APPENDIX A

CASE STUDIES OF QUALITY AND QUALITY ASSURANCE IN THE DESIGN AND CONSTRUCTION OF NUCLEAR POWER PLANTS

A.1 INTRODUCTION

This appendix describes the results of six case studies of nuclear power plant construction projects in the United States. Three of the projects experienced major quality-related problems in design or construction and three did not. The root causes of the performance of each group are identified. Section A.1 presents introductory material on the study's background, purpose, and technical approach. Section A.2 presents conclusions and findings. Section A.3 describes the case study process and summarizes the major findings from each of the case studies. Results of an independent study of the Zimmer nuclear power plant construction project are included in Section A.3 for comparison purposes. References are provided in Section A.4.

A.1.1 Background

In recent years, there has been a series of well-publicized problems relating to the quality of construction and/or design at several nuclear power plant projects in the United States. It is important to understand what caused these problems and why some nuclear construction projects have been more successful in achieving quality than others. In an August 1982 paper to the Commission (NRC 1982), the NRC staff proposed a long-term review and study of the quality problems in the nuclear industry. A key feature of this long-term review was a series of analyses of representative nuclear construction projects having had varying degrees of success with respect to project quality to ascertain the underlying causal factors, or root causes of quality success or failure in nuclear construction projects. These analyses, which included site visits, were called case studies. They began in November 1982 and continued through August 1983. Six case studies were completed: three at projects that had experienced major quality-related problems and three at projects that had not. Three projects were in the range of 25-50% completed; three were recently completed or essentially completed. The projects were located in four of the five NRC regions.

An analysis of Cincinnati Gas and Electric's Zimmer plant was performed recently by Torrey Pines Technology (TPT). Because of the relevance of the TPT findings on Zimmer to the questions addressed by the NRC case studies, results of TPT's evaluation of Zimmer (TPT 1983) are also included in this appendix.

The case studies were not inspections, investigations, or audits, and thus were conducted outside the normal regulatory process of the NRC. For the most part they were limited to the construction sites and licensees' offices (and NRC regional offices); assurance of quality in the design and procurement processes was not examined in the same detail as the construction process.

A.1.2 Purpose

The purpose of the case studies was to determine the essential differences between nuclear power plant projects that had experienced major quality problems in design and/or construction and those that had not, and to highlight the lessons learned. These lessons provide a basis for considering changes to the NRC's activities supporting assurance of quality in nuclear power plant projects.

A.1.3 Technical Approach

Each case study had three phases: a pre-field activity, a field activity, and a post-field activity. The pre-field activity consisted of a general familiarization with the licensee and project, including the project quality assurance program and its history. Relevant NRC inspection and investigation reports and licensing documents were reviewed. Postulated root causes for successes or failures were developed to provide a framework for the subsequent interviewing process.

The field portion of the case studies typically commenced with briefings from the NRC regional offices and from licensee management to two of the case study team members prior to the full-team visit. Then the entire team would meet with the licensee's management at the start of the five-day site visit. During this meeting (and typically as a preface to each individual interview with licensee and contractor personnel), the purpose of the case studies was described. All were told that the case studies were not inspections or audits.

The case study teams were comprised of NRC and contractor personnel who collectively have experience in nuclear plant engineering and design, project management, construction management, operations, systems analysis, quality engineering, quality control, and quality management. Contractor personnel were selected from two national laboratories and from two consultant firms. To assure consistency in each case study, three team members, including the NRC case studies project manager, participated in all the case studies. Three others were assigned on a rotational basis. These six individuals comprised the core group for the case studies.

Twelve other staff from the national laboratories, NRC, and consulting firms participated in selected case studies to provide fresh ideas and perspectives. These individuals included management-level personnel qualified to critique the process. To further ensure that no key elements were being missed in the case study process, the results were periodically reviewed by a peer panel consisting of noted experts in their fields.

In the early case studies, three subteams of two personnel were used; one subteam concentrated on construction management and investigated the interfaces between the licensee and the contractors, paying particular attention to the quality control of construction. The second focused on project engineering and design processes and on interfaces with the architect-engineer, construction management, and quality assurance aspects of the project. The third concentrated on the quality assurance program, its organization, and personnel qualifications and training. A fourth subteam that was added later concentrated on corporate management's functions in the project and its approaches to the assurance of quality for the project.

Typically, 40 to 60 people, from top management to crafts and QC inspectors, were interviewed in each case study. The QA program was reviewed together with selected records, and a plant walk-through was conducted. The case studies did not include any technical review or evaluation of adequacy of plant design or construction. Apart from the plant walk-through, during which time team members were able to talk to additional craft workers, field engineers, and inspectors, no physical inspection of the plant was performed.

The field work concluded at the end of the week with an exit briefing for senior licensee management and staff. In a typical briefing, the case studies project manager presented the team's tentative findings regarding root causes of quality-related problems, or the absence of them, and related information. The NRC initiatives and the Congressional alternatives for improving quality were also discussed, as were the team's perspectives for the licensee to consider to further enhance its quality program. The licensee exit briefing afforded the opportunity to offer additional information, corrections of fact, and agreement or disagreement with the team's tentative findings and conclusions. The exit briefings were typically two to three hours long.

Post-field activity consisted of the preparation of a draft working paper. Subteams compiled individual reports which were incorporated into a case study draft working paper. The draft working papers served as resources for this study.

The information obtained through the interview process was taken at face value; however, several mechanisms for establishing confidence in cogent data were utilized. Generally, the findings and insights were corroborated by comparing information from more than one source:

- by interviewing personnel from a vertical cut of the project organization

- by extensive review of NRC file documents and other sources of data

- by interviews with regional and resident NRC personnel familiar with the project and its history

- by sharing and examining data at daily team caucus meetings.

Further confidence in the primary findings of the case studies can be gained from their similarity to those of the Torrey Pines Technology study conducted for the Zimmer nuclear plant (TPT 1983). The latter study used a different approach and was conducted in greater depth. It is summarized in Section A.3.1.

A.2 CONCLUSIONS AND FINDINGS

1. The single most important factor in assuring quality in nuclear power plant construction is prior nuclear construction experience (i.e., licensee experience in having constructed previous nuclear power plants, personnel who have learned how to construct them, experienced architect-engineers, experienced constructors, and experienced NRC inspectors).

   - This experience brings with it knowledge of the complexity of nuclear plant construction, understanding of regulatory-related quality requirements, the need for management leadership, and many other factors. These factors are poorly understood by those without experience and this lack of understanding leads to quality-related problems. Where licensees had marginal experience in critical areas (e.g., in the transition from construction to operation), they were prone to quality-related problems. The broader their inexperience, the more severe the problems were likely to be.

   - A high degree of design and engineering completion prior to construction, together with regulatory stability, might partially compensate for a lack of experience. There are some data showing that plants having higher design and engineering completion may have fewer construction-related quality problems arising from rework or extended project schedules. Standardization may produce comparable results.

2. A factor that ranks close to experience in importance is licensee management involvement in and control of the project. The project activities that compete with quality (i.e., cost and schedule) are not properly balanced without strong licensee management control and involvement.

   - Licensee contractors do not have the same overall responsibility that the licensee has nor do they have the same authority and resources to deal with quality-related problems. When a licensee abdicates its role, some aspect of quality, cost and/or schedule is likely to be compromised.

   - Licensees are also being forced to take more active roles in upgrading many aspects of the nuclear industry because of regulatory requirements--especially those aspects related to the quality of products or work from equipment suppliers and construction contractors. This has not been a role traditionally filled by licensees for their fossil-fuel (or other types of) plants. Where licensees have followed fossil-fuel practices and chosen not to be involved in supplier and contractor activities, quality-related problems were more likely to occur.

- Some licensees are now exercising the right to approve key A-E/C personnel for their projects to help assure quality and maintain project efficiency.

3. Another essential factor is a management commitment to quality. This is essential to facilitate activities that support quality of construction.

   - All management claims to support quality, but verbal support is not sufficient. An understanding is required of why quality is important (e.g., as an important adjunct to achieve an acceptable level of safety, reliability, or scheduled completion) and how to obtain it. That understanding must be disseminated through the entire project team by training, personal contact, audit appraisals, support of QA/QC staff, incentives and other means.

   - A commitment to quality seems encouraged by financial incentives. These may take the forms of an improved rate of return for high levels of operating efficiency, reduced maintenance costs, etc.--factors that may more than compensate for added construction costs incurred in the interest of quality or enhanced safety of operation. The role of public utility commissions in providing incentives for improved performance (a measure of quality) and adherence to NRC regulations needs to be considered.

   - Safety by itself does not appear to be a sufficient motivation for ensuring good quality. For the most part, industry has been lagging the NRC with respect to assurance of quality. This is evidenced by the fact that industry does not appear to feel that greater attention to quality is needed. That situation is likely to change only when the utility industry focuses on an objective that is more meaningful to them--one that includes safety, perhaps reliability. Licensees seem to believe that their plants are (or will be) safer than the NRC credits them to be; thus, assurance of quality requirements often appear excessive to licensees.

4. Maintaining and documenting adequate quality requires appropriate procedures for all aspects of the project (i.e., construction, design, procurement, etc.). These procedures must be understood, rigorously applied, and adhered to at all levels of the project.

   - There is a spectrum of assurance-of-quality practices ranging from outstanding to marginal in the nuclear industry. The superior practices appear slow to be propagated throughout the industry.

- The source of much contention about the adequacy of quality control in construction is the recordkeeping aspects of procedures. These need not be sophisticated, computer-based methods, but licensees with experience advocate the use of computer-based systems.

- The hiatus in new nuclear plant construction offers the NRC and the industry an opportunity to establish and disseminate improved practices with respect to procedures and records.

5. The case studies revealed several shortcomings in past or present NRC programs that have an effect on assurance of quality:

   - The licensing focus with respect to assurance of quality has been on form, not substance; the NRC's inspection focus has tended to be on records rather than on quality of product.

   - There has been little assessment of management capability as part of the construction permit review.

   - The NRC's inspection presence at construction sites in the past has tended to be irregular and nonconstant and continues to be so in the initial stages of construction.

   - The NRC's construction site resident inspection staff is too small to be expert in all phases of nuclear plant construction and construction management.

   - The NRC has been slow to take action on management issues that are often at the root of quality-related problems.

   - The NRC has failed to treat or sell QA as a management tool.

   - Changing regulatory requirements have resulted in quality-related problems, and this factor has not been adequately addressed by the NRC.

   - The NRC has done inadequate review or auditing in the past to verify quality in nuclear plant design processes.

6. Nuclear utilities are changing. Utility managements are becoming more aware of the special requirements for nuclear plants vis-a-vis other generating methods. Licensee nuclear staffs are increasing in size and capability. The utility industry seems to be assuming a larger role in the engineering services for operations. The transition from A-E to licensee for engineering services and the adequacy of the licensee to perform these services may need to be evaluated by the NRC.

7. The case study approach proved to be a useful tool for identifying and comparing assurance-of-quality practices. NRC regional and site personnel could benefit from case-type studies at other locations to gain insights

into alternative practices and to help avoid regional differences in approaches to quality.

A.3 DISCUSSION

This section describes the case study process and summarizes the major findings from each of the six case studies. The circumstances of each case study are described and the root causes of the quality-related problems--or lack of them--are identified. An independent study of the Zimmer nuclear power project is also summarized.

A.3.1 Case Studies

Case Study A

The licensee of Case Study A is constructing its first nuclear station, which consists of two large (>1000 MWe) units. Unit 1 is presently half completed; Unit 2 is about one-third completed. Construction permits (CPs) were issued in the late 1970s. Initial planning and site selection work commenced in the mid-1970s. Placement of safety-related concrete commenced in 1978.

The attitude of the licensee from the outset was one of confidence and adherence to practices that had worked in constructing previous fossil-fired plants. There was some recognition that nuclear projects would be different from fossil projects, but the differences were thought not to be great and could be largely overcome by hiring some managers and staff with prior nuclear experience. Also, the use of a nuclear plant design that was already well into construction at another location was a very positive factor. Completing the project on time and within budget was an important goal.

The licensee's prior construction experience consisted of about 20 fossil-fired plants. In some cases, the licensee had served as construction manager. The licensee had a construction department headed by a vice-president who was responsible for all utility construction. Over the years, the licensee had developed a close working relationship with, and confidence in, several major construction contractors who worked on its fossil-fired plants. The licensee's construction success for fossil-fired plants was a source of justifiable pride. Each plant had come on-line before schedule and within budget. The plants were of acceptable quality after the usual startup problems, and each plant operated safely and reliably. Quality was something put into the plant by the builders--there was no formal program for quality or the assurance of quality. To the licensee, quality was something that happened if you put good people on the project.

This licensee, in common with others in the industry, had a conservative management philosophy and was adverse to taking unnecessary risks. Contributing to this conservatism is the scrutiny of the public utility commission regarding how the licensee spends money and handles finances. These factors supported the licensee's cost and schedule consciousness.

Given the inherent conservatism of the licensee and the risks and uncertainties associated with nuclear power, why did it elect to build a nuclear plant? Many factors appear to have been involved, including projections of future energy demands, the price of oil and its future availability, the fact that other utilities, including first-timers, had built nuclear plants with apparent success, and analysis showing nuclear power to be not only cost effective but reasonably risk free. Going nuclear may have been a break with tradition, but it still represented a conservative decision.

The project was started under a Limited Work Authorization (LWA), which permitted non-safety-related work to be conducted prior to CP issuance. The licensee was the general contractor for the project. A firm experienced in the design and engineering of nuclear projects was retained as architect-engineer (A-E). A construction company that had previously participated in the construction of several fossil-fired plants for the utility was retained as the civil engineering contractor for the project. The civil contractor's nuclear experience was limited to providing workers for projects managed by other firms. It had never been the prime civil engineering contractor for a nuclear project. The licensee contracted with other firms for the mechanical, electrical and other aspects of the project. In the early phases of the project, the civil work fell behind schedule, and considerable pressure was applied by the Licensee to regain lost time.

About one year after CP issuance, the NRC identified deficiencies in the quality of the concrete work; e.g., severe cases of segregation and/or honeycombing. There had been many nonconformance reports filed regarding the concrete work since the start of the project. The utility agreed to upgrade its quality assurance program for concrete work and to determine through testing if previously poured concrete was adequate. About one month later, a former employee of the civil contractor alleged that surface defects in the concrete had been improperly patched. Concurrently, but independently, the National Board of Boiler and Pressure Vessel Inspectors confirmed code compliance problems with piping installations previously identified by a mechanical subcontractor.

The concrete deficiencies and the National Board findings led to an intensive NRC team inspection, which resulted in shutdown of all safety-related construction activities. The NRC determined there were programmatic questions concerning the licensee's project management, construction management, and quality assurance programs sufficient to warrant stoppage of safety-related construction work until they could be satisfactorily resolved.

The licensee retained a management consulting firm to perform an in-depth analysis of the project. The consulting firm confirmed the existence of, and helped identify, underlying programmatic deficiencies in the project. Their report outlined a 20-point plan to restructure and improve the project. Subsequent to that report, the licensee detailed to the NRC its effort to upgrade and implement its revised program for project and construction management and the assurance of quality.

To assure that the licensee's corrective actions were properly and effectively implemented, the NRC approved a five-step plan for gradual rescission of the shutdown order.

The licensee was permitted to resume receipt inspections of materials at the construction site about one year after the stop work order and after restructuring its project and construction management and quality assurance programs. Limited electrical and pipe installation work resumed six months later, followed by all remaining safety-related work, including concrete placement, in another four months. Unrestricted authority to continue the work was granted when the utility successfully demonstrated to the NRC that its revised project and construction management and quality assurance programs were implemented properly. The total time period from work stoppage to full resumption of all construction activity was about two and one-half years. Substantial non-safety-related civil work was completed while the stop work order was in effect.

During this period, the licensee substantially restructured its project management, construction management, and quality assurance programs (including records management). Substantial numbers of well-qualified people were hired. A nuclear division, whose sole responsibility was the nuclear construction project, was formed. The division manager, a senior vice-president, was located at the plant site. Morale improved considerably and team spirit and project determination pervaded the project.

Three years after the quality problems became so pervasive that all safety-related construction work was halted, the cognizant NRC regional office rated the licensee's QA program "outstanding" (the highest rating) on the annual NRC Systematic Assessment of Licensee Performance (SALP) review. The licensee received the rating of "outstanding" the subsequent year also.

The Case A study team identified the following root causes to be significant in contributing to the major quality failures experienced by the licensee.

<u>The licensee's inexperience in nuclear power plant construction projects, and its failure to appreciate and understand the difference in difficulty and regulatory requirements between fossil and nuclear construction projects.</u> The licensee had managed or overseen the construction of several successful fossil projects and it approached the nuclear project as an extension of the earlier fossil construction activity; i.e., to be managed, staffed, and contracted out in much the same ways as fossil projects. The licensee did not appreciate or understand the difference in complexity and regulation between fossil and nuclear projects and treated the nuclear project largely as just another construction project. The licensee's lack of experience in and understanding of nuclear construction requirements manifested itself as follows: lack of adequate staffing for the project, both in numbers, qualifications, and applicable nuclear experience; selection of contractors the licensee had used previously in building fossil plants, but who had very limited nuclear construction experience; over-reliance on these contractors for the management of the project and evaluation of its status and progress; use of fixed-price contracts where scope of work was inadequately defined; oversight of the project from

corporate headquarters, with only minimal presence at the site; a lack of appreciation for the importance of ASME codes and other nuclear-related standards; a misunderstanding of the NRC, its practices, its authority, and its role in nuclear safety; and an inability to recognize that the piping and recurring concrete quality problems were merely manifestations or symptoms of much deeper underlying programmatic deficiencies in the management of the project.

The licensee's failure to understand and appreciate the potential merit of a formal program to assure quality. The licensee had built fossil units successfully in the past without having a formal program for the assurance of quality. For the nuclear project, NRC regulations required the establishment of a formal quality assurance (QA) program. The licensee viewed this requirement as just another government agency-imposed requirement necessary to obtain a license and treated it accordingly. The licensee inadequately staffed the QA function, in numbers, qualifications, and nuclear experience, and failed to listen to the QA organization when it reported quality problems and it (and other project components) asked for additional resources. Senior management was skeptical about formal QA programs; earlier, successful fossil projects had been completed without a QA program, and there were concerns about the QA organization trying to build an "empire." Quality, they felt, was something that came naturally to their projects.

The licensee's false sense of security in moving from fossil to nuclear construction. The licensee was unaware of the seriousness of the quality problem up to the issuance of the stop work order and had developed a false sense of security resulting in part from the following: past fossil plant successes; use of many of the same contractors who had worked on fossil units; believing the contractors when they indicated that the project had no major problems; believing that similar concrete placement practices and problems were common in nuclear construction; assuming that serious problems would not likely occur since the project's nuclear units were replicates of other plants being constructed by a more experienced utility; and believing that there were no major problems with the project since NRC inspection findings (until the inspection resulting in the stop work action) revealed none, having focused on details and minor problems. The licensee had little concept of the effect that regulatory changes were having on the "replicated" design.

The licensee's failure to adequately manage the project from the outset. This cause is related to the first cause; i.e., inexperience. In retrospect, the project was not being adequately managed by anyone. In the project structure, the role of project manager belonged to the licensee. The licensee acted as general contractor and construction manager, but managed the project more in an overview role. The licensee managed the project from corporate headquarters with minimal site presence and without effective control over its contractors. Accountability for the project was delegated among several organizations within the licensee's organization. The replication of design contributed in some degree to the failure to manage; the licensee felt that any major problem would develop first at the project being replicated, and it would have time to make adjustments on this project.

NRC licensing and inspection deficiencies. For construction permits, NRC licensing review is limited largely to technical and engineering issues. The NRC does not and did not in the case of the licensee, evaluate whether it and its contractors had the experience, knowledge, staffing, or ability to effectively manage and complete a project as complex as the construction of a nuclear reactor. Moreover, the NRC's inspection activity at the site was irregular and nonconstant, with several inspectors in different disciplines visiting individually for only short periods of time, and with no one (until the inspection resulting in the stop work action) recognizing that the reported deficiencies were symptoms of deep programmatic assurance of quality problems. The first resident inspector was not assigned to the site until four months after the stop work order. Just as the NRC, through its regional inspection program, was slow to put together the comments and evaluations coming from individual inspectors, so too was the licensee slow to recognize the extent of the programmatic quality assurance problems. Indeed, the licensee interpreted NRC's early narrow inspection findings as an indication that there were no major problems, and the licensee had some difficulty comprehending the stronger, more pervasively negative findings of the NRC inspection.

At the time of the Case Study A site review, the licensee had effectively implemented substantial modifications and improvements to the management of the project, and the project was regarded by cognizant regional NRC officials as having been turned around and as being something of a model project. The Case Study A team findings supported this assessment.

Case Study B

The licensee of Case Study B has one nuclear station in operation and a second under construction. Both consist of two large units (~1,000 MWe each). The former station has been in operation since the mid-1970s. The latter station is less than half completed. Its CPs were issued in the mid-1970s. Licensee fiscal problems required an approximate 18-month showdown in the construction of the station, so commercial operation is not anticipated until the latter half of this decade.

The licensee is the construction manager for the project. The major construction contractors--civil, mechanical, and electrical--all have had significant nuclear plant construction experience, as have many of the smaller contractors.

The A-E for the Case B nuclear station has had extensive experience in the design and construction of nuclear power plants. Some of the non-safety-related design is being done by the engineering staff of the licensee's holding company.

The licensee has experienced no major quality problems to date in the construction of this nuclear station (and, as far as the case study team knows, none occurred in the construction of the first station, either). There have been minor quality problems in the areas of engineering and construction, but the licensee has taken positive action to correct them. There has not been significant public intervention in the construction permit licensing or construction phases of the Case B nuclear station. No significant fines have been levied against the licensee for nonconformance violations or quality deficiencies.

The Case B study team identified the following root causes to be significant in contributing to the absence of major quality failures.

The licensee has an experienced design, construction, and construction management team. The licensee has had prior experience with a previous nuclear station, and many of the personnel who worked on it are now involved in the present project. This experience has given them an understanding and appreciation of the complexity of large nuclear station construction activities. Many of the staff have 5-15 years experience in nuclear work. The persons contacted, in general, had good qualifications for their assignments. There is a substantial training program and an overall impression of a high level of dedication and enthusiasm to the project. Early in the construction process, it was recognized that craft personnel available in the area needed further training on the special requirements of nuclear work, and this resulted in a comprehensive craft training program. The QA/QC staff is broad and deep in experience and qualifications.

The A-E has designed (and constructed) many nuclear power stations.

The major construction contractors (especially the mechanical and electrical contractors) and the smaller contractors have had previous experience in construction of nuclear projects.

The licensee has an orientation toward, and an attitude supportive of, quality in its nuclear project. The stated management philosophy of insisting on quality was not simply to satisfy the NRC, but to go beyond those requirements to have a reliable and safe operating plant. At higher levels in the management structure, the conviction appeared to prevail that public safety and company profitability demand assurance of quality in the construction (and operation) of nuclear plants, and that it is less expensive in the long run to "do the job right the first time." From the interviews conducted, both at the corporate offices and the site, it was evident that a sense of commitment to quality pervades the licensee's organization at all levels. The licensee volunteered to participate in the first Institute of Nuclear Power Operations (INPO) construction pilot audit and has expanded on it with its own self-initiated evaluation. The quality assurance staff has direct access to an executive vice-president. There was no indication from the interviews of cost/schedule overriding QA/QC. At lower levels, there was an expressed feeling that the company wants to do the job right. Employees at all levels appeared to have a constructive attitude toward the need for quality in general, and the proper application of quality assurance, in specific. A pro-company attitude and good morale on the part of the employees appear to exist.

The licensee manages the project, has clearly defined the responsibilities and authorities of the participants, and has provided adequate procedures to ensure compliance, especially at the interfaces. This is manifest most clearly in day-to-day activities at the site. The licensee is running the job. The licensee does not rely on the major contractors to perform overall management functions. There are limited and defined points of contact through which the licensee directs the work of its contractors. It is also manifest by the fact that the direction for the overall quality assurance program comes from the licensee and not from its subcontractors. Personnel within the licensee's and the major subcontractors' staffs were knowledgeable of their own, as well as others', responsibilities and authorities. (This, despite the fact that the organizational structure is quite complicated and not easily understood at first review; however, within the plant project team, the organizational structure is straightforward). Large geographical separation of some of the major organizations from the site; e.g., the A-E and the Nuclear Steam Supply System (NSSS) contractors' home offices, in particular, was seen to hamper communication.

The licensee supports its quality assurance program with adequate resources and backing. This is manifest by a Product Management Board comprised of senior utility management, senior project management, and senior A-E and NSSS representatives. The Board reviews the project, examines problems and maintains cognizance of nuclear matters. Quality does not seem to be sacrificed for schedule and cost considerations. (The case study team did not have occasion to evaluate schedule and cost pressures, however.) As previously mentioned, the licensee and contractors have good training programs for crafts and quality control personnel. The planning, scheduling, and budgeting activities appear to allow for adequate resources to do the job properly. Chronic delays were not evident. Procedure compliance was stressed at all levels and daily work schedules appear realistic enough to allow work to be completed in accordance with those procedures.

The licensee is proactive in looking for improvement in its assurance-of-quality practices. Key line managers were taken on a retreat by an executive vice-president to consider new approaches for assuring quality. This licensee volunteered to be the first to be evaluated under 10 CFR 50 Appendix B requirements in the early 1970s. Its own QA organization was asked by senior management to study the QA programs of other licensees for possible improvement as early as 1978. The licensee has been involved in one of the pilot studies for the INPO audits. It has also participated in self-initiated evaluations. There were numerous comments and indications in the interviews that problems, deficiencies, and areas of improvement can be surfaced without punitive actions.

The licensee's QA/QC function is active in reviewing, witnessing, and verifying contractors' work and in helping assure that corrective action is implemented. A well-staffed program with good procedures exists to ensure that construction conforms to the design. Licensee construction coordinators, many of whom have been quality control inspectors, do a preinspection of craft work prior to formal inspection by QC. There is feedback of lessons learned from earlier construction experience and from other projects. The licensee and its contractors have an effective corrective action program that brings about needed change. Design reviews by the licensee for constructability and operability were thorough. Licensee management interviewed indicated that they encouraged their staff to surface problems as soon as possible. In the long run, it was more beneficial and cost effective to do it earlier than later.

Case Study C

The licensee of the Case C study had established its own in-house engineering and construction management capability in the 1930s. During the late 1940s and early 1950s, outside A-E firms were used because of unusually large (post-WW II) system expansion requirements. In the mid-1950s, the licensee's earlier practice of doing its own engineering and construction management was resumed.

During the late 1950s and early 1960s, the licensee planned an ambitious program to construct several nuclear power stations. Nuclear power was recognized as a new technology and the licensee took actions to prepare itself for entry into this field. These actions included having observers at the construction sites of some early nuclear power plants, participating in the design of a test reactor, and studying A-Es' designs of proposed nuclear plants. The licensee decided to build its first nuclear plant--a small (<100 MWe) power reactor--through a "turnkey" contract for design and construction. The plant was completed in the early 1960s, and the licensee operated it successfully for about 15 years until it was retired. The licensee capitalized on the turnkey design and construction activity to familiarize its staff with nuclear activities and to enable it to engineer and construct subsequent nuclear plants. The licensee had been successful in engineering and construction activities on a variety of generating technologies and related electrical transmission systems.

During the early- and mid-1960s, the licensee announced plans for several nuclear plants. Environmental and/or seismic problems, coupled with intense intervention, resulted in all but the Case C nuclear station being canceled. These factors were also present in the Case C project, resulting in significant delays and cost increases.

The Case C nuclear station is comprised of two large (>1000 MWe) units. The licensee announced Units 1 and 2 in the mid-to-late 1960s. Construction permits were issued in the late 1960s and early 1970s. Unit 1 of the nuclear station was largely completed by the mid-1970s and fuel was received onsite for both units in 1975 and 1976.

Then a series of required modifications to the nuclear station delayed its completion. These were promulgated by NRC regulations such as pipe-break-outside-containment which necessitated, among other things, relocation of several conduits (1973-75); identification and/or reconsideration of a seismic fault which required such modifications as column stiffening, tank bracing, revised piping changes and equipment supports, diaphragm stiffening, buttressing and foundation changes (1978-79); the Brown's Ferry incident, which required modifications related to cable spreading, inerting atmosphere, new decking, and extensive concrete anchor bolt installation (1980); and the TMI accident, which required installation of extensive additional wiring, sub-cooling monitors, hydrogen recombiners, and other modifications (1981).

It is important to note that, over the time span of about eight years, one of the two units had been within a few months of being ready for fuel loading on several occasions. Thus far, Unit 1 has undergone three hot functional tests and three containment leak tests. Unit 2 has undergone one containment leak test.

In 1981, the licensee received a low-power license for Unit 1. It was suspended two months later following notification by the Licensee to the NRC that the diagrams used to locate the vertical seismic floor response spectra in the Unit 1 containment annulus area were in error. Briefly, the error occurred as follows. The licensee had transmitted to its seismic consultant a sketch with piping loads depicted from which the consultant was to determine the seismic response spectra. There was no indication on the sketch which unit the loadings applied to, although the consultant understood (correctly) that they were for Unit 2. The consultant thought that Unit 1 was a slidealong unit (instead of a mirror-image unit) and performed the analysis on Unit 1 based on that assumption. The information returned to the licensee was marked as "Unit 1." (In fact, the analysis applied to Unit 2, not Unit 1.) The licensee accepted the data at face value as being for Unit 1 and, because it knew the plants to be mirror-image plants, "flipped" the data so as to be applicable to Unit 2. (In fact, the data in the "flipped" condition were correct for Unit 1, not Unit 2.) The seismic response spectra were now incorrect for both Units 1 and 2.

Upon confirmation that wrong diagrams were used in developing Unit 1 design requirements, the licensee reanalyzed the design requirements for Unit 1 using the appropriate containment annulus frame orientation diagrams and determined that, as a result of the error, modifications were required to be made on several Unit 1 pipe supports. These modifications involved such actions as adding snubbers, changing the snubber size, adding braces, replacing structural members, and stiffening base plates.

In an inspection report of seismic-related errors, the NRC stated that the basic cause of this problem appeared to be the informal manner in which the subject data were developed by the licensee and transmitted to its seismic consultant, and the lack of independent review of the data within the licensee's organization prior to submittal to that consultant.

The licensee had been the architect-engineer/construction manager for the Case C nuclear power station. One of the major actions that the licensee took as a result of the aforementioned error was the formation of a Project Completion Team comprised of the licensee's engineering/construction personnel and personnel from a newly hired A-E firm.

An extensive Independent Design Verification Program (IDVP) was initiated in early 1982 in response to the seismic errors discovered in 1981. The Project Completion Team also conducted a concurrent design verification program.

As of January 1983, much of the design and construction required as a result of a wide range of reviews spawned by discovery of the seismic diagram error had been completed. The licensee had applied for reinstatement of the low-power operating license.

At the time of the case study, neither the IDVP nor the licensee's design verification program had revealed significant further deficiencies in the design or construction of the nuclear station. The design errors that were identified were not considered to have prevented the affected systems from performing their functions satisfactorily.

The Case C study team identified the following root causes to be significant in contributing to the quality failures experienced by the licensee.

The primary root cause of the design-related quality problem was the licensee's failure to plan, establish, and effectively implement a management system which provided adequate control and oversight over all aspects of the project. The licensee failed to fully control the flow of information across all the interfaces inherent in the engineering/design process and failed to provide appropriate reviews of the information transmitted.

Several factors appear to have contributed to this failure. Using the experience gained from their earlier turnkey plant and participation of the staff in other nuclear projects, the licensee, after considerable evaluation, assumed the role of A-E for this nuclear project. As previously stated, the licensee had good success with various types of generating projects it had engineered and managed over the years. The nuclear project was fitted into a design, engineering, and management system that may not have been adequately modified to handle all aspects of nuclear work, including the control of quality at design interfaces. Generally, it has been more difficult to apply QA to the engineering process than to the construction process; historically it has not been done effectively and the licensee had similar difficulty. Even though QA was apparently rigorously applied to the construction of the project in question (and growing in strength as NRC requirements and guidance evolved), the licensee did not implement NRC quality requirements for engineering as intensely as it did for construction. The licensee's attitude seemed to be that the engineering organization was comprised of professionals capable of doing what is right without overlaying a stringent formal quality assurance program beyond the normal controls considered part of good engineering practice.

Another factor in the problem of assuring quality in engineering dealt with changes in NRC requirements that occurred between the late-1960s and the late-1970s. It appears that the licensee did not completely understand the implications of the changes as they occurred; hence, an engineering QA program that the Atomic Energy Commission (the predecessor agency to the NRC) might have found acceptable early in the project might not pass NRC scrutiny in the late 1970s.

Secondary root causes also contributed to the quality failures. These included the following.

a. Failure to understand and appreciate the potential merit of a formal institutionalized QA program. This is suggested by the fact that the Project Completion Team adopted the A-E's quality assurance program, even though they were concerned about imposing a new system on the project at a late date. (The licensee's engineering procedures were maintained, however.) Examples of program deficiencies (drawn from various reports on the project and discussions with NRC inspectors) that had occurred during the project and the key indications of these deficiencies were as follows:

Design Control:

- The licensee's engineering staff did not always document important data transmitted to subcontractors.
- Design information was orally transferred to subcontractors.
- Assigned cognizant engineers were sometimes bypassed in the information or approval process.
- Adequate internal communications among the disciplines did not always exist within the licensee's organization.
- Requirements for independent reviews were not always followed.

Control of Instructions, Procedures, and Drawings/Document Control:

- The licensee's engineering management did not develop and/or implement formalized procedures to comply with early QA program requirements.
- In some cases, outdated drawings were used to establish seismic criteria.
- In some cases, diagrams in lieu of released drawings were used--a contributing factor to the seismic problem.

Control of Service Contracts:

- Proceduralized activities for service contracts were lacking to control all interfaces with some subcontractors.
- Informal "letter-type" contracts and documents were used.
- Service contracts were not treated as formally as hardware contracts.
- Formal quality requirements were not placed on some subcontractors until the late 1970s.

b. NRC's failure to sell QA as a management tool. The NRC requirement for quality assurance seemed to come across as just another requirement. The emphasis from the NRC seemed to be on externals--the trappings of a QA program, rather than its substance: develop a QA manual, set up a QA organization, have the QA manager report high in the organization, etc. The NRC tended to lose sight of what it was trying to achieve and failed to provide adequate guidance on what a quality assurance program should be. The NRC failed to inspect against QA requirements in the engineering area to the extent they inspected against QA requirements for construction.

Case Study D

Early in the 1970s, the Case D licensee decided to construct nuclear generating plants. A possible natural gas shortage, the favorable economics of nuclear power, and public acceptance of nuclear power were reasons the nuclear option was deemed by the licensee to be a logical choice. Two projects were initiated, one in which the licensee would be sole owner (and which was later canceled) and the other a joint partnership with the licensee as project manager for all aspects of engineering design, construction, and operation. This latter project comprised two large (>1000 MWe) units. The first-unit operation was projected for the 1981-1982 timeframe, with second-unit operation to follow about two years later. Both have been delayed.

The licensee had no prior nuclear experience, but this was not seen as an insurmountable obstacle. Many other utilities were (or had been) in the same position, and the leaders in the industry were viewed as not having that much more experience.

In selecting an architect-engineer/construction manager/constructor (AE/CM/C), the licensee had compiled a candidate list that included the firm selected. Because many nuclear plants had been on order in the late 1960s and early 1970s, most A-E firms were committed and the licensee realized there would not be an opportunity to select from a large number of firms. It selected a large engineering and construction firm as both A-E, construction manager and constructor, one that had performed well for the licensee in non-nuclear projects. This firm was noted for its ability to complete large construction projects within cost and schedule. Its primary forte up to the early 1970s, however, had been in other than nuclear work. It did not have as extensive nuclear experience as many other A-E or constructor firms. This would be its first major nuclear engineering and design project, and the first nuclear project for which it was construction manager.

When the licensee applied for a construction permit in the mid-1970s, it was received about 6-8 months earlier than either the licensee or its A-E/C expected. While this may have been the result of a national emphasis to streamline the licensing process (a few years previously, the oil embargo had taken place and there was national concern over energy independence), it also had the effect of confirming, in the eyes of the licensee, the effectiveness of the AE/CM/C. The licensee maintained (during the site visit) that rapid licensing resulted in construction being started before an adequate amount of design and engineering (estimated at less than 25%) had been completed.

During the early phases of the project, the licensee was also staffing its own project management organization to fulfill its commitments to the project. Early in the project, the licensee used a matrix-type organization to manage the project. The approach was recognized to be embryonic, but thought capable of doing the job. The licensee recognized that managing a nuclear plant construction project would require a greater involvement than that required for a fossil plant. Project management rested on an organization that had responsibility for both nuclear and fossil projects.

In the course of the project activities, the licensee's staff had to issue some stop work orders to the A-E/C on specific tasks, e.g., work on concrete and on welding on the containment vessel liner. The licensee became concerned that the A-E/C was not accurate in its estimates of cost and schedule status of the project. Further, according to the licensee, the A-E/C was not demonstrating an adequate understanding of quality assurance or how it should be applied to a nuclear plant. The A-E/C wanted to do a good job, but it was not effectively balancing costs, schedule, and quality, according to the licensee. At about this time (mid-to-late 1970s), and perhaps coincident with the cancellation of many nuclear plants, the licensee believes there was a waning of interest by the A-E/C in the project, with a consequent loss of engineering and management resources.

In late-1978, the licensee initiated a six-month study of whether the A-E/C should be replaced. Consultations with other A-Es and constructors led the licensee to conclude that it would do best to support and improve the A-E/C organization and to become more involved in the design and construction activities. Thus, during the course of the project and up into the early 1980s, the licensee increased its involvement in the A-E/C activities. In 1978, following a consultant report that there was a high likelihood of both cost and schedule overruns, the licensee acted to strengthen its project management. It made the power plant engineering and construction manager the nuclear project manager and created a project management team reporting directly to him. About 30 experienced personnel were added from a consultant organization until the licensee could replace them with comparable personnel.

In 1979, the licensee expressed written concern about the A-E/C's performance and directed it to take several actions in the areas of construction supervision, planning, scheduling, control of construction work, labor productivity, and site housekeeping. The A-E/C agreed in large measure with the licensee's assessment and already had begun corrective measures to improve its performance. While some concerns were promptly resolved, others continued to require the attention of the licensee.

Thereupon, the licensee took a stronger stance by trying to help the A-E/C recognize its responsibilities and by injecting more licensee personnel into the contractor's realm of operation in an effort to compensate for the difficulties being experienced. It became more obvious to the licensee as time went on that the A-E/C's strength in this project was as a constructor, and not as an A-E because the engineering effort was not sufficiently leading the construction effort. Instead, construction was essentially driving the engineering portion of the project.

Symptoms of QA program breakdown gradually appeared at the construction site as the project became more involved in complex work. There were allegations of quality control (QC) inspectors having to rush through or overlook inspection functions, being intimidated and threatened by construction personnel, and lacking backing by their site supervisors. There were also allegations about bad construction practices, workmanship, and falsification of records.

Concurrently, the NRC initiated an investigation through its regional office in response to the allegations. Ten allegations were investigated from July 1977 to November 1979. The results of these investigations substantiated the allegations of harassment, intimidation, and lack of support of QC inspectors. The investigation demonstrated shortcomings in the project management and that the implementation of the QA/QC program did not meet the standards required to assure that the facility would be constructed to NRC requirements.

In April 1980, following a lengthy investigation of improper construction procedures and alleged inadequacies in construction and inspection, the NRC issued a Show Cause Order for safety-related sections of the plant. In total, 31 allegations of impropriety were made, and 19 were substantiated. The Show Cause Order findings are summarized in the following partial quotation:

> "This investigation has determined through the examination of current work activities and interviews with over 100 personnel onsite that the QA/QC program at the project is impaired ... Allegations of harassment, threats and intimidations of QC inspectors by construction personnel that were common knowledge through rumors have been substantiated ... Difficulties in controlling structural concrete activities and quality problems in completed portions of structures have been continuing problems at the project since 1977 ... Procedures lacking in clarity, qualitative acceptance criteria, personnel with inadequate training, experience and/or education, production pressures, harassment, and intimidation have all contributed to this situation ..."
>
> "That the project QA management may not fully recognize the requirements for QA/QC organizational freedom is evidenced by a January 4, 1980 lecture by the A-E/C project QA manager ..." "... strongly emphasized the fact that a A-E/C QC inspector's decisions are subject to question, challenge, and supervisory review and reversal ..."
>
> "In the area of soil foundations, serious questions remain as to whether the implaced compacted backfill has met the required densities ..."
>
> "Although safety-related welding activities are at an early stage at the project, serious problems were identified in the areas of welder qualification, welder process controls, and NDE performance interpretation ..."
>
> "Further, although not reviewed during this investigation, Licensee personnel indicated significant problems relative to the storage and maintenance of equipment and processing of quality records ..."

In July 1980, the licensee responded to the Show Cause Order in which it claimed that it had undertaken, along with the A-E/C, a comprehensive examination of their organizations with the intent of enhancing their combined capability to design and construct the plant to conform with all applicable standards and commitments. Both had undertaken major changes in organization, personnel, and procedures to meet this objective.

The licensee contended that these improvements by itself and the A-E/C revitalized the project's QA program.

In spite of efforts to reconcile differences and to establish a credible program, the relationship between the licensee and the A-E/C continued to deteriorate. This culminated in the termination of the A-E and construction management parts of the A-E/C's contract by the licensee in the fall of 1980. According to the licensee, the A-E/C subsequently terminated its construction contract as well.

In September 1981, the licensee replaced the A-E/C with another A-E/C and an independent constructor. The latter was given responsibility for QC and QA activities, reporting directly to the constructor's offsite corporate headquarters. QA/QC activities on the part of the constructor were to be monitored by an independent QA department maintained by the A-E/C. An overview of all QA/QC activities was to be maintained by the licensee. This management system was intended to provide checks and balances to avoid a recurrence of the types of problems that had occurred previously.

Within the licensee's organization, additional changes were made to strengthen the project and to improve oversight over both the A-E/C and the constructor.

Safety-related work resumed in the fall of 1982. Construction completion goal dates for the two units were rescheduled to the mid-to-late 1980s.

The Case D study team identified the following root causes to be significant in contributing to the major quality and quality assurance problems experienced by this project.

The primary root cause for the construction difficulties was the inexperience of the project team. While the licensee had extensive experience in constructing and operating fossil fuel-fired plants, it had not been involved with constructing a nuclear plant. It apparently failed to appreciate the difference in scope and complexity between the two, as reflected in the management methods and procedures applied to the project by both itself and the prime contractor.

The licensee's lack of nuclear experience was further aggravated by the lack of experience of key individuals involved with the construction project. This project was the first nuclear project for the project manager, project engineering manager, and the quality assurance manager. The licensee was organized by technical discipline into a matrixed fossil-nuclear organization. Personnel were shuffled from fossil to nuclear and vice-versa as the need for a particular discipline arose. As a consequence, a requisite core of full-time professionals was slow in developing. The licensee did hire some staff with nuclear experience; however, they were not sufficient to provide the necessary core of competence.

Another problem resulted from the three management levels between the site quality assurance organization and the executive vice-president responsible for the project. The delay and filtration of information caused by this managerial superstructure contributed to incomplete understanding at the executive level of the problems that were developing.

Historically, the licensee had depended upon its contractors to do the bulk of the planning and execution of fossil plant construction jobs. The licensee assumed that this same approach would be appropriate for the nuclear project and, consequently, placed too much reliance on the prime contractor.

While not adequately involved at higher levels of management, in some respects the licensee became too involved at lower levels. Licensee personnel found themselves directly in the approval chain for A-E/C design approvals and other documents. This had the effect of unduly restricting work flow. Everyone in the chain had veto authority, and everyone had to agree. Toward the end of the A-E/C's tenure, the licensee assumed nearly all of the contractor's responsibility in an intensive but vain effort to help the contractor's effectiveness. In effect, the engineering work that was performed was the product of the A-E and the licensee instead of the product of the A-E with licensee overview.

The A-E/C, like the licensee, had inadequate nuclear experience. As a consequence, according to the licensee, the A-E/C did not understand the complexity of nuclear plant design and construction and did not bring to bear the necessary technical and management skills. These problems were aggravated by the earlier-than-expected approval of the construction permit and, therefore, the A-E/C did not have the planned time to come up to speed on design and personnel competence.

Design work proceeded slowly and specifications and procedures were inadequate and formatted in complex ways. There appears to have been insufficient engineering support for design and construction. The capabilities that the A-E/C did have were channeled into those areas in which it had experience, to the neglect of other equally important areas, according to the licensee. Engineering efforts were scheduled based upon dictates from construction. This led to unrealistic demands on the engineering groups. Quality assurance and quality control were also dominated by construction. There were many conflicts between QA/QC and construction in which construction generally prevailed. Project management did not have an adequate understanding of the interfaces and responsibilities for such functions as QA/QC, engineering, design, and construction. As a result, the constructor did not react in a timely, effective way to problems and did not employ proper management systems to reveal the causes of problems and to prevent them from recurring.

<u>There was inadequate management support of quality</u>. Neither the licensee nor its A-E/C appeared to have had a full understanding of quality and quality

assurance concepts as they applied to nuclear plant construction. Although both made verbal commitments to quality, these were not actualized in the construction process. The licensee was not appropriately involved in monitoring the total scope and details of activities and did not know how to take effective corrective action to prevent recurrence of problems. The A-E/C did not sufficiently insulate QA/QC from cost and schedule demands, nor shield them from intimidation or harassment. Consequently, construction supervisors dominated the QA/QC functions, both in the field and in the form of published policy, which emphasized minimizing cost and maintaining schedule. The long chain of command filtered information and introduced inefficiencies into the decisionmaking and implementing processes. To further compound these problems, the licensee had none of its own QA inspectors at the site until 1980. This gave low visibility to management support of quality, which may have been interpreted as a lack of backing from top management for quality.

There was an insufficient review by NRC of the licensee's (and its A-E/C) experience in nuclear plant construction, and an inadequate involvement in the inspection process in the early phases of construction. A recurrent theme was that the NRC licensing process did not adequately address the ability and experience of the project management, nor was there adequate evaluation of whether the nuclear industry had over-extended itself at the time this plant was contracted. The inspection process also tended to ignore management issues. The irregular presence of NRC inspectors at the site early in the project was cited as a contributing factor. The process used by NRC in identifying and dealing with problems was cumbersome and required excessive amounts of time. In effect, the NRC approach was one of allowing troublesome situations to progress to the point that a case could be built for taking the drastic action represented by a Show Cause Order. Some of the problems involving the NRC required up to two years to resolve.

The changing environment of the nuclear industry was a contributing factor to quality-related problems. The rapid proliferation of regulations during the mid-1970s was cited as particularly troublesome, especially since the design of this particular plant was probably less than 25% complete when construction began in 1975 and proceeded more slowly than it should have in relation to construction activities. Regulatory changes from the TMI and Brown's Ferry incidents were also a severe blow to the project, according to the licensee.

Declining energy projections and increasing interest rates made funding plant construction more difficult. Incidents within the industry, such as TMI and Brown's Ferry, reflected into changed design requirements. All of these changes coming in rapid succession further complicated the task for the relatively inexperienced nuclear staff of the A-E/C and its A-E/C licensee-constructor.

Case Study E

The licensee had previously constructed two large (~700 MWe) turnkey nuclear projects in the late 1960s. CPs were issued in 1967 for both units, with one unit achieving commercial operation in 1972 and the other in 1973. The licensee assigned a small group of its own engineers to the project to begin to accumulate a nuclear experience base.

The licensee's next nuclear project was the construction of two 810-MWe units of similar design. Construction of the first unit began in 1969 and commercial operation was achieved in 1976. Unit 2 (Case Study E) was announced in 1971, but major construction did not commence until 1977. The licensee contracted design and construction management (including QA/QC) on Unit 1 to an A-E firm with considerable experience in design and construction of nuclear projects. The licensee performed a project overview function.

The rapid rise in oil prices brought on by the Arab oil crisis in the early 1970s motivated the licensee to restart construction of Unit 2. In 1976, construction of Unit 2 was proceeding under a Limited Work Authorization (LWA); however, work was halted for 15 months by court injunction. After this injunction was resolved, the NRC issued a CP in June 1977 and major construction commenced.

The 15-month delay had advantages. During this period, the integrated management team was structured, a detailed master project schedule was developed, design completion was advanced, procurement of engineered components was continued, and a much more detailed level of planning was achieved. These factors were identified by the licensee as major contributors to the project's success. The licensee recognized that it had the talent to assume full management of the project and made the decision to do so. An integrated management organization using personnel from the licensee and A-E for key positions was established. The integrated management concept worked well and a spirit of teamwork, commitment, and loyalty to the project was achieved.

Advancement of the design was a particularly significant item. The design was approximately 75% complete when construction resumed. Vendor drawings on equipment were available, and construction drawings reflected correct equipment installation details. Some nuclear projects have experienced significant problems because designs were not sufficiently advanced for construction to proceed efficiently. Typically, construction begins with designs about 50% completed, sometimes less.

During the 15-month delay, the licensee had its field engineering work force develop many of the construction activities in considerable detail. This information was used in preparing procedures and was integrated into the design. The licensee also used the time to prepare effective procedures to control the project, including refinement of its own QC procedures.

The licensee had decided to continue procurement of engineered materials during the 15-month delay. This decision resulted in vendor drawings being available to the A-E and to field forces well in advance of equipment installation or construction-related activities.

As a result of its experience and these factors, the project achieved a 59-month time span from start of concrete to completion of cold hydro, static testing, 35 months better than current industry averages.

The licensee experienced no major quality problems during construction; however, on several occasions during construction, extensive reinspection efforts were required because adequate inspection records were not available. For example, an NRC inspection resulted in 12,000 socket welds having to be reworked and reinspected. Other quality-related problems typical of large construction projects also occurred. The licensee provided its QA organization with the following authorities as a check on its QC operations, which reported directly to the construction organization:

- QA held the "N" Stamp for the Licensee, which strengthened its overview function through access to records and the authorized nuclear inspector (ANI).
- QA performed daily surveillance of construction work, including formal audits of the entire project function.
- QA was responsible for the records vault, and through this activity monitored QC inspections.

The licensee stated that having QC report to construction permitted a better working relationship between crafts and QC, and thus better project results. While this action resulted in a more-or-less adversarial relationship between QA and QC, management's message on quality was "do it right the first time." This message supported the licensee's effort to stay on schedule.

The licensee identified what it thought to be the ten most important factors in completing the plant essentially on schedule, within cost, and without major quality-related problems:

1. management commitment
2. a realistic and firm schedule
3. clear decision-making authority
4. flexible project control tools
5. teamwork
6. maintaining engineering ahead of construction
7. early startup involvement
8. organizational flexibility
9. ongoing critique of the project
10. close coordination with the NRC.

Apart from the initial 15-month licensing delay there were no other significant licensing delays. No significant public intervention occurred in the construction phases of the Case Study E nuclear station. No fines were levied against the licensee for nonconformance violations or quality deficiencies during construction and startup of the project.

The Case E study team identified the following to be significant in contributing to the absence of major quality failures.

The licensee had an experienced design, construction and construction management team. A major factor in the project's success was the nuclear experience of the licensee and its staff and contractors. The Case E project had a seasoned group of managers and a tried, although evolving, set of project controls. The A-E commented that an estimated 75% of the skilled labor force carried over from the Unit 1 project to Unit 2. Early in the previous project, an extensive training program was instituted to develop additional craft persons, a factor important to achieving quality. An estimated 50% of the A-E supervision also continued from the previous project.

The licensee recognized the need for effective planning and implemented it. During the 15-month licensing delay, effort was redirected towards developing detailed plans and schedules to facilitate the construction phase. The requirements were integrated into the design and procurement process to minimize disruption of the construction process later. A realistic and firm schedule resulted from the planning process.

The licensee exercised control of the project through strong owner involvement, commitment of resources, and an effective integrated organization. An important root cause for this project's success was the licensee's firm management, including providing all of the onsite quality control and quality assurance functions. Clear decision-making authority was placed at the proper level. The licensee established a matrix organization comprised of its staff and of the A-E/constructor staff that created an environment of affiliation and loyalty to the project.

The project became the priority project for the licensee, who committed the necessary resources for the project. The licensee committed to a project schedule of 65 months (from first concrete to core load) and consistently invested additional resources to maintain or recover schedule whenever needed.

Recognition of the need for early startup involvement. The Case E construction plan had startup logic involved in it with the decision to involve operating personnel at an early time. That decision reflected into certain innovative construction approaches on the project. In previous projects, operations personnel were not involved until the project, or at least major systems, were essentially completed. The operations involvement took place over an 18-month period and included about 60 personnel. There were 494 turnover packages. Early turnover helped resolve problems, including quality-related problems early on.

Problem identification and solution was an important part of the licensee's management philosophy. The licensee followed a policy of resolving problems at the earliest possible time. As problems or changed conditions confronted the licensee, it formed teams to resolve them in a timely manner. An independent engineering verification program was instituted about a year before fuel loading. The A-E maintained a larger field force than on previous plants to process field change requests, nonconformance reports, etc., more rapidly.

The licensee had task forces examining how impending changes might impact construction. To help circumvent delays that might arise from regulatory matters, it maintained three engineering personnel at NRC Headquarters, some at the utility's engineering office, and three at the site to interface with NRC personnel and provide timely responses to licensing questions. It avoided adversarial relationships. On the NRC side, its inspection surfaced problems early, thereby avoiding major issues that might continue long into the construction period.

The licensee achieved a high level of teamwork on the project. In discussing teamwork, the licensee stated that all of the participants in the project worked to meet the project objectives, not their own (sub)-objectives. Heavy emphasis was placed on integrating work with NRC, EPA, trade councils, etc. The entire state Congressional delegation supported the licensing schedule. There were quarterly labor-management meetings (there has been no work stoppage of significance since 1980). Labor was involved in improving productivity.

Interviews with personnel on this project revealed a positive orientation toward the project. They were proud of what they had accomplished--they identified with the project. The reduced number of individual contractors on the job may have been a factor in achieving the strong team effort.

The licensee recognized the merits of an institutionalized QA program and was innovative in structuring and implementing its QA program. This root cause was manifest as follows:

a. The licensee established a single QA/QC program for the project. A single program reduced confusion through fewer interfaces and uniformity of requirements. The A-E made the comment that a single QA/QC program was an asset that avoided gaps in the program with the increased possibility of things falling through the cracks.

b. The licensee had a corporate commitment to quality. The licensee extended its QA program to programs other than nuclear, which indicates its recognition of QA as an effective management tool. It is involved in a program with eight other utilities that audit one another's QA program.

   The licensee's QA organization became the ASME "N" Stamp holder for Case E, which permits greater control of the inspection process and a different perspective than provided by NRC inspection.

c. The licensee balanced schedule and QA commitments. The licensee responded to several setbacks by defining solutions and applying whatever resources it took to resolve each problem and recover schedule. Emphasis on maintaining schedule did not compromise quality. Good management practices can produce quality amidst commitment to schedule.

Case Study F

The Case F nuclear power project was organized in mid-1974 and an application for a construction permit was filed with the NRC for three 1,270-MWe generating units. The construction permit was granted in the spring of 1976 and construction began in June of that year. At the time of the case study (August 1983), the status of the three plants was as follows: hot functional tests were performed on Unit 1 in mid-1983. During these tests, reactor coolant pump problems developed, and cracking was noted in the control element assembly guide tubes, as discussed later. Unit 2 hot functionals are scheduled for early 1984. Unit 3 is about three-fourths completed, with commercial operation expected in 1986.

Several utilities participate in the project with ownerships ranging from about 10-30%. One of them was selected to be the licensee who would manage the project and operate the plant on behalf of the others. The utility selected had no prior nuclear construction experience, but at least one of the presently participating utilities had constructed and operated nuclear plants.

Information provided by the licensee showed that the project was conceived in the early 1970s. The initial planning was done by the licensee with a small staff it had assembled for that purpose, all of whom were experienced in the nuclear field. This staff analyzed what had gone wrong at other nuclear projects and arrived at findings that played an important role in organizing and carrying out the Case F project. They felt that a long-term commitment of qualified people to the project was important, both from the licensee as well as its contractors. They noted that utilities typically tended to do the wrong things and get involved in the wrong places in nuclear projects, such as wanting to approve everything. Utilities often believed they knew more about all aspects of the projects than their contractors or the regulator. It was found that utilities were often very untimely in their actions and decisions, which caused costly delays. Finally, they perceived that utilities often have the wrong type of organization. For nuclear projects, they found that the organization must be both management and detail oriented.

Based on these general findings, the licensee's staff came up with some recommendations that formed the basis for its project organization. First, there should be a strong project concept, both within the licensee's and A-E's organizations--but with a singleness of purpose. Second, the licensee should manage the interfaces. Third, there should be single points of entry for all correspondence to each organization, and the communication channels should be monitored to ensure effectiveness. Fourth, clearly written design criteria should be established and maintained current as changes occurred. Fifth, the licensee should establish which documents produced by the A-E and others it would review. Sixth, the licensee should be responsible for obtaining all project permits and licenses. Seventh, purchasing and construction work should be controlled through administrative procedures (such as having standard terms and conditions for contracts and purchase orders), a qualified bidders list, and work initiation procedures. Eighth, safety and quality must come ahead of schedule and cost, not only for the licensee, but for its contractors, also.

These priorities must also be conveyed to the project regulators. Ninth, adequate systems and procedures must be established to monitor the project.

Based on discussions with the licensee, it was determined that these early recommendations were implemented as follows:

1. An A-E construction manager/constructor experienced in nuclear construction was hired.

2. Contracts with major contractors required a long-term commitment of key personnel.

3. Interfaces were defined and procedures were developed to ensure the proper flow and interpretation of information and to permit monitoring.

4. Frequent meetings were held with the major contractors' senior management to discuss project problems and to facilitate decisions.

5. Contractor responsibilities were defined for design, specifications, purchasing materials, and hiring and managing labor forces.

6. The licensee set up a strong project organization with staff hired from other utilities, architect-engineers, vendors, and the NRC. The head of the licensee's nuclear project had considerable experience with designing and constructing commercial nuclear reactor projects. The licensee's organization actively overviewed and closely monitored its contractors. Construction input was provided early in the design effort. Operations input occurred early in the design effort, also.

7. Licensing activities were assigned to executive levels to help ensure prompt decision making. It was the licensee's philosophy to be responsive to the regulators.

In the context of these recommendations, the Case F project was implemented.

To date, no major quality problems have arisen in the construction of the Case F nuclear power station. Also, no significant public intervention has occurred in the licensing or construction phases of the station. As previously mentioned, significant primary pump problems have occurred in startup operations, and other startup problems have surfaced as well.

The licensee has experienced construction problems typical of large construction projects. Poor communication about project completion existed between the licensee and its contractors, and the licensee took the necessary steps to reorganize the scheduling function. Poor productivity had to be overcome, and the licensee insisted on changes in personnel and organization of its A-E/C. The turnover rate was considered high for the field engineering staff, and the licensee found it difficult to retain a good staff. System walkdowns revealed quality deficiencies that required rework. Unit 1 experienced major problems in the transition from construction to operations. The good management practices that led to construction success were not applied equally to the transition from construction to operation. Unit 1 hot functionals have revealed the primary pump deficiencies. While major quality-related problems have not been experienced in construction, there is a strong possibility that the design verification process supporting new components, such as the primary pumps, was not adequately explored.

The Case F study team identified the following root causes to be significant in contributing to the absence of major quality failures in construction.

The licensee determined in advance the important factors in constructing a nuclear project and took the necessary actions to achieve them, including hiring key personnel with nuclear experience, retaining an experienced A-E/C, and creating an organization appropriate for the project. The licensee recognized from the outset that construction of a nuclear power plant would be different from previous projects it had undertaken. This realization resulted in several key decisions that were strong contributors in avoiding significant quality problems in construction. First was the recognition that fossil fuel plant experience alone would not be adequate for the project staff; selective recruiting of personnel for key positions with nuclear plant construction experience was essential. Second was the licensee's action in retaining an experienced architect-engineer/construction manager/constructor for the project. Third was the recognition that it would not be appropriate for the nuclear construction project to be fitted into an existing organization component; a separate, strong project organization would be required--one which could closely monitor and actively overview the management of the project. The combined experience resulted in many actions appropriate for controlling and monitoring the project. One action that was singled out by the licensee and its A-E was the development of a detailed scale design model (costing several million dollars) of the plant to supplement design drawings as a basis for configuration control. This model, together with a design that was estimated at about 60% complete when construction started, was credited by the licensee and its contractors as being instrumental in facilitating the construction activities and avoiding many problems experienced in other nuclear projects.

On the other hand, a lack of experience has led to confusion and inefficiencies in the startup testing program on Unit 1. That activity does not appear to reflect the same degree of understanding, planning, and preparation that was applied to the construction phases. The startup testing program has been restructured more than once in the past several years. There appears to have been a lack of appreciation that nuclear is a more complex startup process than fossil plant startup, and that turnover from a strong construction manager requires a well thought out transition plan and startup program. The transition was to have the constructor do the prerequisite tests and the operations staff perform the preoperational tests. That did not work satisfactorily for several reasons, but probably primarily due to a lack of a well thought out plan. Startup of the subsequent units involved an operations/construction team involved in both prerequisites/preoperational tests at an earlier stage, with a greater focus on completion of systems (versus the area concept of completion).

During hot functional tests on Unit 1, the pump problems occurred because of a clearance problem between the pump impeller and diffuser, and perhaps compounded by flow conditions that existed during the tests. Previous factory tests of shorter duration had not revealed a similar problem. Cracking in the control element assembly tubes, which occurred during the initial startup tests, also appeared to be associated with the flow conditions. First-of-a-kind equipment, such as the pumps, frequently require modification in the start-up phases of operation. The licensee stated that it had been relying on prior orders for similar components by other licensees to work out the "bugs" on the first-of-a-kind equipment. Nuclear plant delays or cancellations invalidated this approach. Experience would have suggested that a revised approach to permit more extensive design verification testing of such equipment prior to installation would be prudent.

The licensee pursued several management practices, especially the working involvement of upper management, which permitted the project team to function effectively. The working involvement of upper management was important in many respects. They were sufficiently involved that when corrective action was needed, it could be taken in a timely and decisive manner. They set the tone for the project's orientation toward quality, expressed in several ways, but importantly in terms of high plant reliability goals, as well as maintaining quality standards for non-safety systems and for temporary construction. They established a philosophy of good public relations and a nonadversarial working relationship with the NRC. They arranged for appropriate contracting practices and labor relations. They minimized the number of contractors on the project, clearly defined responsibilities of the participants, and established sound procedures for design and construction activities. Finally, they helped assure uninterrupted financial resources for the project. Good management practices appropriate to nuclear projects were clearly another root cause in avoiding significant quality problems in construction.

A relatively high design completion at the start of construction of Unit 1 and the replication of the design for the two subsequent units permitted problems experienced in Unit 1 to be corrected in advance in Units 2 and 3. An example is the transition from construction to operation described previously. The design completion was estimated at about 60% when construction was started. The use of the model as a design model also helped to reduce interferences and resulting field changes. Construction planning activities were enhanced. The licensee adjusted well to the changing regulatory environment over the life of the project.

The responsibility for quality was placed at the working level. Field engineers were required to sign off on inspection hold points before involving the QC inspector. This also helped preclude QA/QC personnel directing the work through the inspection process. The licensee established its QA requirements sufficiently broader than NRC requirements (though with appropriate cognizance) so if the latter were changed, the former would remain unchanged.

The attitude of senior project management that the NRC could help the project helped avoid unnecessary confrontations that were counterproductive. The licensee, as a matter of policy, established a constructive nonadversarial working relationship with the NRC. The vice-president of the Nuclear Department has been the licensee's prime contact in licensing matters and has set the criteria and guidelines for interactions with the NRC. The independent design reviews conducted by the licensee has NRC staff as listeners/observers.

The proceduralized approach to design and construction was an important contributor in avoiding major quality-related problems. The project had workable procedures to control calculations, specifications, procurement, and other facets of the construction process that had been adopted early in the project. The licensee established design criteria for the project in conjunction with the A-E, and they have been the governing guidelines for the project. The document specifying the criteria has been the control document for the life of the project, which extends into operation.

The A-E's resident engineer said that the basis for quality at the project was that the quality control procedures were specific. "It is an expensive process," he said, "but it works."

The constructor prepares work planning procedures/quality control instructions, which control safety-related work for non-safety balance of plant items, though less inspection is applied.

The Zimmer Case Study

Concurrent with the case studies, an independent analysis was made of Cincinnati Gas and Electric Company's (CG&E) Zimmer Unit 1 nuclear project (TPT 1983). The study was mandated by the NRC in a Show Cause Order to CG&E in November 1982. One of the provisions of the Show Cause Order was the requirement that CG&E have a qualified consultant conduct an independent review of the project management of the Zimmer project. Torrey Pines Technology (TPT) was retained by CG&E to conduct this independent review, including CG&E's quality assurance program and its quality confirmation program. The review was to identify the organizational changes needed to ensure that construction of the Zimmer 1 plant can be completed in conformance with the NRC regulations and the construction permit. This section of the case studies report summarizes the TPT findings. The summary is intended to provide additional information from a second perspective on the root causes of quality-related failures in nuclear plant construction.

The selection of TPT was subject to the NRC approval of its independence and capability to perform the review. Several public meetings were held, and the NRC reviewed TPT's proposed program plan for conducting the review. As a result of the program plan review, greater emphasis was placed on evaluating CG&E's management of the Zimmer project and less on a detailed review of procedures, specifications, records, etc. The program plan was also revised to include the evaluation of the Zimmer project management from the inception of the project to the present. The revised program plan was approved by the NRC in a public meeting with TPT on May 26, 1983, with a provision that TPT include an evaluation of the relationship between CG&E and Reactor Controls, Inc., one of the contractors.

The basic approach used in the TPT study was to separately examine key characteristics and aspects of the Zimmer project management and QA programs. As a cross-check, selected "case studies"[(a)] were also examined to assess the collective role and behavior of management in response to specific problems and/or series of events. The specific areas reviewed were as follows:

- CG&E management attitude toward "whistle blowers"
- structural steel in the control room
- 2400 feet of small-bore piping
- welder qualifications.

TPT reviewed the organizational structure, policies and procedures, and QA activities of CG&E, including its interfaces with its contractors: Sargent and Lundy (S&L), Henry J. Kaiser Company (HJK), General Electric Company (GE), Catalytic Incorporated (CI), and Reactor Controls, Incorporated (RCI). The review was divided into four periods: 1) project inception to the assumption of increased construction responsibilities by CG&E in 1976, 2) from 1976 to the Immediate Action Letter in early 1981, 3) from the Immediate Action Letter to the Show Cause Order in November 1982, and 4) subsequent to the Show Cause Order.

Information was obtained by interviewing CG&E's Zimmer project management staff, representatives of contractor organizations, and representatives of related organizations such as the NRC, National Board of Inspectors, and intervenor groups. The interviews included past and present management and other individuals having information pertinent to this review. Selected records and files were examined to obtain relevant documents/information to supplement and verify the information obtained in the interviews. The interviewees and the supplemental documents were selected on the basis of TPT's professional judgment.

The total program effort was approximately 60 man-months; over 3200 documents were reviewed; and approximately 100 people were interviewed, several more than once. The investigation did not include any technical review or evaluation of the adequacy of the Zimmer plant design and construction. No physical inspection of the plant was performed.

The TPT study of the Zimmer project (TPT 1983) showed the following factors to be the important causes of the quality-related problems experienced.

The Licensee and its constructor lacked prior nuclear experience. The TPT report states:

> "... CG&E and, to a large extent, its constructor HJK, lacked prior experience in its assigned roles in this nuclear power plant project. Although in the early 1970s numerous other utilities also lacked prior nuclear experience, the constructor (HJK) of the Zimmer

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(a) Term used by TPT to identify a portion of its review requiring in-depth documentation review, which should not be confused with the NRC "case studies."

project was unique from the standpoint that it did not have, nor did it later obtain, any additional commercial nuclear power plant prime construction contracts. Consequently, it appears that neither CG&E nor HJK had sufficient experience or the external interactions necessary in order to respond in a timely and effective manner to the rapidly evolving, more stringent interpretations of NRC requirements. As a result, it was not recognized until very far along in the Zimmer project that a much more formalized, rigorous approach was needed to control and document the quality of the design and construction of a nuclear plant than that required for the design and construction of a fossil fuel plant. This was probably the single, most significant factor contributing to the present situation at the Zimmer plant ..." (Vol. 1, p. 4).

"... CG&E attempted to use a project management approach at Zimmer that had been previously used successfully in the construction of fossil fuel plants. The approach, which was not unusual at that time, was to rely on a small, dedicated management team using relatively informal management systems and techniques ..." (Vol. 1, pp. 6-7).

The Licensee did not have an adequately sized staff, nor one with adequate experience. The TPT report states:

"... In comparison with other nuclear utility companies, staffing of both CG&E and the subcontractor organizations was inadequate throughout the 1970s. The CG&E management and professional staff was of inadequate size and had insufficient experience and training in the design and construction of nuclear power plants. After the IAL[a] in April 1981, additional staff was recruited, including a large proportion of temporary employees--some in management positions. A small number of CG&E personnel with prior nuclear experience has been added to the staff since the SCO,[b] but it still remains understaffed, and this situation needs to be corrected ..." (Vol. 1, pp. 7-8).

The Licensee failed to manage the project. The TPT report states:

"... Key managers and professional staff were not dedicated solely to the Zimmer project. Several key managers had conflicting responsibilities that detracted from their management overview of Zimmer. Except for short periods of time, the CG&E manager responsible for the entire Zimmer project was not located at the site. These conditions, coupled with the lack of an integrated project management system, contributed to the creation of informal autonomous organizations within the project with lines of communication that were not always consistent with the published project organization charts. Also, there was a too-heavy reliance on contractors for project

(a) Immediate Action Letter.
(b) Show Cause Order.

management and control. The CG&E policy of delegating the responsibility of major elements of the work to reputable experienced contractors is not inconsistent with the approach taken by other utilities in the construction of nuclear power plants; however, CG&E does not have the management system, implementing procedures, and staff required to control the work performed by its subcontractors. The net result was to impair the visibility of the project to CG&E top management ..." (Vol. 1, p. 8).

"... CG&E top management appeared to lack an adequate degree of involvement in, and commitment toward, QA at Zimmer. Up until 1981, the president of CG&E appeared to be insulated from an accurate picture of the status and inadequacies of the Zimmer QA program. The CG&E project organization provided minimal executive summary information to management on overall quality problems, status, and QA program effectiveness. Executive reports generally addressed details and highlighted 'brush-fires,' rather than providing a management perspective ..." (Vol. 1, p. 9).

"... Up to 1981, CG&E lacked effective control over the design function. More audit emphasis should have been placed by CG&E on field design control procedures. This could have helped to identify and correct, in a timely manner, the design control problems experienced at Zimmer. CG&E initiated an intensive effort after the SCO to get this system back on track ..." (Vol. 1, p. 11).

"... CG&E did not provide sufficient direction and support for the establishment of a comprehensive audit program executed in accordance with the requirements and intent of 10CFR50, Appendix B. Consequently, the CG&E QA audit program appeared to be ineffective. Individual problems were attacked, but the magnitude and extent of problems apparently remained largely undetected. Many noncompliances detected by outside audit groups should have been found by the CG&E QA audit group ..." (Vol. 1, pp. 11-12).

"... In general, review of subcontractor's activities appears to have occurred aggressively only between CG&E and HJK. There is little evidence that S&L, RCI, or CI activities were effectively reviewed, monitored, audited, or critiqued by CG&E. This CG&E policy of delegating the responsibility for major elements of the work to reputable experienced contractors is not inconsistent with the approach taken by other utilities for the construction of nuclear power plants; however, CG&E does not have the management system, implementing procedures, and staff required to control the work performed by its subcontractors ..." (Vol. 1, p. 18).

The Licensee failed to elevate its commitment to quality and quality assurance to an equal status with cost and schedule. The TPT report states:

"... CG&E had a corporate fiscal policy that minimized expenditures. Such a policy, taken in the proper perspective, benefits both the ratepayers and the stockholders of the Company; however, this emphasis completely dominated other important priorities, such as quality and quality assurance. Cost reduction and schedule maintenance was encouraged to the extent that construction forces worked only to compliance with the minimum NRC standards and regulations. This approach, combined with the rapidly evolving and more stringent interpretation of these regulations over the years, contributed significantly to the current problems at the Zimmer project ..." (Vol. 1, p. 4).

"... The emphasis was on getting the plant built on schedule, at the minimum cost ..." (Vol. 1, p. 7).

"... Management at Zimmer had not done an adequate job in highlighting the QA program as one of the key elements in the successful construction of a nuclear power plant, or in providing the appropriate level of support that would ensure effective program implementation.

The level and status of the CG&E QA organization through the years was generally inadequate to provide an effective nuclear QA program. The major shortcomings in this area are the small and inexperienced CG&E QA staff, cost and schedule pressures on the QA organizations, and failure to effectively correct and prevent recurrence of problems. CG&E management generally did not establish definitive policies, verbal or written, concerning QA at Zimmer, and no strong message by CG&E management in support of quality and quality assurance was evident. Instead, CG&E management policy insisted that all concerned (CG&E and subcontractors) minimize the time and money spent on QA programs ..." (Vol. 1, p. 9).

"... There exists no effective assurance that documents to be maintained as records are complete, accurate, valid, or readily retrievable. It would also appear that management did not take effective action early enough in the construction project to ensure the validity and availability of these documents. A centralized records center was set up after the IAL, and the turnover of documents from other site locations is in progress. However, progress is slow and it is not being accomplished in a thorough manner.

From the beginning of construction until the present, the corrective action system was generally not effective in assuring that identified discrepancies in material/systems/procedures were investigated in a timely manner, analyzed to determine root causes, and corrected by priority actions to prevent recurrence. Standard management tools to collect relevant data, analyze the data relating to the problem, propose alternatives on the basis of analyzed data and the operating environment, and select solutions were available, but were apparently not utilized or, at the least, were not effective. In addition, there is little evidence to indicate that management established an effective system to track 'open' items to assure their completion ..." (Vol. 1, p. 12).

The NRC failed to impress on the Licensee the importance of quality. The TPT report states:

> "... Quality problems existed during the early stages of construction which remained uncorrected during that period due, in part, to a lack of attention and follow-through on a corrective action course by the NRC. Although CG&E QA was generally responsive to NRC concerns, these concerns were neither extensively nor aggressively pursued by the NRC. Consequently, CG&E management failed to recognize the underlying message in the Inspection Reports (IRs) relating to the problems that existed at Zimmer. As a result, corrective action was not taken in an effective or timely manner. CG&E was allowed to continue construction while being lulled into a false sense of satisfactory performance until the late 1970s and early 1980s ..." (Vol. 1, p. 5).

The Licensee did not have adequate procedures to control the project, nor were those in effect adequately implemented. The TPT report states:

> "... CG&E established an Owners Project Procedures (OPP) Manual for the Zimmer project in 1972 which delineated the project organization, including reporting lines within CG&E, for the major subcontractors (HJK, S&L, GE); defined the responsibilities and authority of the various positions; and named the personnel who would act in those positions. These formal overall project policies concerning responsibility and authority over the functions at Zimmer appear to have been adequate, but they were not implemented adequately by project personnel.
>
> CG&E did not have an integrated, comprehensive set of project management procedures documented and implemented to ensure that all elements of the project (e.g., Construction, Engineering, Quality Assurance, Licensing, Cost, Scheduling, etc.) were coordinated. This impaired communication between departments and, in some instances, resulted in conflicting requirements and/or a duplication of effort ..." (Vol. 1, p. 7).
>
> "... CG&E project management and control systems, including performance measurement and document control, were inadequate. The systems utilized did not integrate the planning and scheduling of various project management activities such as construction, QA, engineering, and, subsequently, the transition to operations. Management reporting systems were also poor ..." (Vol. 1, p. 8).
>
> "CG&E's control of the process of developing, maintaining, and implementing subtier procedures, instructions for work, and inspections that affect quality has been less than effective from the start of construction to the present. There are many instances of inadequate control over design documents, design document changes, welding

forms, inspection methods/procedures, documentation of work accomplished, conformance to work procedures, and QA procedures ..." (Vol. 1, pp. 10-11).

A.3.2 Summary of Case Study Findings

Although no single factor distinguishes nuclear plants that have experienced major quality-related problems from those that have not, a combination of utility/contractor experience and/or personnel experience in nuclear plant construction provides the greatest assurance that quality-related problems will be avoided. Based on the six case studies (and substantiated by the independent review of the Zimmer project), if a utility had constructed previous nuclear plants or if it hired experienced personnel for its own staff and had an experienced A-E/C, it tended to avoid major quality problems. Where the utility depended on non-nuclear, e.g., fossil experience of its staff and its A-E/constructor, it was prone to experience major quality problems. Experience by itself may not preclude major quality problems, e.g., Midland, with an experienced utility and architect-engineer, still it is probably the greatest assurance factor in achieving quality of construction.

Because this study was limited to six case studies (and a review of a seventh), it did not evaluate in-depth a larger grouping of other utilities that have built nuclear plants without apparent major quality problems, and as first-time ventures. However, experience would be expected to be a significant factor, especially in the timeframe of the projects studied for this report.

A second important factor that emerges is the importance of the licensee actively managing the construction project. Projects experiencing major quality problems placed too much reliance on their contractors or their own in-house capability, a reliance that was not justified based on previous experience. The licensee failed to effectively implement a management system that provided adequate control and oversight over all project aspects. Those projects not experiencing major quality problems "ran the project." They were deeply involved in planning, establishing criteria and procedures, approving important drawings and specifications, overviewing their contractors' activities, and identifying and solving problems. They clearly defined the responsibilities and authorities of the participants and monitored the interfaces to assure that responsibilities were being properly discharged. There was often a working involvement of upper management or, failing that, a good understanding of the project's needs in terms of finances, manpower, autonomy (from prevailing practices, etc.) which were provided. As with experience, some nuclear plants may have been constructed where the licensee did not actively "manage" the project (such as in the turnkey projects), but in the present timeframe and based on the case studies, licensee management involvement and control are important factors in constructing plants without major quality problems. Constructing nuclear plants in the 1970s with the many regulatory changes that occurred, with a supporting nuclear industry in which the most experienced A-Es, constructors, and major contractors were stretched to capacity, with the increased complexity of the larger plants, and with rapidly escalating costs, was in a far different environment than those constructed earlier. The requirements that assured success in nuclear construction also escalated.

Success in constructing fossil-fuel plants, together with a little nuclear experience, was no longer sufficient to guarantee that the nuclear project could be completed without major problems (in quality, cost, or schedule). Utilities with only those qualifications, but which avoided major problems, probably had good fortune and astute management who were able to discern impending difficulties and compensate for them accordingly.

Active management of the construction project was clearly shown in those projects that had experienced major quality-related problems, but that had since turned them around. Those which had not completely turned their projects around tended to maintain that "we always managed the project," "it was someone else's fault," or, "it was a fluke." With those which had, there was a change in management involvement. Project leadership emerged clearly. There was no question who was providing project leadership. Senior management was often relieved of other utility responsibilities to devote sole attention to the project; they often moved to the construction site; their project staffs were divorced from those responsible for more traditional generating plants; and substantial additional experienced personnel were hired. Procedures were strengthened and enforced. There was more active involvement with the NRC, especially by upper management. Where necessary, modifications were made to contracting methods to give the licensee more control over quality (fixed-price contracts were often converted to cost-type contracts); there was substantial strengthening of the QA function within contractor organizations. These types of actions are also manifest by those utilities that have not had major quality-related problems.

As utilities gain experience in nuclear project management and develop a core of experienced personnel, they appear able to delegate the project management successfully to lower management without lessening the utility's active involvement in the project. As regulatory stability is achieved and plant designs become more standardized (or plants are more fully designed before construction commences), the more experienced A-E/C probably can assume an increasing degree of responsibility for plant construction without such intense utility involvement.

A third important factor relates to the licensee's commitment to quality, or perhaps to plant reliability. While all (or almost all) personnel interviewed believed quality was important, ranking with safety, those licensees (and their contractors) that had experienced quality-related problems tended not to appreciate that quality assurance was a management tool that would help assure quality in nuclear plant construction. Those who had not experienced major quality-related problems supported their quality assurance programs with adequate resources and backing, and tended to take proactive roles in seeking improvements in their quality assurance programs. They were prone to put responsibility (and authority) at the level where the know-how was and emphasized doing it right the first time. They seemed to place more stress on plant reliability than those who had experienced major quality problems. That is, plant reliability was a more evident concern that surfaced frequently in discussions with the licensees' staffs.

There did not seem to be a particular QA/QC organizational structure, function, authority, etc., that characterized plants with or without quality-related problems. Rather, the six cases presented a variety of organizational arrangements for these functions. Staffs varied in size over a considerable range. QA staffs reported at various levels in the utility/contractor organizations. Some had stop work authority and some did not. Some participated in construction activity planning and some were separated from the day-to-day activities. Some projects had multiple QA/QC programs and some had a single program for most of the construction activities. Some organizations had multiple layers of QA which audited lower levels. No pattern of QA/QC organizational structure or delegation correlated with whether plants had experienced major quality problems or not. Projects having major quality-related problems in construction, when once turned around, tended to establish a strong QA function as their main line of defense against (further) quality failures, whereas those not having major quality-related problems in construction (perhaps arising from their greater experience) emphasized craftsmanship responsibility for quality as their main line of defense.

A fourth important factor relates to procedures. All licensees have procedures, but there was a difference in what was done with them. For those with quality-related problems, one or more of the following conditions existed: they lacked adequate procedures; they had procedures, but did not rigorously follow them; or they relied on them to do what is a management function of overview and control. Those without major quality-related problems spoke of the use of detailed procedures for design, procurement, construction, and inspection activities, and of the need for adherence to them. They seemed to have a better appreciation of their value and limitations than those with quality-related problems. In the six case studies, there was a wide range of sophistication in specifying, using, and auditing procedures. Some quality-related problems could probably be avoided by helping licensees appreciate state-of-the-art applications of procedures and related controls.

The presence of four factors--experience, management control, commitment to quality, and properly implemented procedures--should be sufficient to avoid quality-related problems in nuclear plant construction. There is overlap in the factors; that is, experience will tend to assure that the other factors are appropriately implemented. Evaluation of these factors by the NRC will be difficult because there is a large subjective aspect to them. One senior vice-president suggested that the NRC might appoint a panel of experienced nuclear utility executives to evaluate whether a first-time licensee has the requisite capability to construct a nuclear plant successfully. Their own experience should permit them to adequately evaluate the subjective aspects.

Not all licensees and their contractors fully appreciated the requirements of the regulatory process, nor coped well with the changing regulatory environment. All of the nuclear plants considered in the case studies were under construction during a period of considerable regulatory change (the 1970s). One difference between projects with and without major quality problems lay in how much they relied upon the NRC (or other bodies such as ASME or INPO) as an indicator of construction quality at their projects, and how they related to the NRC. As a class, those with problems seemed to assume that (a) a lack of

NRC prompting or (b) a lack of dramatic action by the NRC on quality-related matters meant no significant quality problems existed. Those without problems were proactive in resolving regulatory matters and anticipating regulatory changes. Those licensees represented themselves (i.e., they were the spokesmen) in dealings with the NRC. They took the initiative and the lead in licensing matters--not their contractors. They understood the implications of the impending decisions. Some licensees stationed personnel at NRC offices to promote rapid resolution of regulatory problems. Those without problems had two other characteristics: they had non-adversarial relationships with the NRC, and they attempted to anticipate the effects of impending regulatory changes on their construction projects. All aspects of this factor could be attributed to one or both of the first two factors--experience and management control.

A factor that does not seem to be recognized by either the licensees or the NRC is that the longer the construction period, the greater the risk of a quality failure, and the greater the need for additional attention to quality matters. The problem has two interrelated facets. First, the longer the construction period, the more regulatory change a licensee will have to cope with. Regulatory changes often result in design changes and rework. These changes and rework are often made under less than optimum conditions, conditions not conducive to quality workmanship. Second, the personnel making the changes may not be the ones who did the (design or construction) work the first time and may not understand all of the assumptions, interactions, or special conditions considered initially.[a] Also, there is some impact on morale from having to make changes, especially if thought to be marginal ones. For projects that have been under construction for an extended period (perhaps eight to ten years or more), special attention to quality matters may be appropriate.

NRC actions, or inactions, also contributed to quality problems that licensees experienced. Quality problems arising from regulatory changes have already been discussed. The NRC's failure (or inability) to adequately evaluate a licensee's management capability to undertake a nuclear project and its understanding of its required role is a major shortcoming in the licensing process. Clearly, some licensees should not have been granted a license under the prevailing environment and conditions, nor with the teams they assembled for their projects.

The NRC's failure to take action with the licensees on a more timely and firm basis allowed poor quality practices to exist and possibly proliferate in the industry while the licensees assumed NRC inaction meant the practices were approved or at least not sufficiently bad to make a big issue of them. In at least some cases, the NRC's presence at the site in the early phases of construction was sufficiently sporadic that the developing poor quality practices were not fully appreciated. Licensees generally believed that an NRC presence was needed at the site continuously from the start of construction.

(a) Modifications to operating reactors may be made under even less optimum circumstances, but the special conditions are less unexpected and potentially better planned for.

Other factors may have played a role in assurance of quality matters, such as failure to appreciate that quality failures were symptomatic of major problems, communication problems, the level of intervention, use of innovative practices, use of detailed design models, etc., but they are considered secondary to those cited earlier. These secondary causes may be useful as indicators that primary root problems may exist. For instance, failure to appreciate that quality failures may be symptomatic of greater deficiencies might point to management failure to understand the merit of a formal institutionalized QA program, or to NRC's failure to convince the licensee that QA is an important management tool. A long period between the inception of construction and operation may be indicative of a failure to manage the project. A failure to respond effectively to NRC quality-related findings may be indicative that the licensee has developed a false sense of security.

The case studies presented a wide variety of approaches and techniques for constructing nuclear power plants. Some of these have been described previously. No single project combined all of the most advanced, efficient approaches and techniques. Some had highly computerized methods for tracking all design, specification, and record information. Others used largely manual tracking systems. Some had a large (100-150) contingent of A-E staff on site to facilitate engineering support; others had a small (~25) contingent (although the trend was towards larger on-site design staffs).

Some projects had detailed, highly computerized, systems-oriented approaches to measuring cost and schedule status. Others used more traditional "bulk" methods or manual systems for tracking. Some had innovative approaches to construction; e.g., concrete placement or sequencing. Other used more commonplace approaches. The effect of those various approaches in achieving quality in nuclear plant construction could not be evaluated. At lower levels of management and at working levels, innovative and efficient approaches and techniques used at other nuclear sites are not generally known. The fast pace and required commitment to a single construction project seems to impede dissemination of good practices. Better dissemination of the more effective procedures and methods is needed in the industry to promote quality.

It appears to take considerable time for a project team to finally "get it all together," unless the project is an immediate follow-on from a similar plant. At least most licensees stated that "things got better" as the project continued. In the latter phases of the project, working relationships were well understood and construction activities tended to flow more efficiently. Unfortunately, when a project is completed, most "teams" are disbanded. A new team has to form when the next project is initiated and, again, it takes time to "get it all together." Much more cost-effective plants, and probably plants with better quality, could be constructed if there was more continuity in the whole nuclear construction (design/construction/startup) process.

The case studies focused on quality-related problems that had occurred in the past and on present practices at projects that had not experienced quality-related problems. The NRC and the nuclear construction industry has changed and is changing. Promulgation of new regulations to address the root causes of what has happened in the past, but which are judged unlikely to occur again, may be counter-productive. In this context, it might be useful to consider the conditions under which major quality problems might recur. These could include the following:

- a first-time utility with a staff or A-E/constructor that have inadequate nuclear experience. This could result in a replay of some of the case studies reported here. NRC attention to licensee's experience, the experience of the licensee's team, and the other important factors identified in the case studies would preclude this situation from recurring.

- a very large growth in the number of nuclear plants being constructed/modified that (again) overwhelms the industry's capabilities. Sufficient data are available to estimate the industry's capabilities at present. These estimates can be adjusted to account for the effects of a nuclear hiatus, retirements, etc. If the capabilities appear to be exceeded, special care can be taken in granting additional construction permits.

- a long delay before nuclear plant construction activities start again, resulting in a dearth of experience in the industry. This situation is similar in nature to that described in the preceding case.

- regulatory actions at federal and state levels which undercut quality. Possible actions range from excessive ratcheting of NRC regulations to state regulatory utility commission actions which are counterproductive to quality. In addition to being evaluated for their effect on cost or safety, regulatory actions should be evaluated for their effect on quality.

The NRC and the nuclear industry need to be aware of the implications for quality that these and similar possibilities hold.

A.4 REFERENCES

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