

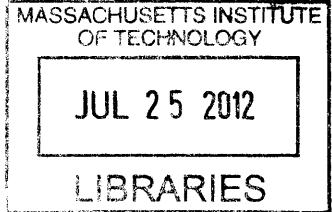
An Examination of the Pursuit of Nuclear Power Plant  
Construction Projects in the United States

by

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ARCHIVES



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# An Examination of the Pursuit of Nuclear Power Plant Construction Projects in the United States

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Nuclear Science and Engineering

## ABSTRACT

The recent serious reconsideration of nuclear power as a means for U.S. electric utilities to increase their generation capacity provokes many questions regarding the achievable success of future nuclear power plant construction projects. The troublesome nature characterizing much of the history of U.S. nuclear power plant commercialization provides impetus for an examination of the reasons behind the unanticipated outcomes of many nuclear power plant construction projects. An examination of the history of U.S. nuclear power provides for both an understanding of the historical context of the technology, in addition to an acknowledgement of the difficulties that have surrounded its commercialization.

This thesis work identifies the factors that have contributed most significantly to the inability of U.S. electric utilities to successfully manage nuclear power plant construction projects. The historical record of these endeavors was used to create a causal-loop diagram. This diagram reflects a generalized decision-making process used by electric utilities when considering the pursuit of nuclear power plant construction. From the results of the diagram, policy changes are proposed that could reduce the susceptibility of the decision-making process to environmental instabilities and increase the overall attractiveness of the technology.

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# **1 Introduction**

## ***1.1 Motivation***

Over the last few years, the United States' Nuclear Regulatory Commission has received a number of license applications for the construction of new nuclear power plants. Since the early 1980's, the U.S. electric utility industry had shown little interest in constructing new nuclear power plants, but clearly the situation is now changing. In recent decades, the electric utility industry has favored the construction of fossil fuel power plants to meet rising energy demands. Apparently, the world's increased attention to climate change and volatile fossil fuel prices have now resulted in the reconsideration of nuclear power as a means to address these cost and environmental concerns. Because the electric utility industry has experienced such a long hiatus from any active pursuit of new nuclear power plant construction, it may be instructive to examine the historical record of U.S. nuclear power plant construction projects. This examination could reveal the nature of the policies that could be best suited for implementation in the future, in order to encourage the success of these projects. A nuclear power plant project remains, to a large degree, the single most significant commitment of capital that a non-government organization can make. Understanding the relevant economic, political, regulatory and environmental issues pertaining to nuclear power over the course of its history could provide the appropriate context for making appropriately informed decisions regarding nuclear power plant construction in the future.

## ***1.2 Thesis Objectives***

The objective of this thesis work is to identify the major factors that have contributed to the difficulties that U.S. electric utility companies have experienced with nuclear power plant construction projects throughout the course of technology's commercialization history. By

identifying these factors, policy changes will be proposed that could bolster the success of future of U.S. nuclear power plant construction pursuits. In order to gain an understanding of these factors, a concise history of the development and commercialization of U.S. nuclear power technology will be presented. This history shall mainly focus on those areas closely tied to the underlying causes of the unanticipated outcomes of many nuclear power plant construction projects.

By developing an understanding of the key factors governing both the motivation and the level of success achieved during U.S. pursuits of nuclear power plant construction, a causal-loop diagram will be constructed. This diagram will demonstrate the interdependencies of the elements influencing the general decision-making process used by utilities to decide whether to pursue nuclear power as a means to expand their electric generation capacity. From this diagram, the major sources of instability inherently present in this process will be revealed. Based on these findings, those factors that could be improved in order to create a more favorable environment will be identified. From the identification of these factors, opportunities for policy improvements that could provide enhanced stability to the U.S. prospects for the expansion of the use of nuclear power in the future will be discussed.

## **2 Emergence of U.S. Civilian Nuclear Power Program**

### ***2.1 Manhattan Project***

The emergence of the use of nuclear energy as a means to generate electric power was unique in that it came as a result of work done to achieve a very different goal: the construction of a nuclear bomb. The technology's military origins strongly shaped the manner in which it was introduced to commercial enterprises. The unusual roots of nuclear power technology provided for heavy government involvement during its period of development and into the early years of its commercialization.

The United States' government's highly secretive Manhattan Project, active between the years of 1942 to 1946, allowed for huge strides to be made in the understanding of nuclear fission chain reactions. Although the focus of this project was the development of nuclear weapons, an understanding of nuclear reactor design emerged as well, since the use of nuclear reactors was required in order to produce material needed for use in weapons. With the successful deployment of two nuclear bombs in Japan in August of 1945, the United States proved to the world its ability to achieve huge technological advancement in a short period of time. Although other nations had been pursuing the same wartime applications of nuclear science, the United States emerged as the world leader in nuclear technology. With this great accomplishment, however, came great burden. Having shown the world the destructive capabilities of nuclear technology, the U.S. needed to prove to the world that it could responsibly use nuclear technology.<sup>1</sup>

### ***2.2 Atomic Energy Commission***

The Manhattan Project came to a close with the passing of the Atomic Energy Act of 1946. This act authorized the formation of the Atomic Energy Commission (AEC). The AEC

was a civilian body in charge of regulating all of the U.S. nuclear activities, in addition to promoting the development of peaceful applications of nuclear technology. The AEC played an important role in establishing the expectation that once the engineering design work for commercial nuclear reactors had been successfully completed, the electricity produced would be far more economical than compared to its fossil fuel competitors. This fundamental belief would play a large role as a driving force for the commercialization of nuclear power for almost three decades.<sup>2</sup>

Under the watch of the AEC were the national laboratories, many of which were formed during the time of the Manhattan Project. The research conducted at these laboratories promoted basic research for both defense and commercial applications. Within this structure, however, lie internal conflicts. The U.S. government placed a high priority on nuclear information. As a result, nuclear technology was guarded as a national secret. This may have been a sensible course of action regarding weapons applications, but presented serious problems for the goal of nuclear power commercialization, as many questions surrounding the industry's interaction with nuclear technology remained.<sup>2</sup>

### ***2.3 Submarine Application***

The U.S. Navy's interest in applying nuclear power to submarine propulsion, combined with Adm. Hyman Rickover's intense enthusiasm for this pursuit, paved the way for the pressurized light water reactor to be chosen as the technology of primary focus. After having spent a few years studying nuclear reactor technology in conjunction with Oak Ridge National Laboratory, Adm. Rickover made the decision in 1950 to pursue the use of pressurized water reactor technology for submarine applications. In retrospect, the important decision that Rickover made was largely a good guess. Other alternative designs had been suggested, but in

Rickover's estimation they would prove to be too expensive or complex. It is also necessary to consider the context of the time in which Rickover was making this important decision. The U.S. was compelled to continue as the leader in nuclear technology after having shown great wartime success in this area. Fearing the advancement of other nations, especially that of the Soviet Union, Rickover's decision provided the solidarity in decision-making that the U.S. needed to steadily progress with its nuclear program.<sup>3</sup>

#### ***2.4 Shippingport: First Commercial Reactor***

Adm. Rickover's decision to proceed with the pressurized light water reactor (PWR) design led to the construction of the STR Mark I test reactor in order to demonstrate the feasibility of the PWR concept as applied to the submarine. The success of this undertaking provided evidence that the PWR concept was promising, and in 1954 work began on the Shippingport, PA commercial nuclear power reactor. The Shippingport reactor would come online in 1957 as the first commercial nuclear power reactor. It is important to note, however, that the Shippingport reactor was largely financed by the AEC. Duquesne Light Company did contribute towards the project by providing the site, some research and development funding for the project, and providing for the operation and maintenance of the plant. Although this indeed demonstrated a financial commitment from the utility, without having raised the capital for the project itself, the project did not provide a complete experience on which other utilities could use to base their future purchasing decisions.<sup>2,3</sup>

#### ***2.5 Reactor Demonstration Program***

With the success of the Shippingport reactor under its belt, the AEC looked to take the next step in the commercialization of the nuclear power reactor. The AEC realized that no convincing argument had been made to the utilities regarding the economic competitiveness of

nuclear power. Therefore, continued progress would require further government subsidization. The AEC believed, however, that nuclear power would prove to be significantly more economic and attractive than its alternatives once the technology had demonstrated its feasibility and reliability in the first few constructed reactors. The AEC firmly believed that as long as a robust nuclear power reactor technology was available, future commercialization would not be difficult, as the technology would be very attractive to the utilities for a variety of reasons. This fundamental belief strongly shaped the approach the AEC took in operating its reactor demonstration program.<sup>2</sup>

The purpose of the reactor demonstration program was to determine the most suitable reactor technology for application to commercial nuclear power reactors, and to gain valuable experience with the technology that could be used for future benefit. Throughout the various rounds of the program, a variety of reactor designs were tested including the PWR, boiling water reactor (BWR), fast breeder reactor, sodium graphite reactor, organic reactor, superheated BWR, heavy water reactor and a graphite moderated helium cooled reactor. Not surprisingly, the projects having the most technological experience were the most successful. The Yankee Rowe (PWR) and Dresden (BWR) projects were completed on time and very close to within budget. Westinghouse already had a relatively good amount of experience with PWR technology through its involvement with the submarine reactor program and the Shippingport reactor. The prior work done by the AEC on its Experimental Boiling Water Reactor combined with GE's own development of the technology provided the experience required for GE's successful implementation of the BWR at Dresden.<sup>2</sup>

Most of the other projects in the program were deemed failures. Foremost, there was simply a lack of resources available to manage the technological difficulties encountered with

the various technologies. This was not too surprising considering the extra attention that had been given to light water reactor technology from the beginning of the navy nuclear reactor program. Still, however, the reactor demonstration program provided enough evidence to demonstrate that many of the other reactor technologies would not be feasible for commercial operation in the very near future. Therefore, with this program the predominance of the light water reactor technology was solidified. Also important was that by investigating the feasibility of many types of reactors, the AEC left itself open to many possibilities, which in turn, protected the program's total failure from any one failure during the program's course. This provided an additional competitive edge for the U.S., as the commercial reactor development programs of other nations were solely focused on one technology at a time.<sup>2</sup>

The utilities' decision to participate in the reactor demonstration program was based more on the personal interest of the utility executives in nuclear power technology, than on any concrete evidence that commercial nuclear power would indeed prove to be economic. Of course, the demonstration program provided for project financing and various subsidies so as to minimize the risk to the utilities, however, the utilities did also have to contribute some resources to the project. Nevertheless, utility participation did not necessarily directly indicate solid industry commitment to the technology in the future.<sup>2,4</sup>

## ***2.6 End of Demonstration Program Status***

The reactor demonstration program allowed for the determination of the most feasible reactor technology for the time: the light water reactor, however, it did not make strides in commercialization aspects of the technology. The predominant philosophy of the time was that as commercial nuclear power plants became better engineered, the economics of nuclear power would follow suit, improving as well. Therefore, the main focus throughout this program was

technological improvement. This approach can be somewhat explained by the mentality surrounding nuclear power, in that it was “just another way to boil water.” At this early stage of nuclear power plant development, a full appreciation of the uniqueness of the technology, and the consequent implications of this, had not been realized. Without this realization, the fledgling industry would concentrate more on how to overcome various technical challenges, rather than focusing on how best to incorporate the technology into the power generation marketplace.<sup>2</sup>

Ultimately, the reactor demonstration program did not make progress in demonstrating the economic competitiveness of nuclear power. The program showed utilities the high risks associated with undertaking the implementation of a relatively new technology. In many cases utilities by themselves were not sufficiently large to take on the risk alone, and paired with other utilities for the demonstration program reactors. Furthermore, coupled with the inherent risks associated with implementing the new technology, the reactors constructed had relatively low electric output, with only one reactor greater than 200 MWe. Consequently, utilities were still extremely hesitant to add nuclear power to their generation mix.<sup>2,4</sup>

### ***2.7 First Independent Commercial Projects***

By 1963, no nuclear power reactor had been built without government funding assistance. Two reactor vendors, Westinghouse and GE, had emerged as the leaders in reactor design. The utilities, however, still had not shown any interest in pursuing projects independently from those that were government subsidized. In order to encourage utility interest, GE came forward offering turnkey contracts, and Westinghouse soon followed with the same offering. The turnkey contracts required the vendor to be responsible for the complete plant. The vendors were to acquire the construction and operating licenses and they were to be responsible for all actions necessary to make the plant fully functional. Some considered this to be a measure of last resort

for the vendors. The vendors justified this approach by believing that there had been sufficient past experience with plant construction upon which to base their judgment for how to proceed with construction planning. The vendors also were strongly confident that nuclear power would prove to be cost competitive. Furthermore, they considered the non-nuclear portion of the plant very similar to those in place for fossil generation and, also, that economies of scale would be easily realized when scaling up the size and output of the reactors.<sup>2,4</sup>

The outcome of the twelve turnkey projects that were ordered proved to be far different from the expectations of the vendor. The projects turned out to be money-losing ventures. The costs of the projects were 90% to 110% more than the original estimates, and due to the nature of the contract, the vendors suffered the losses. There were a few major reasons why the projects did not proceed as expected. Foremost, the construction “learning curve” did not fall into place as planned. Standardization of design proved to be unrealistic, and consequently a large amount of unique design work was required for each project, contributing to cost increases. Coupled with the lack of standardization, was the non-realization of economies of scale. The size of the projects being pursued increased dramatically over a short period of time and the complexity of these larger projects was not anticipated. Finally, several construction infrastructure problems arose due to lack of experience with nuclear-specific technology requirements. Large, low quality steam supply systems were required from turbine vendors. Low quality steam systems were somewhat passé for the turbine vendors as fossil fuel plants were trending towards higher quality steam systems. The steam supply system vendors therefore had to accommodate the nuclear requirements by scaling up production of an older technology. Building large containment vessels also provided for unforeseen technical difficulties, resulting in further delay. Finally, the differences between nuclear and fossil designs triggered conflict within labor unions,

as previously defined construction jobs were now unclear due to the overlapping of responsibilities in the case of a nuclear plant. This difficulty caused further delay, and consequent cost overruns.<sup>2</sup>

### ***2.8 Non-Turnkey Projects***

Although it seemed at first that turnkey contracts were necessary to incite utility interest in nuclear power plants, the poor results from the turnkey projects actually worked to increase utility interest in pursuing their own projects, for which they were solely responsible. Utility interest increased so much that during the same time period, two times as many non-turnkey projects were ordered. This disparity can likely be accounted for the utilities' confidence in their project management capabilities. The utilities believed that the vendors lacked experience in this area, and therefore they themselves would be able to manage the project much more efficiently. The utilities had good reason to feel confident. They were state regulated, operating in a supportive government environment. They also had no significant history of project failures. Therefore, they were confident about their ability to achieve success with nuclear power projects as well.<sup>2,4</sup>

### ***2.9 Trends of the Era of Emergence of Nuclear Power***

The emergence of nuclear power to commercial markets was marked by a great degree of government involvement and subsidy. This was to be somewhat expected given that the roots of the technology were in secret government work, however, the government continued to be heavily involved in the development of the technology, as many believed in the potential for huge economic benefits to be seen from nuclear power. The reactor demonstration program was successful in setting a technology path for future commercialization by identifying light water reactor technology as of primary interest. This largely government supported endeavor provided

deep pockets for the exploration of the feasibility of various technologies in order to reach this conclusion.<sup>2</sup>

The high degree of optimism surrounding the development of commercial nuclear power can be explained by the general sentiment shared by much of the population of the U.S. at the time. Having been a decisive contributor to the Allied victory in World War II, the U.S. was highly confident in its ability to take on challenges. With the development of nuclear technology having been explicitly tied to the ultimate Allied victory, it was a natural progression for the U.S. to be interested in extending the influence of its prized technology to the civilian sector. In pursuing this goal, however, the U.S. neglected to focus on a commercialization strategy that would ensure the success of nuclear power in the marketplace. The presiding attitude of U.S. superiority worked against the future commercial success of nuclear power, as it placed too much faith in the ability of industry members to make nuclear power more attractive than fossil fuel alternatives. Although the U.S. was able to rely on its industrial capacity to provide the resources required for the Allied victory, industry members showed that they were not necessarily able to easily adjust to the demands that the commercialization of nuclear power placed on its resources. Hence, the early road to commercialization was paved with difficulty. With few exceptions, cost estimates for nuclear reactor construction projects were far exceeded; however, because the technology was still in its youth, it was easy to blame the misfortunes associated with the nuclear power projects on reasons due to the natural inexperience surrounding the new technology.<sup>2,5</sup>

The good economic climate of the era did much to bolster the future hopes for increased implementation of commercial nuclear power. During this time period, utilities had the good fortune of operating in a stable regulated environment. They did not have to operate in a

competitive fashion and they mostly had successful histories and strong relationships with state regulators, further encouraging their longstanding success. The era from which nuclear power commercialization emerged, was chocked full of pursuits of large projects, many concerning U.S. infrastructure. Construction of nuclear power plants could be considered to fall into this category of projects. Therefore, the combination of a stable economic and regulatory environment, in conjunction with a supportive mentality towards the pursuit of large projects, provided for an encouraging environment for nuclear power plant commercialization pursuits.<sup>2,5</sup>

### **3 Peak of U.S. Nuclear Power Plant Construction**

#### ***3.1 Surge of Utility Interest in Nuclear Power***

Throughout the early years of the 1970's, orders for new nuclear power plants exceeded those for new fossil plants. This dramatic shift in preference strongly reflected the changes that were occurring within the environment of the electric power generation sector. A change in strategy for power distribution and grid interconnection resulted from the Northeast Blackout of 1965. This disturbance brought into light the lack of interconnectivity existing in the grid linking utility companies. This prompted an interest in the implementation of regional power pools. Increased service territory created the opportunity for an increased demand for baseload power generation, a need that nuclear power could satisfy. The move towards regional power pooling also encouraged the formation of joint venture projects between utilities for the purpose of nuclear power plant construction. This spread of financial risk allowed for the undertaking of a nuclear power plant project to be more attractive.<sup>2</sup>

Also having a large impact on utilities' attitudes towards nuclear power was the increased level of awareness of the environmental impacts of electricity generation, primarily the impacts from burning coal. With more attention placed on environmental impacts, utilities began to worry about the prospect of increased environmental regulation legislation and its cost-escalating effects on plant operation. With nuclear providing an emission free option, utilities began to appreciate it as an environmentally sound choice.<sup>2,4</sup>

Fuel cycle security also became an increasingly important consideration, with the nuclear fuel cycle providing a unique alternative to fossil fuel cycles. The increased attention given to the fuel cycle arose primarily from the utilities' exposure to both unpredictable and rising costs of fossil fuels, which was exacerbated by the oil crisis of 1973. The growing awareness

surrounding the environmental impacts of burning coal also brought into question the feasibility of sourcing lower-polluting varieties of coal. Less-polluting low sulfur coal existed predominantly in Western states. Since many coal plants had been constructed in a “mine mouth” fashion, which allowed only the produced electricity to be shipped across distances, sourcing coal from a far away location could introduce large cost increases.<sup>2</sup>

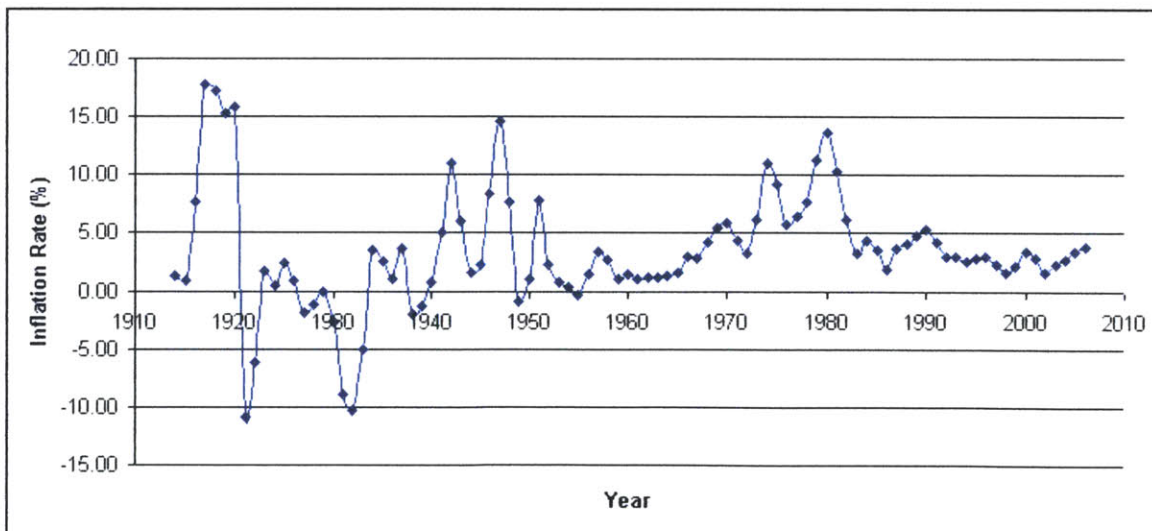
These fuel cycle considerations essentially reinforced the element of generation diversification that nuclear power generation could provide to utilities. This newfound desire for diversification somewhat overshadowed the still weak economic competitiveness that nuclear power plants had demonstrated. Still by the early 1970’s, not many nuclear power plants had been completed. Utilities could easily make excuses for the unpredictable outcomes of early nuclear power plant construction, blaming the outcomes on the difficulties of introducing a new technology into the market. Furthermore, the financial stability of the markets during this period encouraged state regulators to be cooperative in providing the rate increases required by the utilities in order to proceed with their nuclear construction projects. Therefore, the circumstances of the environment in which utilities were making decisions concerning sources of new load growth reflected very favorably upon nuclear power, despite its mixed bag of success during the 1960’s.<sup>2,4</sup>

### ***3.2 Negative Effects of the Oil Crisis***

Although the oil crisis of 1973 helped the case for nuclear power by making it a relatively more economic choice due to its more secure fuel supply, other effects of the oil crisis were far reaching and had an overall negative impact on the prospects for nuclear power plant construction. A primary consequence of the oil crisis was increased energy conservation measures. Energy conservation led directly to a reduction in electricity demand, changing the

utilities' future load growth expectations. Uncertainty in future grid demand served as a major reason for cancellation of nuclear power plant construction projects in the years following the oil crisis.<sup>2,6,7,8,9,10</sup>

The oil crisis also contributed to the growing unstable financial position of many utilities. The rapid increase in the cost of fossil fuels placed an unanticipated burden on utilities. This instability in fuel cost prevented utilities from pursuing long-term projects, as future fuel costs were a point of large uncertainty. The increased attention placed on the environmental effects of electric power production also increased the burden upon utilities. Retrofitting plants to meet emission standards was expensive. Increasing inflation, as shown in Figure 3.1, had the effect of increasing the cost of capital, making it less attractive to pursue new generation capacity expansion. These realities made it difficult for utilities to plan for the future, and especially difficult for planning nuclear power construction projects.<sup>2,7,8,9,10</sup>



**Figure 3.1 U.S. Inflation Rate by Year**

### ***3.3 Regulatory Changes***

Those utilities pursuing nuclear power construction projects in the 1970's, who had persevered through the oil crisis with their construction plans, felt that they must take advantage of economies of scale in order to justify the economics of their projects. Therefore, the size of the plants being ordered increased dramatically. This increase in size led to increased design complexity, placing a heavy burden on the AEC. When the AEC discovered it had not been completely thorough in its requirements it would alter them, making the current projects adhere to the new rules. This resulted in a vicious cycle of delays, as utilities had to reapply for approval from the AEC for the implementation of the new design requirement each time a change was made. This process was referred to as backfitting. It naturally proved to be a resource-draining endeavor for utilities, bringing into question the economics of their pursuits.<sup>2,11</sup>

With both the presence of nuclear power in the U.S. increasing, as well as the size of the actual plants themselves, the technology came under increased scrutiny by the public. Many brought into question the motives of the AEC. From its birth the AEC had had the dual responsibility of regulating the safety of commercial nuclear power reactors, in addition to promoting its acceptance. Now that nuclear power had proved its viability, some believed that this dual responsibility of the AEC could interfere with the quality of its regulatory practices. Increasing public dissatisfaction eventually led Congress, in 1974, to reorganize the responsibilities of the AEC into two separate bodies: the Nuclear Regulatory Commission (NRC) in charge of regulation and the Energy Research and Development Agency (ERDA), taking on the role of the R&D responsibilities of the former AEC.<sup>2</sup>

### ***3.4 Contributions to Unpredicted Project Outcomes***

#### **3.4.1 Significance of Lead-time to Project Economics**

The underlying direct cause of unpredicted outcomes for nuclear power plant construction projects in the 1970's was unanticipated increases in lead-time. Lead-time is defined as the time between the start of construction until the time of full-scale operation. Essentially, it is the time during which the utility is spending money on the project and not collecting any revenues from its operation. Given the magnitude of nuclear power plant construction projects, increases in lead-time can have very profound economic consequences for the utility responsible for the project.<sup>2,11</sup>

Because the utility is not collecting any revenues from the project during its lead-time, it is not able to pay off the interest charges for its incurred debt. Therefore, the interest is continually compounded throughout the entire project lead-time. This effect, coupled with that of inflation, can lead to a large fraction of the total project costs stemming from these time related costs. Inflation related costs arise from project expenditures occurring in the later stages of these projects, thus any decrease in lead-time will lessen the effect of inflationary costs. Project lead-time is also important, because it is used by utilities to plan how future grid demand will be met. Inaccuracies in the lead-time estimation can result in utilities having to purchase replacement power if they are not able to meet grid demand. This further amplifies the cost of the entire construction project.<sup>11</sup>

Lead-time can be considered to be one expression of the degree of uncertainty of a project outcome, since the increased length of lead-time provides a larger time scale for elements of the project to go awry. The argument for minimizing project lead-times has been so convincing that some utilities made technology choices based strictly on the certainty of lead-

time estimates, neglecting the estimated overall economic outlook of the project. Decisions made in this way frequently led to a preference for fossil plants over nuclear.<sup>2,8,11</sup>

### **3.4.2 Economic Factors**

The economic environment strongly shaped the unpredictable course of many nuclear power plant construction projects during the late 1960's and into the 1970's. The economic prosperity of the late 1960's provided opportunity for many utilities to place orders for new nuclear power plants. Given that the nuclear industry was still in its youth, the industrial capacity for nuclear construction was not great enough to meet the demand for new plant construction. Without enough capacity to meet demand, inevitable delays were incurred as regulators, vendors, architect-engineers and the utilities themselves struggled to manage their workloads.<sup>2,7,8</sup>

The general economic decline that ensued following the oil crisis of 1973 caused future electric load growth estimates to be severely diminished. Utilities were faced with a potential future oversupply of electricity if they were to proceed with all of their power plant construction projects. Many utilities that had not invested significant resources into their nuclear power plant construction projects decided to cancel them outright. Those, however, that chose to continue to proceed with their projects were faced with balancing continued progress with the reality of grid oversupply, should their plant come on line too soon. In some cases utilities chose to delay their project for this reason. This however proved to be very costly, as lengthening the lead-time of the project proved to be very costly during this period of high inflation and consequent high interest rates. Further adding to the difficulty of the situation, smaller utilities pursuing nuclear power plant construction projects often had not anticipated the financial demands of the project. This led to additional project cancellations.<sup>2,11</sup>

### **3.4.3 Resource Allocation Problems**

Lack of resources throughout the entirety of the nuclear industry led to increases in lead-times for the majority of nuclear power plant construction projects, despite the fact that many projects were already canceled in the mid-to-late 1970s following the oil crisis. The demands on the nuclear industry had risen suddenly in less than ten years, and the industrial infrastructure had not had time to grow accordingly. Labor shortages were a major contributor to this problem. This was seen in both the construction and regulation sides of the industry. With a large number of projects being pursued simultaneously, a huge strain on resources was placed on architect-engineering firms and regulators. These bodies simply did not have the manpower to keep up with the work demand. Coupled with labor shortages were component shortages. With limited industrial capacity in place to handle the manufacturing of nuclear specific components, manufacturers were not able to meet the spike in demand of plant components. This excess of demand naturally led to both increased material costs for utilities, in addition to increases in lead-time. Furthermore, project delays led utilities and vendors to be out of sync with their schedules, leaving the utility to pay storage costs for materials that they did not yet require at their construction site due to other project delays. Therefore, utilities were not only dealing with the time-related cost escalation due to project delays, but also the cost of not proceeding in accordance with the terms of delivery originally set with the vendor.<sup>7,11,12</sup>

The level of quality control and assurance required for nuclear power plant construction presented many difficulties. Nuclear power plants require a higher degree of quality control during their construction and operation compared to fossil power plants. Implementing this change of behavior among construction workers proved to be very difficult. Lapses in following the quality control standards required retrofitting and rebuilding – costly efforts in terms of both

time and money. The level of quality control required for nuclear components also contributed to the overall cost because the cost associated with manufacturing the high quality components was simply greater. Eventually the construction workforce would become accustomed to the nuclear quality control practices, however, the interim period provided for much frustration and increased lead-times.<sup>11</sup>

One extreme case of quality control problems occurred during the construction of the Zimmer nuclear power plant in Ohio. When it was discovered that a faulty quality control program was in place, and many of the plant's components were defective, the NRC determined the situation to be beyond realistic repair. In 1983 it required work on the plant to cease. This occurred after 97% of the plant had been completed and almost \$2 billion (in dollars of the time) had been spent on its construction. Fortunately for the owners of the plant, it was able to be salvaged and converted to a coal fired generating station, however, the financial losses due to project mismanagement were enormous, indicating the significance of adequate quality assurance programs to the success of nuclear power plant construction.<sup>13,14</sup>

The project management experience of the utility executives, in many cases, fell short of what was required for successful, on-time construction. Frequently the utility executives had not formed an appreciation for the difficulties of nuclear power plant construction, and thus they lacked the understanding of the strategy required to keep the project proceeding as planned. Of course, many of the variables at hand were not in direct control of the executives, however, not having prior experience in nuclear power plant construction, they were not adept in dealing with problematic situations.<sup>2,4,11</sup>

One notable exception in a sea of inadequately mismanaged nuclear power plant construction projects was the St. Lucie-2 project run by Florida Power & Light. FP&L had

developed both construction and plant operation experience by the time it had commenced work on St. Lucie-2. The management involved in this project maintained tight control over activities and also held close political ties with regulators, which strongly helped them in dealing with the regulatory process. FP&L also had a stable labor force to rely on, in addition to no shortage of cash flow. The project management scheme heavily relied on integration of construction and operation teams. The result was that the project was constructed and licensed on schedule. The success of this project served as a huge point of contradiction to the many members of the nuclear industry who had blamed unsuccessful project outcomes on the actions of the NRC.<sup>15</sup>

#### **3.4.4 Regulatory Influences**

State and federal regulatory agencies both contributed to the growth of project lead-time. At the state level, regulators responsible for setting electricity rates began to question the viability of nuclear power projects and were hesitant to cooperate with utilities' demands for rate relief during construction. Previously, when state regulators had been more cooperative with utilities requests, construction work in progress, or CWIP, was readily granted. CWIP allowed utilities to collect project funds through the ratepayers during construction, thus a portion of the rate is specifically for construction costs. This is naturally a very attractive policy for utilities because they are able to keep their interest on debt to a minimum and hence avoid some of the time related costs of the project; however, with the negative economic effects of the oil crisis in play, state regulators became reluctant to increase electric rates. Utilities considered this very unfair, as they considered the regulators to be under-pricing electricity by not including the cost of production capacity expansion. Furthermore, opponents of nuclear power found attacking rate increases to be an effective way to slow down the construction of the plants. Therefore, utilities

had not only to contend with the changing attitudes of the state regulators themselves, but also those of the surrounding electorate.<sup>16</sup>

At the federal level, actions by the NRC contributed to great increases in lead-time due to the great deal of backfitting requirements. During the 1970's NRC standards had increased by orders of magnitude and it became very difficult for utilities to catch up with the new regulations. This process was very costly for utilities, in addition to making it very difficult to set a solid course of action. Essentially, NRC regulation proved to be a moving target for many projects.<sup>9,10,11</sup>

Opportunities for public intervention during the construction and operating license approval stages were ample, and this heavily contributed to further increases in lead-time. While it had been difficult for utilities to foresee the level of public intervention at the construction license approval stage, it would be even more difficult for utilities to predict the political environment several years in the future when they would be seeking an operating license. Delays at the operating license stage would prove to be very costly as the plant had already been constructed and interest on all of the incurred debt would be compounding. Moreover, the plant would have been ready to operate and start collecting revenue, pending regulatory approval. Therefore, the utilities could do nothing more to guarantee success; they simply had to succumb to the political tides.<sup>11,12,17,18</sup>

### **3.4.5 Technology Influences**

The fast scale up in size of the nuclear power plants being constructed also contributed to growth in project lead-time. As discussed previously, the feedback between the growing design complexity for the larger plants and the increased accompanying regulation complexity, led to the requirement for backfitting, causing large project delays. Large nuclear power plant projects

had been pursued initially based on the expectation of economies of scale. With these expectations fading due to the high cost of the increased complexity of these large plants, economic justification for nuclear power became diminished. Furthermore, once these large plants began operating, they often proved to not perform as well as smaller plants. Although the lack of realization of economies of scale and lower plant performance of the larger plants did not directly contribute to increased lead-time for plant construction, they were important metrics of the success of the industry and would be used in the future by other utilities in order to make decisions concerning the pursuit of nuclear power construction projects.<sup>2,7,11</sup>

A lack of design standardization among nuclear power plants using the same reactor technology also contributed to delays in lead-time. Typically only 50% of the design work had been completed by the time that the construction of the plant was started. This was problematic because without fully understanding the final design, the complete requirements for successful construction remained unknown. Once construction had started, the utility naturally would have to begin paying for the cost of the project. Therefore, any delays that came as a result of not having completed the design would be costly to the utility.<sup>19</sup>

A great amount of the design work for most projects still remained to be completed at the start of construction because the plant designs were very tailored to each individual site. No major push for design standardization emerged from either the NRC or the utilities involved in nuclear power plant construction during this time period. The utilities blamed the NRC for not making this more of a priority, while the NRC blamed the utilities and the nuclear industry for not taking responsibility for their own interests in standardization. In many ways the job of the NRC would have been much easier had design standardization been present, however, it was not their responsibility to tell the industry how to construct nuclear power plants. An intrusion of the

NRC into the marketplace forcing design standardization would have been a clear overstepping of its regulatory responsibilities. The industry, however, did not necessarily see that standardization was customer driver and wanted the NRC to be a policy leader on this issue. Considering the large number of nuclear power plant construction projects being pursued at the time, it is easy to understand why the utilities were distracted from realizing how to improve their future nuclear power plant construction projects.<sup>19, 20</sup>

### ***3.5 Trends During the Era of Peak U.S. Nuclear Power Plant Construction***

Environmental factors influencing nuclear power development from outside the industry strongly shaped the attractiveness of the technology during the early 1970's. Implementation of regional power pools and increasing environmental concerns for air quality made nuclear power a very attractive option for utilities. With the onset of the oil crisis, nuclear power also provided an additional element of fuel security. These features of the technology in conjunction with the stable economic climate of the late 1960's, and very early 1970's, provided the impetus for large interest in the construction of nuclear power plants. In this sense, support for the expansion of nuclear power came in large part in reaction to the outside economic environment. The long-standing history of stability in utility companies, combined with its regulated economic structure provided the political and economic backing required for the initiation of these large projects; however, it did not necessarily guarantee success of the projects in the long term.

The oil crisis of 1973 spurred a series of negative reactions towards nuclear power from the utility industry, demonstrating the technology's susceptibility to the outside environment. With increasing inflation and lower than anticipated electric load growth, many nuclear power plant projects were cancelled, or delayed indefinitely, in response to this economic environment.

Utilities simply did not have the capability to plan for anything but the short term when it came to considering projects as large as nuclear power plants.

The NRC emerged as a huge source of instability as it began constantly changing its licensing requirements. Growing public concern for the safety of nuclear power production incited interest in slowing down the progress of many construction projects, further contributing to the overall unattractiveness of the pursuit of nuclear power.

The hostile U.S. political climate surrounding the ongoing Vietnam War further encouraged instability in the political environment with which utilities construction nuclear power plants had to contend. The anti-establishment mentality that arose in response to the U.S. public dissatisfaction with the war was not favorable for the large nuclear power plant projects, which were considered by many to be a symbol of the establishment. This mentality may have played a role in the increased opposition to nuclear power during the 1970's. Although this was not the primary contributor to the unsuccessful nature of many of the projects, the politically unstable environment certainly did nothing to encourage the success of nuclear power plant construction projects.

Many of the internal difficulties that faced the nuclear industry while it pursued the construction of a large number of plants resulted from the general inexperience of the industry. This stemmed from the introduction of commercial nuclear technology by a "technology push" movement, which was largely backed by government support. Because the government had been so involved in the successful development of nuclear power reactors in the early days of the technology, it meant that utility interest in the technology did not stem from its inherent economic attraction, but rather more from a national interest in the use of peaceful nuclear technology. The technology essentially had been fed to utilities without providing for them a

path to achieve very successful commercialization. This conflict allowed for nuclear power to be susceptible, like other technologies competing in an open market, to its political and economic environment. Although there had been strong arguments for its pursuit initially, when political and economic instabilities began to emerge, the plans for the construction of many new nuclear power plants were simply put on hold, or cancelled altogether.<sup>2</sup>

## **4 Nuclear Power Plant Construction After the Three Mile Island Accident**

### ***4.1 Three Mile Island Nuclear Accident***

On March 28, 1979, the United States' commercial nuclear power industry suffered from the worst accident in its history. A combination of bad maintenance practices and operator error led to a partial fuel meltdown at the Three Mile Island II reactor in Pennsylvania. Fortunately, the melted fuel was retained within the reactor vessel, preventing any large releases of fission products into the surrounding environment. The public, however, was greatly scared by the incident and it therefore provided great ammunition to the U.S. anti-nuclear movement. The accident naturally caused great disruption within the industry, but in the long term allowed for the development of safer practices.<sup>21</sup>

### ***4.2 Effects of TMI Accident on Nuclear Industry***

Immediately after the TMI accident occurred, the NRC stopped reviewing applications for new plant construction licenses. The accident had a huge negative effect on the public's perception of the safety of nuclear power. The TMI accident was an extremely embarrassing affair for the NRC. The safety standards set by the NRC had often been the source of criticism in the past. Therefore, the NRC had to react to this accident in a strong manner in order to regain its trust with the industry and public and they proceeded to carefully reexamine their prior safety standards. Therefore, many construction projects suffered new delays as a result of the NRC's detailed review of its regulation practices.<sup>12,18,17, 22</sup>

One area, which came under major scrutiny during this time period, was emergency planning rules. The disorganized response of the Pennsylvania government to the TMI accident brought to light the inadequacies of the rules in place. Requirements for emergency planning

would serve as huge roadblocks for some construction projects, as the review of these requirements provided an opportunity for projects to be attacked by the increasing number of nuclear power opponents that surfaced in the wake of the TMI accident. Most notably was the Shoreham project on Long Island. A political battle ensued over the emergency plans, as a conflict arose between federal and local responsibilities. Since the emergency planning rule outlined the requirements of the local officials in responding to a nuclear accident, its effectiveness relied upon the ability of the local officials to respond in accordance with the plan. In the case of the Shoreham nuclear power plant, the local officials would not agree to cooperate due to their disagreement with the location of the plant, making it impossible for the plant to be licensed for full power operation. The end result was that the completed power plant never went into service. Clearly the utility in charge of this project could never have foreseen this progression of events when it made its initial plans for the project. This project serves as a prime example of a casualty of changing regulation and political environment.<sup>13,14,23</sup>

Ultimately, the influence of many of the factors leading to cancellations of projects in the 1970's increased after the TMI accident. Most importantly, the TMI accident demonstrated to the utilities the instability inherently present within the industry. It became very difficult for utilities to choose to continue pursuing nuclear power construction projects knowing that the success of their project could be influenced so heavily by very outside events. This led many to not see nuclear power as an economic choice for generation, and a large number of project cancellations ensued. The trend of project orders and cancellations is depicted in Figure 4.1.

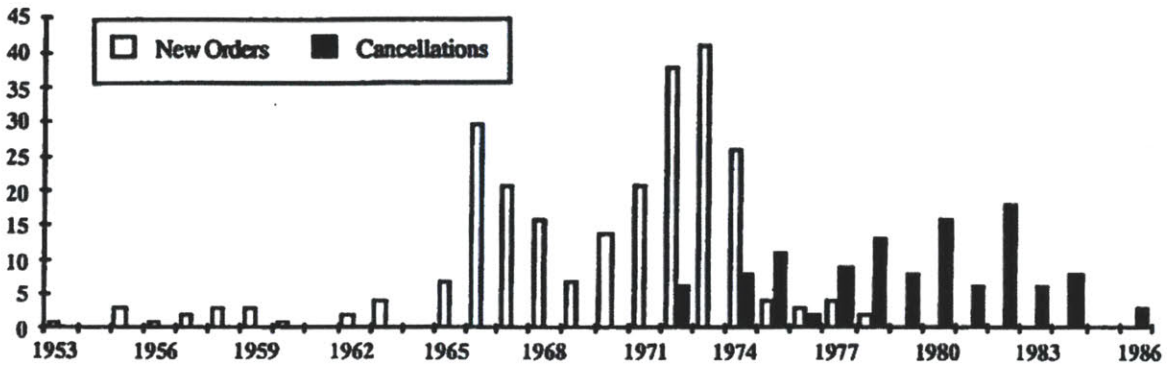


Figure 4.1 U.S. Nuclear Power Plant Orders and Cancellations<sup>24</sup>

### 4.3 Regulatory Response

After having to manage the regulatory backload that ensued following the TMI accident, the NRC realized that some reform in regulatory requirements would be justified in order to allow for a more predictable regulatory review process. Throughout the history of nuclear power plant regulation, opportunities for intervenor access to the regulatory process had often led to lengthy battles between parties of opposing opinions. Although the NRC wanted to retain opportunities for public input in the licensing process, it realized that the level of access that was provided by current rules might be redundant, disrupting the productivity of the project. Therefore, some requirements were altered. Previously, the NRC had required that when making the decision to grant an operating license, a justification for the use of nuclear power, as opposed to other energy sources, had to be given. Also it had to show that electricity demand was sufficient to justify the operation of the plant. Fulfillment of these requirements at the operating licensing stage was not sensible given that the plant had already been constructed. Furthermore,

it presented an additional window of opportunity for interveners to delay the operation, which was costly to utilities.<sup>25, 26</sup>

#### ***4.4 Industry Response***

After having dealt with the regulatory delays following the TMI accident, the utility industry began to realize the benefits that could be achieved from plant design standardization. The industry felt that it had been the fault of the NRC for not strongly encouraging this policy on the industry, however, in reality, the piecemeal nature of the nuclear power plant design and construction industry was just as much to blame for the lack of plant standardization. Also stemming from the costly period of regulatory delay was the utilities' call for risk-informed and cost-informed, backfitting. In determining what degree of backfitting was appropriate, the NRC did not have to demonstrate to the utilities the level of increased safety resulting from its mandatory design changes. Therefore, the utilities believed that risk and cost-informed practices should be implemented in order for backfitting requirements to be sensible in terms of both safety and economics.<sup>14,23</sup>

The TMI accident also revealed to the nuclear industry the need for better communication among nuclear power plant operators. This was due to the fact that the same relief valve that had stuck open at TMI, had also mal-performed at the Davis-Besse nuclear power plant 18 months prior to the accident at TMI. This component failure did not have the same catastrophic effect on the plant at Davis-Besse since the failure was quickly realized and corrected for by the operators. Had the operators at TMI known about this failure, however, the serious accident could have been averted. In order to increase communication among plants the Institute of Nuclear Power Operations (INPO) was born. Its birth signaled the realization of the industry that it was intrinsically tied to each other in a unique way, in that nuclear power plant accidents have the

potential for serious consequences in terms of safety, but also industry public perception. Utilities began to realize that working together to assure a higher level of safety and performance would benefit everyone, as nuclear power plants were not in a position to compete with each other in the marketplace once they had been constructed.<sup>21</sup>

#### ***4.5 Stability Leads to a Bleak Future – Mid 1980's***

Finally by the end of 1984, normalcy returned to the NRC, with the NRC granting more licenses in a single year since 1978, a year before the TMI accident. Also, stability in the financial markets began to return, as the market's overreaction to the TMI accident began to subside. The high inflation also began to subside. These certainly were positive signals to the industry, as many projects that had been in the queue were still being pursued; however, the recent troubling experiences within the industry indicated the likelihood of a very uncertain future.<sup>14</sup>

A major source of instability for utilities pursuing the construction of nuclear power plants was the public utility commissions in charge of regulating the rates that utilities can charge to consumers. These highly political bodies were subject to consistently changing leadership, a feature common to most U.S. governmental bodies. With the commissioners facing re-election or re-appointment frequently, the need to please constituents, who are the electricity consumers, dominated their decision-making. Therefore, their actions reflected only short-term needs and inhibited them from aiding the utilities in their long term planning efforts. This clearly lies in conflict with the lengthy duration of nuclear power plant construction projects. The attitude towards long-term planning was so negative that utilities were penalized for carrying excess power generation capacity. Clearly, these aspects made it very difficult for utilities to carry out long-term projects.<sup>14,23,27</sup>

Public utility commissions also became avenues for project contenders to voice their opinions against the project. Because of the commission's political nature, this strategy was highly effective for project opponents, as this provided a means for them to attack the financial resources available to utilities for the completion of construction. Since utilities often faced cost increases, they had to frequently request rate increases in order to cover the project costs. When the utility was not granted increased rates, they often chose to abandon the project since they would not have the financial means to continue pursuing it. Therefore, public utility commissions were yet another political front that the utilities had to face in order to assure project completion.<sup>14,16,27</sup>

During this time period, questions began to arise concerning the adequacy of the organizations and their leaders in pursuing nuclear power plant construction projects. The wide variation in total cost among projects demonstrated the influence that the effectiveness of project management had on the outcome of the project. It is not surprising that such a variety of results were seen. Utility executives responsible for the nuclear power plant construction projects were generally very inexperienced in managing such large projects and, as a result, proceeded often with much greater caution than in fact necessary to get the job done. Further complicating the issue was the reality that senior management frequently remained too uninvolved with managing the project, leaving important decision-making to those more closely tied to the construction itself. This was problematic because these individuals were typically less informed of the larger context of the entire project management. Also a burden to project success was the frequently present tension between utilities and the NRC. Often utilities were quick to blame the NRC for slow project progress. Certainly changing regulation in response to the TMI accident played a large role in slowing down construction project, but utilities themselves were also implicit in

creating delays surrounding regulation. Not having had experience in constructing nuclear power plants, often utilities submitted construction license applications to the NRC that were very incomplete. Instead of the utility taking responsibility to ensure that design work had been sufficiently reviewed, the burden fell on the NRC to be the critical design reviewer. Therefore, not only did the NRC bear the burden of increased workload, the utilities' lack of attention to detail opened the door for a great amount of dialogue between the NRC and plant constructor regarding design specifics. As a result, construction lead-time would be increased further.<sup>7,13,14,15,23</sup>

#### ***4.6 Late 1980's***

By the late 1980's most of the previously ordered nuclear power plant construction projects had been completed and no new nuclear power plant projects were being pursued. This period of reduced workload for the NRC allowed for both a reflection on its practices and changes to be made in areas in order to improve the efficiency of the licensing process. One change implemented pertained to the level of NRC inspection in operating plants. The NRC began to reward plants for good performance by aligning the degree of inspection required to the performance of the plant. This practice allowed the NRC to utilize their inspection capabilities more effectively and also provided a strong incentive for plant operators to improve overall plant performance.<sup>28,25,29</sup>

The licensing process itself came under scrutiny, as the previous two decades had shown the pitfalls of the current practice of issuing separate construction and operating licenses. This disjointed process had provided ample opportunity for disruption during the course of the project. In order to improve the efficiency of the regulatory process, the NRC adopted a new licensing procedure that would aim to streamline the process. Instead of issuing separate

construction and operating licenses, the NRC instead issued a combined construction and operating license. This change, in addition to the removal of other licensing appeal panels, allowed for the reduction of redundant reviews, which had been a source of great delay in the past. The emergency planning rule was also revised. The change ensured that a lack of cooperation of state and local officials in emergency planning procedures would not prohibit a constructed plant from operating. The NRC also took its first step to encourage standardization of plant design by implementing a design certification process. This process allowed plant designs to be approved by the NRC one time, after which the extent of a project's approval for construction and operation would be dependent upon those areas of the design that are site specific. Although a large fraction of a nuclear power plant's design is site specific, this change in review policy demonstrated the NRC's willingness to increase the efficiency of its operations, and hence the ease with which a nuclear power plant could be constructed. Similarly for siting, the issuance of early site permits would allow for utilities to pre-approve sites for nuclear power plant construction with the site approval lasting for a fixed period of years. This allowed for siting to be a separate issue from plant construction itself. Unfortunately, this process would remain untested for more than a decade as interest in constructing new nuclear power plants fell to a minimum during the 1990's. Therefore, the NRC would have to wait a long time in order to understand if its revised methods would be effective in reality.<sup>30</sup>

#### ***4.7 Impact of Chernobyl Nuclear Accident***

The Chernobyl nuclear accident, which took place in Ukraine in April of 1986, was the most significant nuclear accident that occurred in the history of commercial nuclear power up until recently. Due to operator error in the manner in which an emergency system was tested, a large power spike occurred in the reactor, which led to a consequent steam and hydrogen

explosions in the core. The graphite used for neutron moderation in the reactor design easily caught on fire complicating the situation. Because there was no containment vessel isolating the reactor core from the environment, the radioactive material from the reactor core could easily travel into the surrounding environment resulting in widespread contamination.<sup>31</sup>

The Chernobyl accident was close enough to many European countries that the resulting fallout from the accident scared citizens, who consequently demanded action to be taken against the use of nuclear power by their government. Even though the reactor designs implemented in Europe were inherently safer than that employed by the Soviets in Ukraine, the technological arguments were not convincing enough, and many countries cease their nuclear power operations or scaled back their future plans regarding nuclear power.<sup>32</sup>

The impact of the Chernobyl accident on the U.S. nuclear power industry was far less severe than that for the countries in Europe with commercial nuclear power programs. The U.S. nuclear industry worked hard to communicate the inherent design differences in the Chernobyl reactor that allowed for the accident to be so destructive. Of course, anti-nuclear activists used the accident as ammunition in their attack against the construction of new nuclear power plants. This activism caused increased delay in the operation of the Seabrook nuclear power plant in New Hampshire due to questions raised about the adequacy of the emergency planning procedures. The overall U.S. public support for nuclear power, however, did not suffer greatly, taking only a temporary slight dip as shown in Figure 5.2. The greater physical distance that the U.S. experiences compared to countries in Europe helped limit the negative public response towards nuclear power.<sup>33,34</sup>

The NRC responded to this accident by conducting its own review of the potential implications that the accident could have for U.S. nuclear power reactors. After a year of study,

the NRC came forth stating that no new changes were required due to the more sophisticated safety requirements in place for U.S. reactor designs.<sup>35</sup>

## 5 Age of Operation

### 5.1 *Industry Focus Change*

With interest in constructing new nuclear power plants severely diminished, a new focus on plant operation began to emerge beginning in the early 1990's. Once in operation, nuclear power plants are a source of stability in the generation mix, as nuclear fuel prices are relatively constant compared to fossil fuel prices. Because constructing new nuclear power plants had been determined to be too risky, utilities now focused on ways that they could improve plant output and performance. This allowed them increased economic gains from their investment in the capital of the plant. The primary way to achieve this goal is to increase the electrical output of the plant by adding additional power capacity to the core. This practice is known as a power uprate. Power uprates were recognized to be feasible, as design margins were realized to be large enough to accommodate these changes. The NRC is responsible for validating these changes, but compared to constructing a new plant, this regulatory process was relatively simple.<sup>36</sup>

Another important focus for the industry was the reduction of plant outage length. Reducing the time that the plant is not producing electricity directly increases the plant's capacity factor, which yields increased revenue for the utility. Having already had a few decades of operating and outage experience, utilities were able to build upon their experience in finding ways to reduce operating costs and outage lengths, increasing plant performance. The dramatic increasing trend in plant capacity factor is shown in Figure 5.1.<sup>36</sup>

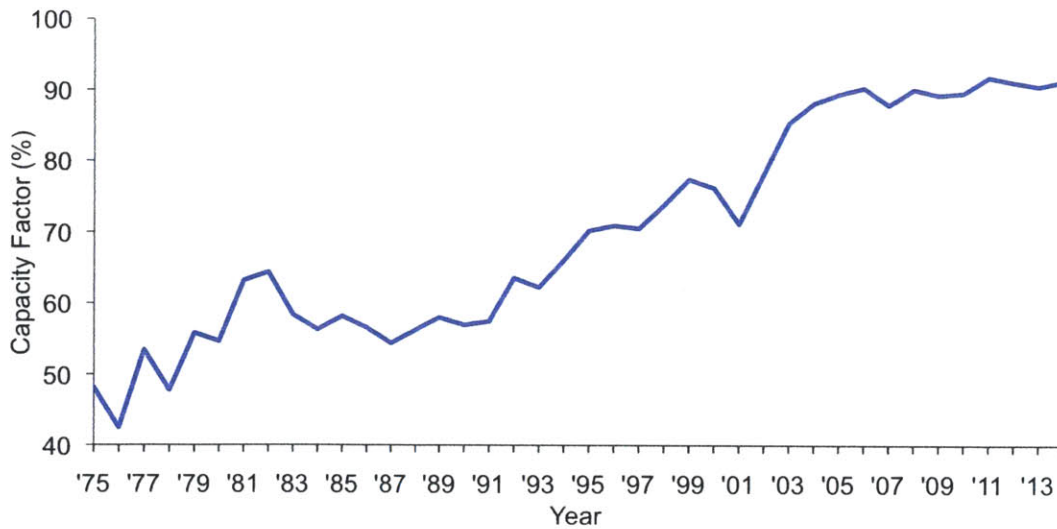


Figure 5.1 U.S. Nuclear Power Plant Capacity Factors<sup>37</sup>

With so much emphasis placed on overall plant performance during this time, the nuclear industry performed very well in terms of safety too, building up a solid safety record. This period of demonstrated safe operation likely played a large role in the generally increasing trend in public support for nuclear power through the 1990's and 2000's as shown in Figure 5.2.

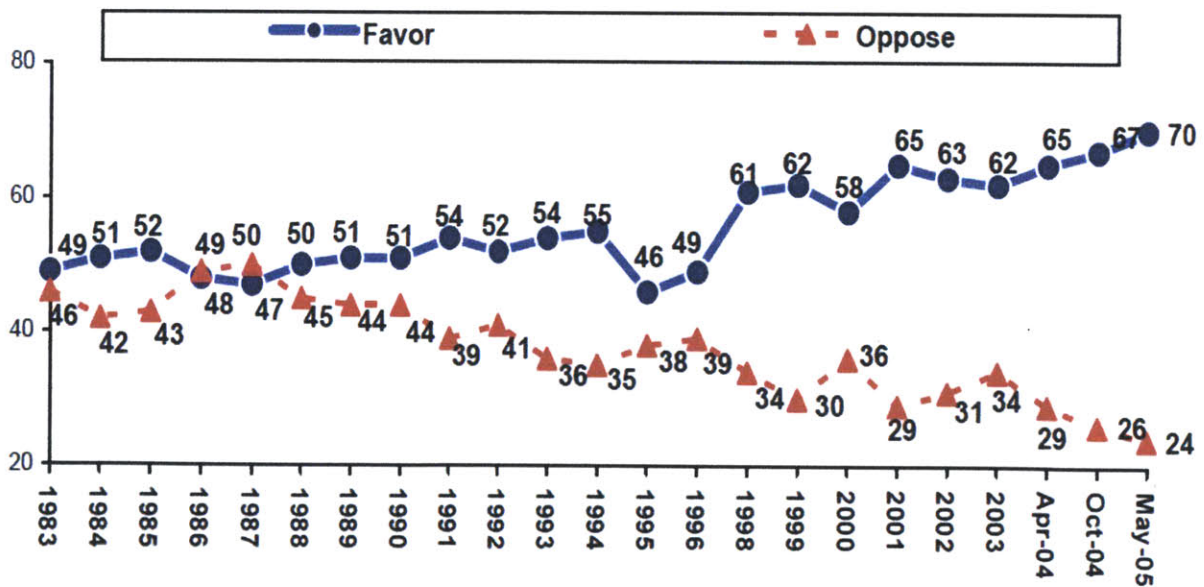


Figure 5.2 U.S. Public Approval of Nuclear Power<sup>38</sup>

## ***5.2 Utility Industry Deregulation***

Inherent changes in the structure of the entire utility industry naturally brought significant organizational changes to the nuclear electric generation industry as well. Electricity deregulation introduced the opportunity for electricity to be treated as a free market commodity. Traditionally, utilities were regulated organizations, meaning that regulators would determine the economic bounds of utilities' operations by delineating service territory and the rates that could be charged to customers. This approach essentially kept the utility industry from operating in a competitive environment. With the introduction of deregulation, the availability of more economically competitive electricity increased, as the choice of electricity provider was available at either the distributor or retail level.<sup>39</sup>

Electricity economic deregulation in the U.S. has had a long evolution. The greatest change in electricity regulation policy came with the Energy Policy Act of 1992. The most significant effect of this act was that it allowed for independent power producers to sell their energy to another organization other than their local utility. It also required that utilities allow transmission of third party electricity through their transmission lines. This policy had the effect of providing for a separation between the electricity generator and distributor. Following the Energy Policy Act of 1992 came the Federal Electricity Regulatory Commission (FERC) Order 888, which most importantly, required utilities to separate their generation, distribution, transmission and power control entities. The FERC, however, did not have the power to enforce this order. The decision to proceed in accordance with this order was left up to each individual state. The states that chose to deregulate electricity pricing were typically those with high electricity prices. The ways in which states have restructured their electric utilities in following

deregulation policy varies greatly, providing for very inconsistent structures across the United States.<sup>39</sup>

As a result of deregulation, there was a large reduction in the number of organizations owning and operating nuclear power plants. This came from the realization that organizations focusing mainly on nuclear power plants would see great economic benefit by utilizing their pooled resources, in comparison to an individually owned and operated nuclear power plant. This consolidation naturally further increased the economic efficiency of nuclear power plant operation. Since electricity was now being sold into a competitive market, these improvements in plant capacity factors yielded increased revenues for utilities.<sup>39</sup>

### ***5.3 Competing Technologies***

With the help of the changes made to the organization of the nuclear power industry resulting from deregulation, it became very clear that nuclear power could be a very economical, and lucrative, way to produce power. The fossil fuel technologies that it continued to compete with for new electric generation capacity, however, still presented tough competition. Natural gas and coal prices had remained low since the 1980's and these resources appeared to remain abundantly available for the foreseeable future. Without any new nuclear power plant construction projects having been initiated since before the TMI accident, the uncertainties surrounding power plant lead-time were far less for fossil fuel plants, making them additionally attractive.<sup>36</sup>

All of these factors pointed to a bleak outlook for the creation of new nuclear generation capacity; however, major environmental concerns regarding climate change due to the CO<sub>2</sub> greenhouse effect began to strongly emerge around the turn of this century. Attention to this environmental issue was a point of great political uncertainty, as the requirement for national

emissions standards for noxious gases, in addition to the creation of a standard for CO<sub>2</sub>, would remain largely in question. This source of political uncertainty made it increasingly difficult for utilities to weigh their options for increasing generation capacity. On one hand, they could continue pursuing coal and natural gas fueled electric generation, however, the economic and technological uncertainties surrounding CO<sub>2</sub> control introduced the potential for unprecedented economic strains for fossil technology. Although nuclear power generation produced few CO<sub>2</sub> emissions, the economics of constructing new nuclear power plants had only a troubling past. Ultimately utilities chose to proceed with expanding their natural gas fired generation as it produced less CO<sub>2</sub> per unit of fuel utilized, compared to coal, and the economics for this kind of generation had been favorable for quite some time.<sup>36, 40</sup>

#### ***5.4 Government Policy Support for Nuclear***

With increased attention being given to the environmental impacts of CO<sub>2</sub> production, the U.S. government looked to develop a strategy to reduce its future carbon emissions. Nuclear power remained an attractive solution to this problem; however, because construction of new nuclear power plants had been nonexistent for many years, the electric generation industry was wary of taking on such a risky venture. In order to promote interest in the construction of new nuclear power plants, the Department of Energy (DOE) commenced the Nuclear Power 2010 Program in 2002. This program covered half of the licensing costs associated with the construction of a new plant. The hope of the DOE was that the demonstration of a successful licensing process based upon the new streamlined licensing procedure would encourage other organizations to consider pursuing the construction of new nuclear power plants. Although the program was successful in increasing interest in new nuclear power plants, because the

government assistance was limited to the licensing process, it would not prove to be an impetus large enough to encourage wide spread interest.<sup>36,41</sup>

The Energy Policy Act of 2005 provided the additional support required to encourage a more serious level of commitment from utilities. This act incorporated a nuclear production tax credit, regulatory risk insurance and loan guarantees. The production tax credit provided for a credit of 1.8 cents/kwh for the first 6000 MWe of nuclear capacity installed that had commenced construction by the start of 2014. The regulatory risk insurance provided for compensation to the utilities responsible for the first few construction projects in order to cover debt costs and power replacement costs for any delays caused by licensing. Loan guarantees offered a government-backed guarantee for up to 80% of the project debt to the lender. Clearly these measures were meant to strongly incentivize utilities to be early pursuers of new nuclear power plant construction. The high capital cost of a new nuclear power plant placed the majority of the focus of this act on the loan guarantee program, as it provided the greatest potential for project risk reduction.<sup>36,41</sup>

### ***5.5 Renewed Interest in Nuclear Power Plant Construction***

The U.S. government's strong policy support for new nuclear power generation in the Energy Policy Act of 2005, combined with soaring natural gas prices provided the impetus for utility interest in the construction of new nuclear power plants. Because utilities had relied on natural gas for nearly all of their electric capacity expansion since the early 1990's, the resultant large increase in demand led to a huge increase in the price of natural gas, as suppliers struggled to keep up with demand. With the future of the price of natural gas in question, utilities could now seriously consider building new nuclear power plants by taking advantage of the new government support programs.<sup>42</sup>

Utilities quickly responded to this situation by assembling COL applications, and in some cases forming consortiums of utilities to do so. By 2009, 26 COL applications had been submitted to the NRC for review. These were the first applications received by the NRC for nuclear power plant construction since before the TMI accident. Clearly these actions signaled a bold statement of support for the expansion of nuclear power by the utility industry.<sup>43</sup>

### ***5.6 Nuclear Power Growth Environment Changes***

While the state of the electric generation sector had been moving in the direction of increased interest in the expansion of nuclear power generation capacity for the first decade of the new millennium, severe disruptions to the economic environment resulted in an attitude change by many utilities regarding nuclear power. This occurred much in the same way that economic changes had affected utilities' interest in nuclear power in the mid to late 1970's. The first blow to plans for the expansion of nuclear power came from the economic recession beginning in 2008. This recession affected the promise of nuclear generation capacity expansion primarily in two ways. First, similar to the situation following the oil crisis of 1973, the load growth demand projections fell sharply. This change in the outlook of capacity requirements resulted in utilities scaling back their capacity expansion projects, directly affecting plans for new nuclear generation capacity. The recession also greatly affected the market for raising the needed capital. With many of the large financial institutions in the U.S. facing failure, or relying on bailouts from the U.S. government to stay afloat, the premium at which utilities could finance nuclear power reactors that had expected costs of \$6 to \$7 billion each, was very high. The combination of the bad economic climate and the perceived high risk of new nuclear power plant construction projects led to an absence of affordable capital for utilities interested in constructing new plants. If the loan guarantee portion of the Energy Policy Act of 2005 had served as an

impetus before for interest in new nuclear power construction, it now appeared to be a requirement for any access to project capital.<sup>44</sup>

To complicate matters, the arrival of shale natural gas to the marketplace caused natural gas prices to fall dramatically. Shale gas is natural gas that has been trapped in shale rock. Previously, it had not been understood how to release it from the rock, however, with the introduction of a new hydraulic fracturing technology, the gas could be made to flow from the rock. This advancement in technology resulted in a huge increase in projected natural gas resources, driving the price down dramatically. Because the focus of the utility industry had been on the expansion of natural gas fired generation for nearly two decades, this sharp improvement in the economics of natural gas delivered a decisive blow to the prospects for nuclear power to compete with natural gas economically.<sup>45</sup>

As a result of these circumstances, several utilities decided to withdraw their license applications from the NRC, including the largest nuclear operator, Exelon, which operates its plants as merchant power plants, in unregulated environments.<sup>43</sup>

### ***5.7 Loan Guarantees***

The first project to receive federal loan guarantees to support its efforts was the Vogtle Units 3 & 4 in Georgia, with majority ownership held by Southern Company. The Vogtle project received a loan guarantee for 80% of its projected costs, at \$8.3 billion. The second project to receive an offer of a loan guarantee was the Calvert Cliffs-3 project, pursued by a joint venture, UniStar, between Constellation Energy and Electricité de France. The credit subsidy cost for this loan guarantee, however, would prove to be too high for UniStar to accept this offer. The credit subsidy cost was set at 11.6% for the UniStar project, constituting \$880 million for a total loan guarantee of \$7.6 billion. Although the figure for the credit subsidy cost for the Vogtle plants

has not been publically released, it has been speculated to be around 1% of the total loan guarantee, a remarkable difference compared to the offer given to the Calvert Cliffs-3 project.<sup>44,46</sup>

This large difference can be explained by the relative risk associated with the projects based on the structure of their operation. The Calvert Cliffs-3 project would sell electricity into the grid as a merchant plant. Therefore, UniStar has no guaranteed buyer of the power that would be produced at Calvert Cliffs, because that electricity would have to compete with other electricity sources at the time that it is being produced. The marketability of the power is dependent upon the circumstances of the market at the time that it is being sold. Therefore its marketability cannot be confirmed while the plant is being constructed. For instance, if natural gas prices were to remain very low, it would be unlikely that the power produced from the nuclear plant would be competitive with that from a natural gas plant, due to the nuclear plant's high capital cost. On the other hand, the Vogtle plant will operate in a regulated structure, within a vertically integrated utility. The costs of the project will therefore be passed on to ratepayers, as long as the state regulators in charge of setting these rates approve them. This structure protects the company by guaranteeing it a buyer of electricity from the plant when it comes online. The success of the project is contingent upon the relationship between the regulator and the utility constructing the plant, as the regulator has to approve electricity rate increases when they are required. Therefore, the regulator has the power to interfere with the success of the project by not approving rate increases if it deems the construction project unsuccessful. This relationship between the utility and regulator therefore holds the utility accountable for irresponsible project management, should that occur.<sup>44,46</sup>

## **6 Potential Impacts of the Recent Fukushima Daiichi Nuclear Accident**

### ***6.1 Accident***

On March 11, 2011 a 9.0 magnitude earthquake occurred off the east coast of northern Japan. The tsunami triggered by the earthquake produced waves of up to 10 meters. Tokyo Electric Power Company's (TEPCO) Fukushima Daiichi generation site consisting of six nuclear power plants lies 40 miles away from the earthquake's epicenter. Although the three of the six units which were operating shut down without problem when the earthquake occurred, the resulting tsunami proved to be highly devastating to the low lying site, which is directly on the coast. The tsunami flooded the emergency diesels providing backup power to the site, leaving only limited battery power lasting only a few hours. Once the batteries were drained, the site remained without power (in station blackout) for over a week. This dire situation presented tremendous challenges to the plant operators as they struggled to meet the cooling requirements of the decay heat in both the reactor cores and spent fuel pools. Complicating the efforts were a series of hydrogen explosions in the reactor buildings, which posed a serious threat to the integrity of the spent fuel pools. Eventually, connections were made to provide for seawater to be pumped into the reactor core, however, extensive fuel damage in multiple reactor cores had already occurred, as evidenced by the release of fission product isotopes into the surrounding environment.<sup>47</sup>

### ***6.2 Near Term Impacts***

The accident at Fukushima Daiichi is of great significance not only because of its magnitude, but more importantly because it is the first time in the history of commercial nuclear power where a significant accident has resulted from primarily uncontrollable external events,

and not operator error. Therefore, this accident has tested the limits of the technology in a very new way. As a result of this event, the NRC will investigate the engineering of the operating plants to see if the susceptibilities to damage revealed at Fukushima have relevance to plants in the U.S. Although these reviews will utilize resources at the NRC, it is not likely to be disruptive to the overall regulatory process as during the aftermath of the TMI accident. The combination of a more experienced regulator and a foreign accident should allow this review process to be minimally disruptive.<sup>48</sup>

One area of potential interest for the NRC as it continues to examine new reactor designs for design certification is the level of avoidable design vulnerabilities that will be tolerated. Although pertaining more to plant siting, the Fukushima Daiichi nuclear power plants demonstrated a significant vulnerability to large tsunamis. It is possible that the NRC may examine certain design features, which can manifest themselves as vulnerabilities in external event sequences much in the same way that the siting of the Fukushima Daiichi plants demonstrated vulnerability. One example of this kind of design vulnerability is the large tank of water stored at the top of the containment vessel of the AP1000 design that is used for passive cooling in the event of a loss of coolant accident. This design feature poses a threat, as the potential for containment failure in a large earthquake is increased due to the destabilizing nature of a high center of mass. Although the AP1000 design gains the feature of a passive cooling system, if the tolerance for avoidable design vulnerabilities becomes diminished, the risk of this feature may be considered to outweigh the benefits it provides.<sup>49</sup>

Also in the near term, the nuclear industry will have to carefully manage its response to anti-nuclear sentiment, which has developed in the wake of the Fukushima accident. Fortunately for the U.S. nuclear industry, the media and public response to the accident is much less

pronounced than the response in the aftermath of the TMI accident; however, the manner in which the industry handles its critics will play an important role in the public's confidence in the industry. Because nuclear power has been identified as a potential significant contributor to the reduction in greenhouse gas emissions, it has retained support from the U.S. government and much of the public, too. The challenges that lie ahead for U.S. nuclear power will likely remain predominantly economic and technical.

### ***6.3 Long Term Impacts***

#### **6.3.1 Impacts on Future Economics**

The Fukushima accident revealed many vulnerabilities existing in commercial nuclear power plants. The industry and regulator response to these vulnerabilities could severely impact the economics of nuclear power in the future. One harsh reality that the Fukushima accident has reinforced is the scale of the economic liability associated with a large nuclear accident. The cost of the cleanup of such an accident could likely prove to be many times over the market capital of large U.S. utilities. Although accidents of this scale may be extremely rare, when making a choice between generation technologies, utilities will always tend to minimize their risk. Choosing fossil fuel plants eliminates the possibility of enormous costs that would be associated with severe nuclear power plant accidents.

The political risks associated with severe nuclear accidents have reemerged as a result of the Fukushima accident. Similar to government reactions of prior nuclear accidents, government leaders feel the need to react decisively to these accidents in order demonstrate their control over the situation. Currently in Japan, other nuclear power plants could face forced shutdowns while actions are taken to improve the ability of those plants to tolerate significant external events. Similarly in response to the Chernobyl nuclear accident, some European countries swiftly acted

to shut down nuclear power plants, some even permanently. Clearly the impact of such a government response can be detrimental to the economics of nuclear power. Without the assurance that a licensed nuclear power plant will be able to operate for its entire lifetime, the economic case for nuclear power is severely diminished. Although the consequences of a nuclear accident can be very dramatic, the viability of nuclear power will remain in question as long as it is at the whim of this type of political influence.<sup>50</sup>

Much of the attention surrounding the Fukushima accident has been focused on the siting of the plant. Clearly the close proximity of the site to the ocean allowed for catastrophic consequences from the tsunami. It is likely that the specifications for siting nuclear power plants will change as a result. Certainly more attention will be placed on the vulnerability of plants lying close to the ocean in the tsunami zones. Requirements could be changed such that plants could be sited only on higher elevation ground and further away from bodies of water; however, this would introduce large new costs associated with the construction of the facility. Large amounts of cooling water must be readily available and not being in close proximity to this resource is highly disadvantageous. Difficulties associated with this problem were evident in the construction of the Seabrook plant in New Hampshire. Not being able to use water in the surrounding estuary for once through cooling, due to the environmental impact of raising the temperature of the estuary, long tunnels were dug to bring in seawater for cooling from the nearby coastline. This naturally introduced a significant cost burden to the project. Another disadvantage of building nuclear power plants away from bodies of water is the decreased access available to bring in large components for the construction of the plant. This can result in cost increases for the project as well.

Because the spent fuel pools at the Fukushima plants were the source of much concern throughout the critical times during the accident, spent fuel management strategies used in the U.S could come into question. The Fukushima accident could potentially provide the impetus for the U.S. to solidify national plans for long term spent fuel storage, but at the least, it could spark consideration to change spent fuel management at individual plants. Because there has been no national long-term storage facility for spent fuel in the U.S., utilities have had to reconfigure their spent fuel pools to allow for additional storage capacity. This practice may now be reevaluated and compared with dry cask storage methods, which do not have a dependency on circulating coolant. Unless a national strategy for long term spent fuel management is adopted in the near future, utilities will have to absorb the costs associated with retrofitting their spent fuel storage capacity.

### **6.3.2 Impacts on Future Technology**

The Fukushima accident demonstrated the heavy price that is paid for relying on active systems for core cooling. Had the Fukushima units been reliant on passive cooling systems it is likely that the consequences would not have been so severe. This scenario provides further justification for the increased use of passive cooling systems in the Generation III+ reactor designs that are currently being constructed today. A reliance on passive cooling systems, however, does not come without uncertainty. The structural integrity of the system must remain intact such that the pathways for natural circulation are kept free of disruption. Maintaining this is foreseeable under normal operating conditions, however, serious external events could bring into question the systems' integrity. With this understood, the extreme length of the station blackout at Fukushima brings to light the severity of an accident scenario that is surrounded by an area devastated by natural disaster. Therefore, when considering plant safety, it will be

important to consider the management of long station blackout scenarios. When taking this scenario into greater consideration, passive cooling systems become increasingly attractive; however, a blending of both passive and active systems could prove to be the design strategy of choice in the future. Although passive safety systems can be very attractive in some situations, the industry's reliance on active systems has provided for a bank of operational knowledge that is very valuable to plant operators. Therefore, it could be considered more beneficial to blend methods rather than change the method all together.

Alternative reactor designs (non-LWR) could also be more aggressively investigated due to inherent safety mechanisms that some feature. Due to the technology lock-in that LWR's have had in the industry it is unlikely that these designs will be commercialized in the near future; however, the vulnerabilities of the LWR design that Fukushima has exposed bring strength to arguments to pursue alternative technologies.

## **7 Conclusions**

A principal contributor to the irresolute nature, and often unsuccessful outcomes, of U.S. nuclear power plant construction projects has been the inherent instabilities surrounding the decision-making environments that play a role in the governance of these projects. Nuclear power plant construction projects are particularly susceptible to these instabilities because of the large financial vulnerabilities and the long time scales that characterize them. Instabilities have been demonstrated at both the level of the utilities in charge of construction, as well as the government in charge of setting policy related to nuclear power plant construction.

Commercial nuclear power technology came to fruition in the U.S. due to large government support throughout its development. The tight government control over this endeavor sheltered the technology from the external influences of the generally fickle marketplace. The success realized during the development of the technology provided for great optimism concerning the future prospects of the technology in commercial markets; however, with no attention having been focused on the development of a commercialization strategy, nuclear power was left to compete in the market based on its economic and technical merits.

Although the economic and political environment allowed for the development of significant interest in the construction of many new nuclear power plants in the early years during which nuclear power was competing in the market, the utility executives responsible for the decision making most often acted in accordance with the short term interests of the company. This type of behavior is not uncommon in U.S. industries; however, it was detrimental to nuclear power plant construction projects, which are characterized by a long time scale. Once the window of time had passed during which initial interest was demonstrated in nuclear power plant construction, the following periods of time present for which nuclear power construction projects

seemed to be a sensible pursuit were too small in order for utilities to continue their course of action. The political and economic environments surrounding the nuclear power industry were characterized by frequent change. Unfortunately for nuclear power, at the government level there was no significant action taken to ensure that these environments remained favorable towards the further expansion of nuclear power.

The lack of stabilizing government action was not the only reason for the unsuccessful nature of many nuclear power construction projects. The inability of utility executives to appropriately respond to the demands of the construction project resulted in many project failures or long delays. Unsatisfactory communication with the NRC, quality assurance demands and the quick scale up in the size of nuclear power all contributed in major ways to less than ideal project outcomes for utilities. As utilities began to appreciate the immense complexity of nuclear power plant construction projects, they shied away from pursuing more projects. The long time scale of the projects allowed for the possibility of many costly project disruptions. These high near-term costs made it very difficult for utility executives to appreciate the long-term low operating costs of nuclear power plants, and thus their popularity declined.

Examining the recent revival of interest in nuclear power plant construction, it is evident that nuclear power, once again, is falling victim to the ever-changing U.S. political and economic environment. A causal-loop diagram depicting the main influences to the decision-making, as identified throughout the course of this thesis work, is shown in Figure 7.1. This diagram shows the result that increased system quantities will have on fellow system quantities, the result being either an increase or decrease in the effected quantity. For example as the “Number of Decommissioning Plants” increases, the “Certainty of Load Growth Estimates” increases as well,

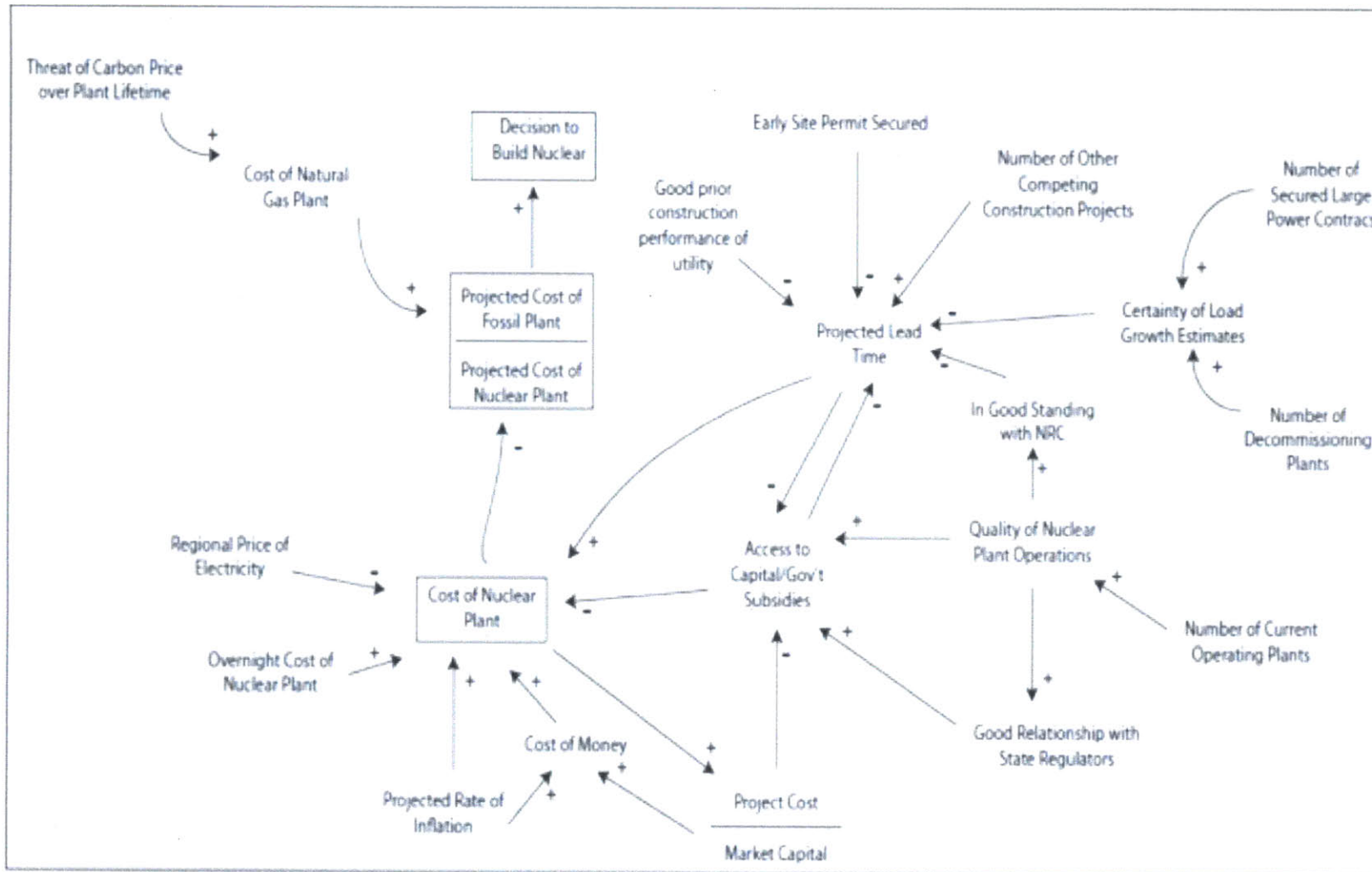


Figure 7.1 Causal-Loop Diagram of Generation Capacity Expansion Decision-Making

indicated by the '+' sign.

The construction of a causal-loop diagram for the decision-making process surrounding the construction of a nuclear power plant is helpful, in that it can reveal those feedback loops that can result in the system becoming unstable. In this diagram, this effect is shown by those feedback loops characterized by an overall positive sign. In the construction of this diagram, two feedback loops stand out prominently as exhibiting unstable behavior. The first is the loop inclusive of the quantities "Cost of Nuclear Plant", "Project Cost/Market Capital", "Access to Capital/Gov't Subsidies" and "Projected Lead-time." Essentially, this loop represents how cost, access to capital and lead-time influence each other. The second loop of significance includes the relationship between "Cost of Nuclear Plant", "Cost of Money" and "Project Cost/Market Capital." This loop shows how the economic climate and plant economics influence the overall economics of the project.

Although these particular loops of interest exhibit an inherently unstable relationship among their factors, these loops are especially susceptible to instability due to their heavy dependence on outside environmental factors, which nothing to do with the construction project itself. For example, the factor of "Projected Lead-time" is depicted as being influenced by five different other factors, with the "Early Site Permit Secured" factor standing alone as a factor explicitly tied to the project of interest. The other factors such as "Certainty of Load Growth Estimates," "Number of Other Competing Construction Projects" and "In Good Standing with NRC" all reflect dependencies on outside environmental factors, leaving little under the control of the organization undertaking the project. Similarly, the other loop of interest concerning project economics shows the heavy reliance of the project on the stability of the economic climate through the factor of "Projected Rate of Inflation." This factor is clearly out of the

control of the organization behind the project, thus demonstrating the susceptibility of nuclear power plant construction projects to environment instabilities. As long the environment in which utilities are making decisions concerning generation capacity expansion is subject to constant change, they will not easily be able to incorporate new nuclear capacity into their generation portfolio.

Nuclear power can succeed in the U.S., but in order to achieve success with new nuclear power plant construction a stable decision-making environment must be created. Internationally this has been accomplished in both France and Japan, where democratic participation surrounding nuclear power plant construction has been limited and economic security has been established through government financial support. The most efficient way to achieve success for nuclear power in the U.S. is through increased government support for the expansion of nuclear power. Although traditionally the U.S. government does not become heavily involved in regulating industry, it has created the stability required for success when a project is of great national strategic need. In the 1970's, a political battle for several years ensued in both the judicial system and in Congress over the legalities of the construction of the Alaska Oil Pipeline. When the oil embargo occurred, however, Congress took quick action to eliminate all barriers to construction of the project and created financial incentives, as now there was an eminent need for increased domestic oil resources. After years of debate, the swift government action allowed for the stability required for the completion of the pipeline.

For new nuclear power plant construction, the primary barrier to entry is the cost of the technology. Too few organizations can take on nuclear power plant construction projects due to the limitations presented by their market capital and electric market structure. In order to reduce the impact of this limitation, the U.S. government can take measures to increase the financial

stability of a project. Because U.S. industrial activities are characterized by limited government involvement, it is unlikely that the U.S. government would create a federal company with the sole purpose of building new nuclear power plants, however, the government could provide increased subsidy to these projects in order to stabilize the project economics. One way of achieving this objective would be to increase the availability of loan guarantees, providing the projects access to additional capital. Although this strategy is being implemented already, it is only on a very small scale and is not widespread enough to meet utility interest in constructing new plants. Loan guarantees are able to provide the government support needed in order for nuclear power plant construction projects to enjoy financial stability, without requiring that the government be involved in the electricity generation business.

Expanding the loan guarantee program, however, will not necessarily provide enough stability for nuclear power to thrive in the United States. A nuclear power plant construction project's heavy reliance on the stability of the regulatory process has played a large role in the demise of many projects and, without question, will remain as a decisive factor in the future success of nuclear power plant construction projects. Although it is important to maintain a strongly independent regulator in order to maintain high safety standards, changes limiting the access of the public to the regulatory review process could allow for more stability in this process. Throughout the history of the NRC, public access to regulation has been slowly eliminated in order to increase the predictability of the process. Although completely eliminating public access may go against the American way of governance, approaching this limit as closely as possible could result in fewer regulatory problems for utilities constructing nuclear power plants.

Although nuclear power in the U.S. has suffered through difficult periods, the operational success of the technology has solidified its position in the electric generation industry. The U.S. response to the recent unfortunate events at Fukushima Daiichi demonstrates this explicitly. Even though a catastrophic accident had occurred, high-ranking government officials have maintained their support for the technology, in addition to the majority of the general public. This continued support demonstrates a large change in the perception of the perceived benefits of nuclear power. In the early days of nuclear power, the alternatives for electricity generation were considered to have fewer negative features than nuclear power. Now, with heavy attention placed on the environmental impacts of CO<sub>2</sub> production, nuclear power is looked upon more favorably. The good safety record of the U.S. nuclear industry has demonstrated that nuclear power can pose little threat to the public.

A supportive public attitude alone will not solely provide for the increased use of nuclear power in the United States. Market stability must be created for the technology in order for it to prosper in the U.S. economy. Given that nuclear power plant technology was born and successfully developed within the realm of the U.S. government, it is not a stretch of the imagination to foresee the U.S. government taking on a larger role in the promotion of expanded use of the technology. Ultimately, it will be a societal decision as to whether large government support for nuclear power will be acceptable. The democratic structure of the U.S. government allows for choices to be made regarding the feasibility of nuclear power plant construction. If concerns over climate change and energy independence grow significantly in the future, it is highly likely that nuclear power will attain the level of attraction that it has experienced in other countries worldwide, as in France and Japan, and more recently China. If the environment evolves to lead the public to accept the government playing a large role in the expansion of

nuclear power generation, it is the responsibility of the government to create the environment necessary to achieve this national energy strategy endeavor.

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