Generating Board (CEGB), electricity demand in the United Kingdom is forecast to decline between 1980 and 2000. The argument for building the Sizewell B powerplant is that cheaper nuclear power will substitute for increasingly expensive oil and coal, but there is much official skepticism about the economic plan from other government agencies. The public inquiry has addressed questions of the likelihood of cost overruns and of public pressure for expensive safety improvements to match those being required in the United States and West Germany (32).

The Sizewell B debate should provide a thorough exploration of many of the issues now facing the U.S. nuclear industry. Furthermore, it will provide one more example of a possible approach to involving the public in decisionmaking on nuclear power. Conceivably such a full inquiry could precede the launching of a "convoy" of new advanced design LWRs when orders pick up again.

The U.S. Industry in an International Context

Although the United States has by far the largest number of nuclear plants of any country, future prospects for the U.S. nuclear industry are regarded as dimmer than those of several other countries, at least by some observers. Mans Lonnroth, a Swedish author of a book on the worldwide nuclear industry (25), describes the coming decade as tough for all nuclear countries since the industry will have to demonstrate that it is a "safe, reliable and economic energy source. " Success will depend in part on the coherence of each country's response to this challenge (24).

The French have been very successful at constructing nuclear plants quickly and cheaply.

They have a large design, manufacturing, and construction capacity much of which has no other alternative use. Among French industries, the nuclear industry has been successful, and there will be considerable pressure to keep it operating even in the face of slower growth in electricity demand than anticipated. The French nuclear industry, however, has had less success in exporting sales than has West Germany or the United States. This is the big challenge for the next decade (24).

By contrast, Lonnroth claims, in the United States a "collapse of the nuclear industry would not seriously affect either the public authorities, the industry at large, or the American society" (24). The U.S. social and political system is more fragmented than either the French or West German system and for this reason may have difficulty developing a coherent long-range strategy in the absence of full consensus. West German governmental processes are as complex and open as those in the United States, but the German nuclear industry acts far more as a single industry. It "views itself as one industry, with one collective will and one identity" (24). For this reason Lonnroth suggests that the technical and economic coordination necessary for a long-range nuclear strategy in West Germany is possible within a series of "interlocking ownerships among the main industrial actors" under the long-range guidance of key West German banks (24).

Japan has had its difficulties with nuclear power, including prolonged siting processes and construction delays. However, Japan has very strong motivation to develop its nuclear industry because it has no indigenous fossil fuels. Japan has also demonstrated the ability to coordinate long-range industrial strategy in other areas and to develop an export-oriented strategy. Japan has become the single most important exporter of heavy electrical equipment and is expected to provide about 25 percent of all exports in this sector from 1975-87 (24). This gives Japan a very strong industrial base on which to develop a nuclear exports business. For the moment the nuclear industry still needs government support. However, such support will not be available indefinitely.

Thus West Germany, France, Japan, and the United States–and perhaps Canada as well–will be competing for a nuclear export market in the 1980's and 1990's. They will be competing for a market that is far smaller than worldwide nuclear industrial capacity and far smaller than previous estimates had projected (see table 29 and appendix table 7B). Several importing countries—Korea, Taiwan, Argentina, and Spain–are working to develop domestic supply capabilities and will be curtailing imports. Many countries are importing far less equipment and engineering and construction management services than they did earlier in the decade.

Given the softness of the export market, it will be difficult for suppliers of nuclear equipment and services to be sustained through the next two decades unless they have some domestic base. Although U.S. firms are involved in 31 plants still under construction, all major components will have been delivered by the end of 1984. For those overseas plants engineered by U.S. AE companies, the basic design is now complete (37). If U.S. suppliers begin to get new domestic orders in about 5 years, they will provide a new basis for maintaining design teams and manufacturing facilities capable of sales abroad. If new reactor orders are delayed for 10 years or more, U.S. firms may find themselves looking to the Japanese, West Germans, or French for joint ventures or licensing arrangements in which the foreign company is an equal, or even dominant, partner. This would be the reverse of the situation in each of these countries early in the history of the nuclear industry.

Nuclear Proliferation Considerations

U.S. and worldwide efforts to restrict proliferation of nuclear military technology are an important influence on the development of international trade in civilian nuclear power (25). The perceived link between the civilian and military uses of nuclear power has stimulated much of the opposition to nuclear power (see ch. 8). The reasoning is straightforward: commercial nuclear power requires the production of nuclear fuels, and some of these fuels and facilities that pro-

Table 29.-Estimated Reactor Export Market (1983-87 inclusive) in Units

	Orders Low	Orders High	Industrial capability	Hardware market Low	Hardware market High	Software market Low	Software market High	Previous suppliers 1960-80 (no. of units)
Europe:		**12**						
North	(0	3)						
Belgium	0	1	1/2	0	0	0	0.5	U.S. *(6),* France (2)
Finland	0	1	2	0	***0.5***	0	0.75	Sweden (2), USSR (2)
United Kingdom	0		1/2	0	***0.25***	0	0.5	—
South	(3	9)						
Greece/Turkey/Portugal.	0	1	***3***	0	1	0	1	
Italy	2	**4**	1	0	0	0.5	1	U s . (I)
Spain	1	**2**	1	0	0	0.25	0.5	U.S. (12), Germany (2)
Yugoslavia	0	**2**	***2***	0	1	0	1.5	Us. (1)
Latin America:	0	**5**						
Argentina	0	**1**	***2***	0	0.5	0	0.75	Germany (2), Canada (1)
Brazil	O	**2**	***2***	0	1	0	1.5	Germany (2), U.S. (1)
Mexico	O	**2**	**2/3**	0	1.5	0	2	Us. ***(2)***
As/a and Pacific:	***2***	10						
China	O	***2***	***2/3***	0	1.5	0	2	
Indonesia	0	1	3	0	1	0	1	
Pakistan	0	1	**2/3**	0	0.75	0	1	Canada (1)
South Korea	2	**4**	1/2	0.5	1	1	2	U.S. (6), France (2), Canada (1)
Taiwan	O	**2**	2	0	1	0.75	1.5	U.S. (6)
Africa and Mid-east:	0	**5**						
Egypt	**O**	**2**	***3***	0	2	0	2	
Israel	**O**	**1**	***3***	0	1	0	1	
South Africa	O	**2**	**2/3**	0	1.5	0	2	France (2)
Total	5	**32**		0.5	15.5	2.5	22.5	
Average annual rate	1.0	**6.4**		0.1	3.1	0.5	4.5	

SOURCE: Mans Lonnroth, "Nuclear Energy in Western Europe," based on research for *Nuclear Power Struggles,* **Allen and Unwin, London, 1983.**

duce them can be used for nuclear weapons. The fundamental premise of U.S. and worldwide efforts to avoid proliferation to additional nations has been to keep civil uses of nuclear energy distinctly separated from military applications, and to try to erect barriers to prevent diversion or misuse of civil nuclear materials and facilities. Technical and institutional aspects of nuclear proliferation were the subject of a previous OTA study and a recent Congressional Research Service paper which is reprinted in full as an appendix to this report (1 1,34).

Although it is technically possible to make crude nuclear weapons from the plutonium in spent fuel from nuclear power reactors, it is more likely from the higher grade plutonium manufactured in spent-fuel reprocessing, and in the operation of breeder reactors (see appendix table 7C). Economic prospects for commercial reprocessing have decreased worldwide as well as in the United States and no nation is currently producing and using plutonium commercially for nuclear fuel. A few countries, most notably France, are working with plutonium for use in breeder reactors.

Current worldwide and U.S. concern about nuclear power and proliferation stems from these considerations about the potential use of civilian nuclear fuels. One fear is that a rapidly industrializing state with a nuclear power base in a troubled part of the world might be tempted to use its civilian program as a base for developing nuclear weapons. The second concern is that some underdeveloped countries with nominal nuclear power programs might obtain enough technology and equipment on the world market to build facilities to produce weapons-usable materials. The grave concern in the 1960's that many nuclear powerplants worldwide would give rise to the wholesale spread of nuclear arsenals has given way in the 1980's to the concern that a few nuclear powerplants and related facilities scattered among some developing countries could bring them much closer to an ability to make nuclear weapons. It is this concern that drives proposals for restrictions on international nuclear cooperation and trade.

Concern about the spread and use of nuclear weapons has led to several international initiatives. The Non-Proliferation Treaty (NPT) pledges its members that do not have nuclear weapons to forego future acquisition of them, and requires verification of the use of civilian facilities by international inspection. It further stipulates that all the nuclear facilities in signatory states without nuclear weapons will be safeguarded, even those that are developed indigenously. This treaty represents a significant departure from practices prior to 1970, and is an important element of the international proliferation regime. However, it has not been as effective as it might have been because a number of nations have refused to participate in the treaty. As shown in table 30, the nonsignatory states include India, Pakistan, Brazil, Argentina, and South Africa.

After NPT took effect, other events stimulated further proliferation concerns. **In 1974, India tested a nuclear explosive that was derived from civilian facilities. Shortly thereafter, France and West Germany agreed to supply enrichment and/or reprocessing plants to nations (Pakistan and Brazil) which had refused to sign the NPT. By the late 1970's, the nuclear supplier countries had** become concerned enough to agree informally to exercise additional restraint in nuclear cooperation and trade, particularly in the area of the transfer of sensitive technology. The United States imposed even more severe restrictions than the other suppliers with the passage of the Nuclear Non-Proliferation Act of 1978.

U.S. policies and controls that guide nuclear cooperation and exports include the following

Table 30.-No-Nuclear Weapons Pledges in Effect in 1981

	Treaty and data of entry into force			
State	Antarctic Treaty, 1961	Limited Test Ban Treaty, 1963	Treaty Prohibiting Nuclear Weapons in Latin America, 1966a	Nuclear Non-Proliferation Treaty, 1970
Argentina	P	s	S[b]	
Australia	P	P	P	P
Belgium	P	P	P	P
Brazil	P	P	s[c]	
Canada	P	P	P	P
Cuba		—	—	—
Egypt	—	P		P
F.R.G.	P	P	P	P
India		P	—	
Iran		P	—	P
Iraq		P		P
Israel		P		
Italy	P	P		P
Japan	P	P		P
Libya		P	—	P
Netherlands	P	P	P[d]	P
Pakistan		s	—	
South Africa	P	P		
South Korea		P		P
Spain		P		P
Sweden		P		P
Taiwan		P		P
Yugoslavia		P		P

P = Party.
S = Signatory.
[a]Not yet in force for all signatories.
[b]Ratified Subject to preconditions not Yet met.
[c]Additional Protocol II applying to Dutch territories in Latin America.
[d]There is some difference of opinion as to whether one small unsafeguarded laboratory should be considered a facility.

SOURCE: W. Donnelly and J. Pilat, "Nuclear Power and Nuclear Proliferation: A Review of Reciprocal Interactions," Congressional Research Service for the Office of Technology Assessment, April 19S3.

items: restrictive conditions for licensing exports of nuclear materials, equipment, and reactors; restrictive conditions for providing technical assistance and transferring technology; restrictions on export of dual-use items that can be applied to weapons programs as well as to legitimate nuclear power programs; post-export controls, or prior rights over what may be done with or to U.S. nuclear exports, such as reactors or fuel; and cutoff of nuclear cooperation and exports to states which violate safeguards agreements with the United States. These restrictions are embedded in U.S. law, particularly in the Non-Proliferation Act of 1978 mentioned above, the Atomic Energy Act of 1954, and the Symington and Glenn amendments to the Foreign Assistance Act of 1961.

Nuclear cooperation and trade has been circumscribed in many aspects by the restrictive conditions and controls intended to prevent the development of nuclear weapons. Specifically, the supply of sensitive nuclear technology to countries that have little visible economic need for it is discouraged by the nuclear suppliers, and particularly by the United States. The supply of items that can be used for both civilian and military purposes has been little affected in the past, but is likely to be more restricted in the future since export control lists are being made more detailed and specific. Importing countries most likely to feel the effects of such additional restrictions include Argentina, Brazil, India, and pakistan.

Pressures from both formal and informal nonproliferation regulation can be viewed as stimulating some nuclear customer countries to seek independence of the major suppliers, either by building up their own nuclear industries indigenously or by finding suppliers who offer less demanding conditions. This could give rise to the emergence of a second tier of suppliers from the more industrialized developing nations, such as Argentina and India, who might not comply with the guidelines of the major suppliers. This could significantly change the character of nonproliferation control.

In part because of fears of loss of U.S. nonproliferation influence and trade, the Reagan administration has shifted emphasis somewhat from the policies of the Carter administration. Rather than emphasize across-the-board denial of nuclear supply, the Reagan administration has promoted the concept that the United States is a reliable supplier of nuclear equipment to trusted countries who are not viewed as proliferation risks.

Conclusion

For economic, political, and technical reasons, the 1980's will be a difficult decade for the nuclear power industry in all countries. Those most likely to survive are those with the political and industrial cohesion to develop a long-range strategy for demonstrating that nuclear power is a safe, reliable, and economic energy source. France, Japan, and possibly West Germany and Canada have a combination of national motivation and institutional coherence that makes it quite possible they will survive the decade with a more viable nuclear industry than will the United States. In the worst case, therefore, if the U.S. industry emerges weakened from a long period with no new orders, these countries may reverse earlier roles and provide some of the expertise and hardware to U.S. companies during the early years of a revival of the U.S. industry.

Appendix Table 7A.–Onsite and Offsite Nuclear-Related Job Vacancies at INPO Member Utilities Mar. 1, 1982

Occupations	Positions[a]	Vacancies: Number	Vacancies: Percent of positions
Managers and supervisors	5,765	432	7.5
Engineers:			
Chemical	179	30	16.8
Civil	872	40	4.6
Electrical	1,518	239	15.7
Instrument and control	506	91	18.0
Mechanical	2,844	327	11.6
Nuclear and reactor	1,427	287	20.1
Quality assurance/control	791	147	18.6
Radiation protection	140	30	21.4
All other engineers	2,229	420	18.8
	10,506	1,611	15.3
Scientists:			
Biologists	144	6	4.2
Chemists	269	37	13.8
Health physicists	404	83	20.5
Other scientists	235	28	14.6
	1,052	154	14.6
Training personnel			
SRO/Relicensed/certified instructors	405	109	26.9
Other technical/scientific instructors	576	100	17.4
Other instructors	188	52	27.7
Support staff...	135	17	12.6
	1,304	278	21.3
Operators:			
Shift technical advisors	416	93	22.4
Shift supervisors	735	119	16.2
Senior licensed operators (SRO)	385	117	30.4
Licensed operators (RO)	1,094	230	21.0
	2,214	466	21.1
Non-licensed operators assigned to shift	2,286	242	10.6
Other non-licensed operators	351	102	29.1
	2,637	344	13.1
Individuals ingraining for SRO licenses	495	22	4.4
Individuals ingraining for Relicenses	878	66	7.5
Individuals ingraining for non-licensed positions	838	246	29.4
	7,478	1,237	16.6
Technical and maintenance personnel:			
Chemistry technicians	1,004	161	16.0
Draftsmen	1,209	98	8.1
Electricians	1,609	172	10.7
Instrument and control technicians	2,463	320	13.0
Mechanics	3,554	244	6.9
Quality assurance/control technicians	793	88	11.1
Radiation protection technicians	1,792	266	14.8
Welders with Nuclear Certification	415	48	11.6
Other technical and maintenance personnel	3,883	312	8.0
	16,742	1,709	10.2
All other professional workers	1,304	125	9.6
Other technical personnel	1,061	114	10,7
Total	45,212	5.660	12.5

[a]This includes persons employed by INPO member utilities, Including holding company positions allocated to the utilities, vacant positions, and contractor positions used in normal operations.

Note: Fifty-five utilities providing offsite information; onsite data comes from 82 plants representing 58 utilities, except onsite vacancy data, which was provided by only 81 piants representing 57 utilities.

Appendix Table 7B.—Nuclear-Generating Capacity Outside the United States

	1980			1981		1985		1990		1995		2000	
	Net MWe installed	Percent of capacity	Percent of generation	Net MWe installed	Percent of capacity	Net MWe installed	Percent of capacity	Net MWe installed	Percent of capacity	Net MWe installed	Percent of capacity	Net MWe installed	Percent of capacity
Argentina	344	3.7	na	344	na	944	8.5	1,642	12.0	2,842	na	3,442	23.0
Austria	0	0	0	0	0	na	na	na	na	na	na	na	na
Belgium	1,667	15.0	23.3	1,667	14.9	5,427	38.0	na	na	na	na	na	na
Brazil	0	0	0	0	0	626	1.0	1,871	4.0	5,606	7.0	10,586	10.0
Bulgaria	1,320	na	na	1,320	na	2,760	na	4,760	35.0	na	na	na	na
Canada	5,498	8.0	9.0	5,498	7.7	10,347	10.5	14,502	13.0	na	na	na	na
China, People's Republic of	0	0	0	0	0	0	0	0	0	3,000	na	16,000	na
Cuba	0	0	0	0	0	0	0	1,320	na	na	na	na	na
Czechoslovakia	992	na	na	992	na	3,192	17.0	10,952	32.1	na	na	18,952	50.0
Denmark	0	0	0	0	0	0	0	0	0	2,600	na	na	na
Egypt, Arab Republic of	0	0	0	0	0	0	0	900	6.7	3,600	na	8,400	28.6
Finland	1,080	12.0	16.5	2,160	22.0	2,160	20.0	2,160	19.0	3,160	25.0	na	na
France	14,400	23.0	24.0	21,930	31.0	38,200	43.0	58,000	54.0	na	na	na	85.0
Germany, Democratic Republic of	1,400	na	na	1,400	na	5,360	na	9,000	na	9,000	na	na	50.0
Germany, Federal Republic of	8,625	12.0	14.3	9,850	10.0	17,700	na	26,704	na	na	na	na	50.0
Greece	0	0	0	0	0	0	0	600-900	5.0	na	na	na	na
Hungary	0	0	0	0	0	1,760	na	4,760	10.0	na	na	11,000	48.0
India[a]	640	2.1	2.7	860	2.7	1,330	2.6	1,800	na	4,030	na	10,000	8.3
Israel	0	0	0	0	0	0	0	0	0	1,800	na	2,700	30.0
Italy[b]	1,424	3.0	1.5	1,424	3.0	1,462	3.1	4,462	6.1	11,462	na	na	na
Japan[c]	5,511	12.0	15.9	15,511	11.7	28,000 – 30,000	15.6 – 16.8	51,000 – 53,000	22.1 – 22.9	74,000 – 78,000	26.7 – 28.2	na	na
Korea, Republic of (South)	587	6.3	9.3	587	6.0	3,815	20.0	11,216	41.5	na	na	na	na
Libya	0	0	0	0	0	0	0	na	na	na	na	na	na
Mexico	0	0	0	0	0	1,308	5.0	2,300	5.0	na	na	20,000	25.0
The Netherlands	505	3.3	7.0	505	3.2	505	3.0	505	3.0	450	2.0	450	2.0
Pakistan	125	na	7.1	125	na	725	na	na	na	na	na	na	na
The Philippines, Republic of	0	0	0	0	0	620	10.5	620	7.2	620	na	620	3.5
Poland	0	0	0	0	0	0	na	4,000	9.0	na	na	23,000	na
Portugal	0	0	0	0	0	0	0	0	0	na	na	2,790	18.0
Romania	0	0	0	0	0	440	na	3,960	20.0	na	na	na	na
South Africa, Republic of	0	0	0	0	0	1,844	7.0	na	na	na	na	na	na
Spain	1,100	3.7	4.7	2,030	6.2	7,655	20.3	2,000	26.1	18,000	32.1	27,000	40.0
Sweden	4,600	16.8	27.0	4,600	na	8,380	26.3	9,430	28.2	na	na	na	na
Switzerland	1,926	17.5	28.4	1,926	17.5	2,871	21.9	na	na	na	na	na	na
Taiwan (China)	1,212	14.5	19.1	2,163	22.4	4,928	31.0	8,728	na	11,578	na	na	na
Thailand	0	0	0	0	0	0	0	0	0	900	10.1	na	na
Turkey	0	0	0	0	0	0	0	0	0	1,000	na	na	na
Union of Soviet Socialist Republics	10,505	na	na	15,790	na	34,135	10.0	90,000	25.0	na	na	130,000 200,000	33.0
United Kingdom	6,457	9.0	12.0	6,457	9.4	9,835	na	10,311	na	na	na	na	na
Yugoslavia	0	0	0	632	na	632	na	632	na	na	na	na	na

[a]Gross MWe.
[b]Percent of capacity for 1985 and 1990 includes share of Super Phenix.
[c]Gross MWe (excluding Fugen). 1980 figures for fiscal year Apr. 1, 1980 to Mar. 31, 1981.

SOURCE: Atomic Industrial Forum List of Powerplants Outside the United States, December 1981.

Appendix Table 7C.—Usability of Nuclear Materials for Nuclear Weapons or Explosives

Material and form	Usability: Direct	Usability: Indirect	Processing required
Plutonium:			
Metal	Yes		
Oxide	Possibility	Yes	Chemical separation
Oxide with uranium in nuclear fuels	No	Yes	Do
Oxide or other forms in spent nuclear fuels	No	Yes	Reprocessing
Thorium: Ore, metal, chemical forms	No	No	
Uranium-235:			
Normal ore, metal, chemical forms	No	No	
Slightly enriched (3-6 percent) metal	No	Yes	Chemical processing to produce uranium hexafluoride for enrichment to weapons grade
Oxide in nuclear fuels	No	Yes	Do
Oxide or other forms in spent nuclear fuels	No	Yes	Reprocessing, chemical processing and enrichment
Moderately enriched (20 percent) metal	Unlikely	Yes	Chemical processing and enrichment
Oxide	No	Yes	Do
Oxide in nuclear fuels	No	Yes	Do
Oxide or other forms in spent nuclear fuels	No	Yes	Reprocessing, chemical processing and enrichment
Highly enriched (90 percent):			
Metal	Yes		
Oxide	Yes		
Oxide in nuclear fuel	No	Yes	Chemical separation
Oxide or other forms in spent nuclear fuels	No	Yes	Reprocessing
Uranium-233:			
Metal	Yes		
Oxide	Yes		
Oxide in nuclear fuels	No	Yes	Chemical processing and enrichment
Oxide or other forms in spent nuclear fuels	No	Yes	Reprocessing, chemical processing and enrichment

SOURCE. W. Donnelly and J. Pilat, "Nuclear Power and Nuclear Proliferation: A Review of Reciprocal Interactions," Congressional Research Service for the Office of Technology Assessment, April 1983.

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Chapter 8

Public Attitudes Toward Nuclear Power

Photo *credit: OTA staff*

Buttons and bumperstickers from the controversy about nuclear power

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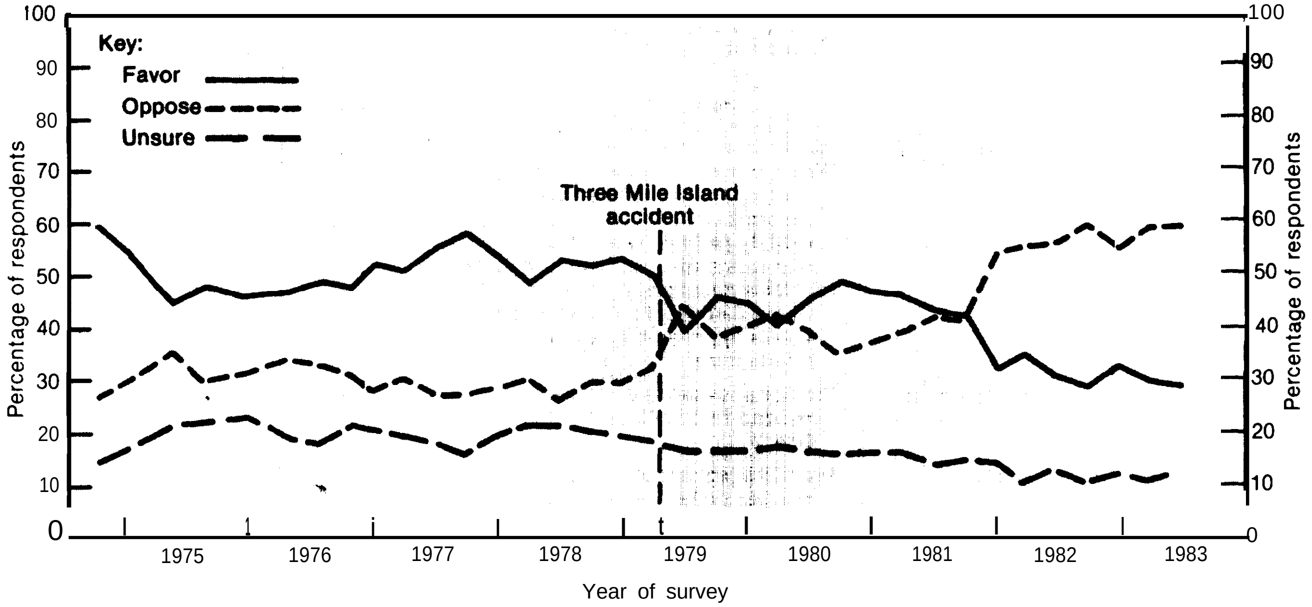
Chapter 8
Public Attitudes Toward Nuclear Power

INTRODUCTION: PUBLIC OPINION AND ITS IMPACT ON NUCLEAR POWER

Public attitudes toward nuclear power have become increasingly negative over the past two decades, with the most recent polls indicating that a slight majority of Americans opposes further construction of reactors. During the 1950's, nuclear power was still in the early states of development, and pollsters did not even bother to survey the public on the issue. In the early 1960's, a few scattered protests against local plants gained national attention, but opinion polls indicated that less than a quarter of the public opposed nuclear power (41). From Earth Day in 1970 through the mid-1970's, opposition levels averaged 25 to 30 percent, indicating that substantial majorities of the public favored further nuclear development. However, by 1976, anti-nuclear referenda appeared on ballots in eight States.

Polls taken between 1976 and 1979 indicated that slightly over half of the American public favored continued construction of nuclear plants in the United States in general, while about 28 percent were opposed and 18 percent unsure. The accident at Three Mile Island (TMI) in April 1979 had a sudden and dramatic impact on these attitudes. As shown in figure 39, the percentage of people who had been in favor of or uncertain about continued construction of reactors decreased immediately following the accident while the number opposed increased (57). In subsequent months, there was some return to previously held opinions, but opposition levels remained much higher than they had been. National polls taken since mid-1 982 indicate a continued slow erosion in support for nuclear power. About a

Figure 39.—Trends in Public Opinion on Nuclear Power



Question asked: "Do you favor or oppose the construction of more nuclear powerplants?"
SOURCE Cambridge Reports, Inc.

third of the public now supports construction of new plants in general, while over so percent are opposed (6, 10, 18). The accident at TMI appears to have accelerated a trend of even greater opposition to construction of new plants near to where those polled live. By the end of 1981, a large majority of those polled opposed construction of new plants in or near their communities. When compared with other energy options, including offshore oil drilling and coal plants, nuclear is now the least favored alternative.

Despite the trend of declining support, the pub lic's overall current attitude toward nuclear power can best be described as ambivalent. For example, a 1983 poll indicates that about 40 percent of the public thinks currently operating reactors are "mainly safe" while slightly over half think they are dangerous and 5 percent are "not sure." There is some evidence that the public looks to nuclear power as one solution to the Nation's long-term energy problems. In a recent survey, the majority of respondents believed that most U.S. energy needs would be supplied primarily by nuclear" and solar over the next two decades, and over a third of those polled expected nuclear power to provide most of the Nation's energy after the year 2000 (14). The majority of Americans favor neither a halt to all new construction nor a permanent shutdown of all operating reactors. Opinion polls on this question have been verified by State ballot initiatives. As shown in table 31, most of the nuclear moratorium initiatives, and all referenda that would have shut down operating plants were defeated in 1976, 1980, and 1982. However, more of these initiatives have been approved in recent years, and many restrictions on nuclear waste disposal have been passed, reflecting public doubts about the technology.

Table 31.—History of Statewide Referendum Votes Dealing With Nuclear Powerplants

Year	State	Proposal	Outcome	Vote split
1976	Arizona	Would halt new construction and reduce operations until safety systems were found effective, liability ceilings lifted, and waste disposal was demonstrated	Defeated	30-70 %
	California		Defeated	33-66%
	Colorado		Defeated	29-71 %
	Montana		Defeated	42-58%
	Oregon		Defeated	42-58%
	Ohio		Defeated	32-68%
	Washington		Defeated	33-67%
1978	Montana	Same as '76 referenda	Approved	60-40%
1980	Maine	Would shut down Maine Yankee	Defeated	41 -59%
	Missouri	Would prevent Callaway plants from operating until safety systems were found effective, liability ceilings were lifted, and waste disposal was available	Defeated	39-61%
	Oregon	Prohibits new construction until waste disposal is available and voters approve in a statewide referendum	Approved	52-48%
1981	Washington	Prohibits issuance of new bonds needed to complete WPPSS Unit 3	Approved	56-44%
1982	Idaho	Prohibits legislation limiting nuclear power unless approved by voters in a referendum	Approved	60-40%
	Maine	Would phase out Maine Yankee over 5 years	Defeated	44-56%
	Massachusetts	Prohibits new construction and waste disposal unless certain conditions, including voter approval in a referendum. are met	Approved	66-33%

Total restrictive referenda placed on ballots: 14
Total approved: 4

SOURCES: Atomic Industrial Forum, State Codes.

The public's ambivalent attitude toward nuclear power is due to a variety of factors including the ongoing debate among experts over reactor safety, individual perceptions of the likelihood of a catastrophic reactor accident, changing personal values, and media coverage of the technology. Underlying all of these factors is increasing doubt about the technical capabilities and the credibility of both the nuclear industry and its governmental regulators. As discussed in chapter 5, weak utility management has led to poor operating performance at some reactors as well as skyrocketing costs and quality-assurance problems at other plants under construction. These problems have led to accidents at operating reactors, causing great public concern.

As early as 1966, when large majorities of the public supported nuclear power, a design error caused blockage of coolant, leading to melting of a small part of the core at Detroit Edison's Fermi breeder reactor (3). Although no radioactivity was released, and the event received relatively little publicity at that time, nuclear critics and some members of the public became concerned. They pointed to a University of Michigan study conducted prior to construction of the plant, which indicated that if the plant had been larger and had been operating at full design power for at least a year, a complete breach of containment combined with the worst possible weather conditions might have led to as many as 60,000 deaths (26). Nearly a decade later, public discussion of the accident increased in response to the 1975 publication of the book, We ***Almost Lost*** *Detroit* (25).

In 1975, a fire started by a worker using a candle to test for air leaks spread through the electrical system of the Tennessee Valley Authority's (TVA's) Browns Ferry plant in Alabama. The fire caused some loss of core coolant in one unit of the plant, and disabled the reactor's safety systems (1 1). Because of confusion about how to put it out, the fire burned out of control for 7 hours before being extinguished. Again there was no loss of life and no release of radiation, but the incident was reported in the national media, increasing public fears of an accident. Critics felt that the Nuclear Regulatory Commission's (NRC's) news release on the event—which emphasized the safe shutdown of the reactor while downplaying the failure of the Emergency Core Cooling System— misrepresented the nearness of a disaster and ignored the lack of foresight which the accident demonstrated.

While these earlier accidents had an adverse impact on popular support for nuclear technology, it was not until 1979 that a single accident had a direct, measurable impact on public opinion as reflected in national opinion polls. That spring, poor maintenance, faulty equipment, and operator errors led to a loss of coolant and partial destruction of the core at the TMI Unit 2 reactor located in Pennsylvania. Radioactive water spilled onto the floor of an auxiliary building, releasing a small amount of radioactivity to the environment, although the total radiation dose received by the population in the vicinity was far less than their annual exposure to natural and medical radiation (31). On March 30, Governor Thornburgh advised pregnant women and preschool children to leave the area within a 5-mile radius of TMI. This advisory was not lifted until April 9. Conflicting statements from authorities combined with obvious confusion at the reactor site before and during the evacuation shook public confidence in the nuclear industry and State and Federal officials. Following the accident, majority support for nuclear power was lost, a trend that continues today. Local opposition to some reactors around the country also increased after the accident, while local attitudes toward other reactors remained favorable (see Case Studies at the end of this chapter).

Opinion polls taken after the accident at TMI indicated that at least half of those polled thought more such accidents were likely. Since that time, other incidents, such as the rupture of steam generator tubes at Rochester Gas & Electric's Ginna nuclear plant in January 1982, have occurred at operating reactors. There is some evidence that the public views these incidents, along with the TMI accident, as precursors to a catastrophic accident that might kill thousands (67).

The handling of reactor safety issues by the nuclear industry and the NRC has led many people to the conclusion that both have seriously underestimated safety problems. For example,

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opinion polls indicate that a majority of the public believed government officials understated the dangers at TMI (57). In addition, since 1973 the nuclear industry has argued that the possibility of failure of reactor emergency shutdown systems is negligible. Because of industry opposition, the NRC delayed regulations requiring extra equipment to avoid an accident in the event of such a failure. However, it was exactly this type of failure that occurred not once, but twice within 4 days at Public Service Gas& Electric's Salem, N. J., plant in February 1983 (38). (See ch. 5.)

The importance of public opinion to further development of nuclear power has been recognized by government and industry but is still little understood (12,75). This chapter attempts to add to the limited understanding of public perceptions and to identify changes in the management of nuclear power that might make it more acceptable to the public. The analysis is limited to public perceptions of operating nuclear reactors and those under construction. An April 1983 OTA stud y, ***Managing Commercial High-Level Radioactive Waste,*** deals with public attitudes toward transportation and disposal of spent fuel and nuclear waste in greater depth.

Actors in the Nuclear Power Debate

As discussed in chapter 1, there area number of groups in the United States with sometimes conflicting interests in nuclear power. The apparent contradictions in public attitudes toward the technology are explained at least partially by the fact that there is not a single homogeneous "general public" in this country. Opinion polls which survey the "general public" may fail to reveal the intensity of individual opinions. For example, the phrasing of the question most frequently asked to gage national public opinion— "In general, do you favor or oppose the building of more nuclear power plants in the United States?" –leaves little room for people who are uncertain or have no opinion. When the question was rephrased in two surveys taken shortly after the TMI accident, over a third of the respondents were uncertain or neutral (45). A national poll taken in 1978 indicated that about a third of respondents were neutral; however, large percentages of respondents were also extremely pro- or anti-nuclear. Thus, it appears that different groups among the public vary in the strength of their beliefs about nuclear power.

During the 1970's, critics of nuclear power and their associated public interest groups became increasingly well-organized at the national level. As shown in table 32, today all of the major national environmental groups are critical of at least some aspects of the U.S. nuclear program (33). In addition to these environmental groups with broad agendas, several organizations, such as the Union of Concerned Scientists and the Critical Mass Energy Project of Ralph Nader's Public Citizen, Inc., focus primarily on nuclear power. Overall, about 1 million Americans belong to environmental and energy groups critical of nuclear power. Total annual expenditures for lobbying, public education, and other activities related directly to nuclear energy are estimated to be about $4 million (33). In addition, these groups rely heavily on volunteer labor and donated resources.

Partially in response to the publicity attracted by nuclear critics, proponents of nuclear technology have also formed advocacy groups, as shown in table 32. Most of the groups supporting the technology are trade and professional associations, although there are some broad-based public interest groups in this category as well. In total, about 300,000 individuals belong to professional societies and public interest groups that directly or indirectly support nuclear energy development. Some groups in this category, such as the American Nuclear Society and the Atomic industrial Forum, focus primarily on nuclear power, while others such as the Edison Electric Institute are utility trade associations with broad agendas that include advocacy of nuclear power among many other issues. In response to the accident at TMI, nuclear advocates stepped up their public education efforts through the creation of the Committee for Energy Awareness (CEA). Current plans call for expenditure of about $27 million in 1983 for CEA, a major increase over previous expenditures of about $6.5 million by all groups combined (42).

Nuclear advocates and critics, including the staffs of public interest groups, are knowledgeable

Table 32.-Major National Groups Influencing Public Opinion For and Against Nuclear Power

Groups supporting nuclear power	Groups opposing some aspects of nuclear power
Category 1: Large organizations with a focus on nuclear energy targeting a broad audience. — U.S. Committee for Energy Awareness — Atomic Industrial Forum — American Nuclear Society *Category* 2: Lobbying organizations with a primary or secondary focus on nuclear energy. — Americans for Nuclear Energy — American Nuclear Energy Council — Americans for Energy Independence *Category* 3: Trade and professional associations that support commercial nuclear energy. — Edison Electric Institute — American Public Power Association — National Rural Electric Cooperative Association — Institute of Electrical and Electronics Engineers — American Association of Engineering Societies — Health Physics Society — Scientists and Engineers for Secure Energy *Category* 4: Industry research organizations indirectly influencing public opinion. — Electric Power Research Institute — Institute for Nuclear Power Operations — Nuclear Safety Analysis Center	*Category 1:* Groups with a focus on nuclear energy and alternatives to it. — Union of Concerned Scientists — Critical Mass Energy Project of Public Citizen, Inc. — Nuclear Information and Resource Service — Safe Energy Communications Council *Category* 2: Large environmental groups that participate in lobbying and public criticism of nuclear energy. — Sierra Club — National Audubon Society — Natural Resources Defense Council — Friends of the Earth — Environmental Policy Center — Environmental Defense Fund — Environmental Action, Inc.

SOURCES Terry Lash, "Survey of Major National Groups Influencing Public Opinion Against Nuclear Power, " Office of Technology Assessment contractor report, April 1983, M & D Mills, "Activities of Groups Which Influence Public Opinion in Favor of Nuclear Power, " Off Ice of Technology Assessment contractor report, May 1983

about nuclear power and much more committed to their beliefs than the general public. They act on these beliefs both in seeking to influence nuclear power policies at the State and Federal level and in attempting to convince the public of their point of view.

The nuclear establishment sometimes blames nuclear critics for the growth of public opposition to nuclear power. However, to some extent these individuals simply are reflecting the concern of the wider public which has grown in response to reactor accidents and the increasing financial problems of the utility industry. In addition, the success or failure of **both** advocates and critics depends in part on public response to their arguments. A 1983 opinion poll indicates that Ralph Nader, a leading environmentalist, is considered very believable on energy matters (9). Electric utility trade associations are considered somewhat less believable, and nuclear industry associations have much lower credibility among poll respondents. Thus, it appears that the public may be more willing to listen to and accept the arguments of nuclear critics than those of advocates.

The Impact of Public Opinion on Nuclear Power

Public concerns about reactor safety, nuclear waste disposal, and rising construction costs have had a particularly notable impact on State policies affecting nuclear power. As discussed in chapter 6, State Public Utility Commissions (PUCs) must grant a license certifying the need for power prior to construction of any type of new powerplant. Because PUCs have veto power over new plants, based on economic and financial criteria, State laws essentially can halt further development of nuclear power. While critics and advocates have been involved in voter-initiated referenda restricting further licensing of nuclear plants, it is ultimately the voters of the State (the "general public") who decide whether or not to approve these restrictions. Table 31 provides a history of State votes on nuclear energy referenda. Overall, the trend appears to reflect accurately the trends shown in public opinion polls, declining from a large margin of suppt for nuclear power in 1976 to an ambivalent position today. While all seven restrictive proposals were defeated in 1976, voters in Oregon and Massachusetts approved initiatives limiting new reactor construction in 1980 and 1982.

In California, State legislators approved a law restricting nuclear power development in 1976 to head off a more stringent Statewide referendum with similar provisions that was then turned down only a few months later. The law passed by the legislature was upheld by the U.S. Supreme Court in April 1983. Other State legislatures and a few PUCs have limited further construction of nuclear plants by legislation or regulation. A complete list of State laws and regulations (including those enacted by voter referenda) affecting nuclear power is given in table 33. Because of these laws and regulations, utilities in 10 States cannot obtain State licensing of proposed nuclear reactors until certain conditions, such as a clear demonstration of high-level waste disposal, are met.

Even in those States where nuclear power development is not limited by law or regulation, State politics can influence utility decisions about

Table 33.—State Laws and Regulations Restricting Construction of Nuclear Powerplants

State	Type of action	Year approved	Citation	Provisions
California	Law-by legislature[a]	1976	Cal Pub Res Code, Sees. 25524.1-25524.2	No licensing of new plants until Federal Government approves a demonstrated high-level waste disposal technology and fuel rod reprocessing technology is available.
Connect i cut	Law-by legislature	1979	H-5096, approved June 18	No licensing of a fifth plant until Federal Government approves a demonstrated high-level waste disposal technology.
	Law-by legislature	1983	H.B. 5237	Limits construction costs of Millstone 3 to rate-payers to $3.5 billion.
Kentucky	Resolution-by legislature	1982	HR-85, adopted March 26	Declares the State's intention to prohibit construction of plants.
Maine	Law-by legislature	1977	Me Rev Stat Ann, Tit 10, Sees. 251-256 (West 1980)	No licensing of new plants until Federal Government demonstrates high-level waste disposal and a majority of voters approve in a referendum vote.
Maryland	Law-by legislature	1981	Ann Code Md, Health-Environmental, Tit 8, Sec. 402	No licensing of new generators of nonmedical low-level waste until Federal Government demonstrates waste disposal or an interstate compact is in effect.
Massachusetts	Law-by referendum	1982	Question 3, Approved Nov. 2 (Chap. 503, Acts of 1982)	No licensing of new plants or nonmedical low-level radioactive waste disposal sites until a Federally approved storage facility is operating, and other conditions, including voter approval, have been met.
Montana	Law-by referendum	1978	Mt Code Ann, Tit 75, Sees. 20-201, 20-1203	No licensing of new plants until all liability limits for an accident are waived, a bond is posted against decommissioning costs, and other conditions, including voter approval, are met.
Oregon	Law-by referendum	1980	Measure No. 7, Approval Nov. 4	No licensing of new plants until Federal Government provides high-level waste disposal and a majority of voters approve in a referendum.
Vermont	Law-by legislature	1975	Vt. Stat Ann, 1970, V.8, Tit 30, Sec. 248c	No licensing of new plants without General Assembly approval.
Wisconsin	Regulation-by Public Service Commission	1978	Dkt No 05-EP-1, Wis Pub Serv Comm, Aug. 17	No licensing of new plants without progress on waste disposal, fuel supply, decommissioning, and other economic issues.
Washington	Law-by referendum	1981	Chap. 80.52, Rev. Code of Washington	No issuance of bonds for major new energy facilities (including nuclear plants) without voter approval.

[a]On Apr. 21, 1983, the Us. Supreme Court upheld the constitutionality Of this law

SOURCES: Atomic Industrial Forum, State Codes, NRC Office of State Programs.

nuclear plants. Whether Public Utility Commissioners are directly elected or appointed by an elected Governor, they are sensitive to State politics and broad public opinion. Public concerns about nuclear power may lead Utility Commissioners to disallow rate increases needed to finance completion of plants under construction or to simply deny a license entirely. Public opposition at the local level, too, can discourage utilities from implementing planned nuclear plants. For example, Portland General Electric in Oregon canceled its planned Pebble Springs reactor in 1982 following a lengthy siting controversy that made the project less economically attractive. The approval of a State referendum in 1980 banning licensing of new plants until waste disposal technology was available contributed to the utility's decision.

Over the past few years, public concern about reactor safety in reaction to the accident at TMI has encouraged additional NRC safety studies and new regulatory requirements, increasing nuclear power costs and making it less attractive to utilities. (A more detailed analysis of the costs of regulatory requirements is included in ch. 6.) This trend is partially a continuation of increasing public concern about environmental quality that began in the late 1960's. Translated into laws and regulations, those concerns drove up the price of both nuclear and coal-fired powerplants as utilities were required to incorporate more pollution control technology into new and existing plants. Negative public perceptions may also affect the availability of financing for new nuclear plants. The financial problems caused by the accident at TMI discouraged some investors and brokers from investing in utilities with nuclear plants underway, driving up the cost of capital for those utilities. Finally, negative public attitudes affect nuclear power's future in less tangible ways: The most gifted young engineers and technicians may choose other specializations, gradually reducing the quality of nuclear industry personnel. And, utilities simply may not choose nuclear plants if they perceive them as bad for overall public relations.

The future of nuclear power in the United States is very uncertain due to a variety of economic, financial, and regulatory factors outlined in other chapters of this report. Both parties to the nuclear debate are bringing these factors before the broader public. Some may argue that the issues are too complicated for the general public to contend with. However, as Thomas Jefferson said, "When the people are well informed, they can be trusted with their own government. " None of the conditions seen by utilities as a requirement for a revival of the nuclear industry–regulatory stability, rate restructuring, and political support-can be met without greater public acceptance. Thus, unless public opinion toward nuclear power changes, the future prospects for the nuclear industry will remain bleak.

THE EXPERTS' VIEW

In contrast to the public, most "opinion leaders," particularly energy experts, support further development of nuclear power. This support is revealed both in opinion polls and in technical studies of the risks of nuclear power. A March 1982 poll of Congress found 76 percent of members supported expanded use of nuclear power (50. In a survey conducted for Connecticut Mutual Life Insurance Co. in 1980, leaders in religion, business, the military, government, science, education, and law perceived the benefits of nuclear power as greater than the risks (19). Among the categories of leaders surveyed, scientists were particularly supportive of nuclear power. Seventy-four percent of scientists viewed the benefits of nuclear power as greater than risks, compared with only 55 percent of the rest of the public.

In a recent study, a random sample of scientists was asked about nuclear power (62). Of those polled, 53 percent said development should proceed rapidly, 36 percent said development should proceed slowly, and 10 percent would halt development or dismantle plants. When a second group of scientists with particular expertise in energy issues was given the same choices, 70 percent favored proceeding rapidly and 25 percent favored proceeding slowly with the technology. This second sample included approximately equal numbers of scientists from 71 disciplines, ranging from air pollution to energy policy to thermodynamics. About 10 percent of those polled in this group worked in disciplines directly related to nuclear energy, so that the results might be somewhat biased. Support among both groups of scientists was found to result from concern about the energy crisis and the belief that nuclear power can make a major contribution to national energy needs over the next 20 years. Like scientists, a majority of engineers continued to support nuclear power after the accident at Three Mile Island (69).

Of course, not all opinion leaders are in favor of the current U.S. program of nuclear development. Leaders of the environmental movement have played a major role in the debate about reactor safety and prominent scientists are found on both sides of the debate. A few critics of nuclear power have come from the NRC and the nuclear industry, including three nuclear engineers who left General Electric in order to demonstrate their concerns about safety in 1976. However, the majority of those with the greatest expertise in nuclear energy support its further development.

Analysis of public opinion polls indicates that people's acceptance or rejection of nuclear power is more influenced by their view of reactor safety than by any other issue (57). As discussed above, accidents and events at operating plants have greatly increased public concern about the possibility of a catastrophic accident. Partially in response to that concern, technical experts have conducted a number of studies of the likelihood and consequences of such an accident. However, rather than reassuring the public about nuclear safety, these studies appear to have had the opposite effect. By painting a picture of the possible consequences of an accident, the studies have contributed to people's view of the technology as exceptionally risky, and the debate within the scientific community about the study methodologies and findings has increased public uncertainty.

The Controversy Over Safety Studies

The Atomic Energy Commission (AEC) completed its first major study of the consequences of a reactor accident involving release of radioactivity in 1957. Commonly known as WASH-740, the study was based on a very small (by today's standards) 165-megawatt (MW) hypothetical reactor. In the worst case, an accident at such a plant was estimated to kill 3,400 people (5). While the study itself did not become a source of public controversy, its findings contributed to concern about the impacts of an accident.

In 1964, AEC initiated a new study to update WASH-740 based on a larger, 1,000-MW reactor. The study team found that a worst-case accident could kill as many as 45,000 people but was unable to quantify the probability of such an accident. Rather than publish these disturbing findings, AEC chose to convey the results to Congress in a short letter. Nuclear critics were very disturbed by this action, which they viewed as an attempt to keep the facts away from the public (22). In recent years, awareness of AEC's handling of this early safety study has added to public skepticism about the credibility of both that agency and its successor, the NRC.

In 1974, AEC published the first draft of the Reactor Safety Study, also known as WASH-1400 or the Rasmussen report. A panel of scientists organized by the American Physical Society (APS) found much to criticize in this report. The panel noted that AEC's fatality estimates had considered only deaths during the first 24 hours after an accident, although radioactive cesium released in an accident would remain so for decades, exposing large populations to adverse effects. The most serious forms of illness resulting from a reactor accident, the APS reviewers argued, would be forms of cancer that would not show up until years after the accident. Other APS reviewers found fault with the Rasmussen report's methods used to predict the performance of emergency cooling systems (23).

On October 30, 1975, the NRC, which had assumed the regulatory functions of the former AEC, released the final version of WASH-1400. Again, there was an extensive, widely publicized debate over the document. The Union of Concerned Scientists released a 150-page report critiquing the study, and in June 1976, the House Subcommittee on Energy and Environment held hearings on the validity of the study's findings (71). As a result of these hearings, NRC agreed to have a review group examine the validity of the study's conclusions.

Three years later, in September 1978, the review group concluded that although the Reactor Safety Study represented a substantial advance over previous studies and its methodology was basically sound, the actual accident probability estimates were more uncertain than had been assumed in the report (35). The panel also was critical of the executive summary, which failed to reflect all of the study findings. The following January, the NRC accepted the conclusions of the review panel. In a carefully worded statement, the agency withdrew its endorsement of the numerical estimates contained in the executive summary, said that the report's previous peer review within the scientific community had been "inadequate," and agreed with the panel that the disaster probabilities should not be used uncritically (47).

Two studies published in 1982 continued the debate over the validity of accident probability estimates included in the Rasmussen report. The first, conducted by Science Applications, Inc. (SAI) for the NRC, was based on the actual operating history of U.S. reactors during the 1969-79 period. By examining the frequency of precursors that could lead to an accident involving core damage or meltdown, SAI estimated that the probability of such an accident during the pre-TMI decade was much greater than suggested by the Rasmussen report (43). In response, the Institute for Nuclear Power Operations (INPO—a nuclear industry safety research group) published a report arguing that SAI's probability estimates were about 30 times too high, and that the actual probability of a core-damaging accident was closer to the 1 in 20,000 reactor years estimated in the Rasmussen report (28). This controversy has not yet been resolved.

While debate over the SAI report was limited to a small community of safety experts, a more recent study aroused a widespread public controversy that continued for several weeks. This analysis, known as the Sandia Siting Study, was initiated to determine the sensitivity of the consequences of reactor accidents to local site characteristics (2). While the Sandia team did not study accident probabilities in depth, they estimated the probability of a "Group 1" or (worst-case) accident involving a core meltdown, failure of all safety systems, and a large radioactive release, at 1 in 100,000 reactor years. The consequences of this and other less severe hypothetical accidents were estimated for 91 U.S. reactor sites using local weather and population data and assuming a standard 1, 120-MW reactor. At the current site of the Salem, N. J., reactor on the Delaware River under the most adverse weather conditions and assuming no evacuation of the local population, a Group 1 accident at the hypothetical reactor was estimated to cause 102,000 "early" deaths within a year of the accident. If the hypothetical reactor were located at Buchanan, N. Y., where the Indian Point plant now stands, a Group 1 accident under the worst-case weather conditions (the accident would be followed by a rainout of the radioactive plume onto a population center) might cause $314 billion in property damage, according to the study estimates.

Although the Sandia report itself did not include estimates of the "worst-case" accident consequences, background information containing the estimates and a copy of the draft report were leaked to the press on November 1, 1982. Media accounts that day highlighted the high death and property damage estimates, while downplaying that part of the analysis which indicated that consequences of this severity had only a 0.0002-percent chance of occurring before 2000 (51). Some accounts suggested that the worst-case consequences had the same probability as the Group 1 or worst-case accident, which was estimated to have a 2-percent chance of occurring before the end of the century.

That same day, the NRC held a press conference to clarify the purpose and findings of the study, and on November 2, Sandia National Laboratory issued a statement saying that wire service accounts "seriously misinterpret the consequences of nuclear power reactor accidents. The probability of a very severe nuclear power reactor accident is many thousands of times lower than stated in these accounts" (63). The nuclear industry took out full-page ads in major national papers to try to counteract the story. At the same time, however, nuclear critics emphasized that the Sandia draft report itself had excluded the worst-case consequence data and argued that "the NRC is once again feeding selective data to the public on the theory that they know best what information the public should have" (73). While nuclear advocates argued that the report's findings on accident consequences had been greatly overstated by the press, critics charged that data were used incorrectly in developing those estimates. Examining the same information on accident probabilities at individual plants used by the Sandia team, the Union of Concerned Scientists found that the likelihood of an accident involving a release of radioactivity might be much greater than assumed in the Sandia report (65). This debate, too, has not been resolved.

The Impact of Risk Assessments on Public Opinion

The release of the Rasmussen report raised particular concerns about nuclear power for some people because of the public disagreements among the "experts" that resulted. In June 1976 hearings held by the House Interior Committee, scientists from the Massachusetts Institute of Technology and Princeton and Stanford Universities, as well as a high-level official of the Environmental Protection Agency, testified about the methodological weaknesses and limitations of the report. Thus, as Princeton physicist Frank Von Hippel pointed out at the hearings, "Instead of dampening the fires of controversy, the publication of the Rasmussen report has had the effect of adding fuel to them" (71).

The controversy over the Rasmussen report, like the rest of the nuclear debate, contains many elements of "disputes among experts" as characterized by sociologist Alan Mazur: arguing past one another instead of responding to what the opposing expert has actually stated; rejecting data that develop the opponent's case; interpreting ambiguous data differently; and, consequently, increasing polarization (41). Both critics and supporters of the study focused on the methodology and quality of data. The debate over the study continues today, with critics arguing that NRC's 1979 statement was a "rejection of the report's basic conclusion," "repudiating the central finding of the Rasmussen report" (23). Meanwhile, INPO challenges the methodology and data of SAI's more recent safety study, arguing that the Rasmussen report's probability estimates are still valid.

Although the general public is uncertain about nuclear power, most people have more faith in scientific "experts" than in any other source on nuclear power questions (20,39,57). Because of this faith, public disputes among scientists and other energy experts, as in the case of the Rasmussen report, have a particularly negative impact on public acceptance of nuclear power. Rather than attempting to follow the debate and sort out the facts for themselves, many people simply conclude that nuclear technology has not yet been perfected. in other words, if the "experts" cannot agree on whether or not nuclear power is safe, the average citizen is likely to assume it is probably unsafe. In Austria, the government attempted to resolve the growing controversy over nuclear power by structuring a series of public debates among scientists with opposing views. Rather than reassuring the public, the debate led to increased public skepticism and ultimately to a national referendum that killed that country's commercial nuclear program.

If public debates about nuclear safety studies have only fueled the fires of controversy and added to public skepticism, what can be done to make nuclear power more acceptable to the public? In order to answer that question, we need a better understanding of the public's perceptions of nuclear power. In particular, it will be useful to compare the public's view of the risks of nuclear energy with the risks estimated by most nuclear experts. For example, if public perceptions of risk were based on misinformation, improved public education programs might be an appropriate response. However, this does not appear to be the case.

FACTORS INFLUENCING THE PUBLIC'S VIEW OF NUCLEAR SAFETY

Perceptions of Risk and Benefit

Studies of risk perception reveal a gap between lay people's judgment of nuclear hazards and the risks estimated by technical risk assessments. In a 1979 study by Decision Research two small groups of informed people in Eugene, Oreg. (college students and members of the League of Women Voters) were asked to compare the benefits and risks of a variety of activities, ranging from smoking to vaccinations to swimming. The benefits of nuclear power were viewed as negligible, and the risks were judged to be almost as great as motor vehicle accidents, which claim about 50,000 lives each year (68).

Although the two groups estimated that the number of deaths from nuclear power in an **average** year would be fewer than the number of deaths from any of the other activities or technologies, they used a very high multiplying factor to indicate how many deaths would occur in a "particularly disastrous" **year. Almost 40 percent of the respondents estimated more than 10,000 fatalities would occur within 1 year, and more than 25 percent** guessed there would be 100,000 fatalities. Many of the respondents expected such a disaster within their lifetimes, while the Sandia study suggests that there is only one U.S. reactor site–Salem, N.J.–at which an accident might cause as many as 100,000 "early" fatalities and estimates that these consequences have only a 10^{-6} or 0.000001 chance of occurring at that site. That analysis suggests that the average American (who does not live near that site) has an even lower probability of being killed within a year of a reactor accident. In general, it appears that public perceptions of the possible **consequences of an accident correspond somewhat with the findings** of the most recent technical studies, but that the **probability of such consequences is greatly overestimated.**

Data from the Netherlands confirm the public's perception of nuclear power as uniquely hazardous. Over 700 adults of varying ages, living at varying distances from industrial activities were asked to judge the "riskiness" of a wide range of activities in 1978 and 1979. Nuclear power was judged to be more risky than most of the other activities and technologies, including drunk driving, transporting chlorine by freight train, and working as a big-city policeman (74).

Several factors appear to enter into people's views of nuclear power as particularly risky. First, respondents in both the Netherlands and Oregon were concerned about the size of a potential accident and the lack of individual control in preventing an accident. In the Oregon study, nuclear risks also were seen as "unknown to the public and to science" and as particularly severe and dreaded. Both the Oregon study and opinion surveys show that about 40 percent of the American public believe that a nuclear plant can explode like an atomic bomb, even though such an explosion is physically impossible. Familiarity also played a role in people's judgments. In the Oregon study, nuclear risks were perceived as greater because they were unfamiliar. Another factor entering into risk perceptions was people's difficulty in assessing the probability of a reactor accident.

People's opinions about nuclear power and other "hazardous" activities and technologies are not determined by perceptions of risk alone. The perceived benefits offered by a technology must be weighed against the perceived risk in determining how acceptable the technology is. Most activities, including development of nuclear power, are undertaken initially in order to achieve benefits, not avoid losses, and for many activities the expected benefits far outweigh the potential losses.

in the case of nuclear power, perceptions of benefit may have played an important role in the trend of public opinion. During the 1950's and 1960's, when electricity demand was growing rapidly, the development of nuclear energy was promoted as a means to meet future demand and there was little apparent opposition to the technology. As electricity demand slowed in the 1970's and 1980's some people may have seen nuclear power as less vital to economic growth, so that concerns about risk became more prom inent in their assessments of the technology. Analysis of recent survey data indicates that judgments of "beneficiality" currently have a strong influence on Americans' acceptance of nuclear power. After safety, the second most important factor in support for nuclear power appears to be the belief that nuclear powerplants are necessary to reduce American reliance on foreign oil (57).

In both the Netherlands and the United States, people living near to nuclear plants have been more receptive to the technology. However, while the Netherlands study appeared to indicate a resigned acceptance of the risks of nuclear power, some surveys in the United States indicate that those living nearby are more aware of the benefits. For example, a majority of people living near Portland General Electric's (PGE's) Trojan Nuclear Station continued to approve of the plant following the accident at TMI in 1979, while customers throughout the entire PGE service territory were ambivalent (7). The primary reason cited for local support of the plant was that it produced needed power. Similarly, residents of the town closest to Maine Yankee nuclear station, who benefit from the jobs and taxes provided by the plant, continued to support the reactor through two statewide referendum votes in 1980 and 1982 which would have shut the plant down. Defeat of the two referendum votes appears to be based primarily on the perception of Maine voters that Maine Yankee provides needed low-cost electricity (see Case Studies).

Despite these favorable local attitudes toward some nuclear plants, opinion polls at other plants show that local support shifted to majority opposition following the accident at Three Mile Island (24). Analysis of survey data at one host community suggests that Federal safety standards are now seen as being too weak. It appears that national events which increase perceived risk can offset local perceptions of benefit.

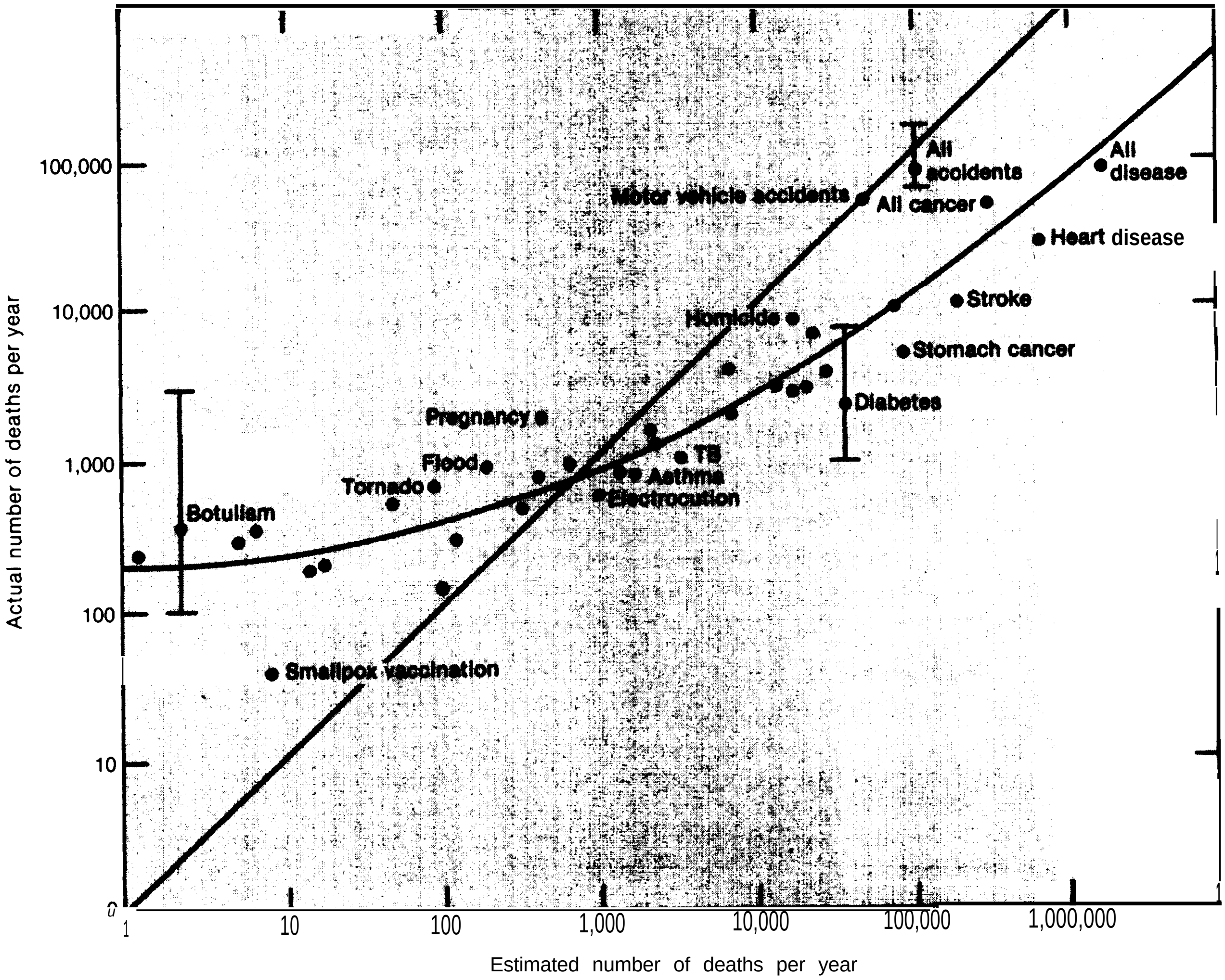
Psychological Factors

The apparent gap between technical studies of nuclear power risks and people's perceptions of those risks has led some observers to suggest that there is little thought involved in the public's view of nuclear power. instead, they argue, people react to nuclear energy on a purely emotional basis. For example, psychiatrist Robert DuPont argues that public concern about nuclear power is a "phobia" resulting from irrational psychological factors (1 7). Geographer Roger Kasperson cites frequently voiced concerns about genetic damage and cancer as evidence of the "emotional roots" of opposition to nuclear power, and psychiatrists Philip Pahner and Roger Lifton have suggested that fears of radiation from nuclear weapons have been "displaced" or "extended" to nuclear power (30,36,55).

Although there can be little doubt that emotional factors enter into the public's assessment of nuclear energy, further analysis of the public's view of risk indicates that the reasoning behind these opinions is more rational than first appears. First, while people may be inaccurate in their assessments of the probability of a catastrophic nuclear accident, they do not appear to overestimate the seriousness of such a catastrophe. Both proponents and opponents of the technology have an equally negative view of the deaths, illnesses and environmental damage that would result from a reactor accident (66). People who are concerned about nuclear safety do not view a radiation-induced death from a nuclear plant accident as significantly worse than a death from other causes, and they do not perceive genetic effects or other non-fatal consequences of such an accident as worse than death. The central area of disagreement between the experts and the concerned public lies in the area of greatest uncertainty even among the experts: the probability and impacts of a major accident (21).

Secondly, lay people appear to rely on somewhat logical internal "rules of thumb" in assessing the magnitude of various risks. As shown in figures 40 and 41 people's assessments of the risks associated with various diseases and technologies correlate fairly well with statistical estimates of the risks. While the **relative riskiness of the various activities was judged somewhat accurately, respondents in the Decision Research study tended to overestimate the risks of low-frequency events. According to the research team, this error results from people's assumption that an event is likely to recur in the future if past instances are easy**

Figure 40.— Relationship Between Judged Frequency and the Actual Number of Deaths per Year for 41 Causes of Death



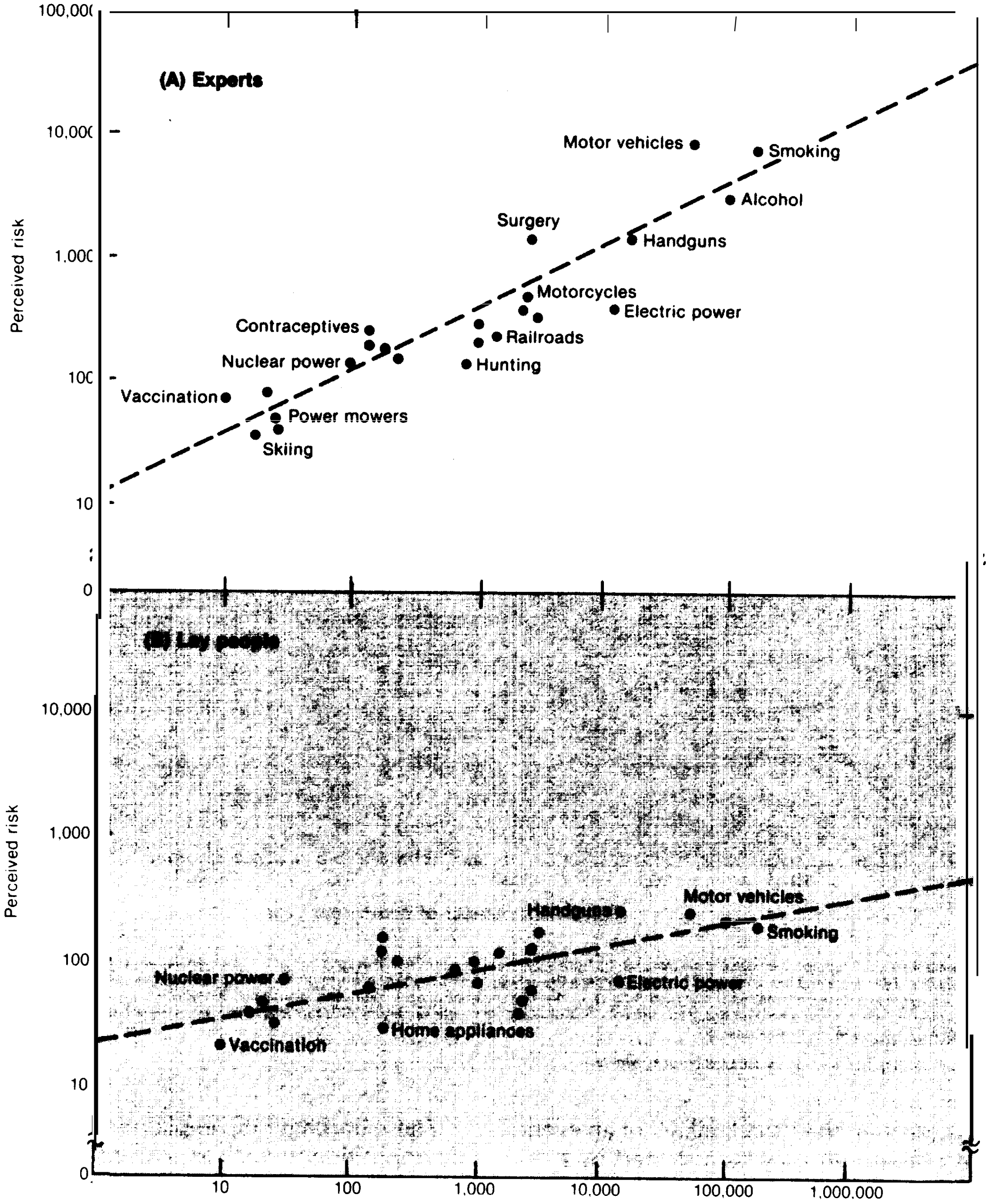
NOTE Respondents were told that about 50,000 people per year die from motor vehicle accidents. If judged and actual frequencies were equal, the data would fall on the straight line. The points and the curve fitted to them represent the averaged responses of a large number of lay people. While people were approximately accurate, their judgments were systematically distorted. To give an idea of the degree of agreement among subjects, vertical bars are drawn to depict the 25th and 75th percentile of individual judgment for botulism, diabetes, and all accidents. Fifty percent of all judgments fall between these limits. The range of responses for the other 37 causes of death was similar.

SOURCE: Slovic, et at. (68). Reproduced by permission of P. Slovic.

to recall. Moreover, the "availability" of an event in people's memories may be distorted by a recent disaster or vivid film. Because life is too short to actually experience all the hazards shown in figures 40 and 41, people tend to focus on dramatic and well-publicized risks and hence to overestimate their probability of occurrence (68).

These findings help explain the increased public opposition to nuclear power reported in opinion polls over the past decade. Nuclear power's historic connections with the vivid, imaginable dangers of nuclear war lead people to associate the technology with catastrophe. Accidents such as the fire at Browns Ferry and the near-meltdown

Figure 41.—Expert and Lay Judgments of Risk Plotted Against Technical Estimates of Annual Fatalities



NOTE: Each point represents the average responses of the participants. The broken lines are the straight lines that best fit the points. If judged and technically estimated frequencies were equal, the data would fall on the solid line. The experts' risk judgments are seen to be more closely asociated with technical estimates of annual fatality rates than are the lay judgments.

SOURCE: Slovic, et al., (68). Reproduced by permission of P. Slovic.

Photo credit: **William J. Lanouette**

In May 1979, 2 months following the Three Mile Island accident, there was a demonstration of about 200,000 people on the U.S. Capitol Grounds. Speakers urged the U.S. Congress to curtail further nuclear construction

at TMI have added to the image of disaster in people's minds. The publicity surrounding these events, movies and books such as "The China Syndrome" and We *A/most Lost Detroit,* and the estimates of deaths in various safety studies have further enhanced the "availability" of nuclear power hazards in people's minds, creating a false "memory" of a disaster that has never occurred at a commercial nuclear reactor. Public education about nuclear safety systems, by identifying the various hazards those systems are designed to guard against, may only serve to increase the perceived risks of the technology.

The Decision Research analysts also compared lay judgments of risks with the judgments of nationally known professionals in risk assessment (see fig. 41). The judgments of experts were much closer than those of the lay people to statistically calculated estimates of annual fatalities associated with various risky technologies and activities (21). However, while the experts knew more facts, their risk assessments also were found to be greatly influenced by personal judgment. Thus, expert studies also are subject to errors, including overconfidence in results and failure to consider the ways in which humans can affect technological systems. This latter problem was demonstrated clearly during the TMI accident, which was caused in part by human error.

Because technical experts, like the general pub lic, face limitations in evaluating the risks posed by nuclear power, it appears that there may be no single right approach to managing the technology. instead, it is most appropriate to involve the public in order to bring more perspectives and knowledge to bear on the problem. There are at least two other reasons for involving the public in decisions about nuclear energy. First, without public cooperation, in the form of political support, observance of safety rules, and reasonable use of the court system, nuclear power cannot be managed effectively. Second, as a democracy, we cannot ignore the beliefs and desires of our society's members (2 l).

While public perspectives already are reflected to some extent in NRC decisions, further efforts could be made to involve the public. More research could be conducted to define and quantify public opinion, and dialog with nuclear critics could be expanded with more attention paid to the substance of their concerns. Perhaps the most important step in reducing public fears of nuclear power is improved management of operating reactors to eliminate or greatly reduce accidents and other operating difficulties. Even though accidents at commercial reactors in the United States have never caused a civilian death, the public views both accidents and less serious events at operating reactors as precursors to a catastrophe. An accident with disastrous consequences already is viewed as being much more likely than technical studies and experts project, and any continuation of accidents or operating problems will tend to confirm that perception. Approaches to increasing public acceptance are discussed in the conclusion of this chapter.

VALUES AND KNOWLEDGE

Which is More Important?

Some analysts of public opinion have argued that basic values—those things that people view as most morally desirable—play a relatively small role in influencing people's attitudes toward nuclear power. For example, Mazur has argued that most of the general public, unlike energy activists, do not "embed their positions for or against a technology in a larger ideological framework of social and political beliefs" (41). In addition, nuclear advocates sometimes suggest that it is primarily a lack of knowledge which leads people to oppose nuclear energy, and that better education programs would increase public acceptance (1 3,42). However, as discussed below, the available evidence calls both arguments into question.

Although energy experts who are very knowledgeable about nuclear power generally support the technology, studies of the effects of slightly increased knowledge on attitudes among the broader public have yielded mixed conclusions. Two studies found greater support for nuclear power among more knowledgeable persons, but another found the opposite, and several studies have found no significant relationship (46). For example, a 1979 survey conducted just prior to the TM I accident revealed only a very weak relationship between knowledge about nuclear power and support for the technology among the general public. These findings supported a "selective perception" hypothesis in which those strongly favoring or strongly opposing nuclear energy selected and used information to bolster their arguments. Attitudes toward nuclear power among all respondents were influenced heavily by preexisting political beliefs and values (58). These results could help to explain why the accident at TMI appeared to have little impact on some people's opinions about safety. For those who already were firmly convinced that nuclear power was safe, the accident confirmed the effectiveness of safety systems. For those who were skeptical, it reinforced uncertainties.

A recent analysis of national survey data provides additional evidence that people's values and general orientations may be stronger determinants of nuclear power attitudes than specific knowledge about energy or nuclear power issues. In this study, sociologist Robert Mitchell tested the strength of the correlation between various "irrational" factors—such as belief that a nuclear plant can explode–and people's assessments of reactor safety. While the analysis showed that the public was generally misinformed about energy issues, this lack of knowledge appeared to have little effect on attitudes toward nuclear safety and hence on overall attitudes toward nuclear power. When Mitchell went onto test the correlation between values and attitudes toward reactor safety, he found a much stronger relationship. Environmentalism was associated closely with concern about nuclear safety among women, while skepticism about whether the future benefits of scientific research would outweigh the resulting problems appeared to have a strong influence on men's concerns about reactor safety (46). Several other studies also indicate that values have played an important role in both the growth of the antinuclear movement and continued support for nuclear power (8,27,32).

Values

A value has been defined as "an enduring belief that a specific mode of conduct or end-state of existence is personally or socially preferred" (61). While all people share the same values to some degree, each individual places different priorities on different values. This ordering of the absolute values we are taught as children leads to the development of an integrated set of beliefs, or value system. Because values have their origins in culture and society, changes in societal expectations can, over time, lead to changes in an individual's value system.

During the 1960's and 1970's, the emergence of new social movements both reflected and encouraged changes in the priority some Americans placed on different values. Values that appeared to become more prominent to many people included equality of all people, environmental beauty, and world peace. Critics of nuclear power (and, to a lesser extent, proponents) were successful in attracting broader public support by appealing to these emerging values, and by linking their organizing efforts with the related peace, feminist, and environmental movements. Until a convincing case is made that nuclear power is at least as consistent with these values as other energy sources, it will have difficulty gaining acceptance with those who place a high priority on these values.

Overall, Americans are very supportive of science and technology, viewing them as the best routes to economic progress (39). The public's enthusiasm is reflected in the current computer boom and in the emergence of a flood of science magazines such as Omni, ***Discover, Science*** 83, and Technology as well as new television programs including "Cosmos," "Life on Earth," and "Nova," and the reliance on high technology by both major political parties. However, this support is tempered by a growing concern about the unwanted byproducts of science, including accelerating social change, the threat of nuclear war, and environmental pollution. The National Opinion Research Center recently compared a national poll of adult attitudes toward science taken in 1979 with a similar survey conducted in 1957. They found that, over the 20-year period, an increasing number of survey respondents believed that "science makes life change too fast" or "breaks down people's ideas of right and wrong." The percentage of respondents who believed that the benefits of science outweigh the harms declined from 88 percent in 1957 to 70 percent in 1979 (46). This curious duality of attitudes may help to explain the public's ambivalent attitude toward nuclear power. While acceptance of the technology has declined, the rate of change has been slow, and votes on referenda have demonstrated that Americans are unwilling to forego the nuclear option entirely.

One of the most undesired products of modern science is the threat of nuclear war. Because of the technological and institutional links between nuclear power and nuclear weapons, opposition to buildup of nuclear weapons leads some people also to oppose development of civilian nuclear energy. AEC, which developed and tested weapons after World War II, was the original promoter of commercial nuclear power. In the late 1950's and early 1960's, growing public concern about radioactive fallout from AEC's atomic bomb testing provided a context for increasing fears about the possibility of radioactive releases from nuclear powerplants. Some prominent scientists spoke out against both nuclear power and nuclear weapons, and links developed between groups opposing the arms race and nuclear power (48). However, after the United States and the Soviet Union signed the Nuclear Test Ban Treaty in 1963, concerns about both nuclear fallout and nuclear power temporarily subsided.

Since the mid-1970's, rapid international development of nuclear power and growing global tensions have led to increasing concern about the possible proliferation of nuclear weapons from nuclear power technologies. Organizers in the peace movement and nuclear critics have built on this concern in an attempt to renew the early linkages between the two movements. Case studies of the Maine Yankee and Diablo Canyon nuclear plants indicate that concern about nuclear weapons contributed to opposition to these plants during the late 1970's and early 1980's (see Case Studies).

Today, a single Federal agency–the Department of Energy—still is responsible for research and development of both nuclear weapons and commercial nuclear power. in addition, some private firms are involved in both nuclear energy and nuclear weapons. These connections encourage a linkage in people's minds between the peaceful and destructive uses of nuclear energy. Due to growing concern about the rapid buildup of nuclear weapons, some groups critical of nuclear energy are shifting resources toward weapons issues. However, most local groups and national organizations continue their efforts to improve the safety of nuclear power as they expand their focus to include nuclear weapons. The linkages between environmental and energy groups and anti-nuclear weapons groups may strengthen the environmental groups and help them maintain their criticism of commercial nuclear power (33).

On the pronuclear side of the debate, organizers have emphasized the importance of nuclear power to national energy independence which is in turn linked with national security. Analysis of 10 years of public opinion polls indicates that a view of nuclear power as an abundant American resource which could reduce foreign oil dependence is a very important factor in favoring continued development of nuclear power (57).

One of the most important values to affect opinions on nuclear power is environmentalism. A 1972 poll by Louis Harris&Associates indicated that many Americans believed that the greatest problem created by science and technology was pollution (46). Polls taken in 1981 indicate that most Americans continue to strongly support environmental laws despite recessions and an increasing skepticism about the need for government regulation of business (4).

The role of the environmental movement in coalescing and leading the criticism of nuclear power has been well-documented. The first national anti-nuclear coalition (National Interveners, formed in 1972) was composed of local environmental action groups (40). By 1976, consumer advocate Ralph Nader, who later became allied with the environmental movement "stood as the titular head of opposition to nuclear energy" (30). Today, all of the major national environmental groups are opposed to at least some aspects of the current path of nuclear power development in the United States. While some of the groups do not have an official policy opposing nuclear power, their staffs stay in close communication, and there is substantial cooperation and support on nuclear energy issues (33). A list of these groups is shown in table 32.

Both sides of the nuclear debate have emphasized environmental concerns to influence public opinion. in the late 1960's and early 1 970's, opponents of local nuclear plants most frequently pointed to specific environmental impacts, such as thermal pollution, low-level radiation, or disruption of a rural lifestyle as reasons for their opposition. During that same period, nuclear proponents increasingly emphasized the air-quality benefits of nuclear power when compared with coal (41). Today, environmentalist opponents of nuclear power are more concerned about broad, generic issues such as waste disposal, plant safety, weapons proliferation, and "a set of troublesome value questions about high technology, growth, and civilization" (30). This evolution of concerns is demonstrated in two case studies of local opposition to nuclear plants. In these cases, environmentalists at first did not oppose the local nuclear plant because it offered environmental benefits when compared with a coal plant. However, those positions were later reversed (see Case Studies).

Along with environmentalism, people's general orientations toward economic growth appear to influence their attitudes about nuclear power. In

1971, political scientist Ronald Inglehart identified a shift in the value systems of many Americans away from a "materialist" emphasis on physical sustenance and safety and toward "post-materialist" priorities of belonging, self-expression, and the quality of life. At that time, he hypothesized that this shift could be attributed to the unprecedented levels of economic and physical security that prevailed during the 1950's and 1960's. Based on analysis of more recent surveys, Inglehart argued in 1981 that, despite economic uncertainty and deterioration of East-West detente, post-materialist values are still important to many Americans. And, he says, those who place a high priority on post-materialist values "form the core of the opposition to nuclear power" (27).

Like Inglehart, psychologist David Buss and his colleagues have observed two conflicting value systems or "worldviews" among Americans (71). Using in-depth interviews with a random sample of adults from the San Francisco area, they identified "Worldview A" which favors development of nuclear power as an important component of a high-growth, high-technology, free enterprise society, and "Worldview B" which includes concern about the risks of nuclear power along with an emphasis on a leveling off of material and technological growth, human self-realization, and participatory decisionmaking.

While different priorities within Americans' value systems appear to influence attitudes toward nuclear power, it is important to recognize that the public is not completely polarized. Inglehart noted that "post-materialist" values can only be given priority when basic human needs are met, making both priorities essential to individuals and to American society (27). An extensive national survey of attitudes toward growth conducted in 1982 indicates that the public may be developing a new perspective that includes **both** a desire to ensure opportunities for development and concerns about environmental quality (60). In this survey, few respondents could be classified as totally favoring either resource preservation or resource utilization, and the majority appeared to be quite balanced in their views on economic growth. Those who leaned toward resource preservation were more opposed to nuclear power than those who favored resource utilization. However, even among those who most strongly supported resource utilization, so percent indicated that no more nuclear powerplants should be built.

Views about "appropriate technology" as defined by the British economist, E. F. Schumacher, may also affect attitudes toward nuclear energy. Most members of mainstream environmental groups share this view, which endorses technologies that are inexpensive, suitable for small-scale application, and compatible with people's need for creativity (44,64). In 1976, Amory Lovins brought nuclear energy into the middle of this technology debate with publication of his article, "Energy Strategy: The Road Not Taken" in *Foreign Affairs* magazine. In that article, Lovins argued that America's energy needs could be met by the "soft energy path" of conservation, renewable energy and other appropriate technologies, and rejected nuclear energy as unneeded, centralizing, and environmentally destructive (37). These concerns were found important in the local opposition to one case study plant (see Case Studies). Residents of that rural area at first objected to the plant on the basis that its electricity was not needed locally, and that the locality should not have to bear the impacts of plant construction when it would not reap the benefits. Later objections were based on the contention that the electricity produced would not be needed anywhere in the surrounding three States.

Advocates of the appropriate technology philosophy fear that increased use of nuclear power will lead to a loss of civil liberties and individual freedom, and decreased world stability due to weapons proliferation. The extent to which these views have been accepted by the American public is difficult to ascertain. National opinion polls showing that the majority of Americans prefer solar energy to all other energy sources and view nuclear power as the least-favored energy option would appear to reflect such values (57). A recent survey conducted in the State of Washington shows that large majorities there share Lovins' view that it is possible to have **both** economic growth and energy conservation (54). In addition, many people, even those skeptical of renewable energy, share Lovins' distrust of large centralized organizations (utilities and the government) that promote nuclear energy.

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Another shift in American value systems that may help to account for increased opposition to nuclear power is a growing distrust of institutions and their leaders in both the public and private sectors. The Vietnam War and the Watergate investigation contributed to growing public cynicism about the Federal Government during the 1960's and 1970's. By 1980, an extensive survey of Americans revealed a dramatic gap between the public and leaders in both government and industry on questions of politics, morality, and the family. Religious values were found to be of profound importance to the majority of Americans, and respondents indicated that they placed a greater emphasis than before on the moral aspects of public issues and leadership (59).

Some early supporters of nuclear power, including prominent environmentalists, felt betrayed by the nuclear establishment when new information about the uncertainties of the technology became known. The nuclear industry's early denials of the possibility of accidents, and the Government's handling of safety studies have contributed to the critics' and broader public's skepticism. Some critics have expanded their activities from examination of technical safety issues to include critiquing the nuclear regulatory process, and groups that formerly were concerned primarily with "watch dogging' Federal agencies have entered the nuclear debate. These activities, and Daniel Ford's recent book, The ***Cult of the Atom,*** which focuses primarily on regulatory "misdeeds" in the early nuclear program, may contribute to the public's disillusionment with government in general and the NRC in particular.

The American public's growing concern with leadership applies to business as well as government. Americans increasingly are skeptical of the ability of both the public and private sectors to produce quality work. According to Loyola University professor of business ethics Thomas Donaldson, survey data indicate that, despite an improving corporate record, the public has become increasingly disappointed with corporate ethics over the past 20 years. Corporations now are viewed as "part of the overall social fabric that relates to our quality of life," not merely as providers of goods and services (1 5).

This growing skepticism about industry and government was reinforced by the accident at Three Mile Island. Post-TMl polls indicate that less than half of the public were satisfied with the way the accident was handled by Pennsylvania State officials and the NRC, and Americans were even less pleased with the utility (General Public Utilities) and the plant designer (57). One observer has described public reaction to the accident as "essentially a crisis in confidence over institutions" (30). A feeling that the nuclear utility was being dishonest helped spark the first referendum to shut down Maine Yankee, and events at Diablo Canyon led to nationwide doubts about the credibility of the nuclear industry (see Case Studies).

A final societal change that has been closely intertwined with negative attitudes toward nuclear power is the growth of the women's movement. Public opinion polls over the past 20 years have shown a strong correlation between gender and attitudes toward nuclear power: Women are consistently more opposed (41). While the strength of this correlation is well-known, the reasons for it are not clear. Environmental values and having young children have been linked with women's opposition to nuclear power (46). Sociologist Dorothy Nelkin argues that women's distrust of nuclear power cannot be attributed to a greater aversion to risk **in general.** Instead, Nelkin's analysis of women's magazines and the feminist press suggests that women's opposition begins with the specific risk of cancer in the event of a major radioactive release from a reactor. personal value priorities, including some women's view of themselves as nurturers or "caretakers of life, " also lead them to oppose what they view as a life-threatening technology (49).

These connections have helped to bring nuclear power as an issue into the mainstream of the women's movement. Women's magazines ranging from Redbook to ***Ladies Home Journal*** to ***Ms.*** have questioned nuclear safety, and the national Young Women's Christian Association (YWCA) took a public stand against nuclear power in 1979. The League of Women Voters has developed a national policy favoring only limited construction of new reactors, and the League's local affiliates have taken even stronger anti-nuclear stands. In 1980, the National Organization for Women (NOW) recommended a resolution opposing the "use of nuclear power in favor of safer energy methods" (49).

While changing value priorities appear to have contributed to increasing public concern about nuclear power over the past 20 years, those priorities could change again in the future. In addition to values, knowledge about accidents at nuclear plants has played a major role in shaping public attitudes. In the future, new information on improved management of nuclear power could lead to a reversal of the current trend of increasing opposition to the technology.

THE ROLE OF THE MEDIA

Both the amount and type of news coverage have played an important role in shaping public attitudes toward nuclear power. As noted previously, people tend to overestimate the probability of certain hazards, including nuclear powerplant accidents, in part because these hazards are discussed frequently in the media.

The Extent of Media Coverage of Nuclear Power

The most detailed analysis of print media coverage of nuclear power currently available is based on the number of articles on the subject indexed in the yearly Readers' Guide to ***Periodical Literature.*** In this study, sociologist Al Ian Mazur compared trends in media attention with trends in public opinion as revealed by national opinion surveys, numbers of plant interventions, and size of protests. This analysis suggested the following three hypotheses (41):

1. The greater the **national concern over a major issue** that is complementary to a particular protest movement, the more easily resources can be mobilized for the movement, and therefore the greater the **activity of protesters.**
2. As the **activity of protesters increases, mass media coverage of the controversy** increases.
3. As **mass media coverage** of the controversy increases, the **general public's opposition** to the technology increases.

At the time of the first citizen intervention against a nuclear plant in 1956, there was a great deal of positive mass media coverage of president Eisenhower's "Atoms for Peace" program. In the early 1960's, most coverage was still positive, but a few protests against local plants—particularly the large demonstration at a proposed nuclear plant site on Bodega Bay, Calif., in 1963–received national publicity. During the mid-1 960's, there was a decrease in both the number of periodical articles on nuclear power and in public opposition as measured in opinion polls. This decline reflected a shift in public concern and media attention away from nuclear issues and toward civil rights and other domestic issues. Beginning in 1968, magazine articles on nuclear power increased to cover local plant siting disputes. Print media coverage rose even higher in 1969, and opinion polls showed a similar peak of opposition the following year.

From 1974 to 1976, anti-nuclear activism and media coverage again increased, with a great deal of national publicity given to the 1976 California referendum. After 1976, both negative public opinion and media coverage fell off, then rose slightly in 1978 and early 1979 and finally rose massively following the accident at TMI in the spring of 1979. Trends throughout 1979 appeared to confirm the linkage between media coverage and public opinion: Public opposition rose sharply immediately following the accident, subsided within 2 months as media attention diminished, and then increased slightly during October and November, coinciding with media coverage of the final Kemeny Commission report **(41).**

Mazur argues that opposition to a technology such as nuclear power will snowball with increased media coverage, whether that coverage is positive or negative (40). The fluoridation controversy of the 1950's and 1960's, like the cur-

Photo credit: Washington Public Power System

A crowd of about 10,000 people protest the mothballing of Nuclear Power Plant No.1 of the Washington Public Power System

rent nuclear power debate, involved complex scientific judgments and pitted the "established order" against advocates of local self-control. During this period of public debate, persons exposed to both positive and negative arguments about fluoridation were more likely to oppose the practice than persons who had heard neither argument, and communities where there had been heated debate were most likely to defeat fluoridation in a referendum. The prominence given to disputes between technical experts over the risks of a technology appears to create uncertainty in people's minds, which in turn raises concern and opposition, regardless of the facts under discussion. If this is true, the media play a key role in encouraging public opposition by giving extensive coverage to the experts' disputes.

Analysis of the extent of television news coverage of nuclear power has been much more limited than analysis of print media coverage. Television nightly newscasts made relatively little mention of nuclear power over the decade preceding the accident at TMI. Within the overall low level of reporting, the trends were somewhat similar to those in the print media: Coverage increased in 1970, and then dropped off again until 1976, with greater coverage between 1976 and 1979 *(70).*

The Content of Media Coverage

Just as there can be little doubt that media coverage influences public opinions toward nuclear power, there also is little doubt that journalists, like most Americans, are ambivalent about this technology. In a 1980 survey, similar percentages of media personnel and the public (about 55 percent) viewed the benefits of nuclear power as greater than the risks, while other "leadership groups" were much more supportive of nuclear energy (59). In another study, attitudes toward nuclear power were measured on a scale ranging from -9 to +9, with a higher score indicating greater support for nuclear power. While scientists were quite supportive of the technology with an average score of 3.34, science journalists were much more skeptical, with an average score of 1.30, and journalists reporting on general issues for major national newspapers *were* slightly less supportive of nuclear power than science journalists, with an average score of 1.16 (62).

Following the accident at TMI, the Kemeny Commission found that the public's right to information had been poorly served. Confusion and uncertainty among the sources of information combined with a lack of technical understanding by the media personnel were identified as contributing to the problem. Many of the reporters "did not have sufficient scientific and technical background to understand thoroughly what they heard." As a result of these difficulties in reporting on emergencies, the commission recommended that all major media outlets hire and train nuclear energy specialists and that reporters educate themselves about the uncertainties and probabilities expressed by various sources of information (31).

The media's need for balance in coverage of many issues, including nuclear power may lead to understatement of the scientific consensus that the technology is acceptably safe. Media personnel are expected to bring various viewpoints before the public, and in the case of a controversial technology such as nuclear power, this generally means quoting both an advocate and a critic in any given story. One analysis of television news coverage showed that over the decade prior to Three Mile Island, most news stories dealing with nuclear power began and ended with "neutral" statements (70). However, among the "outside experts" appearing most frequently in the stories, 7 out of 10 were critics of nuclear power. Thus, while meeting the requirement of presenting opposing views, these stories may have oversimplified complex issues and failed to convey the prevailing consensus among scientists and energy experts. Psychiatrist Robert DuPont, after viewing the same 10 years of television stories used in this analysis, suggested that fear, especially of nuclear accidents, was the underlying motif in all of the stories (16). Another study of 6 years of television news stories about various energy sources found that the risks and problems of nuclear power were emphasized, coal was given neutral treatment, and solar power was treated euphorically (56).

While these studies suggest that television coverage of nuclear power emphasizes the risks of the technology, there is no evidence that media personnel deliberately bias their coverage of nuclear power due to personal convictions. The Kemeny Commission found that overall coverage of the TMI accident was balanced although at times confused and inaccurate. One of the biggest factors in inaccurate reporting at TMI was found to be the lack of reliable information available to the media. For example, national reports that the hydrogen bubble inside the reactor could explode within 2 days were an accurate reflection of the views of NRC's Washington office. Reporters, trusting these views and wanting to "scoop" other reporters, tended to disregard the onsite NRC officials who argued that the bubble could not possibly explode. However, overall, the Commission found a larger proportion of reassuring than alarming statements in both television and newspaper reporting of the accident.

Media coverage of nuclear power maybe influenced by the fact that journalists are trained to be skeptical of news sources, including the nuclear establishment. Informed critics have been successful in publicizing many cases in which the nuclear industry, the Department of Energy, and the NRC have not been completely open about safety problems. For example, during the first 2 days of the accident at Three Mile Island, Metropolitan Edison withheld information on the situation from State and Federal officials as well as the news media *(72).* According to the Kemeny Commission, the utility's handling of information during this period "resulted in the loss of its credibility as an information source" (31). Experiences such as this have led reporters to be particularly skeptical of nuclear industry sources and look to the critics for the other side of any given story.

Proponents of nuclear power are likely to view media treatment of nuclear plant safety issues as biased because of the inherent complexity of those issues. It is important that problems such as construction errors, skyrocketing costs, and operating difficulties be reported to the public. However, since few people (including reporters) understand nuclear technology well, problems may appear more threatening than they actually are. Considerable expertise is needed to sift the facts and accurately interpret them to the public. By comparison, the media are not considered anti-airplane, even though most coverage of that industry focuses on crashes. Because the public is unlikely to view a single plane crash as an indication that the entire airline industry is unsafe, the airline industry is confident that all airplanes will not be grounded. With no such assurances for nuclear power, the nuclear industry may view coverage of accidents as a threat to its survival.

Finally, it is important to note that journalists did not create the nuclear controversy. During periods of greatest public concern, their coverage of nuclear power has increased, which in turn has contributed to still greater public uncertainty. If the media are more critical of nuclear power now than they were in the 1950's, they may be reflecting public opinion as well as influencing it.

WHAT WOULD IT TAKE TO INCREASE PUBLIC ACCEPTANCE OF NUCLEAR POWER?

It is unlikely that utility executives will order any new reactors as long as they believe that a majority of their customers oppose nuclear energy. However, a societal consensus on the necessity for and benefits of the technology may be very difficult or impossible to attain. The previous analysis indicated that the general public and the staffs of some public interest groups are concerned about the possibility of a catastrophic reactor accident. They perceive that the technology offers few or no benefits compared to these risks. In addition, many Americans' personal values contribute to their skepticism of the technology and its managers. These value conflicts may prevent a total resolution of the current controversy. However, attitudes might change either as a result of external events (e.g., another oil embargo or new research findings on the environmental impacts of coal burning) or because of improvements made internally by government and the nuclear industry. External events cannot be controlled, but it is up to the nuclear establishment to demonstrate the safety and economic attractiveness of nuclear power.

Assuming that major improvements were made in management of nuclear power, it would still be difficult to communicate them to the public because of the present lack of trust in government and industry. There are some extremists on both sides of the nuclear controversy whose opinions will not change, regardless of the evidence placed before them. Even more moderate citizens, who are willing to change their opinion on the basis of new evidence, are influenced strongly by preexisting attitudes and values so that they may "filter out" or wrongly interpret new evidence. Finally, for the majority of the public, new information on improvements in utility management of nuclear power will be viewed skeptically unless presented in a manner that arouses trust and interest. However, while better communications are needed, the first and most important step is to make concrete improvements responding to public concerns.

Enhance Nuclear Advantages

Research conducted in the United States and the Netherlands suggests that people's judgment of a technology or activity is influenced as much by their assessment of its potential benefits as by their view of its risks. There are at least three potential benefits of nuclear power that could be perceived by the public: 1) its contribution to na-

Photo credit: William J. Lanouette

Protectors' tent at a demonstration against the Seabrook nuclear plant in May 1977

tional energy and electricity supply, 2) its potential cost advantage relative to other energy options, and 3) the fact that safely operated nuclear plants produce no fossil air pollution.

It is difficult for many Americans to see a need for nuclear powerplants at a time when electricity demand has slowed. While this slow growth is expected to continue over the next several years, new powerplants of some kind still will be needed in the years ahead. Regions experiencing rapid economic and population growth will need new capacity sooner than others. Plans could be developed at a regional level to evaluate the alternatives to meet demand growth. The planning process itself could become a vehicle for public participation, and any long-term cost advantages of nuclear power could be most clearly demonstrated to the public this way.

Under some conditions, nuclear electricity *can* be cheaper than its major competitor: electricity from coal combustion. Standardized plant designs, increased predictability in the licensing process, and improved management of operating reactors all could help to realize the technology's economic potential. New rate regulation systems also could be used to reduce the initial costs of new nuclear and coal powerplants to the consumer. Assuming all of these changes took place and nuclear electricity did indeed offer long-term cost advantages, public opposition to new plants in hearings before State PUCs very likely would be reduced.

However, coal is not the only alternative to nuclear power in meeting national energy needs. Conservation, oil shale, and renewable energy resources all can be used to match energy supply and demand but widespread application of these technologies could be expensive. In Maine, public rejection of a 1982 referendum to shut down Maine Yankee was based in part on recognition that conservation and renewable energy could not quickly make up for the inexpensive nuclear power lost by the shutdown (see Case Studies).

Paradoxically, accelerated R&D on these alternatives might enhance the image of nuclear power and could confirm that they may never be widely competitive. As part of accelerated R&D on alternative energy sources, the environmental costs and benefits of each source should be examined. Environmental groups currently are among the leading critics of nuclear power. These groups also are very concerned about the adverse impacts of coal combustion and other energy sources, and are monitoring research into those impacts. If this research indicated that acid rain was a more serious problem than presently perceived or that carbon dioxide buildup would result in near-term climatic changes, some environmentalists might become less negative about nuclear relative to coal. This shift, in turn, could change attitudes among the broader public.

Public relations or educational programs are unlikely to increase public awareness of nuclear power's potential benefits until those benefits are apparent. This might result either from events outside the industry's control which decrease availability of alternative energy sources (e.g., an oil disruption) or from improvements in management of the technology. Without such actions, public relations programs such as the current Committee for Energy Awareness campaign may have little impact, and possibly even a detrimental effect on public opinion. The response to this campaign from critics may increase public uncertainty and skepticism. Even programs viewed as unbiased by all sides, such as the League of Women Voters Education Fund's (LWVEF) "Nuclear Energy Education Program" carried out in 1980 and 1981, may do little to increase public acceptance until the costs of new nuclear powerplants are better controlled (34). Nevertheless, the low level of public understanding of nuclear technology does indicate a need for more information, and a number of organizations are involved in public awareness campaigns.

Reduce Concerns Over Nuclear Accidents

While increased awareness of nuclear power's benefits might decrease concerns about risk, one of the most favorable things that could happen to the nuclear industry over the next 10 years would be an increasing output of nuclear electricity along with an absence of events causing bad publicity. Presently, both TMI-type accidents and incidents such as the failure of the safety control system at the Salem, N. J., plant are viewed by the public as precursors to a catastrophe. Given the slow rate at which public support for nuclear power has declined, an extended period of quiet, trouble-free operations could have very positive impacts on public attitudes. Chapter 5 identifies a number of approaches to improved utility management of nuclear power, which, if implemented, could help to assure that neither major accidents nor precursors take place.

While a period of uneventful operation of nuclear plants is necessary to restore public confidence, it probably is not sufficient. Maine Yankee has had very high reliability but State voters have twice come close to shutting it down (see Case Studies). In addition, critics probably would remain skeptical. It would be important to demonstrate to them that the period of quiet operation was a result of real improvements and the beginning of a new trend, rather than just luck. However, given the present level of distrust between interveners, the NRC, and the nuclear industry, it might be very difficult to do this.

Several steps could be taken to improve communications between the nuclear community and public interest groups critical of nuclear power. An effort might be made to identify the concerns of particular groups and respond to the substance of those concerns. For example, some groups currently are concerned about insurance. A compromise on this issue might not decrease the groups' fundamental criticism of nuclear safety, but it could improve the climate and allow further negotiations to take place. If the current heated debate could become a reasoned ongoing dialog, the public might be less likely to view the technology as unsafe. As discussed previously, the prominence and stridency of the debate currently increases public uncertainty and encourages opposition.

As part of this effort, the Federal Government could actively encourage involvement of responsible interveners in both regulatory proceedings and long-range planning efforts through funding and other support. In Ontario, Canada, the independent Porter Commission funded knowledgeable nuclear critics to conduct studies and participate in extensive hearings as part of its long-term electricity planning. In the Commission's interim report, health problems caused by improper disposal of uranium mine tailings were identified, and environmental groups were acknowledged for bringing the issue to the public's attention. Similarly, based on testimony from leading critics, the commission found that the probability of a loss of coolant accident causing a meltdown at Ontario Hydro's heavy water reactors was much greater than the Canadian nuclear industry had claimed. Because the Commission not only sought critics' concerns but also acknowledged and responded to them, the process had the effect of moderating some groups' antinuclear positions (see vol. II).

Previous U.S. efforts to involve government, industry, and environmentalists in dialog or "environmental mediation" provide another model for improved communication. Nonprofit organizations such as the Conservation Foundation in Washington, D. C., as well as several private firms have brought all three parties together to discuss topics such as radioactive waste disposal and chemical waste management. By careful staff preparation and beginning the discussions with a common objective (e.g., safe disposal of toxic wastes), these forums have succeeded in developing preliminary agreements on Federal and industry policy.

Nuclear regulators and the industry can increase their credibility with both interveners and the public by emphasizing candor in their public information programs. Prior to the accident at Three Mile Island, the nuclear establishment created the impression that such an accident was so unlikely as to be "impossible." As a result, when the accident did happen, it greatly reduced the credibility of the regulators and the industry. The nuclear establishment should acknowledge that both operating events and more serious accidents can occur, attempt to educate the public about the difference between the two, and demonstrate its preparedness to deal with accidents. For example, TVA immediately reports to the media any event that could be considered newsworthy. This very open approach increases the utility's credibility with both the media and the public. Another positive example is offered by a Midwestern utility that encountered quality-assurance problems during construction. Once the company had greatly increased its construction management capabilities, it launched a public relations effort to educate the public about the problems and the steps it had taken to overcome them. These efforts appear to have increased local trust in the utility. (See Case Studies.)

Two approaches to siting policy might help alleviate the public's safety concerns. Both respond to the public's opposition to construction of new plants near where they live. First, as discussed earlier, some people living near nuclear plants tend to view them as less risky than people who are less familiar with the technology. While some polls show increasing opposition to nearby plants since the accident at Three Mile Island, support for other plants has remained high. This fact has led Alvin Weinberg and others to promote a "confined siting" policy, under which most new reactors would be added to existing sites, rather than creating new sites. This approach has been used successfully in Canada (see vol. Ii) and is supported by some U.S. environmental groups. It is most attractive in the East, where high population density makes remote siting infeasible.

The second approach to dealing with local opposition to new construction is to site new reactors at remote locations. This approach could incorporate "confined siting, " with new reactors clustered at existing remote sites. Alternatively, new sites in remote areas could be identified. In either case, public opposition to such plants could be expected to be much less than opposi-

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tion to new plants in densely populated areas. Opinion polls show that the majority of the public favors remote siting of reactors, and the potential impacts of a major accident would be reduced greatly by this approach. However, the costs of transferring the power to load centers would be much greater, and construction in remote areas might lead to adverse "boomtown" effects on nearby communities.

Public fears of a nuclear accident also might be reduced by controlling the rate of new plant construction. Nuclear critics, fearing the impacts of potential accidents and the possibility of a centralized, undemocratic "nuclear state," base their opposition in part on the rapid scaling up in size and number of reactors in the 1960's and 1970's and on the industry's early projections of a "plutonium economy." These concerns might diminish if the nuclear program were bounded. Some within the nuclear industry also favor a definition of the size of the plant construction program as a guarantee of Federal support for nuclear energy. However, if this definition of size were viewed as an absolute limit on the program, rather than a target to be reached, the public might view it as an indication of Government skepticism of nuclear power. A less drastic alternative would be to limit the **rate** of growth in total nuclear capacity by limiting the number of new construction permits granted in any one year. Current demand projections indicate that rapid growth of nuclear power is unlikely for many years, but a limit might provide reassurance to those who feel the only choices are to eliminate the option now or forever risk an uncontrolled resurgence.

After years of debate, Sweden passed a referendum in 1980 calling for completion of the 12 nuclear-generating units then under construction or planned, with a phaseout after 25 years (the expected lifetime of the plants). While this compromise might seem to offer little future for nuclear power, it did allow construction of six new nuclear plants, with the result that over half the country's electricity is now nuclear. In the United States, a compromise under which regulators and nuclear critics agreed to encourage completion and operation of units currently under construction or planned might be preferable to the current impasse, especially in terms of financial return to investors. It has been suggested that Americans might reach consensus on a 150-gigawatt nuclear program (29). Similarly, the advocacy arm of the League of Women Voters has adopted a national policy calling for a continuation of nuclear power in its current percentage of national energy supply. As energy and electricity demand grow in the future, this policy would allow some growth in the nuclear program. Any such compromise or cap would have to allow for adjustments as nuclear and competing technologies are improved and economics change. In addition, regional differences in the United States might make a State-by-State approach more feasible than a national referendum as in Sweden.

While all of the approaches discussed above might decrease public concerns about current reactors, it is possible that public skepticism about the technology is so great that these changes would have little impact. In this case, other reactor concepts with inherent safety features might be considered. Several alternatives, such as the high temperature gas-cooled reactor (HTGR), the heavy water reactor (HWR), and an improved light water reactor (the PIUS reactor) are discussed in chapter 4. A substantial federally funded R&D effort on one or more of these alternatives might meet with public acceptance, particularly if demand for power picks up over the next two decades. The inherent safety features of the chosen design might appeal to the general public and the choice of design could be used as a vehicle for much greater involvement of nuclear critics. By bringing critics into the R&D program and addressing their specific concerns, consensus might be reached on an acceptable design for future reactors.

Minimize Linkage Between Nuclear Power and Weapons

Another issue that should be addressed in policy decisions about nuclear power is the connection between weapons development and civilian nuclear energy. Given the level of national concern over the arms race, public acceptance of nuclear power cannot be expected to increase substantially until the two nuclear technologies are separated in people's minds. This report has not analyzed the impact of policies that might minimize the linkages between nuclear weapons and power, but the effect on public opinion could be positive. For example, one action that might increase public acceptance by reducing the perceived linkages would be to remove nuclear weapons development from the jurisdiction of the Department of Energy. Another step would be to legislate a ban on commercial fuel reprocessing. Many critics are more concerned about reprocessing than about reactors because plutonium separated from the spent fuel might be stolen and used to construct a bomb or to threaten the public. A legislated moratorium on reprocessing might have greater impact on these concerns than the executive orders imposed by Presidents Ford and Carter that were later revoked by President Reagan. Such a ban might be especially effective if imposed in conjunction with limits on the total growth of the program, as discussed above. In addition, it might be best to keep industry and military waste disposal strictly separate, although some public interest groups support joint disposal, because it encourages action on military waste that has been allowed to accumulate for 40 years (53).

Policy makers also could take action to reduce the possibility of weapons proliferation through careful management of international nuclear power development. A previous OTA analysis identified weaknesses in the existing international nonproliferation regime (52). Recognizing the impact these weaknesses have on public perceptions of nuclear power, Alvin Weinberg has argued, "We must strengthen the Nonproliferation Treaty (NPT) regime and take the next steps, which involve both a reduction in nuclear armaments and a strengthening of the sanctions that can be imposed on those who would violate the NPT" (75).

The link between nuclear weapons and nuclear power also might be reduced in people's minds if more proponents of nuclear power who oppose the continued buildup of nuclear weapons stated their beliefs publicly. For example, Hans Bethe, a prominent nuclear physicist who has been active in the arms control movement and supportive of civilian nuclear power, reaches an audience who might otherwise reject nuclear power along with weapons (48).

In conclusion, current public attitudes toward nuclear power pose complex problems for the nuclear industry and policy makers. However, technical and institutional steps could be taken that might lead the public to view nuclear power as an important and attractive energy source in the years ahead. Constructive leadership and imagination will be required to start this process.

CASE STUDY 1

Maine Yankee: Economics as the Key to Public Support

Despite an excellent operating record, Maine Yankee has become the focus of statewide opposition to nuclear power.[1] However, based on the plant's economic benefits, the voters of Maine twice have rejected proposals to bring its operations to a complete halt. Maine Yankee is owned and operated by the Maine Yankee Atomic Power Co., a consortium of utilities including Central Maine Power (the largest owner). Completed in 1972, the 840-MW plant is located on Montsweag Bay on the south-central Maine coast.

Initial local reaction to Maine Yankee was overwhelmingly positive, based on the construction jobs and tax revenues the plant would bring. Residents of Wiscassett (then around 1,200 people), within whose borders the plant was to be located, generally supported the plant. A few local environmental groups raised questions about emergency evacuation planning, the impacts of thermal discharge, and waste disposal during operating license hearings in 1972, but most Maine residents remained relatively unconcerned about the plant.

In 1974, Central Maine Power (CMP) announced plans to build another nuclear plant at Sears Island, further up the Maine coast. Although the plant was never built, this proposal led Pat Garrett, a retired engineer living near the planned site, to organize Safe Power for Maine (SPM). Garrett's work on radiation protection during World War II made him concerned about the impacts of a reactor accident. Three years later, at an SPM rally, Garrett's description of the impacts of a full-scale reactor accident made a vivid impression on Ray Shadis, who lived about 2 miles from Maine Yankee at Edgecomb.

In March of 1979, the NRC ordered Maine Yankee to shut down while the implications of a faulty computer code used to design for earthquake resistance at the plant were examined. Later that month, the accident at Three Mile Island coincided with a minor earthquake at Maine Yankee, causing increasing local controversy. Shadis, who increasingly had become angered at what he considered to be arrogance on the part of Maine Yankee representatives in dealing with seismic risk, discovered that there had been a spill of radioactive water at the plant during the shutdown process. His belief that the utility should have made the spill public was the impetus for a town meeting in the Edgecomb Town Hall in April which drew nearly 1,000 people.

This overwhelming response inspired Shadis and his wife to initiate a referendum vote on closing down the plant. By March of 1980 they had organized the Maine Nuclear Referendum Committee and presented the Maine Secretary of State with over 50,000 signatures; a special election was called for that September. To coun-

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[1] This case study is primarily based on phone interviews conducted during March 1983. The following persons were interviewed: Ray Shadis (organizer of the 1980 referendum campaign); Pat Garrett (Safe Power for Maine); Don Vigue (Maine Yankee Atomic Power Co.); Gordon Weil (formerly with Maine Governor's Energy Office); Tom Kinder (Fund for Secure Energy); John Menario (Committee to Save Maine Yankee); and Denise Goodman (free-lance journalist).

ter the Referendum Committee, a business consultant and CMP setup the Committee to Saw ." Maine Yankee (CSMY), raising over $800,000.[2] The funds were used for advertisements, speakers, and a direct mail campaign emphasizing the economic advantages of the nuclear plant. CSMY projected that replacing Maine Yankee with oil-fired electricity would add 30 percent to the average residential customer's bill.

The Referendum Committee emphasized three issues in its campaign: the magnitude of a potential accident and its devastating effect on the coast of Maine; the impact of radioactive waste on future generations; and the concept of franchisement, in which people have the responsibility to make their own value judgments a nuclear power and other issues that affect their lives. With less than $150,000, the committee relied heavily on the fairness doctrine to obtain media coverage of their views,

Following a large voter turnout, the referendum committee lost, by 41 to 59 percent. Observers on all sides agreed that economics had been the deciding factor in the vote. Near the end campaiof the:hard Hill, professor at the University of Maine at Orono who was well known for his expertise renewabin energy public debate argued in a that these resources could not make up for the lost Maine Yankee power. From then on, the referendum committee had trouble refocusing the campaign on health and safety issues and ultimately los.

The large turnout and vote split in the 1980 campaign encouraged a new Maine Nuclear Referendum committee* try again, and the issue was placed on the ballot as part of the regular 1982 election. This time, however, the referendum proposed to shut down Maine Yankee after 5 yews, in order to allow time for a smooth transition to conservation and renewable energy sources. CSMY again launched a counter-campaign.

In November 19$2, Maine voters again chose to keep Maine Yankee operating, though by a narrower margin (56 to 44 percent). Economics -r@ the key factor in the vote. An independent analysis by the Governor's Energy Office had found that electricity prices would increase by 10 to 25 percent if Maine Yankee were closed down. Despite a counter-study by the referendum committee, most voters were convinced that expensive cdl-fired generation would be required. In addition, the referendum committee's credibility on health and safety issues was hurt by a U.S. Centers for Disease Control the claimllenging t leukemia rates were higher than normal around Maine Yankee.

Public attitudes toward the Maine Yankee plant are similar in many respects to national attitudes. Residents @f Wiscassett, which benefits from the revenues, x always have supported Maine Yankee. Environmentalism, too, has a strong influence on concerns about the plant. Many of the leaders of the referendum moved to Maine because of the * @ s remote, rural character. Concerns about nuclear war were instrumental in mobilizing opposition Yankee, ie and the nuclear weapons freeze mhelpednt probab attract votes in favor of the referendum. Another issue that had a strong influence on the debate was the credibility of the utility. Exit polls taken after the first referendum indicated that some people, who supported Maine Yankee for economic reasons, voted to shut it down because they disliked CMP. Ultimately, however, this same Yankee independence led the voters to keep the plant, which they viewed as an economic necessity, running.

[2] Information on sources of funding in 1980 and 1982 for both the Referendum Committee and the Committee to Save Maine Yankee was provided by the Maine Secretary of State's office.

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cidence of a massive public protest based in part on concerns about earthquake-stance and an apparent industry failure to provide that resistance appeared to many people to vindicate the - protectors. In addition, PG&E's handling of the event may have contributed to doubts about the nuclear industry's credibility. When an independent study confirmed the quality-assurance problems with the seismic restraints, a PG&E spokesman dismissed the finding as being"a certain informality" in the utility's"seismic sentice contracts."

Public reaction to Diablo Canyon has reflected national trends in several respects. Early concerns about specific environmental impacts and support among some environmentalists gave way to broader concerns about seismic risk, need for power, and, ultimately, the competence and credibility of the utility. Conflicting scientific studies of seismic risk appear to have increased public skepticism about the plant, and the accident at Three Mile Island caused a sharp increase in local opposition.

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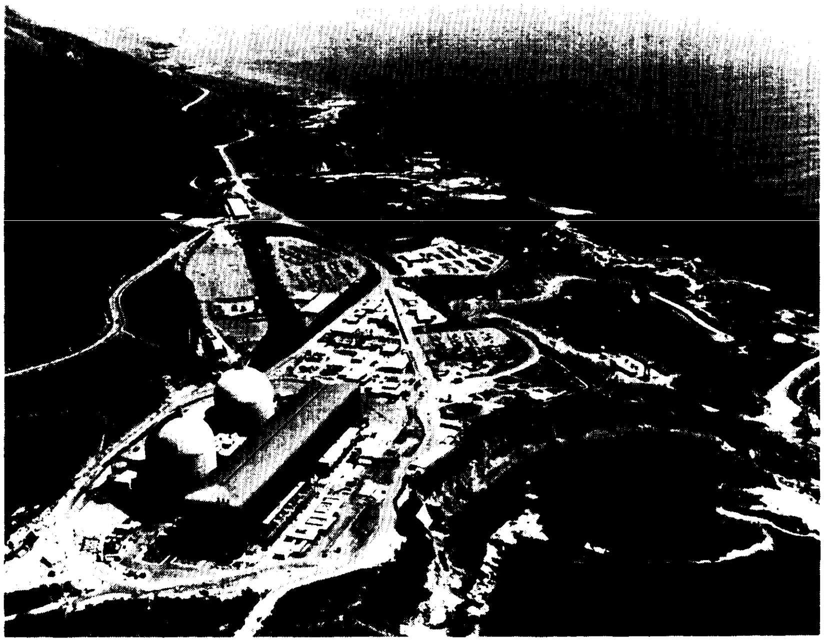

Photo credit: Pacific Gas & *Electric*

Demonstrations and court actions called attention to issues of seismic design at Diablo Canyon

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Chapter 9

Policy Options

Photo credit: Ontario Hydro

Pickering nuclear station has four identical CANDU units built in 1973 and four more scheduled for completion in 1985. Standardization helped reduce construction costs and improve operator training

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Chapter 9
Policy Options

INTRODUCTION

The previous chapters have painted an unpromising picture of the future of nuclear power in the United States. Projections for new central station generating capacity over the next 20 years are much lower than those of just a few years ago. The high financial and political risks involved with nuclear plants suggest that any central station capacity that is added would be coal-fired. Under existing conditions, there are few incentives for utilities to select nuclear plants and many reasons to avoid them.

It can be highly misleading, however, to forecast future decisions on the basis of existing conditions. Some of the problems that appear so formidable now will diminish. The plants under construction now were designed according to concepts developed 10 to 15 years ago. Any future plants can be expected to incorporate major changes that have been backfitted onto existing plants and other changes that have been suggested to improve operation. In addition, much has been learned about how to construct plants more efficiently, While these and other changes would go far toward eliminating the large cost overruns some utilities have experienced, they probably are not sufficient to restore confidence in the financial viability of the technology. Other concerns exist that these changes will not address. Therefore, it is probable that additional initiatives, including Federal actions, will be required if the country concludes that nuclear energy is to continue to grow past the plants now ordered.

As recounted in chapters 1 and 3, there are reasons why the Nation could decide that it would be in the national interest to maintain a domestic nuclear option. Nonfossil fuel energy sources may be urgently required for environmental reasons within several decades, and nuclear energy could be the most economical source that can be readily deployed. Even if such environmental conditions do not materialize, it could be economically prudent to retain a generating source other than coal. The energy outlook for the early 21st century, when oil and gas reserves will become seriously depleted, is very uncertain. If it is reasonably possible that nuclear power will be seen as very desirable or even indispensable within 20 or 30 years, it probably is more efficient to have a continuous learning curve than to try to put the industry back together when it is needed.

There are, of course, reasons for opposing these arguments. Even if it is conceded that it would be in the national interest to have the nuclear option, that does not mean it is the responsibility of the Federal Government to ensure it. The economic penalty for not having more nuclear plants would not be crippling (though the total dollar penalty could be quite high) (2,4), and as shown in chapters 3 and 5, unless nuclear plants are built and operated well, they are not the most economic choices. If any more serious accidents occur, forcing long shutdowns and expensive backfits, the economics of nuclear power will be very hard to defend. Thus, it could be more productive economically to concentrate on the development of alternative energy sources.

Therefore, policy options presented here are not intended to prop up a terminally ill industry, but to cure the problems of an industry that is salvageable and which the Nation decided was needed. **In addition, some of the options can be of importance for ensuring that existing reactors operate safely and economically regardless of the** choice about the industry's future.

The next section presents a series of policy goals and options that might be considered by Congress. For some of these, a lead congressional role would be needed. For others, congressional action may be no more than general policy setting and oversight because the main initiative must arise elsewhere.

One of the difficulties facing policy makers is that few if any of these options will be very effective by themselves. Actions need to be taken on a broad front, but the responsibility for these actions is diffuse.

The third section, therefore, groups the options according to three different strategies: first, no change in Government policy as it currently appears; second, remove obstacles in the way of further orders for nuclear plants; third, stimulate more nuclear orders. These strategies correspond to different levels of involvement to which policymakers may want to commit the Government.

The success of these strategies depends in turn on two other factors: the need for nuclear power and how well the industry manages its present reactors. Therefore this section also includes economic and industry management scenarios that are combined into four different futures to help evaluate the strategies.

POLICY GOALS AND OPTIONS

In order for nuclear power to become more acceptable in general, progress must be made in several different areas. Reactors must be more affordable, operations of existing nuclear plants must be improved, concerns over potential accidents must be alleviated, and public acceptance must be improved. This section discusses the specific policy initiatives that would contribute to these goals. The goals and options are listed in table 34. Under each goal the options are listed not by importance, but in order of ease of implementation according to the strategies discussed later.

Goal A: Reduce Capital Costs and Uncertainties

At present, nuclear reactors pose too great a financial risk for most utilities to undertake. Few utilities can support such a great capital cost for the length of time required to build a nuclear plant, even if lifecycle cost projections show that it would be the cheapest power source over the lifetime of a powerplant. Not only are capital cost estimates high, but the actual cost could be much higher if designs continue to change during construction. As discussed in chapters 3, 4, and 5,

Table 34.—Summary of Policy Options

	Strategy[a]	Congressional role
A. Reduce capital costs and uncertainties		
1. Revise the regulatory process for predictable licensing	One	Oversight, legislation
2. Develop a standardized, optimized design	One	Moderate R&D funding (design)
	Two	Major R&D funding (demonstration)
3. Promote the revision of rate regulation	Two	Inquiry; FERC regulation
B. Improve reactor operations and economics		
1. R&D programs to improve economics of operations	Base Case	Minor R&D funding
2. Improve utility management of nuclear operations	One	NRC oversight
3. Resolve occupational exposure liability	Two	Legislation
c. Reduce the risk of accidents that have public safety or utility financial impacts		
1. Improve confidence in safety	Base Case	NRC oversight; minor R&D funding
2. Certify utilities and contractors	Two	Legislation
3. Develop alternative reactors	Two	Major R&D funding
4 Revise institutional management of nuclear operations.	Two	Inquiry, oversight
D. Alleviate public concerns and reduce political risks		
1. Accelerate studies of alternative energy sources	Base Case	Minor R&D funding
2. Address the concerns of the critics	One	Oversight, legislation
3. Control the rate of nuclear construction .,	One	Legislation
4. Maintain nonproliferation policies	Two	Oversight of legislation
5. Promote regional planning for electric growth	Two	Legislation

[a]Strategies incorporating these policy options are described later in the chapter: Base Case, Strategy One, and Strategy Two

SOURCE: Office of Technology Assessment.

this situation should improve even without any policy changes, but probably not enough for utilities to be confident in their estimates.

Policy options intended primarily to support this goal are discussed below.

A 1. Revise the Regulatory Process

Regulatory reform has many proponents in the nuclear industry who argue that the licensing process is unpredictable and unnecessarily time-consuming. Some revision may be necessary (if not sufficient) for a resurgence in nuclear plant orders.

Efforts to change licensing will encounter difficulties, however, if they do not account for other points of view. The primary purpose of nuclear regulation is to ensure safety. As discussed in chapters 5 and 6, some utilities and contractors have not performed adequately. In such cases, difficulties with regulation indicate that regulation is working. **In addition, nuclear critics object to any attempt to limit their participation in the regulatory process, and suspect that changes to enhance efficiency would reduce their effectiveness in raising safety** issues. Since critics have considerable influence on public opinion, it will be difficult to achieve enough of a consensus on such revisions. Thus, a complete package of regulatory change should improve the predictability and consistency of licensing nuclear plants while simultaneously ensuring their safety and adequate public participation.

Major proposals for legislative action concern early approval of designs and sites, the hearing process, combined licenses, and backfits. These proposals are evaluated in chapter 6. It is likely that efficiency and predictability could be enhanced by banking designs and sites, and this change could be structured to allow adequate opportunity for public participation. It is less clear that revising the hearing process or combining construction and operating licenses would improve efficiency or allow for adequate public involvement until the technology is more mature. Tighter management within the Nuclear Regulatory Commission (NRC), perhaps with stricter congressional oversight, might make sufficient progress in these areas.

Nuclear utilities are especially sensitive to backfitting, which can be very costly and time-consuming. The controversies surrounding backfits and the proposals for change have been described in chapter 6. There are two related problems. One is that individual backfit orders do not always take into account the impact on other parts of the plant. The second is that estimates of overall gains in safety are not made to weigh against the full cost. The prospect of ever greater costs associated with future backfits to completed plants increases the uncertainty of investment in nuclear power. Decisions on backfits generally have been made implicitly and with little consistency. It is difficult to develop a universally acceptable formula for these tradeoffs since safety is not easily quantifiable, and regulators are reluctant to factor in costs if this could result in any decrease in safety.

Several proposals have been made to revise NRC's backfit rule and procedures. All proposed revisions have recommended changing NRC's definition of a backfit to make it more explicit. **In addition, it is generally suggested that threshold standards for invoking a backfit order be more clearly identified, along with the procedure for implementation.**

These changes could be accomplished through administrative rulemaking, as proposed by NRC, or through legislation, as supported by the nuclear industry and the Department of Energy (DOE). Legislation could make backfit decisions more consistent but would have serious drawbacks if it attempted to be too precise. The techniques for quantifying safety improvements are still somewhat crude, and any cost-benefit analysis would be inherently uncertain and subject to bias. Institutionalizing cost-benefit considerations through legislation also may reduce NRC's flexibility to improve the process later. Such legislation also might be perceived by nuclear critics as restricting safety improvements that might be necessary even if they do not meet the cost-benefit criteria because of all the uncertainties in the technology. A productive Government role in this area might be to develop and refine risk assessment and cost-benefit analysis methodologies so that they can be more confidently applied in backfit decisions.

A2. Develop a Standardized LWR Design, Optimized for Safety, Reliability, and Economy

For a variety of reasons discussed in chapters 4, 5, and 6, the reactor plant designs currently available could be significantly improved. An effort that rethinks the concepts by which reactors have been designed could result in light water reactors (LWRs) that are cheaper, safer, more operable, and perhaps smaller than the present generation. This effort would draw on all that has been learned about the characteristics of good, safe reactors and integrate the best features into a package that would represent the best of technology. The design philosophy would emphasize resiliency and passive safety features as well as affordability and economy. The system would be subjected to intensive analysis from every possible perspective to ensure that, insofar as possible, all contingencies had been covered.

To a degree, the Westinghouse effort on the advanced pressurized water reactor described in chapter 4 meets these objectives. The rationale for a Government role is that a complete reactor and plant design is extremely expensive, and no corporation is likely to be able to finance it unless it sees a major market, which is not now the case. In addition, there are several technical questions such as the unresolved safety issues requiring additional R&D that is best funded by the Federal Government. A Government-initiated nonproprietary design could more easily draw on the work of more than one vendor or architect-engineer as well as a coordinated R&D program, and be available to more producers. Therefore, a national design could have a better chance of being truly optimized. The safety analysis also might be more convincing since it would be done in a more open atmosphere, with direct feedback to the design to improve safety to the maximum extent possible. There is also a growing feeling that current reactors have overshot the ideal size. U.S. vendors are unlikely to be in a position to redesign their new reactors to be smaller.

There are several advantages to a standardized design. The cost would be much more predictable, since most of the regulatory and construction uncertainties could be cleared up before construction started. Costs also could be lowered by incorporating improved construction techniques. It should be cheaper to operate because it would be designed to operate at a higher capacity factor, lower fuel cycle costs and lower operator exposure. Even if the technology were similar to present reactors, this new design package might represent a major improvement in the acceptability of nuclear power.

There are also disadvantages, however. It would be at least as expensive for the Government to sponsor such a design as it would for a corporation—perhaps several hundred million dollars if a demonstration were required. In addition, a Government lead in developing a new design might imply to some groups a dissatisfaction with present designs serious enough that existing reactors should be shut down.

A3. Promote the Revision of Rate Regulation

The process of rate regulation in most States was designed for an era of relatively small capital cost increments and declining costs per kilowatt-hour. High interest rates and high capital costs for new generating capacity have strained the system so seriously that changes may have to be made before utilities resume ordering new central station capacity. The current overcapacity gives utilities a welcome respite, but large construction programs will be needed once again.

Regulatory changes that should be considered here are: 1) rate base treatment of utility assets that takes inflation into account, 2) some construction work in progress (CWIP) to be included in the rate base, and 3) real rates of return on equity appropriate to the actual investment risk. These changes and others are discussed in detail in chapter 3. Their general intent is to even out rate increases and provide greater financial stability for utilities and their customers.

A difficulty for Federal policy in this area is that rate regulation is the prerogative of the States. If Federal action is to be acceptable, it must be taken in a way that makes it in the interest of the States. Federal encouragement of long-range regional planning and regulation (see option D5) may be useful since many States are finding that their regulatory programs are encountering increasing difficulties in forging satisfactory compromises. To some extent, regulation of wholesale power sales by the Federal Energy Regulatory Commission (FERC) influences State regulation. In the summer of 1983, there was extensive congressional debate on legislation restricting FERC allowance of CWIP. Consumer opposition to CWIP has been intense because it allows payment for facilities before they are of any use to the ratepayers. Some States, however, do have partial CWIP allowances.

Goal B: Improve Reactor Operations and Economics

Decisions on the desirability of future reactors will be based not just on capital cost projections (as improved under goal A) but also on the performance of existing reactors. The low reliability experienced at some plants negates their potential economic benefits and raises concerns over safety. Investors, critics, and the public will be opposed to more orders if some plants are noticeably unreliable. Thus, it is in the interests not only of the specific utility involved but of the industry as a whole to improve operations at all plants. Other means for improving the economics of existing reactors could also improve the outlook for nuclear power as a whole.

The specific options toward this goal follow.

B 1. Support R&D Programs to Improve the Economics of Operation

DOE and most of the nuclear steam supply system (NSSS) vendors have modest programs for developing extended burnup for fuel elements. There would be a national benefit from expansion of these programs. Fuel cycle costs could be reduced slightly, and the volume of spent fuel accumulation would be decreased considerably (perhaps by 40 percent). This latter factor, by itself, could justify a significant Federal effort. Saving 40 percent of the spent fuel would not reduce the spent fuel problem proportionately, but it would ease the total burden considerably in the long term. The objection generally voiced to a Federal program is that private industry could handle it. While this is probably true, a Federal role would expedite matters and improve our international competitive position. A long-term R&D program could provide further benefits.

B2. Improve Utility Management of Nuclear Power Operations

None of the policy options discussed in this chapter will do as much to improve the attractiveness of nuclear power for all the parties to the debate as improved utility management. Many utilities were unprepared for the complexities of nuclear power and the dedication required. This situation was perhaps unavoidable, given the overenthusiasm gripping the nuclear supply industry and the Federal nuclear promoters. By now, however, we are in a period of operation, not expansion. Utilities now have the primary responsibility, and all utilities responsible for nuclear plants must be adept at carrying it out.

it is important to recognize that much is being done to improve the quality of operations as discussed in chapter 5. The Institute for Nuclear Power Operations (IN PO) was set up for precisely this purpose and has developed a large number of specific programs. The NRC has shifted some of its scrutiny from the plants to the organizations running them. It is not yet clear whether these efforts will be sufficient.

Specific areas for attention are training and organizational structure. Both previously had been left to the discretion of the utility but are now being addressed by both the NRC and IN PO.

Requirements for training show a remarkable variation. Good training programs are expensive, and qualified instructors are in limited supply. It is important to set standards for training and establish reasonable programs for achieving them. INPO is beginning to do this by establishing a training accreditation program. It also may be necessary for NRC to impose these standards to achieve the optimum progress. The NRC probably has the statutory authority to do this, but a congressional directive would expedite NRC actions. Careful observation of the results of INPO's efforts is important to see whether additional NRC action is necessary.

Criteria for organizational structure will be harder to define. One factor that is apparent, however, is that the highest levels of the utility management must be involved with the plants and committed to their good operation. Again, the NRC probably has the authority to command attention at the utility headquarters, and is attempting to do so. Still greater resolve seems to be in order at some utilities, however, and congressional encouragement of NRC to make this a high priority item would help.

Both the NRC and INPO know which utilities are most in need of upgrading their management. All utilities are strongly influenced by the experiences of these few. Strong measures may be required to get the operation of these plants up to minimally acceptable levels. Congressional expresson of the importance of a strong management commitment would be a significant incentive for the NRC and the utilities.

B3. ***Resolve** the Financial Liability for Occupational Exposure*

The weapons testing program has focused attention on compensation for injuries arising from exposure to radiation. New approaches are being developed for compensating test participants and downwind residents, and the industry is concerned that these plans will be applied arbitrarily to commercial nuclear plants (and possibly the medical industry). The proposals under consideration for the weapons tests plaintiffs link radiation exposure to the probability of contracting cancer, and then award compensation based on that probability. With this approach, claimants who receive the most exposure also receive the greatest rewards. Recent legislation in Congress proposes awarding $500,000 to a claimant if there is at least a 50-percent chance that the cancer developed from the radiation exposure. At lower levels of exposure that may only result in a 10- to 20-percent chance of cancer, the claimant could receive $50,000. This proposal is controversial for two reasons. First, the nuclear industry contests the relationship between low radiation doses and cancer since there is insufficient scientific or technical basis to support it. In addition, many claimants who were exposed to low doses would receive compensation for cancers that were not produced by radiation but by other causes. Critics would argue that excluding such cases would deprive a large number of potential victims of just compensation.

Exposure levels during the weapons tests were considerably higher than expected occupational exposures at nuclear reactors. Some workers will, over their lifetimes, nevertheless accumulate a high enough dosage to qualify for awards if the floor is at the 10- to 20-percent level. Hospitals also may find themselves liable for the exposure from X-ray machines and nuclear medicine. Compensation for test victims is an important social issue. It also is important to recognize that it has implications for the nuclear industry that could be serious if the awards are large.

Goal C: Reduce the Risk of Accidents That Have Public Safety or Utility Financial Impacts

Nuclear reactor safety is a function of the design of the plant, the standards by which it is built, and the care with which it is maintained and operated. If any of these are deficient, safety will be compromised, perhaps seriously, and costs may well escalate unexpectedly. Option A2 has discussed how to improve the designs of the next generation of LWRs, but this alone may not be adequate. It would not affect existing plants, and it may not go far enough in assuring safety in future plants. Without a consensus that nuclear reactors now are safe enough, there are unlikely to be any more. Therefore, ways to improve the safety of both present and future reactors are explored under this goal.

The quality of the people involved appears to beat least as important as the design of the plant. Option B2 discusses how to improve utility operation, but again this may be inadequate by itself. Some utilities simply may be unable to improve their performance sufficiently. Others may think they have done so but experience the same difficulties in construction when they order another plant. Two options discussed under this goal can be considered if utility improvement is inadequate. Construction permits and operating licenses could be reserved for utilities and contractors that can demonstrate the commitment to build and operate the plants to the exacting standards required. Second, different institutional arrangements might be considered to replace utility management of reactors, This option also could be effective in stimulating further growth of nuclear power if utilities are reluctant to order more.

Cl. Improve Confidence in the Safety of Existing and Future Reactors

As discussed in the options above, there has been a continual evolution in designs because of frequent discoveries of inadequacies with respect to safety or operation. As our understanding of the technology has improved, formerly unforeseen accident sequences or conditions are recognized. Unquestionably, the technology is maturing, but there is considerable dispute over how much farther it has to or can go.

Part of the problem has been the partitioned nature of the safety analysis both in the industry and the NRC. Each system may be thoroughly scrutinized, but the entire plant is not viewed as a system, and responsibility for analyzing its overall safety appears to be lacking.

No amount of analysis will uncover all potential problems, but an intense analysis of each plant could identify design or operating flaws before they caused problems. These studies are expensive, but a few utilities already are undertaking them in their own interests. The intent is to discover weak points in the design and develop measures to address them, whether by changing plant equipment or modifying operations.

Other efforts to improve safety could focus on improving the analytical techniques. As has been stated above, probabilistic risk assessment is a useful tool that is still imprecise. Development of this technique would be beneficial for both safety and economics. This will involve mainly improving the data base for failure rates and analyzing the human element, as is done in the aircraft industry.

The existence of unresolved safety issues, and the probable introduction of more as new concerns are developed, undermines confidence in safety. Resolving them expeditiously would eliminate some safety concerns, demonstrate a commitment to maximum safety on the part of the NRC, and permit more stable cost projections for future plants. Resolution of some of the issues may call for modifications on existing plants. While the utilities would not welcome such expenditures, the overall reduction of uncertainties and the gains in safety would be useful.

C2. *Certify Utilities and Contractors*

It is readily apparent that some nuclear plants are not being built and operated skillfully enough. As discussed earlier, all plants may be hostage to the weakest because an accident, or even poor performance, reflects on all. If the persuasive approach of option B2 is insufficiently effective in improving nuclear plant management, more drastic steps could be warranted.

For existing reactors, the NRC evidently already has the power to suspend an operating license if a utility is incapable of managing a reactor safely. Few people expect the NRC to do this without the most compelling evidence of incompetence. If higher standards are to be enforced, it probably will only be with congressional legislation. Such improved standards would be in the best interests of the industry even though their implementation could be traumatic. Even if this authority were never invoked, it could be a strong incentive to utilities to improve their performance. The result would be greater confidence in the safety and operability of reactors.

Future reactors present a slightly different picture. Utilities have learned that building reactors is very difficult, and few, if any, would embark on a new construction program unless they were confident they had the ability. Even then, however, other parties of concern may not share that confidence. Certification of utilities as having the necessary ability and commitment to build and operate a reactor to high standards would ensure that many of the expensive mistakes of the past were not repeated. This would reassure many of the critics of nuclear power as well as investors, utility commissions, and the public. It also might be necessary to eliminate from contention contractors who had not demonstrated their capability of meeting the exacting standards required for nuclear construction. Presumably utilities would know better than to select these contractors, but some past experiences have been so poor that making it official would increase confidence.

Even though this option is not likely to prevent any plants from being built, it would be viewed by the industry as another set of regulations to meet in what they consider to be an already overregulated enterprise. The utilities also may resent having a Federal agency judge utility management quality. An independent peer body analogous to that being set up for review of medicare inpatient treatment might meet with better acceptance.

There are no clear criteria as to what constitutes good management concerning construction of a nuclear powerplant. Nevertheless, as part of a strategy to rebuild confidence in the technology, this option clearly bears further examination.

C3. *Develop Alternative Reactors*

DOE has carried on a modest program for R&D on the high temperature gas-cooled reactor (HTGR). Given a higher commitment, the HTGR might develop into a superior reactor. In particular, it has inherent safety features that at least temporarily would shield it from some of the safety concerns of the LWR. Further, if problems develop with the LWR that are too difficult to solve economically, the HTGR probably would be the next available concept in this country. An enlarged R&D program could prove vital in maintaining the nuclear option.

On the negative side, it has to be noted that gas reactors have not been a great success anywhere, and most countries have turned to the U.S. developed LWR technology. Estimates of future costs and reliability are much more conjectural than for the LWR. Many utilities would be reluctant to turn to a less familiar technology that might turn out to be subject to many unforeseen problems. Such uncertainties will only be resolved by a substantial R&D program. To a greater degree than for the standardized LWR discussed above, a thorough demonstration of the entire HTGR concept, including licensability, costs, operability, and acceptability would be required. This would necessitate an increased development program at DOE.

Even if the HTGR is not seen as a replacement for the LWR, there are still several reasons for supporting an R&D program paced to make it available early in the next century. it would use uranium more efficiently than LWRs, has relatively benign environmental impacts, and could be used for industrial process heat. A small, modular form also has been proposed that could have major safety and financial advantages and be particularly well suited to process heat applications.

It is harder to see a role for heavy water reactors (CANDU) in this country. CANDUs are working extremely well in Canada. At least some of that success, however, is due to the managerial environment in which the nuclear industry operates in Canada. Transplanting it to this country could lose these advantages, and would necessitate industry learning and investing in a quite different technology. While the technology can be mastered, a significant research program would be necessary to adapt CANDUs to our regulatory requirements, or vice versa. It is not clear that this effort is warranted compared to other alternatives such as the HTCR or improved LWRs.

The final alternative reactor discussed in chapter 4 is the PIUS, which was conceived largely to meet safety objections to the LWR. While radically different from the LWR in some ways, it still is an LWR. Therefore it has an element of familiarity that the others do not. The concept, or at least some features of it, appear promising, but only a significant research effort will confirm the feasibility of the design since it is still a paper reactor concept, There is great uncertainty over this concept, but if the research program does prove out the expectations of the developers, the reactor could be deployed rapidly. PIUS could be perceived as much safer by the public and critics.

Development of new technology will not by itself solve the problems of the industry. However, it will play a vital role in **an overall** upgrading, whether the end result is an improved LWR or an alternative concept.

C4. Revise the Institutional Management of Nuclear Power if Necessary

If a utility has its license revoked as in option C2, or such action seems likely, it might think of turning the plant over to a different operating agent instead of just shutting it down. Utilities already use a large number of consultants and service companies for specific tasks. Operating service companies, discussed in chapter s, could bean extension of these, or they could be other utilities that have established good records and are prepared to extend their expertise to other reactors. The NRC would be satisfied that the plant was being given the management attention required, the utility would have its plant operating again, probably at higher availability than before, and the public would have greater assurance about the commitment to safe operation.

There are potentially serious liabilities to the idea, however. No utility would like to admit that it is incapable of operating its plant safely and would be reluctant to turn to another operating company except under extreme conditions. The contract between the two would have to be carefully worked out to determine who would pay for modifications and maintenance. If a serious accident did occur, plant restoration costs and liability for offsite damages would have to be spelled out. Premature plant closure due to unexpected deterioration could be another problem.

There do not appear to be any legal impediments to the idea that would require legislation. However, Congress might want to encourage the NRC, and perhaps the Justice Department, to undertake further analysis.

Alternative institutional arrangements also could be formed to encourage nuclear orders i n the future. If individual utilities are unable to undertake the risk, consortia of utilities, possibly including vendors and architect-engineering firms etc., might be able to do so. Alternatively, Government-owned power authorities might be the only way to maintain the nuclear option. These concepts are explored briefly in chapter 5.

Goal D: Alleviate Public Concerns and Reduce Political Risks

The issue of public acceptance has permeated this report for good reason. If the long-term trend in public opinion toward increasing opposition (described inch. 8) is not reversed, there will be few, if any, more orders for nuclear plants.

Many of the options discussed above are relevant to this goal. Nuclear energy will not be acceptable so long as there are spectacular examples of out-of-control cost escalations and a continuing series of alarming operating events. A major accident involving offsite loss of life would almost certainly preclude future plants and quite likely close many operating reactors. Therefore, almost any action to improve operations and safety will pay dividends in public acceptance. The options discussed here are intended to reduce the controversy or to confine a role for nuclear power.

01. Accelerate Studies of Alternative Energy Sources

One of the major factors affecting public opinion against nuclear power is the feeling that the risks associated with it outweigh the benefits. As long as other energy sources are available that are perceived to be both more economical and acceptable, there is little incentive to favor nuclear energy with its more controversial risks. Therefore, as more information is developed on the resource base, costs and impacts of these alternatives, better decisions can be made on the relative merits of nuclear energy.

The major competitor of nuclear power for new central station plants is coal. Yet coal is arousing concerns (e.g., carbon dioxide and acid rain) that may exceed those of nuclear. Significant research is going on in these areas, and the answers are crucial for nuclear power. The sooner they become available, the easier it will be to make informed decisions.

Some analysts feel that natural gas resources have been greatly underestimated. This cannot be confirmed for many years, but there is an im-

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portant data-gathering role for the Government. If gas remains plentiful and is permitted as a boiler fuel, it will reduce the competitiveness of nuclear energy. From a different perspective, it also might be useful to expand R&Don the solar energy options that appear promising. Some of the euphoria about solar energy has withered under the hard light of costs, but some technologies such as photovoltaics are still candidates. Accelerating these technologies actually could be beneficial to nuclear power. If they ultimately prove to be not widely competitive with nuclear energy, we would know that sooner. If they are reasonably competitive, then the Nation has another option.

None of these proposals is particularly controversial, though some might be expensive. In general, decisions on these options will be made on a basis other than one's attitude toward nuclear power. The outcome, however, could be very important to the future of nuclear power.

D2. *Address the Concerns of the Critics*

Critics of nuclear power have long felt a deep distrust of the industry and the NRC. They feel that their concerns have been ignored or downplayed while the Nation plunged ahead to build more reactors. The mistrust is mutual. The industry feels that nothing would change the mind of the critics.

Bridging this distrust will be difficult at best. For those critics who do not want nuclear power under any conditions and for those in the nuclear industry who refuse any concessions, resolution probably is impossible. However, opposition to nuclear power is not monolithic. Many critics have specific concerns over the technology and its implementation. These critics tend to be technically knowledgeable and respected in the environmental and anti-nuclear communities. Further, some in the industry are aware of these concerns and appear to be willing to engage in a useful discussions. It is with these groups that a bridge might be constructed.

One important step is to resolve the safety concerns that have already been identified, as discussed under option Cl. Further steps may be required to convince critics that every effort was being made to identify previously unrecognized safety concerns and implement solutions at existing reactors.

The most straightforward way of providing this assurance is to involve critics directly in the regulatory process. This might be done through contracts to supply specific information or review material (intervener funding), by including technically knowledgeable critics on the Advisory Panel for Reactor Safeguards, or by creating an office within the NRC that would serve as a liaison to the critics.

Few proposals generate as much controversy as this one. Industry sees it as opening the floodgates to implacable opposition that would make any progress impossible. Utilities see it as presaging a steady stream of new backfit orders and unnecessary regulations. Much of the NRC sees it as an unwarranted infringement on its process. If it is to be implemented, congressional direction will be needed. It may be worth the effort. Nuclear technology is still imperfect, and the sooner problems are discovered, the sooner the technology can be improved. Involving the critics is likely to speed this process. I n addition, improvements in public support is a prerequisite for more orders; public support is unlikely to improve as long as the controversy over safety is so bitter; and this controversy is unlikely to die down until most of the concerns of the critics have been addressed. Given the current impasse there may be little to lose by trying this approach.

D3. Control the Rate of Nuclear Construction

Many of the concerns over nuclear power originated during the late 1960's and early 1970's when projections of very high growth seemed to be on the way to being realized. People became alarmed over the thought of 1,000 reactors or more around the country, many reprocessing plants with spent fuel and plutonium shipments requiring security that disrupts normal transportation and threatens civil liberties, and the ever present possibility of accidents. The industry itself found the rapid expansion more than it could adequately manage.

Lower projections of nuclear growth have reduced some of these concerns. However, a resumption of orders might rekindle the fears of another "too rapid" expansion.

Establishing a controlled growth rate may give assurance that the early. concerns about overexpansion would not recur. As discussed in chapter 8, the 1980 Swedish national referendum limiting the total number of reactors appeared to quell the political controversy.

Controlling the growth rate might realize this improvement in public acceptance without precluding all future orders. The limit could be in the form of capacity that could be granted construction permits in a year, or a sliding scale to allow nuclear construction to remain at a roughly fixed fraction of total new capacity. If utilities' interest in new nuclear orders revives to the extent that the growth rate could be exceeded, the NRC would allocate the permits using criteria of regional need and ability to manage the technology as discussed under A3 above. There is no intrinsic difficulty in the Government allocating limited permits (e.g., airline routes were limited for many years).

This policy option would be controversial, at least at first. The industry would argue that it would constitute unwarranted interference in the marketplace and would distort economic decisions. **In particular, if nuclear reactors turn out to be the most economic form of electric power when managed carefully and** if fully redesigned, controlled growth could result in a misallocation of resources. However, until public acceptance improves noticeably, no utility is going to order any reactors. If controlled growth were instrumental in improving public acceptance to the point that orders resumed, it would be of major assistance to the industry. Furthermore, the burden of proof should be on the industry that it could manage a rapid increase of orders, since many of the present problems came from the last surge. The NRC has the authority to prevent such a surge by insisting on preapproved designs and evidence of utility capability, but a congressionally imposed limit would be more convincing to the public and the critics.

D4. *Maintain a Strict Nonproliferation Stance*

Proliferation has been one of the major concerns of the critics and the public. All known reactors could be used in some fashion to facilitate the production of nuclear weapons. If nuclear power is to regain public trust, this linkage must be minimized.

One step is to keep the U.S. weapons programs and power programs sharply distinct, both technically and institutionally. Separate waste disposal programs could be one step, even though the material is not much different. Consideration also might be given to removing the weapons program from DOE though that would be a complicated decision beyond the scope of this study.

A related suggestion is to consider a ban or extended moratorium on reprocessing. Reprocessing is the focus of much of the opposition to nuclear power. A long-term legislated moratorium, perhaps coupled with the controlled growth in option D3 and the extended burn up of option B1, would eliminate many of the major causes of concerns.

D5. *Promote Regional Planning for Electric Power Capacity*

One of the major reasons for the poor public opinion of nuclear power is the perceived lack of need for it. As discussed in chapter 3, this need is unlikely to be readily apparent before the late 1990's. By then, many utilities may be finding their own capacity fully committed and bulk power purchases less available. Without major changes in the way we generate and use electricity-changes that are highly speculative now —the Nation will need substantial new generating capacity to come online by 2000, and perhaps sooner. Some regions with high growth rates from population shifts and economic changes will experience the need earlier.

Planning for electric growth can make clear what the choices are and what the consequences might be. These plans could help build a consensus on the necessary additional capacity and load management. At the least, plans would provide a format for discussion. in conjunction with the controlled construction rates discussed above, such plans could be quite effective.

National planning is probably too large a scale to be useful. State planning may be too small considering the growing regional nature of power wheeling. Regional planning appears best to capture the commonality of interests, This might be combined with regional rate-setting as mentioned in chapter 3.

insofar as nuclear power is concerned, this proposal might not make any difference. It would not by itself eliminate any barriers to new reactors and might even raise an additional layer of regulation. On the whole, however, it should allow utilities that decide they should build a reactor to make a stronger case for it by showing how it will benefit the customers in the long run.

This policy option would be implemented by setting up regional planning authorities, possibly with ratemaking authority, that are agreed to by the States. It is important that these authorities also have authority to determine power needs. Such responsibility should not go by default to Federal agencies such as the NRC, which are not well equipped to make such determinations. The concept of regional authorities appears promising, but it has not been studied in detail in this project.

MAJOR FEDERAL POLICY STRATEGIES AND THE LIKELIHOOD OF MORE ORDERS FOR NUCLEAR PLANTS

It should be clear from the other chapters in the study that **none of the individual policy options described earlier in the chapter is sufficient by itself to improve significantly the prospects for more nuclear orders.** There are too many different problems that have to be addressed before nuclear power can be again considered a viable energy option for the future.

If several of these policy options are coupled in an overall strategy, however, they may be collectively much more effective. These strategies should include options directed toward each of the four policy goals described earlier in the chapter: reduce construction costs, improve reactor economics, reduce the risks of accidents, and alleviate public concerns. Most of the policy options will be controversial to some extent. For this reason, it is likely to be necessary to take steps that meet the concerns of several different groups at once: utility executives, critics, investors, regulators, and the public. The divergence among the views of these groups should be clear from the rest of the study.

In the face of the controversies surrounding nuclear power and the uncertainties surrounding its future, one obvious Federal course is to make no changes in Federal policy. **If such is the case, future nuclear orders will be heavily influenced by two sets of conditions outside the direct control of the Federal Government: economic conditions and improvement in nuclear industry management. In the section that** follows, the prospects for new nuclear orders in the absence of new Federal policies, the Base Case, are examined for each of four nuclear futures that assume different sets of economic conditions and industry management success.

The two other strategies described here assume various degrees of Federal intervention on several fronts. The first of these, Strategy One, would merely remove obstacles to further nuclear orders. A more active approach, Strategy Two, would go further and attempt to stimulate more nuclear orders. The four futures described under the Base Case also are examined for each strategy to help evaluate how successful the strategies might be under different conditions.

There are also two variations on these strategies that are not analyzed in detail in this study but are worthy of consideration. One of these, a variation on the Base Case, would make several changes in Federal policy to encourage more market competition between nuclear power and other generation (and load management) technologies. The other, a variation on Strategy Two, would consider nuclear power, not so much as an important aspect of U.S. energy policy but as a key element of U.S. industrial and world trade policy.

The Base Case and two strategies are outlined in table 35 with the policy options, discussed in the previous section, listed for each strategy. There is also a brief description of the two variations with a general description of the probable policies under each.

Base Case: No Change in Federal Policies

There are several reasons why policy makers might choose a strategy that avoids any major changes in the current Federal laws and regulations affecting nuclear power. Some policy makers may view nuclear energy as unimportant or undesirable, while others may feel that the Federal Government already has done enough for the industry, making further legislation unwarranted. Still others may not wish to take any action right now. At present there are many uncertainties about future electricity demand, the environmental impacts of coal combustion, and the potential of conservation and renewable resources which will affect the necessity for and attractiveness of nuclear power. Policy makers may prefer to wait 5 or 10 years to see how these uncertainties are resolved before revising current nuclear energy policies. Finally, policy makers may feel that Federal legislation would have little impact on the industry and that economic forces will ultimately determine its fate.

Table 35.–Major Policy Strategies (and the policy options included in each)

Strategy	Policy Options Included
Base Case: No change ***in Federal nuclear policy: Three*** noncontroversial policies that would be useful even in the absence of more orders	
Goals	*Policy Options*
Improve reactor economics	(B1) R&D to improve fuel burnup
Reduce accident risk	(Cl) Improve analysis of reactor safety
Alleviate public concern	(D1) Accelerate studies of alternative energy sources
Variation: Sharpen market competition of nuclear power	
This strategy, not analyzed in detail, would include some or all of steps towards: reduction or removal of Federal subsidies for nuclear and alternatives; marginal cost pricing; deregulation; full costing of external impacts	
Strategy One: Remove obstacles to more nuclear orders: Three policies above plus *five* others	
Goals	*Policy Options*
Reduce capital cost barrier	(Al) Revise regulation
	(A2) Assist funding of standardized optimized LWR design
Improve reactor economics	(B2) Improve utility management
Alleviate public concerns	(D2) Address concerns of critics
	(D3) Control the rate of nuclear construction
Strategy Two: Provide a moderate stimulus to more nuclear orders: *Eight* policies above plus *eight* others	
Goals	*Policy Options*
Reduce capital cost barrier	(A2) Assist funding of a demonstration of new LWR designs
	(A3) Promote the revision of rate regulation
Improve reactor economics	(B3) Solve occupational exposure liability
Reduce accident risk	(C2) Certify utilities and contractors
	(C3) Develop alternative reactors
	(C4) Revise institutional management of nuclear operations
Alleviate public concern	(D4) Maintain nonproliferation policies
	(D5) Promote regional planning for electric growth
Variation: Support the U.S. nuclear industry in future world trade	
This strategy, not analyzed in detail, would support industry and utility R&D and export financing policies aimed at obtaining a major share of the future world market in nuclear and other advanced electrotechnologies.	

SOURCE Office of Technology Assessment.

A "no change" strategy would continue the current Federal policy toward nuclear power. DOE could continue to fund R&D of both the LWR and alternative reactor types at about current levels. Although current NRC efforts to reduce backfit orders and streamline the licensing process would continue, there would be no major legislation and no fundamental changes in present regulatory procedures.

This strategy does assume continuation of two fairly controversial Federal policies. One assumption is that Congress will renew with no major changes the Price-Anderson Act, limiting the liability of plant owners and constructors in the event of an accident (described in ch. 3). Part of the act expires in 1987 and if it were not renewed, it could have a significant impact on the nuclear power industry, although how much and what kind of impact has not been analyzed in this report. A second assumption is that the Nuclear Waste Policy Act of 1982 is implemented successfully and the feasibility of safe waste disposal will be demonstrated.

The strategy also assumes that three noncontroversial policy options (actually expansions of existing efforts) discussed in the preceding section could be implemented: (B I) R&D for higher burnup and other improvements to reactor economics would be funded; (Cl) Safety concerns would be addressed more vigorously; and

(D1) research into problems and opportunities for alternative sources of electricity generation would be accelerated.

The likely outcome if Federal policy is not changed will depend on two major factors—the success of industry efforts to eliminate current problems, and the economy. Two alternative sets of external economic conditions are considered here. One would result in a relatively high demand **for new central station generating plants and the other in** low growth. Similarly, the potential range of results of current industry efforts to improve the viability of nuclear energy are represented by two different outcomes: relatively successful and only moderately successful. These outcomes, or scenarios, are summarized in table 36, and will affect the impact of each of the other two strategies described in this report as well as the Base Case results. These scenarios are not predictions or projections of the future, but instead brief sketches of a few of the possible combinations of events that could make nuclear power more or less attractive to utilities over the next 10 years.

Economic Conditions: Two Scenarios

The major economic factors that will affect future demand for nuclear power are the rate of growth in electricity demand, the price and availability of alternative energy and electricity sources, and inflation and interest rates. All of these factors are discussed in greater detail in chapter 3 and summarized only briefly here.

Economic Scenario A: More Favorable to Nuclear Orders.—As shown in table **36,** Economic Scenario A includes a combination of those economic factors that could be expected to make nuclear power more attractive. In this scenario, rapid price increases for oil and gas might accelerate the shift to electricity helping create a moderately high increase in electricity demand

Table 36.—Four Scenarios Affecting the Future of the Nuclear Industry

Economic Scenarios Affecting the Nuclear Industry

Variable	Scenario A: Favor more orders	Scenario B: Hinder more orders
Electricity demand (average annual growth rate 1983-93	3.5%	1 .5 "/0
New capacity needed in 1995 (GW) would have to be ordered in late 1980's[a]	161	0
Additional capacity needed between 1995 and 2000 at same demand growth rate (GW) would have to be ordered by 1992	218	84
Price of alternative fuels:		
Oil and gas	Real price increases ***faster*** than price of electricity	**Real** price increases ***at same rate* as** electricity
Renewable	Real price remains higher than price of electricity	Price becomes competitive with electricity
Inflation rates and interest	Low	High
Environmental impacts	Concerns about acid rain, global CO_2 increase	No constraints on fossil

Industry Improvement Scenarios

Variable	Scenario A: Major improvements	Scenario B: Modest improvements
Average construction time	7 ***years***	12 years
Operation of existing reactors	70% availability	60°/0 **availability**
Safety risks	Currently operating reactors shown much safer	Little progress on unresolved safety issues
Reportable operating events	Almost none over decade; management improvements obvious	Continue at current rate; much media coverage

[a]See ch. 3 for a complete discussion of assumptions used in capacity projections; GW as used here means GWe.
[b]Possible factors In price increases: limited gas reserves; tight international oil market; increased environmental controls on coal burning.
[c]Steady reserves of oil and gas; continued conservation eases demand.

SOURCE: Office of Technology Assessment.

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(3.5 percent per year). This rate of growth in demand, coupled with a moderate need to replace aging powerplants, is expected to create a need for 161 gigawatts (GW)* of new central station generating capacity by 1995 and an additional 218 GW by 2000. Given the time required to complete new generating plants, utilities would be expected to order this much capacity in the 1983-93 decade.

Under this scenario, increasingly stringent environmental restrictions could make new coal plants very expensive. If this price increase occurred at the same time as the projected growth in electricity demand, utilities would be faced with the need for new capacity while their most important fuel was becoming considerably harder to use. As a result, nuclear power would appear much more attractive to utilities placing powerplant orders. If the inflation rate and prevailing interest rates were relatively low, capital costs of nuclear plants would be more manageable and predictable for utilities. Low inflation and the decreasing construction costs over the next few years will stabilize rates to consumers, very likely lessening hostility to utilities. In addition, the benefits of nuclear power would grow in the eyes of the public as electricity demand increases.

Economic Scenario B: Less Favorable to Nuclear Orders.—If the economy follows this path, nuclear power remains relatively less attractive. In this scenario, moderate price increases of gas and oil slow the shift to electricity. **In addition, renewable energy sources** become more competitive with central station electricity. As a result, there is only slow growth (1.5 percent) in average annual electricity demand, and no new generating capacity must be completed in the decade. However, even at this slow rate of growth, if moderate numbers of existing plants are retired, about *84* GW of new generating capacity would be needed by the year ***2000,*** and this capacity would have to be ordered in the 1983-93 time period. With relatively small increases in the price of coal, and high interest rates driving up the capital costs of nuclear plants, utilities would be more likely to invest in coal-fired plants.

***One gigawatt equals 1,000 MW (1 ,000,000 kW) or slightly less than the typical large nuclear powerplant of 1,100 to 1,300 MW.**

in Economic Scenario B, rapid inflation over the next few years would cause continued price increases and continued high interest rates during completion of the ***30*** nuclear plants now under construction. Utilities would be forced to request large rate increases from utility commissions as the plants are finished. These rate increases, combined with the slow growth in electricity demand, would cause consumer opposition and increased public skepticism about nuclear power. All of the assumptions included in Economic Scenario B would be expected to make new nuclear plants less attractive to utilities.

Management Improvement Conditions: Two Scenarios

Industry and utility success or failure to make substantial improvements in the management of the nuclear enterprise will be reflected in several indicators: leadtime to build nuclear plants; average plant availability; progress on unresolved safety issues; and frequency of precursor events. These subjects were discussed in chapters 4 and 5.

Management Scenario A: Major Improvement.—In Management Scenario A, the nuclear industry would be very successful at overcoming some of its current difficulties without government assistance. Utilities currently operating reactors would overcome operating and safety problems, creating a steady improvement in reliability of operating reactors. Improved operation of existing plants and projections of reduced construction costs would make nuclear power more economically attractive to investors and public utility commissions as well as to consumers.

Management Scenario A assumes that operating plants and those completed over the next decade would be shown to be much safer than presently assumed because of improved operations and better understanding of the technology. Improved analysis and information (e.g., the ongoing research into "source terms") could demonstrate other safety characteristics (as discussed in ch. 4).

Two consequences would follow from these safety improvements. First, the management changes would greatly reduce major events, such as the failure of the automatic shutdown system at the Salem, N. J., reactor, which are viewed by the public as precursors to a major accident. Second, the new information on the small amount of radioactivity released in the event of an accident would temper the reaction to the few operating events that did occur over the decade. **These safety gains should be helpful in reducing public opposition to the technology and further increasing investor confidence.**

In addition to the improvement in utility management of operating reactors, the nuclear supply industry would be offering improved standardized LWR designs such as the APWR currently being developed by Westinghouse and Japan. Under current regulatory policy, the NRC could give licensing approval for a complete design, and, if a plant were built exactly to the design, there would be few regulatory changes during construction. **Thus, the regulatory environment would become somewhat more predictable without any major Federal legislation.**

Management Scenario B: Minor Improvements.—In Management Scenario B, some of the **weaker utilities would fail to improve their** performance despite the efforts of INPO and the NRC. Average availability for operating plants would be only about 60 percent, and there would be little progress in solving unresolved safety issues. poor management of operations would continue to cause precursors to serious accidents, and the media would continue to give extensive coverage to these near-accidents and major construction problems. One operating event might be so significant that a plant would have to be shut down for several months to a year for repairs. Without an adequate insurance pool, this would cause a major rate hike to cover purchased power. The long construction periods, continuing operating problems, and rate hikes due to outages would increase investors' and consumers' skepticism of the technology.

without Government intervention, this scenario could be expected to have very negative consequences for the industry regardless of external economic events.

Four Nuclear Futures Under the Base Case: No Policy Change

The two sets of economic conditions described above combine with the two management scenarios to form four futures that illustrate the range of possibilities for more nuclear orders. Future One is a combination of favorable economic conditions (Scenario A) and major improvements in management (Scenario A). Future Four combines the least favorable scenarios. Futures Two and Three are intermediate. The discussion that follows describes the factors under each future that would affect decisions on new nuclear plants. The four futures and their likely outcomes are summarized in table 37.

Future One.—Under the assumptions of Future One, there is a clear need for more generating capacity, the cost of other fuels is rising rapidly, operating plants are performing well, and industry offers improved, standardized designs. As discussed in chapter 8, public acceptance of nuclear

Table 37.—Four Combinations of Economic and Management Scenarios Under the Base Case

	Economic Scenario A: More favorable Fairly rapid growth in demand; utility alternatives costly; low interest/ inflation.	**Economic Scenario B: Less favorable** Slow growth in demand; alternative energy available; high interest/inflation
Management Scenario A: Major improvement 7-year construction time; 70% per availability; safer reactors; few precursor events	**Future One** Some further orders possible, especial. Iy if standardized preapproved designs are available.	[redacted]
Management Scenario B: Minor improvement 12-year construction time; 60°/0 availability; little progress on safety; continued precursors.	Future Three A few well-managed utilities may order plants over the next decade.	**Future Four** More orders very unlikely before 2000; a few possible after 2000.

SOURCE: Office of Technology Assessment.

technology is influenced by perceived benefits as well as by perceived risks. Therefore, the increased electricity demand in Economic Scenario A, combined with the safety improvements envisioned in Management Scenario A could be expected to increase support for nuclear energy. Utilities would be more confident that plants could be completed without unreasonable delays due to changing regulations or intervention.

Under these circumstances, and if the 7-year construction period for some recent plants appears achievable for new plants as well, **some utilities might be willing to order new nuclear plants even without changes in Federal policy. However, most utilities would still be deterred by uncertainties and risks, especially regulatory delays and costs.**

Those utilities with a need for new capacity might choose to share these risks by forming a consortium. This consortium could order several plants based on the best current design and share the necessary startup costs with component manufacturers. Under current regulatoy procedures, the NRC could grant simultaneous construction permits for three or four new plants. The SNUPPS consortium in the early 1970's is a prototype of such an effort (see ch. 5). If the plants were built in strict accordance with the complete design, there would be only minimal requirements for changes during construction.

A problem-free licensing and construction process would demonstrate to other utilities the benefits of standardization and show that at least some utilities were committed to the technology. **Given the need for additional power and the consortium's expected success, nuclear orders might "snowball" without any major Federal action.**

Future Two.–The safety and management improvements, reduced construction times, and expected increased public acceptance under Management Scenario A would make nuclear power a more attractive option. However, the assumed slow growth in electricity demand in Economic Scenario B would make utility investment in any type of new powerplant unattractive throughout most of the decade.

As discussed earlier, Economic Scenario B envisions that 84 GW of new electric-generating capacity would have to be ordered only at the end of the 1983-93 decade. By then, the absence of orders and slowdown in construction would have eliminated many suppliers of nuclear plant components and services, increasing the cost of a new nuclear plant. This cost increase, combined with high inflation and interest rates, might offset the savings from reduced construction times envisioned in Management Scenario A, further discouraging nuclear orders. Given the overall risks and uncertainties, it is unlikely that a utility would order a nuclear unit unless its projected costs were much lower than a similar coal plant. This is unlikely, however, because poor business prospects would keep nuclear companies from investing heavily in the design and analysis needed to reduce costs.

At most, only one or two utilities could be expected to order a nuclear plant under Future Two, given no major change in Federal policy. Any orders that did occur probably would come from a very experienced nuclear utility and most likely would be in the form of initiating or completing construction at a currently inactive plant site. **However, it is more likely that there would be no orders at all over the next decade under these circumstances.** Given some utilities' current problems with nuclear energy, no utility would want to be the only company venturing into a new nuclear effort.

In the 1990's, with few or no new orders, the U.S. nuclear industry would lose most of its expertise in plant design and construction, and suppliers of key components would drop out. De**spite these problems, some utilities could be interested in ordering reactors toward the end of the century, especially if demand growth starts to increase.** By then, the utilities would probably find a Japanese, French, or West German design preferable to outdated U.S. plant designs. If U.S. companies wanted to offer the most current reactor designs, they might have to license them from foreign companies, perhaps the very ones they had licensed to build LWRs in the first place. In either case, as discussed in chapter 7, U.S. companies probably would still have the resources to tailor the designs to American needs and to build the plants.

Future Three.-The poor management conditions of Management Scenario B, under a policy of no change in Federal policies, would create serious tensions between the need for nuclear powerplants and continued opposition (by investors, critics, and the public) to their high costs and risk. As discussed previously, this scenario envisions constraints on fossil fuel combustion, encouraging utilities to consider purchasing nuclear plants, Those utilities with successful experience in building and operating nuclear plants would not be deterred directly by the poor experiences of others. Indirectly, however, all utilities are "tarred by the same brush" aimed at the weaker utilities by the NRC actions, the public, investors, and others. Thus, the lack of major industry improvements envisioned in Management Scenario B would cause present uncertainties to continue.

Moderate interest and inflation rates assumed under economically favorable Economic Scenario A might help to offset the cost escalation resulting from the lengthy average construction period expected in Management Scenario B. This would moderate the "rate shock" as new plants came on line, reducing consumer opposition slightly. Public perception of increased electricity demand could be expected to offset concerns about safety risks slightly, perhaps returning public opinion to a 50-50 split on the technology.

The **net effect of favorable economic conditions combined with little change in the state of the industry and no major Federal policy change would be that, at most, only a few utilities would order new nuclear plants over the next decade.** Despite the constraints on fossil fuel combustion, most new plants would be coal-fired, with environmental controls to meet current regulations. With only a few new orders, subsequent events would follow the path outlined for Future Two. In essence, the U.S. nuclear industry would slowly decline, and any new nuclear plants ordered after 1995 might be of foreign design.

Future Four.–With the combination of both Management Scenario B (Minor Improvement) and Economic Scenario B, there is little prospect for any nuclear orders with no change in Federal policies. Continued management and safety problems at plants currently operating and under construction, slow growth in electricity demand, and increasing competitiveness of other fuels, create a climate in which no utility could be expected to order a new nuclear plant. In the inflationary environment expected under Economic Scenario B, utilities would be very reluctant to invest in capital-intensive plants of any type. Instead, utilities could be expected to match supply and demand through load management, efficiency improvements to existing coal plants, and cogeneration, contributing to the slow overall rate (1.5 **percent)** of growth in electricity demand.

Near the end of the 1983-93 decade, some utility executives might order relatively inexpensive combustion turbines to supply the 84 GW of new capacity needed by 2000. Although Economic Scenario B expects moderate gas prices, an increased reliance on gas and oil for electricity generation might drive up prices, resulting in much higher electricity prices. Despite high interest and inflation rates, a few utilities might order coal- fired plants in the early 1990's. The electricity from these plants would be rather expensive because of the high capital costs, further**ing** dampening growth.

Most designers and equipment suppliers would leave the business, leaving a much smaller U.S. industry. Because public opposition would be high under this combination of scenarios, utilities would be unlikely to order new plants from abroad, and no new nuclear plants would be built in the United States before 2000.

Even in Future Four, however, **there is a possibility that new nuclear units could be built after 2000.** As discussed in chapter 7, the U.S. nuclear industry is very resilient. By maintaining its expertise with fuel service and waste disposal business, the industry still should be capable of building a reactor (probably based on foreign designs and components) if events after *2000* created a renewed interest in nuclear power.

Base Case Variation: Let Nuclear Power Compete in a Free Market

Electric utility investment decisions are shaped as much by regulatory practices as by the market. This section notes some of the problems in investment decisionmaking which may have an impact on orders for nuclear powerplants and proposals intended to bring the discipline of the free market to generating capacity investments.

The first problem is that the regulated retail price of electricity is based on the average cost of all generating sources, but any incremental demand must be met with new generating capacity. Under some conditions new generating capacity costs considerably more than average. This is especially true if existing capacity includes a high proportion of largely depreciated coal-burning units or older nuclear units. Under these circumstances there is a mismatch between the price signals consumers receive, and the decisions utilities have to make.

A second problem is that regulation combined with inflation can discourage investment in capital-intensive projects such as nuclear powerplants even if they are the least expensive options in the long term. in times of inflation, regulators tend to delay increases in allowed return to equity investment, and the actual return lags behind the allowed return. Furthermore, inflation combined with book value accounting tends to load the capital costs of a project into the early years where it will be difficult to accommodate them in the rate base. Some of these problems have also been tackled in proposals for rate return **(e.g., regional rate** regulation, CWIP, trended original cost, etc.) described elsewhere in this chapter.

The most comprehensive proposals for changes fall under the general heading of the "deregulation of electric utilities." Such proposals range from selective deregulation of sales of wholesale power among utilities to a massive restructuring of the electric utility industry into unregulated generation and transmission (G&T) companies and regulated distribution companies. The theoretical advantages and disadvantages of various kinds of deregulation and the many practical problems were analyzed in detail in a recent comprehensive report (1 O).

Overall, the analysis concluded that the theoretical benefits of more comprehensive forms of deregulation are sufficiently uncertain, and the practical problems sufficiently difficult, that any move towards deregulation should proceed slowly and cautiously. The report also identified some limited steps toward deregulation that would encourage the kind of competition among generating technologies that is most likely to lead to short- and long-term gains in efficiency. These steps include: 1) more Federal encouragement of power pooling and coordination, 2) rate structures (including experimental deregulation) for wholesale power sales regulated by FERC that encourage efficiency of operations, 3) encouragement of utilities to form generating and transmission companies within holding company structures, 4) mergers between small utilities partly to facilitate the contractual arrangements within power pools, and 5) encouragement of retail rate structures that reflect the incremental cost of increased electricity demand.

Step 5 above includes "marginal cost pricing," another category of proposed change. The rate structure could be adjusted so that customers pay more for electricity at times of day or in seasons when it costs more to provide. Alternatively, customers could be charged more for each incremental block of electricity they purchase. A move toward marginal cost pricing may be useful to encourage load management, especially in regions where capacity utilization is poor. It is less obvious how to use marginal cost pricing to improve the accuracy of the price signals with respect to nuclear power. Nuclear power is base load electricity generation and would be affected only slightly by seasonal or time-of-day pricing. Further, rate regulation would have to be modified to account accurately for the true marginal cost of nuclear generated electricity. Because of the peculiarities of current rate regulation described in chapter 3 (and addressed in policy option A3), the cost of the first year of nuclear power is more than twice as much as the 20 or 30 year levelized cost which is the true marginal cost.

Another problem with the current system is that some of the costs of different sources of electricity are not fully reflected in the private cost of such sources. Nuclear power receives some direct or indirect Federal assistance of several kinds: 1) Federal limits on public liability following a nuclear accident (the Price-Anderson Act), 2) Federal subsidies for uranium enrichment, and 3) the Federal cost of nuclear safety regulation and nuclear R&D. Coal-fired electricity also receives Federal assistance from: 1) black lung payments (currently about $1 billion/year); 2) Federal coal mine regulation; and 3) no charge for air pollution within regulatory limits.

investment comparisons for nuclear power and competing generating technologies would be more accurate if these subsidies were eliminated. This study has not analyzed the consequences of reducing Government support, such as R&D or the effects of eliminating the Price-Anderson liability limitations. It does seem clear, however, that such acts would be viewed by both the industry and the public as signaling a lessening of the Government's commitment to nuclear power. At this point, the industry can ill afford such signals. Therefore, it should be recognized that taking these initiatives, whatever their overall merits, may well be tantamount to ending the nuclear option, at least for the foreseeable future.

Strategy One: Remove Obstacles to More Nuclear Orders

The intent of this strategy (see table 35) for a list of policy options) is to establish an environment in which utilities would be more likely to consider nuclear reactors if demand does pick up over this decade and, at the same time, to establish policies that would win the support of nuclear critics and the public.

The policy options included here work together to achieve these ends. Two of the options, (Al) revise regulation and (A2) develop standardized optimized LWR designs, are closely linked. These options would eliminate some of the major concerns utilities have over nuclear. It is more difficult to predict how to gain the necessary public support. Strategy One includes three policy options designed to reduce the controversy over nuclear power and the concerns of the public: (62) improve utility management of nuclear plants, (D2) address the concerns of the critics, and (D3) establish limits on future nuclear construction within the context of a balanced energy program.

Of these policy options, the easiest to implement is the involvement of the NRC **in upgrading utility management. Such a program already exists. The challenge is to make it motivate utilities to excellent performance (as is discussed in ch. 5) rather than merely to avoid getting** in trouble with the NRC. This is probably only possible if the NRC program is developed in close cooperation with IN PO. There are several possible ways discussed earlier to involve interveners more closely in monitoring and improving nuclear plant safety. This policy option is likely, however, to stimulate substantial opposition from utilities unless it is clear that it is closely coupled with licensing and backfit reform.

The effect of Strategy One on utilities' perceptions of costs and schedules would be mixed. Licensing and backfit reforms would help assure utilities that they could build the plant as designed once a construction permit were approved. However, opening the process more to the critics introduces another element of uncertainty, especially for the first few orders. Furthermore, these proposed reforms would not necessarily dramatically reduce capital costs, so electricity from average cost nuclear plants still could be perceived as more costly than electricity from average cost coal plants in most U.S. regions (see ch. 3).

The impact of Strategy One on orders for new nuclear plants also would vary sharply for each of the four nuclear futures described above for the Base Case. As can be seen in table 38, the impact of this strategy under each of the four futures does not differ greatly from the impact of the Base Case. **In light of the considerable difficulty that** would be involved in implementing the five policy options, this finding suggests that Strategy One maybe only marginally effective.

Future One.—Under these conditions that are relatively favorable for more nuclear orders, Strat-

Table 38.-Alternative Nuclear Futures Under Strategy One: Remove Obstacles to More Nuclear Orders

	Economic Scenario A: More favorable	Economic Scenario B: Leas favorable
Management Scenario A: Major improvement	**Future One** A few **orders likely if utilities are willing to be the first; a consortium and/or turnkey contracts could initiate ordering.**	[redacted]
Management Scenario B: Minor improvement	**Future Three** **Orders unlikely because of low public acceptance and continued regulatory difficulties, perhaps enhanced by the greater participation by the critics.**	**Future Four** Orders unlikely even after 2000.

SOURCE: Office of Technology Assessment.

egy One would increase the likelihood relative to the Base Case. Utilities would have greater confidence that a new reactor could be built close to the projected cost and schedule. Most major design questions would have been worked out before construction had started. The NRC essentially would have approved the design and apparently would be ready to move an application through expeditiously. Critics would have been given ample opportunity to critique the design. Controversy over nuclear power would be noticeably lower because the last of the present reactors under construction would be complete without a continuation of the cost overruns they are now experiencing, and operating reactors would show considerably improved performance,

Under such circumstances, vendors might be willing to encourage the first orders by offering a fixed price "turnkey" contract. The first few plants might not be much less expensive than present plants under construction, but simplified engineering and cumulative construction experience would be expected to cut the cost of a typical plant 20 to 30 percent from current levels (see chs. 3 and 5). Utilities might hesitate to order the first few plants largely because of doubts that cost and regulatory problems really had been solved. Sharing the risk with the vendors would do much to alleviate these concerns. If the experiences of the first few orders were favorable, further orders could be expected in line with demand growth.

Intervener involvement in the licensing process for standard designs combined with the effects of good management on plant operations should reassure nuclear critics and reduce the reasons for opposition to nuclear power in licensing procedures and electricity rate hearings. The strong need for more powerplants coupled with the relatively high prices and environmental problems of coal in Economic Scenario A increase the relative advantage of nuclear and also reduce opposition at State regulatory hearings.

Future Two.– If economic and industry management conditions are less favorable than they are in Future One, the policies of Strategy One will not succeed in stimulating very many orders. In Future Two, industry management is assumed to improve substantially but electricity demand grows slowly and inflation and interest rates are high, discouraging capital expenditures. Because of fewer precursor incidents, public acceptance grows, but there is little obvious need for nuclear powerplants.

With only 84 GW to be constructed by 2000, there would be little pressure to diversify into nuclear. With few prospective orders, vendors and architect-engineers would be unlikely to take the risk of offering turnkey projects. A few utilities, seeking to preserve the option, might make a point of at least considering a few nuclear plants. The new standardized designs, especialy if smaller than current designs, and streamlined licensing could make reactors competitive with coal. **Under Future Two, Strategy One has a somewhat better chance than the Base Case of leading to a few more orders by the end of the century.**

Future Three. -Under these conditions, Strategy One actually could reduce the prospects for new nuclear orders from what they are under the Base Case. With continued poor plant operating performance and continued precursor events, nuclear critics will not be satisfied that adequate progress is being made. With inter-venors more closely involved in safety regulation, the lack of progress on resolving safety concerns could increase the time devoted to particular safety issues. **Even with high growth, the utilities are likely to regard more nuclear orders as too risky, not only from technical problems raised by the NRC and the critics, but also from the financial impact of public opposition on rate hearings and investor decisions.**

Future Four.– Finally, the policy options of Strategy One could diminish still further the prospects for nuclear orders under the dismal conditions of Future Four which combines both adverse economic conditions and little industry improvement. The combination of intervener involvement with poor industry improvement and little apparant need for nuclear power could create conditions of public opposition that would make orders unlikely even after 2000.

Strategy Two: Provide Moderate Stimulation to More Orders

Strategy Two builds on Strategy One. It assumes that efforts to remove obstacles to more nuclear orders would be inadequate, largely because utilities still would be unconvinced that the problems were resolved. **As** in Strategy One, policy measures to reduce capital and operating cost of nuclear plants are combined with policy measures to make nuclear power more acceptable to nuclear critics and the public.

The first policy option is a demonstration of the reactor(s) developed under A2 as discussed in Strategy One. The main purposes would be to show that the reactor could be built according to design and that the licensing process could handle it as expected. **It** could be expected that private industry would fund most of this project since technological feasibility is not i n question, but significant Federal participation could be required.

A second step is (A3) Stimulate improved rate regulation treatment of capital-intensive projects. No Federal budget is required for this policy option but sensitive Federal leadership is needed since rate regulation traditionally has been left to the states.

Strategy Two adds a politically controversial step to improve operating economics with (64) Reduce uncertainty about occupational exposure liability. Clarifying occupational exposure conditions and ranges of possible payments to exposed workers with health problems might add expense to the operation of nuclear plants but would reduce the uncertainty which accompanies an unspecified liability (which could be the subject of private lawsuits, such as is now happening with asbestos exposure liability).

Strategy Two includes three additional options to reduce the risk of a reactor accident. (C2) would

Table 39.—Alternative Nuclear Futures Under Strategy Two: Provide a Moderate Stimulus to More Nuclear Orders

	Economic Scenario A: More favorable	**Economic Scenario B: Less favorable**
Management Scenario A: Major improvement	**Future One** Some plants ordered by about 1990; more by the end of the century.	[redacted]
Management Scenario B: Minor improvement	Future Three **New orders likely only if Government options to improve management have a** big impact on utilities and public opinion, resulting **in Future One; new reactor types would be useful.**	**Future Four** **Government actions to improve** management and R&D funding of new reactor types should improve prospects **for** more orders after 2000.

SOURCE: Office of Technology,

require the NRC to restrict construction licenses for nuclear plants to qualified utilities and construction contractors. Substantial Federal funding, up to several billion dollars over 10 years or more, would be required for a second step: (C3) Fund a major R&D program on alternative reactor types. If this option is pursued at a high level, the demonstration LWR probably would be deleted. For a third option, (C4) Revise institutional management of utilities, there could be controversial changes in Federal and State utility regulation, antitrust law and other long-standing institutional guidelines. These steps should ensure the availability of reactors and operators in which the public could have great confience.

Substantial changes in public acceptance of nuclear power are needed to accumulate the political capital for either large Federal budget expenditures or for Federal efforts to change utility rate regulation or utility institutional management. Two options included in Strategy Two go further than the steps in Strategy One to alleviate the public's concerns about nuclear power and sharpen the basis for judgment about the long-term need for nuclear power. (D4) reduces concerns over the linkage between nuclear power and nuclear weapons by such steps as banning reprocessing. (D5) encourages or requires the use of regional planning and perhaps rate regulation, to improve the consensus on the long-term need for capital intensive technologies such as nuclear power.

Future One.–Strategy Two would have a big impact on conditions such as those in Future One which hypothesizes rapid demand growth and successful industry improvement, but also utility reluctance to place the first nuclear order after a hiatus in orders and substantial public controversy.

Perhaps the best vantage point from which to appreciate the possible need for Strategy Two is from a look forward to 1993 under the assumptions of Future One if there have been no nuclear orders even though Strategy One has been implemented. It is likely that the main obstacle to any nuclear orders would be utility uncertainty that all the problems had actually been resolved, despite the steps in Strategy One. By 1993, more coal fired capacity would have been ordered over the previous 10 years than existed in 1983, but concerns over the environmental impacts would be rising sharply. Stringent new emission regulations would appear probable, but would be very expensive. The costs of other fuels also would be rising rapidly. Other industrial countries, especially France, Japan, West Germany, Great Britain, and Canada would have maintained their nuclear programs, and their cheaper electricity could give them a competitive edge in certain areas of international trade. Utilities would have raised their standards of nuclear operation such that mishaps rarely would occur and reliability would be high. Americans in 1993 might well wonder what went wrong with our national decision making,

What would Strategy Two have accomplished in the same period? How would utility uncertainty have been reduced? Under the conditions of Strategy Two, utilities would have a clear demonstration of Federal government commitment to resolving the problems with nuclear power and good reason to expect that nuclear plants definitely would be cheaper than coal plants in most regions of the country.

By 1990, the standardized design would be sufficiently well proven that interveners, NRC and nuclear designers would be satisfied that it was very resilient to any accident sequences anyone suggests. It would be clear to all that construction of the first standardized plant was proceeding smoothly on schedule and within budget. The NRC would offer a construction permit based on its previous review of the existing design, with only site specific characteristics to be approved. The financial burden on utilities would be lessened because of reduced construction cost and changes in rate regulation, and, perhaps, because smaller reactors would be available. Alternatively, the HTGR or one of the other reactors could be in an advanced stage of development.

Given the strong demand, low interest rates and relative unattractiveness of other fuels in Economic Scenario A, there is little doubt that utilities would order nuclear plants if they were convinced costs would come down and public acceptance would be sufficient to avoid serious economic risk to the plants. Nuclear critics and the public would have been reassured by a decde of steadily improving nuclear plant performnce, the closer involvement of interveners in licensing, a nationally agreed limit on future nuclear construction and the several other measres of Strategies One and Two. In addition, the obvious need for generating capacity would lead to considerably greater public acceptance for more nuclear plants by 1993.

Under these conditions, some plants would be ordered in the early nineties and probably a larger number in the late nineties. Strategy Two thus makes probable what is only a possibility under the same favorable conditions of Strategy One. While it is difficult to be precise, this policy package could lead to more nuclear orders even under conditions somewhat less stimulating than in Economic Scenario A. A growth rate in electricity demand averaging 2.5 percent might have the same probability of initiating nuclear orders as 3.5 percent did under Strategy One.

Future Two.– If utility management were improved but economic conditions were much less favorable to nuclear orders, as in Future Two, much of the effort going into standardized design could be wasted. When the time came for new orders n-ear or past 2000, a foreign design, an alternative reactor type, or possibly photovoltaics might appear more appropriate. Thus, this effort might be dropped if demand growth stays low. An effective program to develop alternative reactor technology could prove to be the crucial reassurance to utilities contemplating new orders after 2000. Utilities that might be unwilling to be the first or second to order a new reactor type might be willing to be the third or fourth.

The other steps of Strategy Two (coupled with two decades of good management) would be useful in changing the climate of public opinion to be more receptive to nuclear power in the long term. With demand growth of only 1.5 percent annually, such changes are likely to be important even when there has been good utility management.

Future Three. -Strategy Two might not be feasible if utility management of nuclear reactors improved very little, as is assumed under Future Three and Future Four. The consensus that would be required for the large Federal budget expenditures and the changes in Federal-State relations on utility rate regulation would not emerge.

For Future Three, with favorable economic conditions for nuclear orders, Strategy Two might be implemented in stages beginning with options to restrict construction licenses to qualified utilities (C2)—and perhaps revoke operating licenses as appropriate,—and changes in utility institutional structures (C4), allowing utility service companies to take over poorly run plants. In effect, these actions would change the situation to that of Future One.

If these actions are insufficiently successful, future orders probably would be contingent on the development of inherently safe reactors which, by allaying many safety concerns, would restore some degree of public acceptance.

Future Four.–Strategy Two would be very hard to justify for Future Four with both little industry improvement and unfavorable economic conditions. The options to improve utility management, however, would help improve public acceptance for after 2000, which is the earliest nuclear orders might be placed. It also is possible that a modest level of investment in new reactor types could lead to a more ambitious effort in the nineties when public acceptance would be improved as a result of NRC efforts to improve utility management.

Strategy Two is clearly a high-risk, high-gain strategy. Under the circumstances of Future One it could assure the future of the U.S. nuclear industry, although it might not even be necessary to stimulate nuclear orders if the industry itself takes sufficient steps to improve the technology and if demand for electricity grows rapidly. Under other circumstances, Federal efforts and funds could produce little of value (Future Two) or be impossible to carry out (Futures Three and Four).

Strategy Two Variation: Support the U.S. Nuclear Industry in Future World Trade

In this variation of Strategy Two, the Federal Government also would play an activist role in supporting the U.S. nuclear industry. The rationale for this variation would come, however, from a completely different source. Rather than regard nuclear power as an element of U.S. energy policy, the strategy would treat the nuclear industry, and related electrotechnologies, as key elements of an emerging U.S. industrial policy.

Several assumptions about the current nature of world competition in nuclear technologies underlie this approach. One is that the advanced reactor designs now underway with joint U. S.-Japanese teams will establish a new standard LWR for the 1990's that will make more modest improvements obsolete. These designs—probably to be licensed jointly by Japanese and U.S. vendors—may well account for any nuclear orders in the 1990's. These designs should give both the United States and Japan a very strong position in world nuclear trade.

The second assumption underlying this approach is that there will beat least one more generation of non breeder reactors after these advanced LWRs become available. The slowdown in plant construction, potential for extended burnup and new uranium discoveries all would make it likely that nonbreeder reactors will be competitive for several more decades. The standardized LWR discussed in option A2 or one of the advanced alternative reactors in C3 could be the choice.

The question is: should the U.S. Government encourage a strategy of R&D that leads to the next stages of reactor development beyond the joint Japanese-U.S. vendor projects? Several elements of a general industrial policy could be applied to nuclear power: 1) support for R&D into product development, 2) relaxation of antitrust prohibitions on cooperation among businesses during the product development stage of R&D, and 3) financing assistance in export promotion through the Export-Import Bank (7,8).

Such a strategy might be especially productive because of the historically low spending on R&D by the electric utility industry. The $250 million budget of the Electric Power Research Institute (EPRI) represents only about 0.25 percent of electric utility sales each year. General manufacturing industries spend about 2 to 3 percent of sales on R&D and high technology industries may spend up to 10 to 15 percent.

A major increase in R&D for the electric utility industry could be allocated among:

- elect rotechnologies for industry such as plasma reduction of iron or microwave heating;
- commercialization of photovoltaics and the solid-state control technology needed to integrate them in the grid; and
- a more advanced nuclear reactor for beyond *2000.*

It seems likely that a balance among support for different advanced generating technologies, including photovoltaics as well as advanced nuclear reactors, will be necessary to get widespread support. Utilities also are likely to favor diverse R&D because of the financial risk inherent in relying on single technologies.

One approach to obtaining funding for such an R&D effort is to make the treatment of R&D in utility rate regulation more attractive. The telephone industry traditionally has included R&D in the rate base in most States.

Federal action in support of this policy strategy would have several elements:

1. Selection of these technologies as a significant element of U.S. long-term industrial policy, and expansion of these R&D programs.
2. Legislation providing incentives or requiring States to allow R&D expenditures in the cost-of-service.
3. Increased Federal funding for some joint EPRI-DOE projects,
4. Elimination of antitrust penalties for vendor cooperation on an advanced reactor design.
5. Consideration of long-term loans such as the Japanese government made available to the semiconductor industry.
6. Attractive financing to foreign customers for nuclear technology exports-through the Export-import Bank.

Implementation of such a strategy would give the U.S. a headstart in world competition just when U.S. orders could be expected to pick up because of load growth and replacement of existing plants. It could result in a healthy nuclear industry with brighter export prospects, and more attractive options of both supply and demand for the electric utility industry. Electricity consuming industries would also benefit, some quite significantly.

There are some obvious difficulties with this strategy. Given the Federal system, it may be very difficult to get State support for more favorable treatment of utility R&D expenditures. Although some R&D will be carried out by manufacturers, a comprehensive strategy will not work unless a major part of the impetus comes from the electric utilities. Utilities should derive a major part of the benefit, aside from being able to buy the developed product. Another difficulty is that electrical demand technologies and advanced generating technologies may not seem as important as other U.S. industries in claiming a role in a general high-technology industrial strategy. Current strategies tend to focus on computer, semiconductor manufacture, and biotechnology rather than traditional manufacturing industries. The R&D effort would also have to be designed with care to ensure that the funds are spent productively.

CONCLUSIONS

The scenarios and discussions of the previous section underscore the conclusion that there is no simple key to restoring nuclear power as a national energy option. Nor is there any assurance that even a rigorous set of policy initiatives would do so. Uncertainties over the future growth rate of demand for electricity are at least as important as the policy options analyzed here. At the very least, a moderate demand growth rate and moderate improvements in management of existing plants are prerequisites for creating the conditions under which utilities could consider ordering additional nuclear plants.

The problems and uncertainties are great but not insurmountable. If the technology and its management improve sufficiently that confidence in both safety and economics is much higher, if nuclear regulation shows a parallel improvement, and if financial risks are shown to be less than financial rewards, then nuclear power would be a logical part of our energy future. To see how this might be so, consider the seven sides to the nuclear debate discussed in chapter 1:

- The nuclear industry would have a product that was thoroughly analyzed, demonstrably safe and economically competitive.
- The NRC would have exhaustively examined the design and be confident that few additional issues would be raised once a construction permit had been granted.
- PUCs would have more confidence that a utility would not bankrupt itself with a new reactor because costs would be predictable at the start due to matured designs and regulatory stability, and operation of existing plants had proven to be in the best interests of consumers.
- Investors could expect more favorable regulatory treatment from the PUCs as well as having more confidence in the economic attractiveness of nuclear power.
- Critics would have far fewer specific concerns with safety and the overall threat of a "nuclear economy." This would lower the intensity of the controversy even if few critics changed their minds on the inherent desirability of nuclear power.
- The public would be more supportive because of the lowered controversy, the improved operating records of existing plants, and the more visible benefits.
- Finally, utilities, or generating entities set up to replace or supplement them, would see this improved environment for nuclear power, the predictability of costs and operations, and the affordability and competitiveness of the new plants, and would be much more receptive to proposals for new nuclear plants.

The purpose of the policy options discussed above is to assist in the transition from the pres-

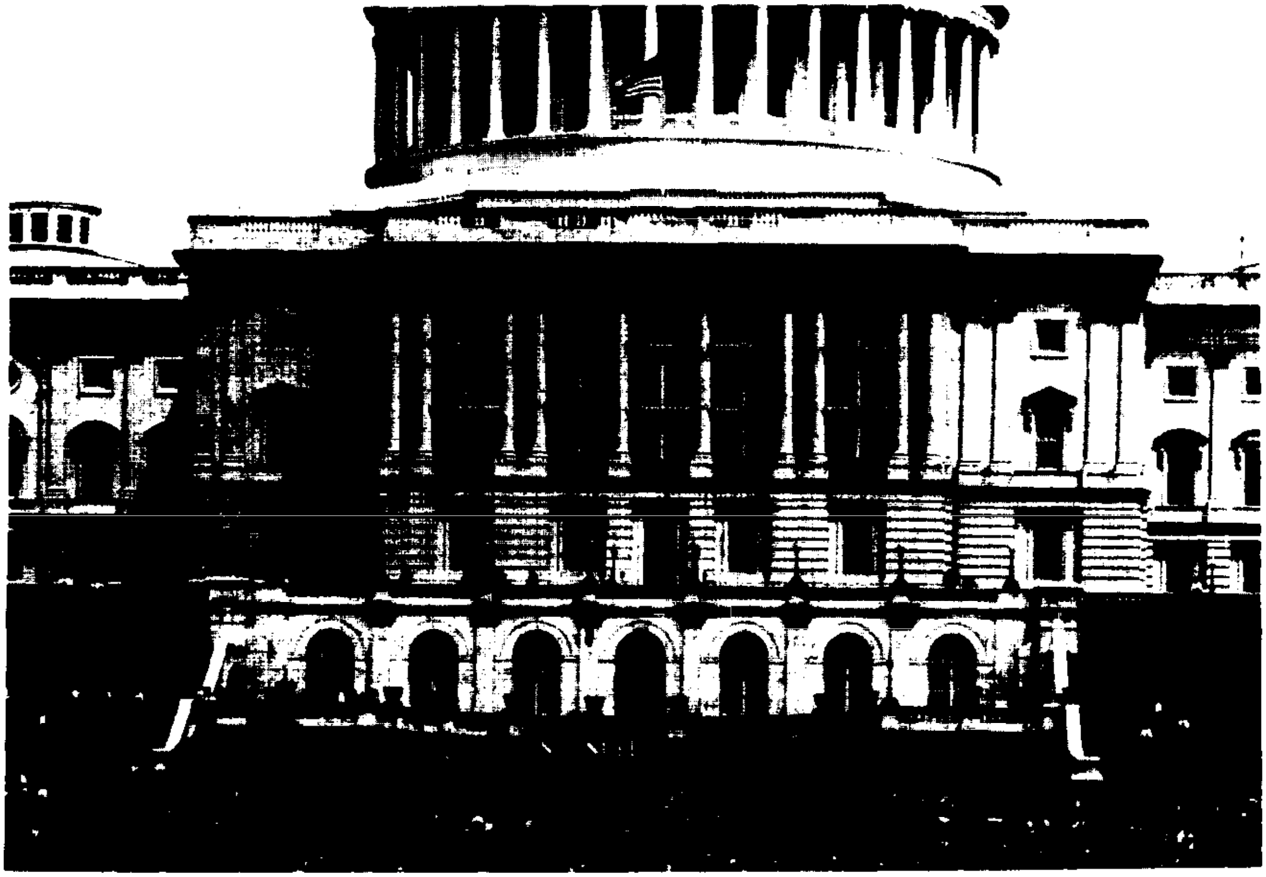

Photo credit: William J. Lanouette

Demonstration in front of the Capitol after the **accident** at Three Mile Island

ent situation to this future. However, it is impossible to say with any certainty how much improvement in any one factor is necessary, or how much each policy initiative would contribute. These problems are interdependent: none can be solved in isolation, but the progress on each will assist in the solution of others.

The future listed above corresponds to Future One in the previous section, coupled with as many policy initiatives as it takes to start nuclear orders. Strategy One might be adequate. Strategy Two probably would be, but we cannot say for sure. The uncontrollable uncertainties are simply too great. For instance, future plants can be designed to be safer than existing plants. industry already is working on this. The national design of Strategy One would improve on this and be more convincing to critics because of the openness of the design effort. The inherently safe reactors of Strategy Two would be more reassuring, but would introduce cost and operational uncertainties. How far is it necessary to go to achieve a consensus that reactors are safe enough? It seems reasonable to assume that greater safety would result in greater acceptance, but there is little direct evidence to support that view or to quantify the relationship.

Any policy strategy should be flexible enough to try things that may not work or may be found inappropriate to changing conditions, and to discard the less successful initiatives in favor of the better ones. The strategy should include elements dealing with the technology, its management, nuclear regulation, financial risk, and public acceptance.

Additional nuclear plants essentially have been rejected by the American people because of perceptions of the current technology and its management. Major improvements will have to be made to restore their faith. To be successful, a strategy must recognize the different concerns and try to balance the interests. In particular, the role of the critics in any nuclear resurgence will be crucial. Critics have been the messengers to the public of many of the real problems with nuclear power. They will continue to play that role until they have been shown that the problems have been solved or rendered inconsequential. They also can be the messengers, even if only by losing interest, when they are convinced that nuclear power as a whole is a minor problem compared to other societal concerns. It is difficult to conceive of how public acceptance can be improved significantly while knowledgeable critics still are voicing real concerns.

The outlook for the nuclear supply industry is bleak but not hopeless. New policy initiatives can set the stage for a turnaround. Without appropriate action, it is likely that the option of domestically produced nuclear reactors gradually will fade away. If such is to be the future, the decision should be made consciously, with the knowledge that even the nonnuclear futures available to the Nation contain risks and drawbacks. Nuclear power can be a significant contributor to the Nation's energy future, but only if the efforts to restore it are undertaken with wisdom, humility, and perseverance.

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Appendix

List of Acronyms and Glossary

List of Acronyms

ACRS —Advisory Committee on Reactor Safeguards
AE —architect-engineers
AEC –Atomic Energy Commission
AFUDC –allowance for funds used during construction
AIF –Atomic Industrial Forum
AGR —advanced gas reactor
ANS –American Nuclear Society
ASME –American Society of Mechanical Engineers
BWR —boiling water reactor
CAA –Clean Air Act
CEGB –Central Electricity Generating Board
COL —construction and operating license
CP —construction permit
CPCN –Certificate of **Public Convenience and** Necessity
CRBR –Clinch River Breeder Reactor
CRGR –Committee for Review of Generic Requirements
CRS –Congressional Research Service
CWA –Clean Water Act
CWIP —construction work in progress
DOE –Department of Energy
DRI –Data Resources, Inc.
EIS –Environmental Impact Statement
EPRI –Electric Power Research Institute
ERDA —Energy Research and Development Administration
ER –Environmental Report
FEMA –Federal Emergency Management Agency
FERC —Federal Energy Regulatory Commission
FSAR –Final Safety Analysis Report
GAP –Government Accountability Project
GCR –gas cooled reactor
GNP –gross national product
GPU –General Public Utilities
HTGR —high temperature gas-cooled reactor
HWR –heavy water reactor
IDCOR –Industry Degraded Core Rulemaking Program
IN PO —Institute of Nuclear Power Operations
JCAE –Joint Committee on Atomic Energy
KWU —Kraftwork Union
LMFBR –liquid metal fast breeder reactor
LWR –light water reactors
MITI –Ministry of International Trade and Industry (Japan)
NAS –National Academy of Sciences
NASA –National Aeronautics and Space Administration
NCRP –National Commission on Radiological Protection
NEIL –Nuclear Electric Insurance Ltd.
NEPA –National Environmental Policy Act
NERC –Northeast Electric Reliability Council
NML –Nuclear Mutual Ltd.
NPCC –Northeast Power Coordinating Council
NPDES —National Pollutant Discharge Elimination System permit
NPRDS –Nuclear Plant Reliability Data System
NPT –Non-Proliferation Treaty
NRC —Nuclear Regulatory Commission
NSAC —Nuclear Safety Analysis Center
NSSS —nuclear steam supply system
NTOL —near-term operating licenses
NUTAC –Nuclear Utility Task Action Committee
OECD –Organization for Economic Cooperation and Development
OL —operating license
OTA –Office of Technology Assessment
PCRV –prestressed concrete reactor vessel
PG&E –Pacific Gas & Electric Co
PHWR –pressurized heavy water reactor
Plus –process inherent ultimately safe reactor
PRA –probabilistic risk assessment
PSAR –Preliminary Safety Analysis Report
PUC —public utility commission
PURPA —Public Utility Regulatory Policies Act
PWR –pressurized water reactor
RNPA –regional nuclear power authority
RNPC –regional nuclear power company
SAI –Science Applications, Inc.
SEE-IN –Significant Events Evaluation and Information Network
SER –Safety Evaluation Report
SNUPPS–Standardized Nuclear Unit Power Plant System
SPDS –Safety Parameter Display Systems
SPP –Southwest Power Pool
SRP –Standard Review Plan
TM I –Three Mile Island
TVA –Tennessee Valley Authority
WPPSS –Washington Public Power Supply System

Glossary

absorption, neutron: Any reaction in which a free neutron is absorbed by a nucleus, including capture and fission.

Allowance for Funds Used During Construction (AFUDC): An account in the income statement of a utility in which interest is accumulated on the construction expenditures for construction work in progress that has not been entered into the utility's rate base and is therefore not yet earning a cash return on investment. The accumulated interest is then added to the actual construction expenditures when the plant enters the rate base.

base loaded: Keeping a power station continuously loaded at the maximum load because it is one of the lowest cost power producers on the system.

boiling water reactor: A reactor cooled by water that is allowed to boil as it passes through the core. This coolant is used directly to produce the steam which generates electricity.

capacity factor: Ratio of average plant electrical energy output to rated output.

chain reaction: The continuing process of nuclear fissioning in which the neutrons released from a fission trigger at least one other nuclear fission.

cladding: The term used to describe any material that encloses nuclear fuel. In a water-cooled power reactor this is the fuel rod tube.

Construction Work in Progress (CWIP): An account on the asset side of the utility's balance sheet that includes all construction expenditures for plant and equipment on plant that has not yet been placed in service.

construction leadtime: The time required to complete construction of an electric generating plant, usually defined from either date of reactor order or construction permit to commercial operation.

containment building: A thick concrete structure surrounding the pressure vessel and other reactor components. It is designed to prevent radioactive material from being released to the atmosphere in the unlikely event that it should escape from the pressure vessel.

control rods: Long thin rods that are positioned among fuel rods to regulate the nuclear chain reaction. Control rods are composed of material that absorbs neutrons readily. They interrupt or slow down a chain reaction by capturing neutrons that would otherwise trigger more fissions.

coolant: Fluid that is circulated through the core of a reactor to remove the heat generated by the fission process. In reactors that have more than one coolant system, the fluid which passes through the core of a reactor is known as the primary coolant. It absorbs heat in the core and then transfers it to a secondary coolant system.

core: The region of a reactor in which the nuclear chain reaction is initiated, maintained, and controlled. Coolant is constantly circulated through the core to remove heat produced by the fission process.

decay heat: The heat produced by radioactive decay of materials that are primarily the remnants of the chain reaction.

deplete: To reduce the fissile content of an isotopic mixture, particularly uranium.

elasticity: The ratio of change in demand for a product (in this case electricity) to change in a category of prices, or to change in income.

emergency core cooling system: Any engineered system for cooling the core in the event of failure of the basic cooling system, such as core sprays or injectors.

enrichment: The process of increasing the concentration of one isotope of a given element.

fabrication: The final step in preparing nuclear fuel for use in a reactor.

fast breeder reactor (FBR): A reactor cooled by liquid sodium rather than waste. In this type of reactor, the transformation of uranium-238 to plutonium occurs readily. Since plutonium fissions easily, it can be recycled and used as fuel for a breeder reactor. The conversion of uranium to plutonium is so efficient in an FBR that this reactor creates more fuel than it consumes.

feedwater: Water, usually from a condenser, supplied to replenish the water inventory of components such as boilers or steam generators.

fertile: Material composed of atoms which readily absorb neutrons to produce fissionable materials. One such element is uranium-238, which becomes plutonium-239 after it absorbs a neutron. Fertile material alone cannot sustain a a chain reaction.

fissile: Material composed of atoms which readily fission when struck by a neutron. Uranium-235 and plutonium-239 are examples of fissile materials.

fission: The process by which a neutron strikes a nucleus and splits it into fragments. During the process of nuclear fission, several neutrons are emitted at high speed, and heat and radiation are released.

fission products: The smaller atoms created when a nucleus fissions. The mass of the fission products is less than that of the original nucleus. The difference in mass is released as energy.

fossil plant: A powerplant fueled by coal, oil, or gas.

fuel: Basic chain-reacting material, including both fissile and fertile materials.

fuel cycle: The set of chemical and physical operations needed to prepare nuclear material for use in reactors and to dispose of or recycle the material after its removal from the reactor. Existing fuel cycles begin with uranium as the natural resource and create plutonium as a byproduct. Some future cycles may rely on thorium and produce the fissile isotope uranium-233.

fuel rod: An assembly consisting of a capped zircalloy or stainless steel tube filled with fuel pellets.

half life: The period required for an unstable radioactive element to decay to one-half of its initial mass.

heat rate: A measure of the amount of fuel used to produce electric and/or thermal energy.

total heat rate refers to the amount of fuel (in Btu) required to produce 1 kilowatt-hour of electricity with no credit given for waste heat use.

incremental heat rate is calculated as the additional (or saved) Btu to produce (or not produce) the next kilowatt-hour of electricity.

net *heat rate* (also measured in Btu/kWh) credits the thermal output and denotes the energy required to produce electricity, beyond what would be needed to produce a given quantity of thermal energy in a separate facility (e.g., a boiler).

interest coverage ratio: The ratio of a firm's earnings to its current interest obligations.

isotopes: Atoms having the same number of protons, but a different number of neutrons. Two isotopes of the same atom are very similar and difficult to separate by ordinary chemical means, Isotopes can have very different nuclear properties, however. For example, one isotope may fission readily, while another isotope of the same atom may not fission at all.

light water reactor: A general term that refers to all nuclear reactors which use ordinary water as a coolant. This includes pressurized water reactors and boiling water reactors, which are the predominant reactors in the United States.

load: The demand for electric or thermal energy at any particular time.

base load is the normal, relatively constant demand for energy on a given system.

peakload is the highest demand for energy from a supplying system, measured either daily, seasonally, or annually.

intermediate load falls between the base and peak.

load factor is the ratio of the average load over a designated time period to the peak load occurring during that period. Also used as a synonym for capacity factor.

load eye/e pattern is the variation in demand over a specified period of time.

loss-of-coolant accident (LOCA): A reactor accident in which coolant is lost from the primary system.

market potential: The number of instances in which a technology will be sufficiently attractive-all things considered—that the investment is likely to be made.

market-to-book ratio: The ratio of the market price of a firm's stock to its book value.

MWe: Megawatts of electrical energy.

MWt: Megawatts of thermal energy.

moderator: A component (usually water, heavy water, or graphite) of some nuclear reactors that slows neutrons, thereby increasing their chances of being absorbed by a fissile nucleus.

neutron: A basic atomic particle that has no electrical charge. Neutrons and protons, which are positively charged particles, form the central portion of the atom known as the nucleus. Negatively charged electrons orbit the nucleus at various distances. The chemical and nuclear properties of an atom are determined by the number of its neutrons, protons, and electrons.

neutron poison: The general name given to materials that absorb neutrons. These materials either interfere with the fissioning process or are used to control it.

nuclear island: The buildings and equipment that comprise the reactor and all its emergency and auxiliary systems.

nuclear steam supply system (NSSS): The basic reactor and support equipment, plus any associated equipment necessary to produce the steam that drives the turbines.

once-through fuel cycle: A nuclear system wherein nuclear materials are introduced into a reactor only once; they are not recycled.

plutonium: An element that is not found in nature, but can be produced from uranium in a nuclear reactor. Plutonium fissions easily, and can be used as a nuclear fuel.

power density: The power generated per unit volume of the core.

pressure vessel: A heavy steel enclosure around the core of a reactor. It is designed to withstand high pressures and temperatures to prevent radioactive material from escaping from the core.

pressurized water reactor: A reactor cooled by water that is kept at high pressure to prevent it from boiling. Primary coolant passes through the core of a

PWR, and then transfers its heat to a secondary coolant system. Steam is produced from the heated water in the secondary system.

primary coolant: The fluid used to cool the fuel elements. It may be liquid or gas.

qualifying facility: A **cogenerator or small power producer that meets the requirements specified** in the Public Utility Regulatory Policies Act of 1978–in the case of a cogenerator, one that produces electricity and useful thermal energy for industrial, commercial, heating, or cooling purposes; that meets the operating requirements specified by the Federal Energy Regulatory Commission with respect to such factors as size, fuel use, and fuel efficiency); and that is owned by a person not primarily engaged in the generation or sale of electric power (other than cogenerated power).

radioactive decay: The process by which a nucleus of one type transforms into another, accompanied by emission of radiation.

radioactive waste: Waste materials, solid, liquid, or gas, that are produced in any type of nuclear facility.

rate base: The net valuation of utility property i n service, consisting of the gross valuation minus accrued depreciation.

reactor: A facility that contains a controlled nuclear fission chain reaction, It may be used to generate electrical power, to conduct research, or exclusively to produce plutonium for nuclear explosives.

reactor containment boundary: The pressure envelope in which a reactor and its primary cooling system are located.

reactor vessel: The container of the nuclear core or critical assembly; may be a steel pressure vessel, a prestressed concrete reactor vessel (PCRV), or a low-pressure vessel (e.g., a calandria or sodium pot).

reprocessing: Chemical treatment of spent reactor fuel to separate the plutonium and uranium from the fission products and (under present plans) from each other.

safeguards: Sets of regulations, procedures, and equipment designed to prevent and detect the diversion of nuclear materials from authorized channels.

safety system: A mechanical, electrical, or instrumentation system or any combination of these, whose purpose is the safety of the reactor or of the public.

scram: The rapid shutdown, via introduction of neutron absorbers, of the chain reaction.

seismic load: The stresses imposed on a component by a seismic shock.

shutdown: The act of stopping plant operation for an y reason.

spent fuel storage pool: The pool of demineralized water in which spent fuel elements are stored pending their shipment from the facility.

spent nuclear fuel: Material that is removed from a reactor after it can no longer sustain a chain reaction. Spent fuel from a light water reactor is composed primarily of uranium and contains some radioactive materials, such as fission products. Spent fuel also contains some valuable nuclear materials, such as uranium-235 and plutonium.

steam generator: The main heat exchangers in a pressurized water or gas-cooled reactor powerplant that generates the steam that drives the turbine generator.

thermal efficiency: In a powerplant, the ratio of net electrical energy produced to total thermal energy released in the reactor or boiler.

thermal load: The stresses imposed on a component due to restriction of thermal growth caused by temperature changes.

thermal neutron: A neutron whose energy level has been lowered sufficiently so that upon collision with another atom it will cause the atom to split and release energy. Neutron energy levels can be lowered by recoil off moderating atoms.

thorium-232 (Th^{232}): A fetile, naturally occurring isotope from which the fissile isotope uranium-233 can be bred.

turbine generator: The assembled steam turbine coupled to an electric generator that produces the electric power in a powerplant.

uranium: A metallic element found in nature that is commonly used as a fuel in nuclear reactors. As found in nature, it contains two isotopes—uranium-235 and uranium-238.

uranium-233 (U^{233}): A fissile isotope bred by fertile thorium-232. It is similar in weapons quality to plutonium-239.

uranium-235 (U^{235}): The less abundant uranium isotope, accounting for less than one percent of natural uranium. Uranium-235 splits, or fissions, when struck by a neutron. When uranium is used as a fuel in a nuclear reactor, the concentration of uranium-235 is often increased to enhance the fission process. For example, the fuel for light water reactors contains about 30/0 uranium-235.

uranium-238 (U^{238}): The more abundant uranium isotope, accounting for more than 99 percent of natural uranium. Uranium-238 tends to absorb neutrons rather than fission. When it absorbs a neutron, the uranium atom changes to form a new element-plutonium,

water hammer: The shock load imposed on a flowing pipeline by the rapid closure of a shutoff valve.

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