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THE FUTURE DEVELOPMENT AND ACCEPTANCE
OF LIGHT WATER REACTORS IN THE U.S.

by

THE MIT LWR STUDY GROUP

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ABSTRACT

This report summarizes a two-year effort by the M.I.T. Light Water Reactor Study Group to assess the institutional, regulatory, technical, and economic factors influencing the development and deployment of LWR technology.

The nuclear industry is confronted by a mix of problems which, if not addressed, may soon eliminate LWRs as a practical source of electric energy. The Study Group found that technical developments could improve nuclear plant capacity factors by 10 percent; furthermore, substantial economic benefits are possible through better use of existing technology, further technological improvements, and various financing schemes. However, the most pronounced problems are institutional and social, not technical and economic. Regulatory and institutional problems in licensing, constructing, and operating nuclear plants have created such uncertainty in the electric utility sector that the economic and environmental advantages of LWRs are seriously jeopardized. Regulatory constraints, unpredictability of government policy, unnecessary construction delays, and the resultant difficulty in obtaining the large-scale financing needed for new plant construction all discourage the electric utility sector from making long-term commitments to nuclear power. In the absence of a concerted government attempt to resolve these and other problems, public mistrust and legal intervention in the nuclear industry grow increasingly serious. Thus, the technical and economic improvements that could benefit the industry will be negated unless the government, the industrial sector, the electric utilities, and the public address the regulatory and institutional problems that are threatening to cripple the industry.

PREFACE

This Final Report to the Office of Nuclear Energy Programs, United States Department of Energy, summarizes the research activities of the M.I.T. LWR Study Group. Contributors to the Final Report include:

Ali Abbaspour, Graduate Student, Department of Nuclear Engineering
Dennis Bley, Graduate Student, Department of Nuclear Engineering
Michael Driscoll, Professor, Department of Nuclear Engineering
Sadek El-Magboub, Graduate Student, Department of Nuclear Engineering
Kamran Gharamani, Graduate Student, Department of Nuclear Engineering
Michael Golay, Associate Professor, Department of Nuclear Engineering
David Lanning, Professor, Department of Nuclear Engineering
Robert Marlay, Graduate Student, Department of Nuclear Engineering
Timothy Montgomery, Undergraduate Student, Harvard University
Dana Mukamel, Graduate Student, Department of Nuclear Engineering
Norman Rasmussen, Professor and Chairman, Department of Nuclear Engineering
David Rose, Professor, Department of Nuclear Engineering
Isi Saragossi, Graduate Student, Department of Nuclear Engineering
Richard Sclove, Graduate Student, Department of Nuclear Engineering
Song-Feng Wang, Undergraduate Student, Department of Nuclear Engineering
David White, Graduate Student, Department of Nuclear Engineering
David Wood, Senior Lecturer, Sloan School of Management, and Associate
Director, Energy Laboratory

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1. INTRODUCTION AND SUMMARY

The M.I.T. Light Water Reactor Project was organized in September 1976 under the sponsorship of the Office of Nuclear Energy Programs, Department of Energy (then ERDA). The objectives of the project were:

- (i) To analyze the institutional and regulatory issues influencing the development and deployment of nuclear power in the United States,
- (ii) To identify and evaluate technical initiatives to improve the productivity of nuclear plants, and
- (iii) To analyze in economic terms the impact of regulatory, institutional, and technical initiatives upon the capacity and generation mix decisions of utilities, upon consumption of scarce fuels such as oil and gas, upon electricity demand, and upon the discounted aggregate cost of energy delivered to consumers.

The findings of the project are presented in a series of technical and working papers (see References). This Final Report presents a summary of our analysis and findings. The principal findings are:

- (1) The most pronounced problems are institutional and social. Failure to solve them will effectively eliminate the nuclear option. Regulatory and institutional problems in licensing, constructing, and operating nuclear plants are eroding the economic and environmental advantages of this technology over alternatives such as coal, oil and gas, and solar. The continuing social debate reflected in regulatory actions is threatening to eliminate the nuclear option without a political consensus having developed to that effect.
- (2) Institutional and technical aspects of nuclear power cannot be fully separated. Our survey of vendors and utilities indicates that investments in both technical developments and actual generating capacity are being seriously limited by uncertainty as to future conditions for technology deployment. Further, comparisons of U.S. and European regulatory procedures indicate that U.S. procedures contribute significantly to uncertainty.
- (3) A substantial number of technical improvements is attainable. Our analyses indicate that nuclear plant capacity may be increased by 64 to 74 percent through technical developments in turbines, steam generators, condensers, pumps and valves, as well as improvements in fuel management, the fuel cycle, and

the fuel itself (leading to the possibility of nuclear in load following). Reductions in capital costs by as much as 5 to 30 percent may be possible by such technical initiatives as plant standardization.

- (4) Substantial economic benefits are possible both from increased use of the existing technology and from further technical developments. Economic benefits of continued development of nuclear technology versus a five-year total moratorium in nuclear construction equal $\$13.0 \times 10^9$ in discounted energy costs to consumers. Technically feasible improvements in nuclear productivity are estimated to provide an $\$18.0 \times 10^9$ reduction in discounted energy costs over that period, with savings in total oil and gas consumption of 40×10^9 barrel equivalents.
- (5) Uncertainty about the future of the utility sector and the difficulties accompanying this uncertainty tend to proliferate instability. For example, our ambivalence about the social merits of nuclear power in the long-term or inordinate delays in deciding on a policy of waste disposal tend to discourage electric utility companies and vendors from making long-term commitments, which in turn encourage anti-nuclear attitudes.
- (6) DOE (and other federal agencies) need to deal with the full range of principal difficulties associated with nuclear power. Most important is public acceptance, which arises from a long educational process of building public understanding of energy options, energy costs, and environmental and social consequences. Included here are options and attitudes with respect to both energy conservation and provision, direct and indirect impacts on international stability, social costs and benefits that lie outside conventional economic time frames, and so forth. Also, we see a need to bring closer together the principal option developers (presently the federal government), the industrial sector, the electric utilities, and the public.

2. INSTITUTIONAL ISSUES

2.1 Uncertainty

The most serious problems facing the U.S. nuclear power sector are not technical; they are social and institutional. Chief among them is the proliferation of uncertainty and its effects on the perceptions and actions of the electric utilities. Technical solutions alone, therefore, will not save the nuclear option. It is the utilities that must buy new power plants, and in a climate of excessive uncertainty they will not do so. Thus, although many governmental and nongovernmental actors are involved, we concentrate primarily on the electric utility sector.

Some of the causes of uncertainty have been discussed fairly thoroughly by others and the required action seems relatively clear (e.g., with regard to uranium availability), while others, although much mentioned, demand further attention. We see four major sources of uncertainty:

- (1) changing regulatory constraints
- (2) unpredictability of government policy
- (3) construction delays due to intervention by critics of nuclear power
- (4) difficulty in obtaining large-scale financing for new plant construction. (This problem arises partly as a consequence of the first three, and partly from the general difficulty of obtaining large sums of capital in times of inflation and economic instability. We feel that amelioration of items 1 - 3 would change the investment climate substantially; but analysis of the industry financing problem is beyond the scope of this study.)

Each of these is discussed below.

2.1.1 Changing Regulatory Constraints: Lack of a sufficiently articulated philosophy makes it impossible for utilities to predict what

direction future regulatory changes will take. Even after a plant has been completed, changing regulations can require installation of new equipment or expensive backfitting. Although this can be expected in cases where pressing environmental needs or safety issues were not foreseen when a plant was originally licensed (e.g., retrofitting sulphur dioxide scrubbers on coal-burning plants), the utilities nevertheless perceive nuclear regulatory requirements to be overbearing.

Utilities that must double their entire historical investment to construct nuclear plants risk bankruptcy if future regulatory changes make them uneconomical to operate (in comparison to other options) before they have returned their initial investment. Changes in environmental requirements similarly delay and restrict siting.

2.1.2 Unpredictability of Government Policy: The second major source of uncertainty is the utilities' perception that the Federal government's attitude toward nuclear power is unpredictable. Despite promises to act, the government has neither developed a national waste disposal plan nor made a firm commitment to the domestic use of nuclear power. The inherent fallacy of completely isolating the regulation from the promotion of nuclear power (doing so allows each actor to pursue its own goals without regard for the effects its actions might have on the others) has caused the bureaucracy to operate at cross-purposes. Among the resulting regulatory-induced technical problems are:

- (1) the fuel adjustment clause, which fails to encourage development or use of low-cost fuels
- (2) environmental requirements and limitations on site availability, which limit potential future cost reductions
- (3) regulatory agencies working at cross-purposes, a good example of which is the Seabrook, N.H. nuclear plant, where both the EPA and the NRC have alternately granted and denied permission to proceed with construction

2.1.3 Intervention by Critics: Anti-nuclear groups, partly by intervening through the courts and partly by fostering a climate of social unacceptability, have made the future of nuclear power very uncertain. Public opposition to nuclear power therefore deserves careful attention, both with respect to its overt aspects and its implicit social content.

The anti-nuclear debate arose partly from the intellectual legacy of nuclear weapons, partly from fear of the unknown, and partly because various environmental and other groups gradually shifted their focus from simple chemical polluters (until about 1970), to large polluting industries in general, and finally, to the nuclear power sector. Until recently this distrust was exacerbated by the relative lack of responsiveness to social issues by the Congress, the Executive branch, and the nuclear industry.

Gradually, the original concerns over environmental hazards were subsumed in a much wider, highly-politicized debate. Technical and environmental issues now appear more often as weapons used to accomplish broader social objectives, leading to deception by both sides as each shows selective inattention to different parts of the problem. For example, the pro-nuclear sector tends to ignore problems inherent in large-system management, the long-term effects of energy, etc. The anti-nuclear sector likewise tends to perform fairly shallow comparative assessments. Some intervenors, having larger social objectives in mind, attempt to keep the real or conjectural difficulties with nuclear power highly visible to the public, which in pragmatic political terms means keeping the problems from being solved in order to eliminate the nuclear power option as quickly and effectively as possible.

We see nothing to prevent this sort of polarized debate from being transferred to other energy sources once public consciousness has been raised. For example, coal suffers from several well-known difficulties and could be in for harsh treatment as its problems become more widely publicized.

The structure of American government is not well prepared to reduce this polarization. Purposely designed as a weak federal system in terms of imposing decisions from above, American government makes it relatively easy (as compared to a strong parliamentary system) for issues to cycle throughout the system several times before decisions are reached. It is difficult for semi-independent executive, legislative, judicial, and regulatory groups to agree. The resulting virtually unlimited opportunities to intervene have prevented decisions from serving as indicators of possible future regulatory changes.

2.2 Present Effects of Uncertainty

Uncertainty shortens the time perspectives in which utilities operate. The utilities are inherently conservative due to 40-year equipment lifetimes, slow staff turnover, and continued similarity of product. Afraid to undertake such expensive and risky projects as constructing nuclear power plants, the utilities, accustomed to looking 40 years ahead, instead find themselves forced into the schizophrenic position of having to concentrate on short-term strategies (such as doing nothing) until the public mood and political climate change.

Furthermore, the electric utilities do not have sufficient incentives to prepare for their long-term future because others (mainly DOE) are doing the R,D&D work and the utilities are not closely coupled to the process. Also, the electric utilities, especially after being

criticized for advertising (deemed inappropriate for a regulated industry), are either unwilling or unprepared to participate in further socio-political debate. When nuclear opponents raise broad social criticisms of nuclear power, the utilities find themselves unprepared to reply and hence fall onto the defensive. The public, believing the utilities have nothing to say in defense of nuclear power, gradually becomes more sympathetic to the opposition.

2.3 Likely Long-Term Effects of Continuing Uncertainty

Since the electric utility sector's rewards are based not on building nuclear reactors, but rather on providing reliable low-cost service, the utilities' perceptions of uncertainty and its consequences force them to seek unilateral relief can unilaterally, mainly by opting out of highly controversial issues and technologies. As the utilities try to reduce their public vulnerability, the most visible of these issues--nuclear power--will be the first to collapse. The principal nuclear vendors, anticipating such reactions (and none of them having more than 25 percent of their business in nuclear power), may selectively opt out even earlier. We suggest that such changes may occur as early as 1980.

The collapse of the nuclear industry will not be an isolated result, because uncertainty looms with respect to other energy sources like coal, including not only how to mine, transport, and burn it in environmentally acceptable ways, but also uncertain future costs. The electric utilities will likely decide that their best strategy is to wait for external events to force a new public consensus--for turbine systems, oil, gas, coal, or whatever--and then to respond.

The dangers of making decisions in such capricious ways are obvious. If the nuclear sector collapses it cannot be easily rebuilt. The principal impediments are:

- (a) the large vendors would demand assurances of governmental financial and policy support (which the government would not be able to provide),
- (b) the utilities would demand similar guarantees of supportive government intervention, and
- (c) small specialized suppliers (of pumps, valves, etc.), having built up a technological infrastructure in vain, would have abandoned the field and would not wish to resume the activity.

More drastically and realistically, the private utilities may opt out of the generating business altogether and concentrate instead on the relatively calmer business of distributing electricity. As in most other industrialized countries, power generation would then be left to public corporations like the TVA. Many people connected with the utility industry and with option preparation are now discussing this possibility, but none seem willing to initiate public debate on this important yet highly sensitive issue. We believe that a shift towards public ownership of generating facilities requires serious discussion, if only to forestall an unanticipated shift in that direction.

2.4 Specific Issues and Tasks

Several specific issues need attention, particularly by DOE. Effective action, however, requires consensus building among the many sectors involved. We see the following as essential to assuring the continued viability of the nuclear option:

- (a) more direction by the Federal government in dealing with energy issues, especially nuclear ones,

- (b) restructured long-term R,D&D for the electric sector, and
- (c) increased public confidence in energy decision making.

2.4.1 The Need for Government Direction: To reduce uncertainty, the Federal government must provide the utilities with an indication of the direction future regulatory changes are likely to take. This requires an articulated working policy with respect to nuclear power that includes a clear commitment to nuclear power, a national waste disposal plan including fuel reprocessing (probably via international agreement), and a clarification of the philosophy underl in he nuclear regulatory process. These activities need to be decided in the context of a comparative assessment of available options: coal, conservation, and so forth.

All of these actions require the government to take a leadership role--something it has not yet done. The public cannot foresee energy problems that lurk just over the horizon, and subsequently will not call for government action until it is too late. The lead time needed to develop and/or construct new generating facilities is so long that, when shortages have become acute enough to attract widespread public concern, waiting five or ten years longer may be economically disastrous.

2.4.2 The Need to Restructure Long-Term R&D for the Electric Sector: The R,D&D structure of the electric sector and, a fortiori, of the nuclear sector, exists in its present form not because of logical planning, but rather by happenstance. The problem is that the principal option users--the electric utilities--have little direct voice in which options are prepared for the future. Conversely, the principal option developers--the Federal government and particularly DOE--lack sufficient input from the utilities regarding long-term needs.

This schism developed because the task of preparing new technical options, traditionally left by the utilities to the large vendors (GE and Westinghouse, for example), became uncomfortably expensive for any single vendor. By default, the Federal government gradually took over the task, first with nuclear power and, more recently, with fossil fuels. This separation of option users from developers is more acutely felt in the U.S. than in other countries where electric power systems are public and, hence, not as remote from other government sectors.

The total amount invested in energy R,D&D nationally is 2 to 3 percent of total gross sales, with approximately two-thirds invested by the Federal government. The total percentage is not unreasonable, at least ab initio. AT&T, which, like the power generation sector, is capital intensive, regulated, and long-lasting, for decades has spent nearly 3 percent of its gross income on R&D through Bell Laboratories. This has enabled it to stay at the forefront of communications technology without government support.

The main difference between the electricity-generating and the telephone sectors is that the former is fragmented and poorly organized while the latter is not. This lack of coordination as well as the utilities' reluctance to concern themselves with pressing social issues have been widely recognized. The Electric Power Research Institute (EPRI) was founded in 1973 in response to a 1971 Senate challenge to the industry to address its own future as well as environmental and other social problems. EPRI's present budget is under \$200 million, less than 0.3 percent of the nation's total electric bill. The electricity-related R,D&D tasks picked up by the Federal government amount to \$1,708 million (FY'1979), about 2.5 percent of the electric power bill.

Consider now the advantages of an expanded consortium designed to bring the electric utilities, the government, the national laboratories, and industry closer together.

In accordance with the equitable custom of encouraging beneficiaries of the R,D&D process to pay development costs, the utilities might charge customers 1 or 2 percent more for every KWhr sold, thereby raising about \$1 billion for long-term electricity-related R,D&D--an appropriate sum for the task at hand. Not only would the Federal government be able to reduce its sponsorship of energy R,D&D, but the utilities, because they would help determine how these funds were spent, would be stimulated to prepare for their own future. Thus, the developers and the users of energy options need to be brought together. An energy consortium, consisting of representatives of the utilities, the Federal government, the regulators, the national laboratories, the private sector, and the public, could meet to determine which avenues of long-term energy R,D&D ought to be pursued.

The energy consortium would distribute funds to various private sector research organizations, universities, and national laboratories to pursue promising R,D&D areas. The utilities would be more closely coupled with promising R,D&D areas. The utilities would be more closely coupled with the R,D&D process and the allocation of R,D&D funds would better reflect a consensus on national energy needs and development priorities.

New arrangements of this sort may already be starting informally. As an example, the Oak Ridge National Laboratory (ORNL) Director and the TVA Chairman agreed on the usefulness of ORNL performing R,D&D and TVA performing initial demonstrations of new systems. Details

remain to be worked out, but any such significant activity will necessarily involve the industrial sector (whose response depends on whether they see these ventures as leading to real commercialization), environmental and regulatory agencies (as TVA plans to put new systems into its operation), the public, and the Federal government (now in a less central role). If such cooperation succeeds, it will be by having faced many of the same institutional issues that a national consortium would have to face.

2.4.3 The Need to Increase Public Confidence in Energy

Decision Making: We do not believe that any satisfactory resolution of energy problems or uncertainty can come without better public understanding of the issues and their possible solutions. This is a long-term consciousness-raising and educational activity that would take many years to accomplish. The Federal government has failed to distinguish between short-term propaganda and long-term education in the public interest. All too often, it has abandoned the latter for fear of inadvertently becoming the former.

DOE's 1979 budget allocates no funds for educational activities. $\$63.4 \times 10^6$ are listed for information collection, analysis, and distribution, but nearly every dollar relates to the transfer and utilization of technical data in the Department's professional activities. Failure of the government to exercise its role as a legitimate representative of the public interest has left an intellectual vacuum into which have rushed many others, all offering personal visions of what the future should look like.

Public faith in "big government" and "big business" is at a nadir. As energy shortages become increasingly severe, the public will

be asked to make greater sacrifices in its life-style and the importance of public confidence in the energy decision-making process will be greatly magnified. A citizenry resentful of a "technocratic elite" arbitrarily deciding the fate of the nation will not heed the pleas for conservation that will be so critical in the future.

3. REGULATORY ISSUES

3.1 Introduction

This portion of the LWR project was initiated because of the recognition that a major impediment to acceptance of nuclear technology in the United States is the system of public safety and environmental protection regulation. We conclude that the most significant deterrent to the growth of nuclear power in the United States currently is the regulatory system. This is true because the system provides an effective and attractive avenue for the expression of popular opposition to the use of nuclear power. Without such opposition we believe the regulatory system could operate efficiently; however, some unique features of the U.S. system leave it very vulnerable for use as a vehicle for political action by anti-nuclear groups. In other western countries this is not the case.

Our work does not assess whether the public health, safety, and environmental protection criteria under which nuclear power is regulated are adequate. Attention instead focuses upon how these criteria are implemented.

The work consists of two major parts: an examination of the experience and perceptions of the U.S. nuclear utility industry regarding Light Water Reactor (LWR) technology; and an examination of the nuclear regulatory systems and nuclear utility experiences in England, France, Sweden, and West Germany. These countries were selected because they are all industrialized; are culturally similar to the United States; have substantial nuclear power experience; and have differing nuclear regulatory systems and utility ownership patterns. Thus, an examination of nuclear power in these countries provides a context for comparison with the U.S., and a basis for formulating of policy recommendations.

3.2 Nature of the United States Nuclear Regulatory System

There are two aspects to the United States nuclear regulatory system: the procedures followed in performing the various regulatory tasks, and the structure of the political system that has determined those procedures. Most attempts to "reform" the regulatory system have been concerned with improvements in the efficiency of regulatory procedures; much less attention has been given to structural changes.

"Reform" attempts that focus on questions of the efficiency of procedures are likely to be ineffective, since most of the fundamental problems of nuclear power regulation arise from the nature of the regulatory system itself, not from the procedures through which it acts.

Inherent in the idea that the nuclear regulatory system is inefficient is the belief that proper public safety and environmental protection goals can be met with a smaller commitment of time and money. The principal means by which licensing inefficiency is expressed is through delay in granting Operating License and Construction Permits. Such delays impose costs, several types of which are important as weapons in the current political "guerrilla warfare" being waged against use of nuclear technology. Pressure groups that oppose its use have found that their ability to impose uncontrolled nuclear project costs upon utilities via licensing delays gives them the means to negotiate directly with utilities for modification of such projects. More importantly, the possibility of encountering such uncontrolled costs has had a "chilling" effect within many utility companies regarding plans to embark on new nuclear projects.

The United States nuclear licensing process is structurally deficient in several important ways:

(a) Great attention is paid by the public and the collective governmental regulatory system to issues of public health and environmental impacts associated with nuclear technology, while similar questions arising from the use of alternative energy technologies--especially coal--are either ignored or treated as being much less serious. As a result, the environmental and safety risks of nuclear power are considered in a vacuum, with no context for judging the relative magnitudes of the effects being considered. It also results in an unbalanced protection of the environment and public health, with nuclear hazards being reduced to very low levels and some non-nuclear effects being tolerated without concern at much greater hazard levels.

(b) The nuclear regulatory system is required to resolve a set of questions that are mainly political rather than technical. This burden--which the system is inadequate to carry--is the principal cause of the current nuclear licensing "crisis." It is notable that the foreign nuclear regulatory systems which we studied maintain a clear separation between political and technical questions, confining themselves to the latter class of issues. This is a major factor in the much greater efficiency of these European systems. Examples of such political questions are those concerning acceptable levels of risk, the need for power, and the cost-benefit balancing of a project.

(c) If political issues are to be removed from nuclear project licensing, alternative avenues must be established to resolve them. The idea is later developed that the United States' nuclear regulatory system emphasizes promotion of health and environmental values at the expense of economic values. This occurs in this instance because the American political system does not balance such opposing social values. Thus, by default, the balancing of such values must be incorporated into regulatory decision making.

(d) The role of the public (i.e., intervenors) in licensing nuclear projects is a unique feature of the United States' nuclear regulatory system. Such participation stems from the American tradition of having the functions of the bureaucracy easily accountable to the citizens. However, the effects of such participation in nuclear plant licensing are different from those which are widely perceived. Intervenors are mainly credited with raising important reactor safety issues previously ignored by NRC staff. Intervenors and "public interest" groups have been important in publicizing neglected safety issues and in exploiting them in licensing proceedings, but not in identifying them initially.

3.3 Results of the United States Nuclear Utility Survey

Historical Data: The purpose of the survey is to quantify the uncertainty and associated costs that have been experienced in U.S.

nuclear projects, to try to assess the degree to which such uncertainty affects utility willingness to use LWR technology, and to identify aspects of the nuclear regulatory system that contribute significantly to such uncertainty. The results of this work are presented in the 1978 report, "Effects of Environmental Protection and Public Safety Regulatory Practices Upon Light Water Reactor Economics", MIT EL 78-009. In the survey, all U.S. electric utility organizations that have prime responsibility for a current nuclear project were contacted. All but two of the organizations contacted agreed to cooperate with the study.

The major points are summarized below:

- o Since the late 1960's the ability of a utility to obtain a construction permit according to the originally anticipated schedule has been very poor, and in recent years most licensed power plants have required substantially longer durations for Construction Permit Licensing than the nominal 22-month duration specified by the NRC.
- o The range of licensing duration varies substantially from plant to plant, indicating that the licensing process is highly unpredictable and that utility companies have historically tended to underestimate significantly the required durations.
- o The time required to build a plant has grown steadily during recent years, as power plants have grown larger and more complex; a deviation from the mean construction time of approximately 10+ months is typical; and the ratio of the longest to the shortest construction time in a given docket year typically falls in the range of 1.3 to 2.0.
- o When historical nuclear plant unit capacity costs are discounted for escalation and interest during construction, it is seen that for plants coming on-line since 1974 costs remain approximately constant. The scatter in the data arises from regional differences in labor costs and safety requirements. Therefore, the contention that nuclear plant costs continue to grow steadily is false.

It is impossible to state with any useful degree of precision what fraction of total delays in the U.S. nuclear projects is due to the

regulatory system; however, a consensus exists that the regulatory contribution is significant. This situation stands in marked contrast to that of the foreign countries examined in our work, where the consensus is that the regulatory systems are not important contributors to wasteful nuclear project costs.

It is also clear from our interviews with utility managers that the prospect of large uncontrolled costs provides an important disincentive for the use of nuclear technology in the U.S., in spite of the fact that utility personnel generally believe that nuclear technology is safe, reliable, and--in most parts of the country--economically competitive. Several utility companies have decided to defer all future nuclear projects until uncertainties associated with the regulatory system are substantially reduced.

3.4 Examination of Foreign Nuclear Regulatory Systems

The purpose of examining the systems of nuclear regulation in selected foreign countries (England, France, Sweden, and West Germany) is to observe the various nuclear histories under different regulatory systems.

Table 1 summarizes the characteristics of the nuclear utility and regulatory systems in each country. Note that the utility patterns and nuclear regulatory systems of the U.S. and Sweden are similar while those of the remaining countries are not. In addition, Sweden, West Germany and the United States have effective nuclear moratoria while France and England do not.

The nuclear regulatory systems that are most dramatically different from that in the United States are those of France and England. The European regulatory systems examined differ from one

TABLE 1
Nuclear Power Regulatory Situations in Some Western Industrial Countries

Country	Utility Pattern	Utility Ownership	Regulatory Pattern	Local Site Veto Possible?	Public Hearings Required?	Extent of Public Record?	Frequency of Power Plant Construction Delays from Regulation	Current Nuclear Moratorium?	Form of Opposition to Nuclear Power
United States	Local	Mostly Private	National, State	No	Yes	All	High	Effectively Yes	Political Guerrilla Warfare
France	National	Public	National	No	Usually*	Rulings Only	None	No	Political, Violent
England	National	Public	National	No	Sometimes*	Rulings Only ²	None	No	Consciousness Raising
Sweden	Local	Half Public, Half Private	National	Yes	Usually* ¹	Most	Low	Yes	Political
West Germany	State	Mostly Public	State, National	No	Usually*	Rulings Only	None	Yes	Political, Violent

*Legislative-type hearings

¹Can result in site veto

²E.g., preliminary safety analysis report; identities of regulatory staff members are kept secret.

³Records protected by Official Secrets Act

another in the procedures used. However, in comparison to the United States system, the similarities among the European systems are more important than their apparent differences. These similarities arise from the similar nature of the political systems under which they operate--all of which are very different from that of the United States. The most important common feature is that each of these countries has a parliamentary system of government in which the majority party(ies) in the parliament also control the national executive branch. Since each of these countries is relatively small compared to its neighbors than is the United States, there is in each a more strongly perceived need for economic coordination by the government. Consequently, the governmental mandate for definition and promotion of both economic and public health and environmental protection goals is much clearer than in the United States, and explicit balancing of such values is performed in the formulation of national policy. In addition, control of the executive by the majority party largely eliminates the conflicts between the legislative and the executive branches which often arise in the American system. Consequently, the formulation of clear executive policies--which are then implemented by the bureaucracy--is much more efficient in the European systems, with conflicting political values being compromised in the formulation of the policy. In the European systems the economic justification of a nuclear project and the general public health and environmental protection goals governing the project are formulated at the same levels (ministerial) of government as national policy. In the American system the latter set of goals are formulated (at least implicitly) as state and national goals which are implemented locally, but a comprehensive national economic plan is not explicitly formulated

at any governmental level, except with regard to federal budget and monetary policy. Thus, the mandates of United States governmental agencies are weighted unequally toward protection of public health and environmental values at the expense of economic values. In fact, in the U.S. there is no general explicit mandate to consider economic factors in public health and environmental regulation of nuclear projects.

In both the U.S. and the European countries the major level of regulatory enforcement is at the local individual project level, but in all of these countries attempts at national or regional public health and environmental enforcement actions are also evident--especially in France and England.

Due to the lack of a clear policy in the United States regarding many political questions affecting nuclear power projects (e.g., need-for-power, definition of socially acceptable safety levels, etc.), many such questions are left, by default, to be resolved in individual nuclear project licensing procedures. This happens because national economic policy is fragmented and public health and environmental goals are incompletely expressed. In the European nuclear regulatory systems, on the other hand, such political questions are resolved through the political process, and the processes of nuclear project licensing are insulated from the need to resolve such issues. Thus, European nuclear project licensing is concerned mainly with resolving technical questions of public safety and environmental protection, while that in the United States is confused by the additional burden of political questions, which it is poorly equipped to treat. This is a major reason for the perceived failure of the American nuclear regulatory process.

In each of the European countries there is a tradition that the bureaucracy is relatively immune from interference by private parties. Thus, in all of these countries the ability of a citizen affected by governmental action to seek satisfaction or a modification of an action by the responsible agency is much more severely limited than in the United States. As a result, bureaucratic actions can be less inhibited by the possibility of criticism because effective avenues for direct individual opposition to such actions are largely unavailable, and because agency actions would generally be taken in executing clearly-established executive policies. The major option for a citizen or interest group opposing a particular bureaucratic action is to modify the position within the controlling political party responsible for the executive policy being implemented. Consequently, opposition to the nuclear power programs in these European countries has been expressed mainly by political means--by attempting to modify the positions of the pro-nuclear parties and by trying to strengthen the anti-nuclear parties. Anti-nuclear groups have not been a large factor in the process of licensing individual nuclear plants. Uniformly, both electric utility and regulatory respondents in the countries surveyed reported that needless licensing delays are not significant factors in nuclear projects. The anti-nuclear groups in these countries, partially reflecting frustration in being unsuccessful in opposing individual nuclear projects, have expressed opposition through numerous violent demonstrations, notably in France and West Germany.

A symptom of the degree to which the regulatory processes in these European countries is closed to the public is indicated by the fact that the official files regarding individual nuclear project regulatory

actions in all of the countries examined (except Sweden) are substantially closed to the public.

Another important aspect in which the European nuclear regulatory systems differ from that in the United States is that of public hearings concerning nuclear projects. In all of the countries examined, public hearings occur early in the process and are of the legislative-type, conducted without cross-examination, with witnesses not under oath, and with testimony being presented for the information of the agency conducting the hearing. Except in England and West Germany, the hearings arise in the context of land-use or zoning, to determine whether a proposed site is appropriate for nuclear power use. In Sweden such hearings are held by the Water Court. The local government can veto a nuclear project at this stage. It is important to note that the results of such hearings generally consist of either a decision regarding whether the site can accommodate a nuclear project successfully or a report to the ministry in charge of nuclear regulation. In each case a citizen appeal of the results of the hearings is possible only if it can be shown that improper procedures were followed. Appeals regarding the substance of decisions reached in the hearings--as is possible in the United States--are usually not permitted.

In all of the European countries surveyed no significant delays in nuclear projects were reported because of flaws in the nuclear regulatory system. By contrast, such delays in United States nuclear projects are widely reported to be one of the most serious disincentives for LWR use. In addition to the systematic features cited previously, several organizational features are generally found to aid the efficiency of the licensing process in the European systems.

In each of these countries (but especially in France) the regulatory climate has a strong element of mutual cooperation, personal trust, and spirit of reasonable compromise between the equipment vendors, the utility company, and the governmental regulators. This arises from several factors:

- (a) The number of personnel and organizations involved is relatively small, and with low turnover. This permits personal relationships to arise through long-term association and personnel transfer among organizations;
- (b) Effectively all of the actors from the various organizations are engaged in a plan sanctioned by the central government to install a desired level of generating capacity at a desired level of safety;
- (c) The technical judgment of the staff is used to evaluate proposed designs, and very few rigidly codified judgmental criteria are employed; and
- (d) A spirit of reasonable compromise exists in treating areas of technical uncertainty since the detailed licensing process is largely immune from non-governmental review and criticism.

By contrast, in the United States the regulatory climate is adversarial, legalistic, cumbersome, and sometimes acrimonious. There are several reasons for this:

- (a) The numbers of personnel and organizations involved nationally are large. Thus, more rigidly formalized procedures are required.
- (b) In attempting to standardize the licensing process, a large literature of judgmental criteria has been developed, including Congressional legislation, federal regulations, individual agency guidelines, and judicial rulings--all of which must be respected by regulatory decision makers.
- (c) No national or state-level electric energy development plans become incorporated into the licensing review as judgment criteria.
- (d) Initial regulatory decisions are subject to subsequent administrative and judicial reviews and may be rendered moot by the actions of other uncoordinated agencies.

- (e) Access to the process by interested non-governmental parties is relatively easy.
- (f) The process involves consideration of issues that are both political and economic (e.g., the need for new generating capacity), which in other national regulatory systems are kept out of the regulatory process.
- (g) The process often requires consideration of generic technical issues on a plant-by-plant basis, so a specific plant-related decision acquires importance far beyond the single plant being licensed.
- (h) There is a climate of public distrust of its governmental agencies and of large private organizations. This has been translated into a political atmosphere that rewards caution and punishes risk-taking decisions by politicians and by governmental officials.

3.5 Conclusions

The foregoing discussion indicates that the basic fault of the United States nuclear regulatory system is its failure to resolve technical questions of public health and environmental protection when it is also encumbered by responsibility for political questions, which it is not prepared to treat. Improving this situation requires creation of alternative institutional arrangements to address these political questions--preferably at the same levels of government at which national public health and environmental protection policy is determined. The value of such modifications is illustrated clearly by the efficiency of the nuclear regulatory systems of England, France, Sweden, and West Germany, where such modifications are in effect.

There is currently an effective nuclear moratorium in the United States, in large part because of the great climate of uncertainty that exists among electric utility organizations as a consequence of the unpredictability, capriciousness, lack of dependability, and perceived illogic of the overall nuclear regulatory system. This situation could

be dismissed merely as a nuisance for utility executives if it were not for the large economic, social, and environmental costs that society pays in using this system. If these costs are to be reduced, substantial structural and procedural modifications of the current system will be required.

4. TECHNICAL ASSESSMENT OF LIGHT WATER REACTOR IMPROVEMENT

4.1 Strategies for Fixed Cost Improvements

Capital cost is the major component of the fixed cost. A second component of the fixed cost is the Operation and Maintenance (O & M) costs. The term "fixed" is used for those costs that are independent of the quantity of electricity generated. This is strictly true for capital cost and the operation part of the O & M cost; the maintenance portion of the O & M cost, though often described as variable, is included here since it is convenient and in any case is only a small portion of the total cost. It is also recognized that "fixed cost" varies with other parameters, the most important of which is time. Such parameters are included in the following assessment of the fixed cost.

4.1.1 Capital Cost Assessment of LWR Power Plants: Capital cost accounts for about 90 percent of the fixed (i.e. non-fuel) portion of the electricity busbar cost. This was reflected in the way the effort of this group was allocated: major attention was given to capital cost, while relatively minor attention was given to the other fixed cost component, the O & M cost.

Early in the study, a survey was conducted that included most LWR equipment vendors and A/E firms, and also about 30 utilities in the United States. Questions were presented in the form of defined variables that would be evaluated under a set of applicable assumptions. These variables describe the current status of the LWR capital cost, its future trend, the effectiveness of various improvement options, and the influence of the limiting factors. Variables related to the O & M cost were also included. Additional comments were requested. The results of

the survey were tabulated in statistical format and used as needed in the report. The overall results indicate a value of \$592/KW (1977 \$) for the capital cost, as explained in the following section.

Capital Cost Base Case: The survey data were first used to formulate the base case of LWR power plant capital cost. The computation was done with the CONCEPT Code, Phase 5, February 1978. The base case problem describes the current status of capital cost, from which variations can be investigated as conditions change for each other problem. The following table specifies the base problem and summarizes the computed results.

The base case problem:

Plant power capacity, MWe	1200
Number of generating units	1
Reactor type	PWR
Cooling system	Mech. Draft Tower
Location	Boston, MA
Date of NSSS commitment	1/1/77
Date of C.P. issue	1/1/81
Date of commercial operation	1/1/88
AFDC effective annual rate, %	9.0

Results:

<u>Fore Cost (1977)</u>	<u>\$/KWe</u>	<u>%</u>
Equipment Cost	216	16.1
Labor Cost	129	9.6
Material Cost	67	5.0
Indirect Costs	180	13.4
TOTALS	592	44.1
<u>Tail Cost (1988)</u>	<u>\$/KWe</u>	<u>%</u>
Overall Rate of Escalation during Construction 6.76 percent		
Cost of Escalation during Construction	312	23.2
TOTAL TAIL COST	904	67.3

Results (continued):

Allowance for Funds Used during Construction	<u>438</u>	<u>32.6</u>
Commercial Cost (1988)	1341	100

The fore cost of a particular year is the cost of the plant if it could be completely built in that year. Since the plant construction takes several years, the fore cost value changes with escalation. The tail cost is the sum of the fore cost at the beginning of the project and the cost of escalation during construction (CEDC). When the allowance for funds used during construction (AFDC) is added to the tail cost the sum is called the commercial cost, which is the sum of all expenditures up to date of commercial operation. The fore cost for coal plants with scrubbers is \$515/KWe.

Contribution of Capital Cost Elements: Five elements constitute the capital cost. Four of them are the fore cost components: equipment, labor, materials, and indirect cost accounts. The fifth is time. The contribution of each of the first four is shown in the right column of the base case results as a percentage of the commercial cost. The contribution of the fifth element, time, is the sum of the CEDC and the AFDC, about 56 percent of the commercial cost. CONCEPT Code calculations show that the commercial cost variations are linear functions of the element variations, whose slope is nearly the fraction of the element contribution to the commercial cost. This illustrates the independence of the five elements. For the first three elements this result is true when the cost variations are caused by price variations rather than by

changing required quantities. The major items of indirect cost are the home-office engineering and construction facilities and equipment, which are responsible for 3.5 and 3.2 percent of the commercial cost, respectively. Their influence on capital cost is similar to that of the first three elements.

The fifth element, time, has peculiar characteristics. It is the largest contributor when measured as the sum of CEDC and AFDC, whose quantity is the years of the project lead time modified by the project cash flow, and its unit cost is in terms of the annual CEDC and AFDC rates. It is not a completely independent element that merely adds to the fore cost; it also augments the fore cost. The major contribution of time comes in the case of project delay, i.e., when the date of NSSS commitment is fixed. The commercial cost variation is still linear, but has a large slope. One year's change makes a difference of about 10 percent of the commercial cost, and 1 percent change in the AFCD rate makes about 5 percent change in the commercial cost. The interesting result emerges when the date of commercial operation is fixed and the project lead time varies. Here no significant change in the commercial cost occurs, because the resulting opposite variations of the CEDC and AFCD almost cancel each other.

Capital Cost Trend: A result of a study covering the 1967-1987 period shows a steady increase in the commercial cost at an average annual rate of 10.2 percent. Lately, the change in commercial cost has been even more dramatic. The past 4-1/2 years have shown an increase in the fore cost from \$211/kWe to \$592/kWe, or about a 26

percent annual rate of increase. In addition, the project lead times have increased by about 50 percent on the average, over the same period. Throughout the 1970s project lead time has increased at a rate of 9 to 10 months each year. Capital cost is expected to rise at an average rate of \$56/kWe/yr until about 1990. This is despite the fact that the plant sizes have doubled during the first half of this period and the specific cost of large plants is about two-thirds of that of plants of half their size, if built simultaneously.

Causes of Capital Cost Increase: The various causes of increases in capital cost are related to one of two categories: increased unit-cost and/or increased requirements. The first category is associated with, say, wages or steel prices, while the second is associated with increase in quantity required. The unit cost increase is merely due to the general escalation, and no specific commodity required for LWR plant construction has shown any sign of resource depletion. The escalation of LWR capital cost, though about 1 percent higher than that of general inflation, is mild when compared to other essential commodities such as housing, whose rate of escalation in the 1960-1978 period was 8.54 percent.

There are many causes under the increased requirements category. Larger unit size has increased, among other things, the amount of capital investment required for a power plant project. This results in many cases of schedule delay due to financial difficulties, which only worsens matters. Design changes to improve the plant availability and meet evolving safety and environmental

requirements have added more equipment, materials, and associated labor as well as having increased the indirect costs and stretched lead times. In the cases of equipment and material, both quantity and quality requirements are increased. Lower productivity is another cause, associated with increased paper work, design complexity, and schedule irregularities, as well as the faster increase of demand on the labor force relative to the increase in supply of qualified workers. Public intervention is another cause that affects the lead time at the various stages of the project, and especially before issuance of the CP. There are also other factors, such as changing accounting methods by regulatory amendments, which in at least one case results in increasing the AFDC by 33 percent.

Possible Improvement Alternatives: Several improvement alternatives have been identified or proposed, mainly targeted at the time element of capital cost. For convenience they are divided into three sets: 1) optimization of current practices, 2) standardization, and 3) improved industry structure and finance.

Optimization of Current Practices: The first strategy in this set is to pursue a scheme of design optimization that concentrates on cost minimization. As a relevant example, use of remote multiplexing in plant (non-safety) control system may reduce commercial cost by close to 0.5 percent. Another strategy is to improve project management in an integrated manner at all phases of planning, design licensing, and construction of LWR power plants. Both these schemes require

the expertise and resources of vendors and architect/engineer and construction firms. Given the current industry structure, this report merely emphasizes anticipated actions by the different industry members with regard to this type of improvement.

Standardization: Four options have been investigated in this category. The first is Flotation. Although this concept has been around for a decade and was one of the earliest three recognized by the AEC, no practical success has been cited yet. The first plant is expected to be completed by 1988 at the earliest. In the meantime, the utility response is affected by licensing uncertainties surrounding this option. The question of potential increased risk of a core melting accident is a major issue. The current cost estimates show a commercial cost of about 85 to 90 percent of that of the base case. However, these estimates may not hold once the first plant is built.

The second option is Duplication. This is defined as several similar plants that are licensed simultaneously. It has been practiced in two different ways. First, one utility licenses a package of units, whether they are at one site or at different, but nearby sites. This method has gained considerable success and wide use. The second way includes the SNUPPS method, when several utilities license similar plants at sites thousands of miles apart. The success of this option has been distorted by financial and load reduction problems. In

this case with respect to the CP lead time, the gains were relatively significant. Independent of site-related and non-technical factors, the time savings may reach 20 percent. The cost reduction is in the range of 6 to 13 percent, depending on intermediate events.

The third option is Replication. It is the last considered by the AEC, and hence the least exercised. Given the market conditions in the last few years, this option did not have a fair chance; the few replication cases have not shown any success, although they do not provide sufficient evidence for fair conclusion.

The fourth is the Reference System option. This met the greatest enthusiasm of the industry. Several Reference System designs have been licensed. They differ in scope of design from NSSS and Balance of Plant, to Nuclear Island and Turbine-plant Island. Almost all recent applications include some aspect of this option. The main target of relatively reducing the CP lead time has been successfully demonstrated. Once the CP is issued, the construction schedule could be reduced by 6 to 12 months, with commercial cost savings of about 10 percent.

The last three options do not constitute a set of mutually exclusive alternatives, since they can be applied simultaneously. This in fact reduces the applicability of replication and attracts attention away from flotation. Standardization has mainly addressed the physical portion of plant and could not help with site-related problems which have

become critical issues. The site issue has placed undesirable limits on standardization.

Improved Industry Structure and Finance: This set of improvement schemes is expected to play a role complementary to the above strategies. The first of three areas in this category is concerned with licensing procedures. Early site-approval, as proposed by the NRC, is expected to be beneficial, but success is limited by state and local governmental influence. The limited work authorization helps to complete up to 3 percent of construction before the CP issue. If the LWA-to-CP period does not exceed a year, capital cost gain is realized. Otherwise, the associated AFDC can destroy the benefit, especially if it takes as long as four years after LWA to obtain the CP. Negative experiences have led several utilities not to exercise this option. Another proposed scheme in this area is a Periodic Freeze on regulatory changes, which could help to ameliorate uncertainty problems.

The second area is a proposal for movement toward large utility systems, whose activities would include all aspects of power generation, aside from equipment manufacturing. This proposal is supported by the success of large utilities (Commonwealth Edison, Duke, and TVA) in attaining lower capital cost, with savings ranging from 4 to 30 percent in most of their regions.

The third area is improved financial methods. The CWIP in Rate Base is compared to the conventional method. This is

shown to be a special case of a general method under the designation of Ultra-Accelerated Depreciation (UAD) methods. The basic idea is to expense a portion of the current construction expenditure as a depreciation allowance and match it with increased revenue from currently operated units. A mathematical model to evaluate this method has been developed. With a simple version of the model, the early results show that the UAD method is promising. Further detailed analysis will be carried out as part of future work.

Limiting Factors: Seven major factors are identified as follows:

Size: An upper limit on size, imposed by regulatory and technological considerations, diminished any further benefits of economics of scale.

Regional Characteristics: Population density, climate, and topography affect the capital cost which varies between the regions of U.S. by 15 percent of median value.

Constitutional Division of Authority: This prevents any imposition of coordinative programs to reduce licensing conflicts among various government levels.

Public Acceptance of Improved Finance: Public acceptance, either directly or through the regulatory bodies, is a prerequisite to implementing any financial improvement scheme.

O & M Considerations: Capital cost reduction via decreasing special and material requirements by tightening plant lay-out may distort the fixed cost through increased O & M requirements.

Growth of Power Generating Capacity: This affects the site availability and more cost is involved in upgrading sites.

Manufacturing of Equipment: Project schedule improvements are limited by equipment delivery time. Two years is the shortest practical period between NSSS commitment and start of construction.

Conclusion: Current LWR capital cost, although still economically attractive, has risen to the point where predictable variations and costs overruns exceed the acceptable level of uncertainty.

Improvement strategies are feasible where standardization plays a central role, and Duplication with complete Reference Designs provides a prime benefit. Effective standardization will be accomplished only when site-licensing and project financing improvements are also implemented.

4.1.2 O&M Cost Assessment of LWR Power Plants:

The 1977 value of O & M cost is 2.15 mills/kWh, with a standard deviation between 50 to 60 percent of this value. This corresponds to about \$10.8 kW yr, or about 10 percent of the busbar fixed cost. It seems that the O & M cost is gaining more importance relative to its current share of fixed cost. Although the O & M cost for LWR plants is a little higher than that of O & M cost for fossil plants, both are experiencing similar escalation patterns.

Labor wages and requirements exhibit an important contribution to O & M cost. Although the labor share is only about 30 percent of the O & M cost, it influences about 50 percent of its value through related expenses.

Activity-wise, the most important O & M categories are the maintenance of reactor plant, miscellaneous nuclear power expenses, steam expenses, operation supervision and engineering, and maintenance of electric plant, whose contributions to O & M cost are 24, 20.8, 14.4, 10.5, and 10.5 percent, respectively. While these five categories have a total contribution of 80 percent of the O & M cost, they dominate 90 percent of the O & M cost increase.

The major causes of O & M cost increases have been increased safety and environmental requirements; security issues are gaining in importance and are expected to have a dominating effect on future O & M cost behavior.

Optimization of current practices is the general strategy for O & M cost improvement. Optimization is concerned with items such as plant layout improvement regarding O & M tasks, O & M procedures, and plant supplies and spare-parts inventories. Accounting measures that exclude or specifically categorize backfitting expenses charged as annual O & M expenses is another step toward improvement. Co-location has been found to provide savings of as much as 37 percent of O & M cost.

The trend toward increased O & M cost makes it appropriate to recommend a future study and analysis of current and future O & M cost conditions in order to provide better understanding of causes and improvement strategies.

4.2 Strategies for Capacity Factor Improvement

4.2.1 Introduction: Nuclear power plants as presently operating are the economically favored choice among central station options in many regions of the U.S.. Nevertheless, significant benefits accrue as nuclear station capacity factors are improved.* To the consumer of electricity, improved output from existing stations offers a large dollar return: the high replacement power costs that occur when low incremental cost nuclear stations are out of service usually appear as fuel adjustment changes. For the utilities there is the potential for greater customer satisfaction and more reliable operation of existing equipment, thereby reducing the need for additional reserve capacity and delays in constructing new plants. This conservation of installed plant

*Capacity factor is the ratio of annual electrical energy production (measured in kilowatt-hours) to installed annual capacity (installed electrical power capacity in kilowatts multiplied by 8766 hours, the number of hours in one year).

complements the conservation in end-use already being promoted and offers a solution to the near-term electricity shortages implied by the low generating reserve margin forecasts of the National Electric Reliability Council. As discussed in earlier sections, uncertainties about financing, regulation, and public acceptability have caused utility planners to perceive it as necessary or at least prudent to delay expansion decisions.

Various public and private groups could motivate improvements in power plant productivity. Candidates include the nuclear steam supply system vendors, the architect-engineers (A/E), the Electric Power Research Institute (EPRI), the electric utilities, the consumers of electricity, the state utility regulators, and the U.S. Department of Energy (DOE). The factors motivating each of these groups are examined below:

- (a) The vendors, lacking adequate incentive because there is little immediate profit to be realized, direct their interest toward future sales as opposed to servicing past sales. Nevertheless, vendors are offering improved maintenance packages as well as enhanced availability through standardized designs.
- (b) The A/Es do contract work rather than independent development, but they too have sensed a need for improved plant productivity. Responding to utility demands, A/Es now propose to design enhanced availability plants and to develop productivity improvement programs.
- (c) EPRI has been active in identifying problem areas and supporting long-term basic research, but its total budget limits contracts to relatively small project size. Particularly problematical are organizational constraints that essentially preclude large demonstration contracts with specific utilities.
- (d) The individual utilities at first would seem to have the most to gain: reduced costs, improved profits, consumer good will, and the opportunity to delay new construction. Unfortunately we see important deterrents at work here too. Utility management and engineering staffs are production-oriented, seeking to get the most out of existing systems rather than improving them. Developing improvements is less cost effective when applied to a single plant than when applied to many plants. Rate structures in most states allow utilities to immediately pass along the major cost of outages

through fuel adjustment charges. Finally, some rate structures designed to encourage improved capacity factor are in reality counter productive, penalizing a utility in the long run for short-term improvements.

(e) The role of consumers is restricted to applying political pressure on utilities and regulators. Unfortunately, this pressure can be misdirected. For example, some "public interest" groups try to convince consumers that fuel adjustment charges are penalties resulting from the expense of building nuclear power plants rather than the cost differential between nuclear and fossil fuels, which can be reduced by better utilization of existing nuclear plants. Clearly, there is a need to educate the public. Although unorganized consumers cannot be expected to direct efforts to improve capacity factor, they will be the principal beneficiaries and the other factors should be attentive to their needs and desires.

(f) State regulators exist to protect the interests of the general public and many are becoming concerned with nuclear plant productivity and its effect on fuel adjustment charges. Some are beginning to examine utility management methods to determine if modern techniques are being used to minimize the delivered cost of electricity. Because regulatory agencies have not developed expertise in reliability and decision-optimization methods, they are not now in a position to wisely apply much pressure in these areas. Moreover, these are separate and independent state agencies that cannot impose a uniform incentive across the entire industry. We note that their growing interest is in itself encouraging utilities to act positively early on--before regulatory guidelines are established and become rigid.

(g) DOE is in an excellent position to become the motivating force. The major beneficiary of improved nuclear plant productivity would be the general public rather than a specific private interest; therefore we believe that government agency action would be particularly appropriate. DOE can mobilize extensive resources to solve specific technical problems; widely disseminate recommended changes in equipment design, plant construction, and management practices; and perhaps provide uniform, technically-competent guidance to the various state regulators to help them understand the complexities of productivity management and the long-term implications of regulatory practices in this area.

Given the need for productivity improvement and several groups which could pursue that goal, what is the likelihood of economically realizing growth in nuclear plant capacity factor? The remainder of this section will show that overall improvement is not only possible, but also that in several areas it would be quite advantageous.

4.2.2 The Range of Economic Benefit: As defined earlier, capacity factor can be considered a measure of the effective size of a power plant. As such, it is a direct multiplier of the dominant fixed cost terms in expressions for the busbar cost of electricity (mills/kilowatt-hour). Capacity factor also has second-order effects on the remaining cost terms, on the growth of electricity demand, and on the growth of the nuclear industry. These effects are demonstrated by the analyses discussed in Chapter 5, which use the MIT Regional Electricity Model (REM) to study responses of the U.S. energy system to various changes in technical, economic, and institutional conditions. The net long-term result of a fractional increase in capacity factor (say, by 10 percent) is a drop in the busbar cost of electricity by a like amount (again 10 percent). The short term effect is even more pronounced; production from existing nuclear plants can displace that from existing coal and oil plants with a cost savings of between \$200 thousand and \$1 million per day for a 1000 megawatt-electric plant.* This enormous savings in replacement power cost means that saving 1 percentage point in annual capacity factor is worth about $\$9.0 \times 10^5$ per plant year. Using our reference scenario (Chapter 5, Table 3) as an estimate of the number of nuclear plants in operation in 1997, and applying a 10 percent discount rate, that 1 percentage point change in capacity factor translates into \$1.3 billion present-worth savings for those improvements

*The wide range in replacement power cost is caused by many factors, but most important is system load. Within a given region (power pool) plants are loaded preferentially--lowest incremental-cost plants first. A value of $\$2.0 \times 10^5$ per day from the low end of the range is used in the cost estimates of this chapter.

affecting all plants, and \$600 million present-worth savings for those restricted to new plants coming on line after 1985.

How much improvement is possible? Capacity factors now average near 60 percent. Allowing about 8 percent for refueling, a little over 1 percent for load following and coastdown, and at least 5 percent for regulatory shutdowns and deratings, the upper limit on capacity factor is about 85 percent. The reader is cautioned that this is an upper limit, not a reasonable goal; diminishing returns would render it prohibitively expensive. The best performing half of existing plants presently averages about 75 percent capacity factor. This is a more realistic goal and we expect that raising the average capacity factor by 10 to 15 percentage points will be economically viable. The present-worth savings to the economy through 1997 could approach \$15 billion.

4.2.3 Analysis of Annual Capacity Factor Data: Annual capacity factor data was analyzed statistically in an attempt to model capacity factor as a function of plant size, age, vendor, reactor type, and calendar year. No significant trends were identified for boiling water reactors (BWRs), leaving the best model as simply the mean value of 55.6 percent subject to a very wide standard error of 15.3 percent. For pressurized water reactors (PWRs) significant variations with size and age were found, as shown in Figure 1.

The standard error is again quite large, 13.9 percent, meaning that neither model explains a great deal of the data. It follows that the models are not very useful for predicting performance of new plants. It is hoped that including annual capital cost and O & M cost data, as well as an indicator variable for geographical region, will improve the models, but such an effort is reserved for future work.

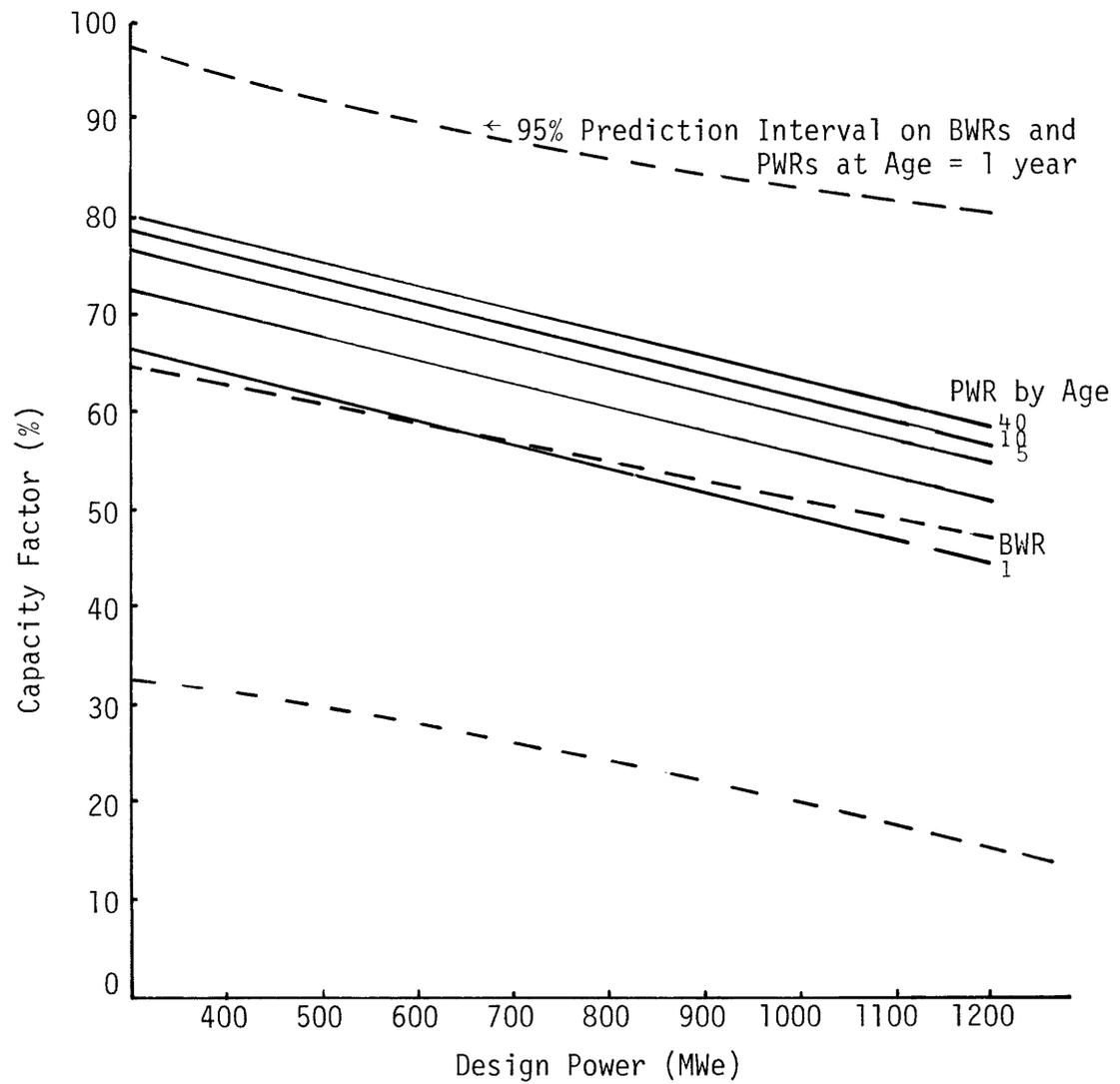


Figure 1. Nuclear Plant Capacity Factor

To reduce some of the data scatter, especially that due to periodic refueling, a moving average technique (which averages several years together) has been applied to data for all plants. The result of this analysis is a reasonable average value for capacity factor that grows over plant age for the existing mix of light water reactors (LWRs).

The MIT Regional Electricity Model (REM) mentioned earlier requires a single input value of capacity factor over all time for LWRs. Because capacity factor has a direct effect on capital cost, an economically discounted capacity factor would seem to be the most appropriate time average to use. A 10 percent discount rate was applied to the time-dependent LWR capacity factor model developed by the moving average technique. The resulting 64 percent capacity factor is used in the reference scenario. (This is higher than the average of about 60 percent mentioned earlier because that average is presently dominated by very young plants. Capacity factor for a mix of LWRs grows with age.)

By varying the values of capacity factor input to REM, we determine the effects of this change on the electric generation mix, the cost of electricity, energy demand, alternative fuel usage, etc. Three values beyond the base case have been analyzed: 50, 75, and 85 percent. The 50 and 75 percent values obtain from the moving average analysis; they are the discounted values of the upper and lower semi-midmeans. These are useful points since they indicate the potential savings of a program to bring the poorer performers up to a level proved attainable by half the existing plants. Likewise they show the cost incurred if the good performers are permitted to slip into the range of the lower half. Although the goal of this portion of the study is to examine improvement programs, the lower figure will provide useful information in case

unforeseen problems begin to drive performance down. Also it can show the net cost of reduced performance that could result from efforts to minimize capital costs. The 85 percent value is the technical, but economically untenable, upper limit discussed above. These REM runs show the savings to be expected over the range of interest and feasibility neglecting the costs of the improvements. Another run includes capital costs and capacity factor changes for several specific improvement plans (see Chapter 5).

4.2.4 Strategies for Improving Capacity Factor: Capacity factor averages near 60 percent. Scheduled outages (mostly refueling outages) account for about 10 percent of lost production, forced outages for 10 percent, and power reductions for 20 percent. Attempts to increase productivity by improving availability (a measure of outage time) ignore half of the lost energy production. The major cost is lost energy production, i.e., replacement power cost, not the number of adverse events. We concern ourselves, therefore, with the product of frequency of occurrence, fractional power reduction, and duration of reduction. Certain high frequency events, such as shutdowns due to operator error or instrument malfunction, were previously assumed to be of major importance. Detailed analyses have been presented showing that these two categories dominate total outages. Most of these outages, however, are of very short duration and their total effect on capacity factor is almost negligible when compared to other factors. Table 2 lists the principal contributors to reduced capacity factor. Regulatory problems, second in magnitude, are not discussed in the technical assessment segment of this study; they were examined in Chapter 3.

Significant improvement is offered by a variety of possible actions: new component designs, standardization, redundancies, improved plant layout, improved preventive maintenance, addition of advanced control and monitoring systems, and optimizing planning techniques applied to spare parts inventories, maintenance scheduling, and contingency scheduling. Because many of the techniques can be applied to the same problem, because correction of one problem may affect another, and because maintenance on various systems can be accomplished during an outage caused by some unrelated problem, the benefits from separate improvements add less than linearly. To analyze this complex problem we have used decision-risk analysis techniques. Our first step in each case was to prepare a decision tree detailing options for improvements. Figure 2 shows a simplified tree for condenser outage problems to illustrate our approach.

We see economic improvements of over 10 percentage points in capacity factor worth over \$11 million per plant year that could benefit from DOE support.

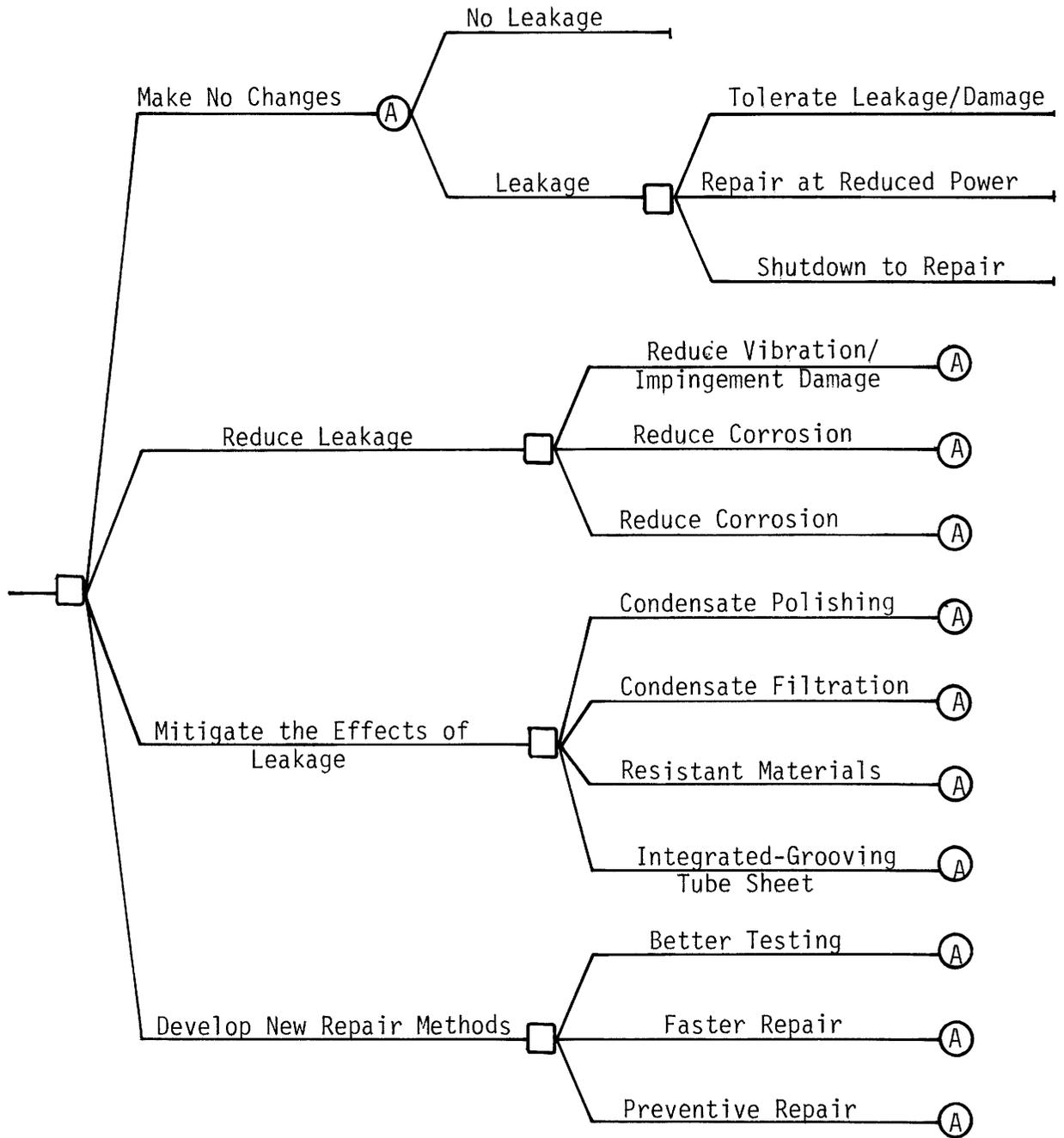


Figure 2. Simplified Tree for Condenser Outage Problems

TABLE 2

Principal Contributors to Reduced Capacity Factor

Contributor	Contribution	Projected Savings per Plant per Year (millions of 1979 \$)
Refueling Outages ^a	13.4 %	\$ 4.8
Regulatory Restrictions	4.7 %	none
Nuclear Fuel ^b	4.3 %	\$ 0.5
Turbines ^c	2.3 %	\$ 2.1
PWR Steam Generators ^d	1.2 %	\$ 1.1
Condensers ^e	1.0 %	\$ 0.9
Pumps and Valves ^f	4.2 %	\$ 2.0

- (a) Reduction of average refueling time from 49 to 30 days would provide annual savings of nearly \$4.8 million per plant. Further efforts to reduce refueling outage duration are not expected to yield significant savings because other required maintenance now done in the shadow of refueling would keep the plant shut down. The 30-day refueling appears to be an attainable goal and would save 5.2 percentage points in capacity factor. Computerized outage management could help optimize scheduling and ensure that delayed jobs do not enter the critical path. Improved training and refueling tools promise significant benefits. DOE could disseminate planning codes and information about successful training and could support development of improved refueling equipment.
- (b) Power reductions due to fuel failures have historically offered benefits of about \$3.9 million per plant year. As discussed in the nuclear fuel cycle section of this report, corrective actions may have solved most of the early problems. Lack of data on the newer fuels makes the magnitude of the remaining problems uncertain. One area of continuing concern is power-cycling of Zircaloy-clad fuel. About \$500 thousand per plant year would be saved if nuclear plants could come to full power more quickly. The same improvements permitting rapid power ascension would allow load-following operation--a fact of great importance when installed nuclear capacity exceeds the base load requirements in a region. Nuclear plants retain their economic advantage over coal plants whenever they operate at similar capacity factor and in some parts of the country even when operating 30 points lower. Thus the ability to load-follow offers large savings in the future. EPRI, the utilities, and the fuel manufacturers are following fuel problems quite closely, so DOE's role is not clear in this area.
- (c) Large turbine designs have been relatively stable for many years and the major problem with one manufacturer's low pressure blading has apparently been solved by design change. Two areas of trouble appear often--bearing and control system failures. New monitoring systems may offer advance warning of developing problems; the possibility of repair before failure could save significant outage time. Advanced control systems should offer higher reliability than the older electro-mechanical systems. DOE could support R,D&D in turbine control and monitoring systems, with possible savings of \$2.1 million per plant year.
- (d) Steam generator problems appear to be unending. The solution to each existing problem brings new hazards. Denting, presently the key problem, threatens to require replacement of several steam generators at costs exceeding \$100 million per steam generator, neglecting replacement power cost. The catastrophic nature of this problem has already brought the attention of much of the industry, EPRI, and DOE. It is hard to judge what the future holds for steam generator problems, but the support of DOE and the entire industry should not be

eased until several years of trouble-free operation have been demonstrated. The potential for disastrous expenses exceeding all other productivity problems is very real. At historic levels steam generator problems cost \$1.1 million per plant year.

- (e) Condenser failure occurs primarily by tube damage-corrosive attack on internal surfaces and impingement damage on external surfaces. Choosing the proper tube material greatly reduces the first problem (titanium looks particularly promising) while various mechanical support and protective arrangements can be used to ease the second. Condenser failure directly costs \$900 thousand per plant year. Since many years of design experience have not solved impingement problems, it might be appropriate for DOE to support R,D&D in this area. Solution of condenser problems is also a key path to reducing steam generator failure, which would save another \$1.1 million per plant year.
- (f) Although pumps and valves contribute significantly to lost energy production, the problems are distributed over a variety of components operating in many different environments. Fortunately a few specific components and generic problems account for a large fraction of the problems. Seals on PWR reactor coolant pumps and BWR recirculation pumps average almost \$800 thousand per plant year. Steam leaks and packing leaks on pumps and valves cost about the same amount. Primary relief valves contribute nearly as much. An R,D&D program in these three areas could reduce pump and valve problems by over 50 percent. Although these are old problems that have existed in conventional power plants for decades, their solutions have never been worth so much. A dedicated effort would reap substantial economic benefit.

4.3 The Nuclear Fuel Cycle

As with most aspects of nuclear power, the nuclear fuel cycle is presently more constrained by executive, legislative, and judicial action (or the lack of it) at all levels, than by the lack of adequate technology. This pervasive institutional impasse has had its greatest immediate effect on factors contributing to plant costs.

While this investigation has focused on these immediate concerns, some attention is due to the fuel cycle because of its historical role as contributor to reduced plant capacity factors, its present role as a major issue in the nuclear debate, and its longer-term impacts on the nuclear economy, which will be felt through the fuel cycle.

The commercial nuclear power fuel cycle has provided the low energy costs needed to justify this capital-intensive form of electric-power production. Nuclear fuel costs have even declined slightly as a relative contributor to the overall cost of nuclear-generated electricity. Nevertheless, a major problem has been loss of capacity factor due to defective fuel. This loss, amounting to roughly 4 percent of capacity (as discussed elsewhere in this report), has contributed an economic penalty equal to the original cost of fabricating the fuel. The problems are now felt to be under control--either having been resolved or approaching resolution. Accumulating experience and developing incentives to avoid restrictions on load following should lead to continuing improvements in this area.

There are obvious institutional deadlocks over fuel reprocessing/recycling and waste disposal. The former is due in part to concerns over weapons proliferation, and both involve long-term radiological safety. There is a panoply of subsidiary and peripheral issues, but these two generic concerns threaten to have the greatest long-term impact. If a satisfactory accommodation were generally perceived to be possible in these areas, then several decades of operation with the current once-through LWR fuel cycle could be contemplated with equanimity. In fact, core design and fuel management strategy changes (primarily increasing burnup and the number of staggered core batches) could probably improve the once-through ore utilization in a LWR to the point that it equals ore utilization in the fuel-recycle mode (in current LWR designs). Failure to reach consensus robs the nuclear option of its role as an energy strategy for non-transitory scenarios: only fuel recycle into breeder reactors elevates nuclear power to the status of an enduring solution to future energy needs.

The future role of the stand-alone LWR, even apart from the resolution of institutional impediments, is closely linked to the widely-debated issue of the uranium cost/supply relationship, an issue of inherent and perhaps irreconcilable uncertainty. Since ore costs amount to 50 percent or more of projected lifetime fuel-cycle costs for LWRs now coming on-line, this component is the primary determinant of the future economic prospects for the LWR. Our analysis shows that the scarcity-related rate of increase in the (constant dollar) price of yellowcake should be roughly two-thirds the rate of increase in uranium consumption. Ore costs will become increasingly onerous until at some point, estimated to be \$150/lb U_3O_8 in 1978 dollars, the unmodified LWR will no longer be competitive with either coal-fired units or breeder reactors. One cannot predict with certainty when this will occur, nor even when a believable prediction can be made. For present purposes, however, it is important to recognize that increasing the plant capacity factor and reducing as-built costs will provide an important margin against the long-term impact of rising fuel cycle costs. Core design, fuel management practices, and separative work consumption (hopefully using new and cheaper technology) can also be traded off to reduce the use of increasingly expensive U_3O_8 . Advanced LWR designs can be anticipated in response to a convincing threat of technological obsolescence, whether in the form of resource depletion or immutable policy.

The application of available technology and the development and deployment of technological innovations in the nuclear fuel cycle are considerably blocked by governmental pre-emption and policy, and the lack of timely, enduring regulatory action. Indeed, private-sector technology

in the back end of the cycle is unlikely to survive. Even apart from regulatory uncertainty, policy uncertainty underlying the need for intact fuel assembly disposal, for example, is sure to deter unsubsidized entrepreneurship. Paradoxically, however, there are prospects of Federally-originated requirements for the creation of substantial new technology, outside of that generated by normal market incentives. The development of ultra-high burnup fuel for use in the once-through fuel cycle is one likely example. Long burnup is considerably less attractive in the recycle mode from a fuel cycle standpoint, and might therefore not be anticipated as a vendor- or utility-originated R&D objective. Even here, however, the situation is not simple since one can presume such fuel would have enhanced reliability in applications demanding lower burnups. Such considerations can form the basis for near-term technical collaboration despite the lack of parallel policy objectives.

In summary, we have severely circumscribed in-depth analyses of the fuel cycle in our detailed technical investigations. Reducing plant costs and outages pose more immediate problems, with larger and faster payoffs, and, perhaps more importantly, there is a consensus among all interested parties that these goals are desirable. To be sure, there is need for parallel action on the fuel cycle; but the nature of the problems faced do not appear to mesh very well with the problems examined here.

5. ECONOMIC ANALYSIS OF LIGHT WATER REACTOR DEVELOPMENT

5.1 Introduction

Improvements in LWR technology, such as lower capital costs and increased plant availability, decrease the costs of delivering electricity. Lower costs will result in increased investment in LWR technology relative to competing technologies by decreasing the price of electricity in proportion to the increased share of nuclear in meeting electricity demand, thereby increasing electricity demand due to substitution of electricity for competing direct fuel uses. Thus LWR technology improvements increase the use of LWR both through increasing the share of LWR in total generation and increasing aggregate generation through fuel substitution. Evaluating the benefits to consumers of improvements in LWR technology therefore requires a framework that accounts separately for these different effects.

Our approach to estimating the direct and indirect consequences to consumers and the utility industry of changes in factors influencing LWR technology costs and availability has been to employ the M.I.T. Regional Electricity Model (REM). This model provides a framework in which to analyze and account for the interactions between capacity expansion and generation mix decisions, the demand for electricity and competing fuels and the regulatory process, which sets the price of electricity. The important independent variables to be specified in using the model include:

- o gross national product (GNP), personal income, manufacturing value added, population, and inflation;
- o national average fuel prices for oil, gas, and coal, and either the price of uranium or a cumulative uranium cost/production schedule; and

- o capital, fuel cycle, and operation and maintenance costs for each of nine plant types, including uranium- and plutonium-fueled LWRs, HTGR, LMFBR, coal, oil, gas hydro, and turbines; maximum plant availability factor by plant type.

Model outputs include: (i) the demand for electricity and competing fuels (oil, gas, coal) by state for residential, commercial, industrial, and electric utilities; (ii) the capacity expansion plans by plant type for 10 utility regions, and together with the generation mix schedule necessary to satisfy demand, the financial flows to support expansion; and (iii) regulated electricity price determined by Public Utility Commissions. Thus REM provides a framework within which the direct and indirect effects of improvements in LWR technology or in institutional and regulatory factors influencing LWR cost and efficiency factors may be evaluated.

Our approach employing REM has been to develop and analyze a reference scenario using values for independent variables consistent with no major policy or technology initiatives. The reference scenario is then adjusted to reflect the effects of some particular initiative--say, the effects of plant standardization upon capital cost. Results are then compared with the reference case and summary measures--such as changes in discounted delivered energy costs or in use of petroleum--are calculated.

A note of caution is in order when interpreting the results of our analysis. The results of the reference case should not be construed as a "most likely" forecast. While the reference case does reflect current expected costs, prices, and efficiencies, as well as the realization of current expansion plans, we do not offer it as a forecast. Rather it should be construed as a benchmark from which differential effects may be calculated. We are much more confident in the ability of REM to project the differential effects of cost and efficiency changes than we are of

TABLE 3
Key Parameter Values for Reference Scenario

FUEL PRICE (CURRENT DOLLARS) ^a				ECONOMIC GROWTH	
Coal (s/ton)	Nat. Gas ^b (¢ MCF)	Oil (\$ Bbt)		Real GNP Growth:	-2.1% 1974
1975	24.82	155	8.18	Real Value Added	
1980	33.31	201	15.47	In Manufacturing:	0.0% 1976
1985	48.30	395	22.97	Real Personal	
1990	64.54	713	33.97	Income:	3.8% 1976
1995	90.52	1085	50.48		-1997
				INFLATION RATE	
				Nonfarm Wholesale Price Index	
				12.5% 1974	
				8.5% 1975	
				5.5% 1976 - 1997	
				POPULATION GROWTH	
				1.2% Per Year	1974 - 1997

UNIT CAPITAL COSTS (KILOWATT) (For New England in Current Dollars):^c

	COAL	OIL	NATURAL GAS	NUCLEAR	GAS TURBINES
1975	407.0	280.2	248.0	455.2	134.0
1980	629.6	486.8	442.0	723.4	178.8
1985	862.6	780.0	672.4	991.0	228.6
1990	1181.8	1110.0	920.8	1358.2	288.0
1995	1619.0	1520.0	1261.8	1860.8	362.6
	COST OF U ₃₀₈ (\$ POUND) (CURRENT DOLLARS)		COSTS OF SEPARATIVE WORK (\$ SWU CURRENT DOLLARS)		INFLATOR
1975	12.51		75.70		1.000
1980	27.17		111.09		1.307
1985	55.29		145.19		1.708
1990	93.88		189.76		2.232
1995	141.13		248.01		2.918

NOTE: Data are in 5-year intervals; however, they are available on an annual basis.

^aValues in Table 3 are average national prices, natural gas and oil at the wellhead, and coal at the minemouth. Transportation markups are added on for each region in the model. It is assumed that the average wellhead price for natural gas is 40¢ MCF less than new contract prices shown in Table 3.

^bThe natural gas price shown corresponds to the average contract price for new intrastate sales. This price is used in the model to determine the merit order of existing natural gas plants for generation purposes. The model is constrained to build no new natural gas plants in the simulation.

^cIn the model regional variations in plant capital costs are given relative to New England.

our own ability to use the model to forecast future levels of electricity demand and electric power sector investment patterns and production behavior.

5.2 Reference Scenario

Table 3 presents reference scenario values for key input variables to the model. Additional assumptions of the reference scenario include no domestic fuel reprocessing (stow-away fuel cycle), a ten-year planning and construction period for LWR plants, and a restriction that no natural gas-fired plants may be constructed. Given these assumptions and the input data of Table 3, the major results of the reference scenario are:

(1) Table 4 summarizes national electricity demand for the period 1975-1995. National electricity demand is projected to grow at 4.7 percent per year. The growth rate is higher in the earlier years (4.9 percent per year 1975-1985) than in later years (4.6 percent per year 1985 - 1995). The assumption about the GNP growth rate has an important influence upon our results. For example, decreasing or increasing the GNP growth rate by 10 percent (from 3.8 percent to 3.3 percent and 4.3 percent respectively) changed national electricity demand from 4.8 percent to 4.5 percent and 5.2 percent, respectively. Regional variation in electricity demand growth is substantial, ranging from 2.6 percent per year in the Middle Atlantic region to 7.9 percent per year in the Mountain region.

(2) Table 5 summarizes the national shares in generation for nuclear, coal, oil and gas, hydro, and IC in 1975-1997. Nuclear power increases its share in generation from 10 percent in 1975 to 46 percent in 1995. Nuclear capacity in 1995 is projected to be 399 GWe operating at a national average capacity factor of .64. The share of coal based generation is projected to be 38 percent by 1995. The regional variation of generation shares is significant. For example, in 1995 nuclear accounts for a high of 74 percent of generation in the East-South Central region and a low of 4 percent of generation in the Mountain region.

(3) Fuel consumption patterns change significantly over the period. Electric generation consumption of oil and gas decreased from 760 million barrels equivalent (MBE) in 1975 to 492 MBE in 1997. Coal consumption for generation increases from 346 to 670 million tons over the period, and consumption of uranium increases from 13.7 to 92.3 thousand tons. Cumulative uranium consumption by 1997 is projected to be 1,045 thousand tons.

TABLE 4

Electricity Demand, National and for
Selected Regions for Selected Years
Reference Case (MMWe)

	National	Mid-Atlantic Region	Mountain Region
1975	1878	233	102
1980	2329	259	178
1985	3043	303	330
1990	3914	352	467
1995	4827	414	540

TABLE 5

Generation by Plant Type
Reference Case (MMWe)

	LWR	Coal	Oil & Gas	IC	Hydro
1975	193.7	900.0	464.8	5.6	314.3
1980	419.9	1031.6	506.4	7.0	364.2
1985	899.5	1291.1	434.5	9.2	408.5
1990	1266.0	1753.6	431.8	11.7	451.1
1995	2224.0	1835.9	260.3	14.5	492.4

(4) The discounted cost of total electricity and directly competing fuels used in the residential, commercial, and industrial sectors over the period 1977-1997 is \$1,838 billion (5 percent discount rate).

5.3 Analysis of Initiatives

The objective of developing and analyzing the reference scenario is to provide a benchmark from which the impact of changes in LWR costs, efficiencies, and availability can be measured, due either to technical or policy initiatives. The particular initiatives under consideration are developed in detail elsewhere in this Final Report and may be summarized as follows:

- a. Reductions in capital cost of LWRs due to a variety of technical initiatives including, most significantly, plant standardization,
- b. Changes in maximum capacity factor for LWRs,
- c. Continuation of the present "de facto" moratorium on investment in nuclear capacity, and
- d. Change in the definition of the rate base to include construction work-in-progress.

5.3.1 Capital Cost Reductions: Several scenarios involving changes in the capital costs of LWRs have been analyzed.* Of greatest interest is the summary scenario in which the combined initiatives of Section 4.1 are analyzed. The net effect of these combined scenarios is estimated to be a reduction in LWR capital costs of approximately 10 percent from the reference scenario (\$592 to \$532/KW, in 1977 \$).

The net effect of a decrease in LWR capital cost is to reduce the busbar cost of electricity from nuclear, thereby decreasing the regulated price of electricity, increasing the demand for electricity,

*Capital costs are here defined as net of financial charges during construction, the measure most appropriate when evaluating R,D&D initiatives.

increasing investment in nuclear as well as nuclear's share in the generation mix, and decreasing generation from other sources relative to nuclear. This is precisely what happens when R,D&D initiatives are pursued leading to a 10 percent reduction in nuclear capital costs for plants initiated in 1980. Thus by 1997, and measuring relative to the reference scenario:

- The price of electricity has decreased to 81.7 mills/kWh (down 6.3 percent).
- Electricity demand has increased to 5325 MMWH (up 5.9 percent),
- Nuclear capacity is 495 GWe, up 7.1 percent, and nuclear's share in total generation is 51.8 percent (up slightly from 51.3 percent).
- Cumulative consumption of scarce oil and gas over the period has decreased 390 MBE from 14,770 for electricity generation. Total discounted economic costs of electricity and directly competing fuels are reduced about 0.2 percent from \$1.838 * 10¹².

5.3.2 Changes in LWR Capacity Factors: Next we consider the effect of changes in LWR capacity factor upon demand, capacity expansion, generation, and fuel use. Again a variety of scenarios have been analyzed, but the most interesting involves the implementation of improvements leading to an increase of 10 percentage points (from .64 in the reference scenario) in the maximum available LWR capacity. As with the decrease in capital costs, such capacity factor improvements are of considerable economic importance to society. Thus:

- Electricity prices decrease to 81.7 mills/kWh, down 6.2 percent. Demand increases to 5536 MMWH, up 5.3 percent.
- Nuclear capacity is 551 GWe, up 19.3 percent, and nuclear's share in total generation is 61.9, up significantly from 51.3 percent in the reference scenario.
- Cumulative consumption of oil and gas over the period 1977-97 is down 17.7 percent from 14,770 MBE. Total discounted energy costs are down 0.8 percent from \$11,838 * 10¹².

Hence, the economic gains from initiatives to improve nuclear capacity factor are substantial.

These economic benefits are calculated under the assumption that improvements in capacity factor are obtained through improved scheduling and management of maintenance and refueling, and have no measurable costs. An alternative scenario is that improvements in LWR capacity factors can result from increases in capital expenditures. Such an analysis is provided in Section 4.2, where it is shown that around the present capital cost and capacity factor, a 1 percent improvement in capacity factor may be obtained with a 0.4 percent increase in capital costs. Using this relationship we analyze the effect of an investment of 4 percent increase in capital costs to obtain a 10 percent increase in capacity factor, investments beginning for plants initiated in 1980. The economic benefits are still substantial. Thus, by 1997:

- Total electricity demand is up 2.9 percent from 5257 MMWh.
- Nuclear capacity is 520 GWe, up 12.8 percent from the reference case, providing 59.3 percent of generation.
- Cumulative consumption of oil and gas are down 2.2×10^9 barrels equivalent, and discounted total energy costs over the period are down $\$9.0 \times 10^9$.

5.3.3 Continuing the De Facto Moratorium: Sections 2 and 3 discussed the institutional and regulatory issues influencing development and use of LWRs. We concluded that one product of these issues is vendor and utility uncertainty, which is reflected in risk-averse investment behavior. In large part the investment behavior of the past 4-6 years reflects this uncertainty. While our analytical capability does not yet include an explicit representation of the response of investment behavior to this type of uncertainty, we can analyze the consequences of a continuing moratorium on nuclear construction for whatever reasons. Such

a scenario will involve two elements: a constraint on nuclear capacity construction of a specified time, and an explicit characterization of the rate of recovery for vendors at the end of the moratorium. For our present purposes we assume a five-year absolute construction moratorium beginning in 1978, followed by a five-year vendor capacity recovery period. Under these assumptions we can expect:

- An increase of electricity prices from 87.2 in the reference case to 94.0 mills/kWh, with a corresponding 4 percent decrease in electricity demand.
- Nuclear capacity is reduced to 218 GWe, down 48.7 percent from the reference case. On the other hand, coal capacity is 557 GWe, up 32.3 percent from the reference case.
- Cumulative consumption of oil and gas is increased over the period 1977-97 by $.81 * 10^9$ barrels, and total discounted energy costs are increased by $\$13.0 * 10^9$.

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